SMALL-FORMAT DIGITAL CAMERA USE IN GEOGRAPHIC INFORMATION SYSTEM

AGRICULTURAL APPLICATIONS

by

STACEY D. LYLE

(Under the Direction of E. Lynn Usery)

ABSTRACT

The United States Department of Agriculture's (USDA) Farm Service Agency (FSA) is currently developing a geographic information system (GIS) of common land units (CLU) in order to automate and coordinate the collection of spatial data that will provide the capability of identifying landowners, land boundaries and land usage. The FSA currently uses 35 mm color slide film aerial images to assist in this development as well as to perform crop compliance monitoring to ensure a uniform regulatory system for storage of agricultural products and timely provision of high quality food products to domestic and international food assistance and development programs, and to achieve domestic farm program objectives. This research proposes a new method and technology for employing a small-format digital camera system with direct georeferencing to improve the current 35 mm slide film process. An analysis of a direct georeferencing method will be investigated by collecting the exposure station locations using the extended Real-time Kinematic Global Positioning System (eRTK-GPS) within the aerial platform. This research demonstrates and documents the utilization of a small-format digital camera for generating aerial images used to update the GIS for crop monitoring. A discussion of the procedures to develop such a system is included. Quantitative results demonstrate centimeter accuracy within 35 kilometers from the base station with the aerial eRTK-GPS solution. Qualitative analysis of the photographic value for interpreting land boundary and usage within the GIS with the digital camera are presented. The methods of implementing the images from a small-format digital camera system for a GIS are defined. This research dissertation is methodological in examining new approaches with potential advantages over present approaches.

INDEX WORDS: small-format digital camera, geographic information systems, direct georeferencing, USDA FSA, common land units, crop monitoring

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DEDICATION

To my wife, Cynthia Michelle Lyle, and my devoted family for their unswerving support of my every endeavor.

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CHAPTER 1

INTRODUCTION

Purpose of the Study

Agricultural systems make up over 15 percent of our national gross domestic product and generate one trillion dollars in economic activity each year (Bailey and Meador 2002). The Farm Service Agency (FSA) within the United States Department of Agriculture (USDA) performs multiple services that support the agricultural industry. One such activity includes crop commodity operation, or *crop compliance*, which ensures a uniform regulatory system for storage of agricultural products, timely provision of high quality food products to domestic and international food assistance and development programs, and achievement of domestic farm program objectives.

Price support is offered to farms for the equitable delivery of benefits and services in improving and promoting the economic stability of agriculture. These services use aerial photographic images to monitor the compliance of farmers by monitoring crops for land use productivity. Aerial images are used to identify *crop type* and *acreage* planted. This information is connected to the grower and land to form an information system that the price support is offered. The use of geographic information systems (GIS) is essential in managing the ownership of land being observed and identified. Current methods of data collection for GIS include the use of film-based images for photographic identification of crop types and areas by utilizing 35 mm slide film images.

The USDA FSA employs obsolete methodologies for monitoring crop compliance by using 35 mm slide film aerial images projected from a 35 mm slide projector. Figure 1.1 illustrates a system in which a 35 mm slide film projector is positioned above a digital orthophoto quarter quadrangle (DOQQ) large format film print. The projector is manipulated to adjust for scale and tilt. This is currently the georectification methodology employed by the USDA FSA. To obtain the crop type and acreage 35 mm slide film is projected onto the existing DOQQ that has a common land unit (CLU) of land ownership information manually inscribed on the DOQQ film print as seen in Figure 1.2. A white sheet is often used first to assist in identifying the crop type by illuminating the colors, tones, patterns and textures. Next, the area is digitized, with a table top digitizer and recorded with the appropriate CLU information (USDA FSA, 1996).

A new method is proposed within this research that suggests the development of a small-format digital camera imagery system that is directly georeferenced in an airborne environment for the crop compliance monitoring and development of the GIS. This process includes a small-format digital camera, which is flown with the extended Real-Time Kinematic –Global Positioning System (eRTK-GPS) to supply a direct georeferenced position and orientation of the camera exposure station. Georeferencing is a ground registration technique whereby a digital image is processed so that the columns and rows of the resulting product are aligned with a northing and easting coordinate system. According to Wolf and Dewitt (2000 p. 189) georeferencing is often referred to as rectification; however "the term rectification is reserved for the process of removing effects of tilt from an aerial photograph." Direct georeferencing up until now has focused on a direct rectification. For the context of this research direct georeferencing will refer to the use of an orthogonal transformation to account for shift, scale and rotation.

It is expected that the eRTK-GPS will provide optimal accuracy of the exposure station to an accuracy of 5-10 centimeter root-mean-square error (RMSE), which equates to an adequate position for this application (Lyle and Wilson, 2000a). A test area is evaluated to determine the accuracy of the eRTK-GPS in an aerial platform. A comparison of the eRTK-GPS to post processing GPS is provided. Ground control points (GCP'S) are used to evaluate the accuracy of the direct georeferencing solution.

An evaluation of the different small-format digital camera systems is provided within this research dissertation. The final purpose of this study will to provide a method for the USDA FSA to use the direct georeferenced small-format digital camera to develop a crop monitoring GIS.

Significance of the Study

The principle objective of this research is to investigate the use of a small-format digital camera in GIS for the agricultural applications of compliance monitoring and development of a land information system (LIS) to coordinate ownership of crops with the common land unit (CLU).

This system provides a georeferenced remotely sensed airborne image solution in near real-time. During flight, the aircraft is navigated to the target site, where aerial images and eRTK-GPS positions are recorded. Images are then georeferenced to a local coordinate system and overlaid on an existing DOQQ to be further georectified to remove gross tilt errors.

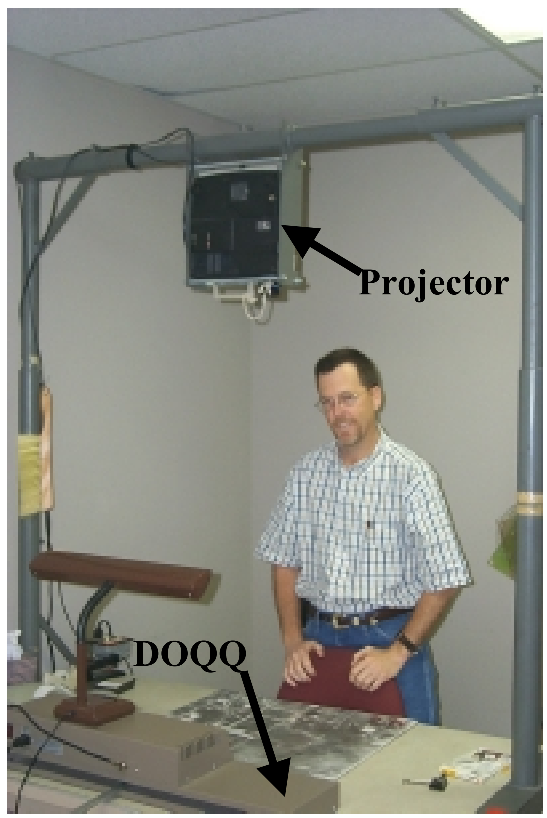

Figure 1.1: 35 mm Color Slide Projector at USDA FSA Office Projecting on a DOQQ Large Format Print.

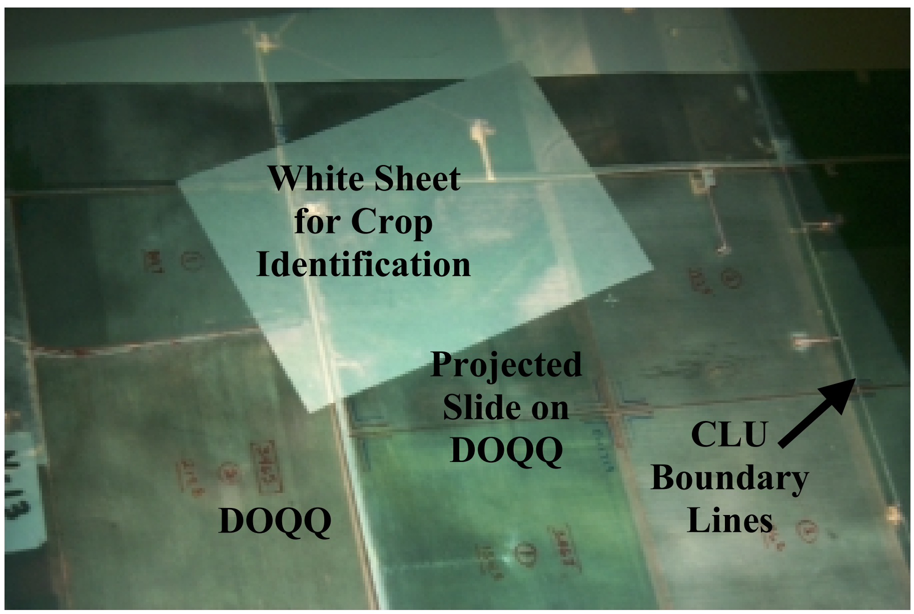

Figure 1.2: Projected 35 mm Slide DOQQ Large Format Print with CLU Boundary Lines Inscribed.

It is proposed that the direct georeferencing of digital images without the need of ground control will speed the photo rectification, crop identification and area extraction process in agriculture compliance monitoring. The final product will be a planimetric image with a user-defined georeferenced coordinate system. The feasibility of using a small-format digital camera to collect images without ground control will also be analyzed. The significance of a small-format digital camera in agriculture remote-sensing applications is discussed. Davis, (2002c) has shown the viability of a small-format digital camera for crop compliance. The proposed research in this dissertation will add to the innovation of a small-format digital camera by evaluating small-format digital video camera with direct georeferencing.

Advancements in improved crop production can be directly linked to the use of GIS and remote sensing (Usery *et al.*, 1995; Clark 1997; and Perry *et al.*, 2000). The demands for more reliable and affordable images are required by the agriculture industry to improve analysis. Images must meet the accuracy and resolution to develop a GIS for spatial analysis, image identification of crop type, and the measurement acreage. The time between capturing images and analysis must be efficient to improve the system.

Although satellite images such as Landsat, Quickbird, and Ikonos are available at spatial resolutions of typically 1 to 30 meters, it is difficult to interpret and extract crop type and acreage accurately for use within a GIS, based on the satellite imageries resolution and availability (Mostafa and Scharz, 2000). Lower resolution imagery makes it difficult to identify crop type. Higher resolution would improve this problem, but this imager is not often available during or immediately before crop harvesting. Cloud cover often prohibits satellite image availability of specific target areas. Airborne film-based imagery can often obtain imagery under or between cloud cover brakes. Film-based airborne imagery systems can improve spatial resolution. Time is taken for film processing, image scanning procedures and manual image georeferencing. Also, the film-based airborne imagery systems are expensive compared to a small-format digital camera solution.

Digital aerial photographic imagery solves spatial resolution, time to produce a final product, and economical issues. Film based data collection and image-processing analysis involve human interaction and processing. Improvements offered with digital imagery methodology will deliver a real-time or near real-time product (Maas, 1997b).

Thesis Statement

How can a small-format digital camera system be used with direct georeferencing to improve and replace the current 35 mm color slide film methods used by the United States Department of Agriculture Farm Service Agency in developing a geographic information system of crop compliance?

The research will use the following methods to meet the objectives of the system:

- Testing and development of an airborne eRTK-GPS solution
    - Direct analysis for long baseline solution on fixed spatial georeferenced monumentation
    - Evaluation of different communication systems for aerial platforms
    - Mounting GPS antenna in a location referenced to the digital camera system
    - Mathematical transformation values from eRTK-GPS and tilt information for georeferencing images
- Development of a small-format digital camera system
    - Investigation of different current consumer camera systems that include still digital frame (DF) and digital frame video (DFV)

- Analysis of new digital sensors to meet the needs of USDA FSA crop compliance imagery
- Research and development of new methodologies of data acquisition

- Comparison of digital images to film and other optional readily available images for monitoring crop compliance

  - Analysis of the digital images for photographic interpretation capability
  - Development of procedure to establish the crop compliance GIS
  - Discussion of the use of the CLU as a cadastral GIS layer

Assumptions

For the purpose of this research some assumptions are made. Tilt within the exterior orientation is small based on the imager size. Correction from tilt can be collected with a magnetic or inertial sensor. The resolution of these sensors would not improve the tilt error by a significant value.

The GIS software will utilize a resampling technique when it displays the image with the associated georeferencing parameters. The GIS currently used by the USDA will be able to use the small-format digital images to update its crop monitoring reporting. The base layer imagery that is used by the USDA FSA are existing DOQQ's or high resolution satellite data. The small-format digital camera system would not replace this current base layer imagery, but it would be used to analyze the crop type and area from year-to-year for crop compliance.

The USDA FSA proposes that the use of a small-format digital camera in place of the existing 35 mm slide film solution to acquire aerial photography for crop compliance and GIS data collection will become the standard protocol for the USDA FSA (Davis, 2002c). It is further suggested that new technologies and methodologies be developed to allow for an autonomous real-time solution by improving the data capture procedure. A cognitive shift in current human interaction to an automated methodology is proposed.

Description of the Dissertation Format

The final research dissertation is a series of peer-reviewed papers of the research and procedures for aerial small-format digital images usage in a GIS for crop compliance monitoring. The conclusion drawn subjectively communicates the results of this research. Some duplication of information in the introduction and literature review will be found in the peer-reviewed papers. The duplication is intended to acquaint the peer-reviewers with the merits and problem of this research. This research dissertation is presented in the following format:

CHAPTER 2: CONCEPTUAL FRAMEWORK: LITERATURE REVIEW

- A critical review of literature is presented to establish the conceptual framework of the research that directly relates to USDA FSA and other research.
- USDA FSA 35 mm Slide Film Current Concepts
- USDA FSA GIS
- USDA FSA Search for Alternatives
- Prior Research of Small-Format Digital Camera for GIS Applications
- USDA Small-Format Digital Camera
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- Chapter Summary

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- Defining Global Positioning Systems
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- Example of Direct Georeferenced Computation
- Conclusions

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- First peer-review paper presenting results to meet research objective of direct georeferencing with eRTK-GPS.

CHAPTER 5: INVESTIGATION INTO SMALL-FORMAT DIGITAL CAMERA SENSORS FOR DEVELOPMENT OF USDA GIS OF CROP COMPLIANCE

- Second peer-review paper researching and determining the best format digital camera sensor.

Chapter 6: US DEPARTMENT OF AGRICULTURE AND FARM SERVICE AGENCY CROP COMPLIANCE MONITORING GIS

- Third peer-review paper providing the methodologies of utilizing small-format digital camera imagery for developing a GIS.

SUMMARY AND CONCLUSION

- Summarized results and discussion of the research methods.

CHAPTER 2

CONCEPTUAL FRAMEWORK: LITERATURE REVIEW

Introduction

A critical literature review was made to assist in defining the research problem. Presented are the findings of prior research and publications directly related to this research dissertation. This chapter is an evaluation of similar or directly related research studies and results. Many of the details typically found in a literature review that relates to what has been accomplished in the filed of this research is presented in the methodologies section as many of the concepts within the reviewed papers are key in development of the methodology.

USDA FSA 35 mm Slide Film Current Concepts

This section will review the current published method of collecting the aerial compliance images with 35 mm slide film. This information is a summary from the USDA FSA Aerial Compliance Handbook 2-CP.

USDA FSA crop compliance checking falls to state USDA FSA offices for coordinating and conducting aerial compliance flights. Aerial compliance is used for performing measurements for areas 25 acres or larger (USDA OK FSA, 2001). USDA FSA state agencies submit flight information such as begin date, completion date and compliance methods.

FSA counties contract to have areas flown with 35 mm slide film, then review slides for suitability and acceptability, then index the slides for easy access using slide carousals, trays or projectors. Aerial compliance activities use the equipment listed in Table 2.1 to collect the data (USDA FSA, 1996).

A definition of terms for flight operations is shown in Table 2.2. The procedure for acreage verification for crop compliance with the use of aerial 35 mm slide images begins with a predetermination of the target's approximate area with a length by width rectangular model. The target length coincides with the longest distance of the target area. The target width is then calculated to be 0.6667 of the target length. To exclude any distortion in the slide, the image coverage is calculated by multiplying the target length and target width by 1.1. The altitude of the aircraft is proportional to the coverage length as the focal length of the camera is proportional to the desired slide length of scale as seen in Equation 2.1 on Table 2.3 (USDA FSA, 1996). Generally, a USDA county office will utilize consistent methods and specifications of a previous county target size. Aerial contractors are required to collect standard coverage areas.

FSA requires that flights take place when the maximum color contrast so crop identification can be achieved. Flights for data will be commenced in conditions in which haze and light angle of incidence are consistent. Once image data are collected, slides are sent for film processing. This can take from three to five days based on the geographical location to the nearest commercial 35 mm slide film processing center.

Table 2.1: USDA FSA Aerial Compliance Approved Equipment.

Equipment	Specification
Aircraft	Small, suitable adaptable aircraft with a hole cut in the floor through the underside, for example, Cessna 152.
Camera	35 mm single lens reflex camera with a focal length of 20 – 28 mm having at least a 2.8 f-stop and a shutter speed to 1/1000 and appropriate filters to take pictures through haze.
Film	Kodachrome 64 (KR 135), Ekatchome, or equivalent.
Positioning Equipment	Camera support to provide protection and stability Spirit level to ensure camera is vertical when picture is taken
Projector	35 mm projector equipment with the following: remote control with focusing capabilities minimum capacity of 50 slides, and lens, such as 76mm Kodak projection lens f 3.5 or equivalent.
Rear Projection Unit	Must project a clear image at a 90-degree angle to an appropriate surface. A DA-Plex acrylic screen is recommended for best results.
Digitizer	Must determine acreage directly from slide images projected to any scale.
Test Grids	Used to set accuracy of 4-point setup with digitizer to correct for tilt, distortion and scale differences.

Slides are added to the projector and indexed accordingly. Slides are then used to identify crops and measure acreage for compliance reports by determining the exact area designed for specific cropland or land use. The owner, operator or other tenant of an agriculture property subject to compliance often requests the service for measurement.

Measurement service as determined by the FSA must be done in a timely manner. Targeted crops, which are about 10 to 15 percent of total crops in crop support, must first be found manually by checking past information or tax records along with USGS 7.5 minute quadrangle sheets. This process may be time consuming, thus the development of a GIS that can link the information of land ownership to crops and support level is proposed. Regardless of complexity, service rates shall be set to cover costs for the following measurements:

- measuring crops after planting;
- staking and referencing acreages to be planted;
- measuring acreage that has been adjusted;
- verifying crops and disaster acreage;
- making crop appraisals and reappraisals;
- re-measuring any acreage that had been measured previously;
- measuring or sampling farm-stored commodities; and
  verifying production evidence.

Table 2.2. Definition USDA FSA of Aerial Terms (USDA FSA, 1996).

Term	Definition
Altitude	The height of the plane above ground. The maximum altitude above sea level which maybe be safely flown without oxygen is 12,000 feet.
Coverage	The total ground area covered by a single slide. The coverage area is about 21 percent larger than the target area. This eliminates the need to use the edges of the slide, which may be distorted.
Focal Length	Either of the following: - The distance between the camera lens and the film expressed in millimeters. - The distance between the projection lens and the slide expressed in inches.
Projector to photograph distance	The distance required to obtain the proper scale. The minimum distance for proper focus of the slide image is approximately: 6 inches for a 3 inch-lens 14 inches for a 4 inch-lens 21 inches for a 5 inch-lens 28 inches for a 6 inch- lens
Target	The area on the ground that is the subject of the slide.
Target Length	The dimension of the long side of the target. The target length is always the relationship to the long side (36 mm) of the slide.
Target Width	The dimension of the short side of the target. The target width is always the relationship to the short side (24 mm) of the slide.
Slide Image	The projected image of the slide on rear projected digitizer.
Slide	A photographic transparency that measures 35 mm long and 23.3 mm wide mounted in a 2 by 2 inch frame.

Table 2.3: Equations for Aerial Imaging (USDA FSA, 1996).

Term	Definition	Equation
Target Length (TL)	Longest length of target area rectangular model	
Target Width (TW)	TW = TL x 0.66667	Eq. 2.1
Coverage Length (CL)	CL = TL x 1.1	Eq. 2.2
Coverage Width (WL)	CW = TW x 1.1	Eq. 2.3
Altitude (A) Focal-Length (FL) Slide-Length (SL)	A / CL = FL / SL $A = \frac{FL \times CL}{SL}$	Eq. 2.4 Eq. 2.5

These costs are passed to the producer and, ultimately, to the consumer. Costs can be elevated based on the time factor of producing a final product. USDA outlines the cost to include:

- measuring equipment and supplies;
- training field assistants, inspectors and digitizer operators;
- travel cost involved in training and performing measurements services;
- determining service charges;
- accepting requests and handling measurement service fees;
- performing pre-work layout, such as pre-delineating and digitizing;
- supervising field assistance and digitizer operators; and
- reviewing and notifying farm operator of completed service.

Before measurements can proceed, the 35 mm slide must be georeferenced. The procedure for this task begins with setting the images to the desired scale proportional to the focal length and flying height by adjusting the slide projector position manually. The slide projector is rotated and shifted to match the existing large format print DOQQ photographs that contain the land information boundaries scribed on the image. Four permanent reference points are taken from the 35 mm slides that are visible on an older county office large format print photograph in DOQQ format. A rectification is made using digitizer settings. The digitizer adjusts measurements by assessing the four ground points. The digitizer has an internal calibration method that ranks the rectification calibration. The digitizer will also alert the user if an area of interest is too far from the four-point calibration. Digitized areas become static information and can only be used to generate area. All information and production from digitizing such as polygon shape and vertices, are lost based on the data not being stored with the existing digitizing systems.

USDA FSA GIS

This section will discuss current methodologies and research in implementing crop compliance monitoring. Discussion on other USDA agencies utilization of the small-format 35 mm slide film for GIS applications is presented.

The USDA FSA Aerial Compliance Handbook 2-CP (1996) is used to inform USDA FSA field offices of the methods and processes for contracting, obtaining, and reporting acreage with aerial 35 mm slide images. This handbook is used to establish the framework of the GIS application within this dissertation. This standard government document contains all information necessary to establish a county compliance and measurement office. The methodology outlined offers critical information that can be quickly accessed to meet the needs of the users. The taxonomy of the document follows the procedures of data collection and processing. Information about the procedure for obtaining the photos is explicit in assisting the aerial vendor and county office as discussed in Section 1.

Processing of the imagery to compute the acreage is mainly procedural in content. The handbook does not give a scientific approach to the requirements set forth in the photogrammetric process. It offers no theoretical basis for the procedures, but simply outlines the procedures of aerial crop compliance monitoring. Little attention is given to the science of image rectification. This has resulted in users operating with little knowledge of photogrammetric area calculation and the importance of the rectification process. A manual process of data collection of the area is used which does not allow the storage of the digitized polygon for insertion into a GIS.

After reviewing this handbook, serious doubts about the final product accuracy of 0.1 acre are raised. Communication with the USDA FSA office in Nueces County, Texas substantiates the same conclusion. This dissertation establishes a better method of capturing the area polygons and improves the accuracy of the data collected.

The requirement of improving the accuracy of the areas obtained with digital imagery has been addressed (Harrison *et al.*, 2002). The National Recourses Inventory within the National Resources Conservation Services used digital imagery, image processing and GIS to automate data inventory collection using the USDA FSA 35 mm slide film products. It was shown that the 35 mm slide film scanned using SprintScan 35 software produced a large size image on the order of 60 Mb per image (Harrison *et al.*, 2002). Davis (2002b) similarly investigated this and found that images 6 Mb was adequate, therefore a lower resolution scan could be used. Harrison *et al.*, (2002) concluded that this method of scanning and georectifying was had a considerable "up-front" cost and unanticipated risks suggesting that a digital camera is necessary.

Typical photogrammetric and remote sensing properties, such as scan rate, data storage, naming convention, color balancing, and mosaicking must be considered with digital imagery (Welch and Jordan, 1996). Here Welch and Jordan (1996) define the parameters of raster imagery in a GIS. Results show that the image size in uncompressed format is considerably larger in storage then a compressed image. This work is critical to this dissertation in dealing with scanned or raw digital imagery. Moving digital imagery from a small-format camera in real-time to a storage or processor will have to be considered.

It is often overlooked that the georeferencing process is still a critical element in the area computation. Each scanned image must be rectified using ground control points (GCP's), often obtained from DOQQ's products or Mosaicked Digital Ortho Quad (MDOQ's). With the scanned image, new methodologies and considerations arise.

Other methods of improving the process of acreage measurement have been attempted with the new program of developing a CLU within a GIS. USDA FSA is developing a seamless digital line data map of land information within a GIS of common land boundaries (USDA FSA, 1998). This new procedure addressed in the USDA FSA CLU handbook does not establish a new method of obtaining imagery, but only establishes the GIS layers.

Use of satellite imagery such as Landsat, Ikonos, and Quickbird has been discussed for assisting in crop compliance (Heald, 2002). Heald (2002) presents the USDA FSA concepts of utilizing a GIS to replace the current method. This descriptive article defines the procedural and conceptual stages that the USDA FSA will go through to build the GIS. Suggestions of methodologies of using satellite imagery, DOQQ's and scanned 35 mm slide film is presented within the publication.

It is worthwhile to acknowledge that these products will aid in improving the methodology and process of collecting the acreage, but the photogrammetric product produces higher spatial resolution and higher temporal resolution as needed in crop compliance (Anderson *et al.*, 1999). Anderson *et al.* (1999) discusses how the elements of agriculture are in phases. These phases need deliverable aerial images in a timely data scale. Satellite solutions do not meet “the problems associated with improving the temporal fidelity” (Anderson *et al.*, 1999, p. 1119). It is suggested that local companies using airborne technologies address these issues. Temporal resolution is defined as the time interval between measurements in data collection (Lo and Yeung, 2002). Temporal resolution is critical in crop monitoring as change detection can better be analyzed. Improving the temporal fidelity, or time between data capture, of the same area could be achieved with small-format digital aerial camera and thereby creating a higher temporal resolution of imagery.

The satellite imagery must also be georeferenced. The imagery serves other purposes that are not directly addressed with satellite images, such as aiding the farmer and county office in determining new crop-lines for crop rotations, conservation work, crop insurance, and land management activities (Bailey and Meador, 2002). Bailey and Meador (2002) offer other usages of the imagery. The complexity and intensity of scanning and georectification of the 35 mm slide film overburdens the benefits.

The small-format camera continues to support the USDA field offices and the farmers. The USDA FSA, like others, concluded that moving to an all-digital system can improve accuracy and production. This section discussed the importance of using a GIS to replace the current method.

USDA FSA Search for Alternatives

In research conducted by the USDA FSA on imagery requirements and possible alternatives to current practices, a recommended plan of action was proposed in a recent white paper for supporting FSA farm programs (Williams, 2002). The standard requirements of the FSA are:

- maintain farm records and boundaries;
- identify and verify crop type, color, and coverage;
- measure acreage +/- 0.1 acre;
- image acquisition;
- share data;
- support GIS in a digital format; and
- provide FAA security- flight plans within 24 hours, instrument flight rules, visual flight rules.

To meet the FSA requirements in 2002, a multi-source program of using a small-format camera or DOQQ's was suggested (Williams, 2002). Small-format imagery will allow locally acquired and locally rectified service centers. In order for a small-format image to cover the same area as large-format image, a mosaic method must be applied or higher altitudes must be flown. The USDA FSA developed a cost analysis of three alternatives to image existing counties covered in FSA crop compliance.

Table 2.4: Expected Cost for USDA Small-Format Versus Large Format (Williams, 2002).

Estimated Annual Cost of Alternatives					
Alternative	**FY02**	**FY03**	**FY04**	**FY05**	**FY06**
Small-format Georectified	$2,767,000	$8,610,000	$14,760,000	$19,680,000	$19,680,000
Large-format Geo-orthorectified	$5,400,000 Ortho-rectified	$16,800,000 Ortho-rectified	$28,800,000 Ortho-rectified	$28,400,000 Ortho-rectified	$28,400,000 Ortho-rectified
Large-format Georectified	$4,095,000	$12,740,000	$21,840,000	$29,120,000 Ortho-rectified	$29,120,000 Ortho-rectified

Table 2.4 shows three possible alternatives that were researched; (i) Small-format Georectification, which has the small-format 35 mm slide film georectified with the DOQQ's, (ii) Large-format Geo-orthorectified, which has 9" x 9" imager taken and orthorectified, or (iii) Large format Georeferenced, which has 9" x 9" only georectified, but start orthorectifying after FY04. A 2-meter scan rate of the large-format images was suggested (Williams, 2002). This would also eludes to the use of high-resolution satellite imagery.

Georectification would meet the requirements set forth by the FSA, but in some areas geo-orthorectified images would be better suited to remove distortion that would cause problems in overlaying CLU layers in a GIS. These areas would include land that has varied ground relief. CLU is the smallest unit of contiguous boundary polygon vectors of common land-cover. The GIS includes owner, tenant, and common producer association.

This can be achieved by georeferencing and differential rectification using USGS Digital Elevation Models (DEM's). The 30-meter spacing of the DEM is adequate based on the large land structures.

Conclusions were drawn that suggest that alternative three be pursued (Williams, 2002). To accomplish this alternative the USDA should seek partnerships with other local, state and national agencies to share the cost.

Converting the 35 mm slides to a digital format so that heads-up digitizing (digitizing scanned images on a computer screen) can be utilized is one method that has been researched. The USDA FSA Aerial Photography Field Office (APFO) recommends the scanning and naming of the 35 mm slides for injection into a GIS (Davis, 2002b).

Davis (2002a,b, and c) pioneered many of the accomplishments in searching for alternative methods of collecting the crop compliance images for digital computation. Davis (2002c) did not perform a direct georeferencing method, but used the GPS with the DOQQ's to georectify the imagery.

Davis (2002c) research will be defined in more detail in later section. Davis (2002a,b,c) research proved the most up-to-date information investigated by the USDA FSA and provides many concepts that are useful for this dissertation. This section discussed some alternative methods that other related and direct researches have attempted to improve the existing method. Utilization of a small-format digital camera appears to be the best method. Review of other research of small-format digital camera for GIS application is discussed.

Prior Research of Small-Format Digital Camera for GIS Application

This section will discuss in detail the previously referenced application of small-format digital camera for GIS applications. Small-format digital cameras aerial photography for large-scale, small-area mapping has been demonstrated to have good potential (Mason *et al.*, 1997).

Mason *et al.*, (1997) demonstrated the use of a Kodak DCS460 digital camera for mapping small areas. Improvements in the mounting of the small-format digital camera and pointing precision of GCP extraction are concluded. It was found in the review of literature that applications using small-format digital cameras referenced the continual problem with image size and data transfer. Mason *et al.* (1997) found it took ten images at 18 MB each to cover the research area. After collection the images were easily transferable to a PC. Other problems that arose with this small-format digital camera were that the 24 bit images are interpolated from the original 12-bit color image. This interpolation step hindered the true quality of the image.

Small-format digital cameras have not seen wide usage due to some of the limitations that exist (Gravel *et al.*, 1999). In this application Gravel *et al.*, (1999) showed the surveying total station integrated with a small-format digital camera in a terrestrial format. Images are rectified using points located with the surveying total station allowing for terrestrial photogrammetry. This application found limitation of transfer and size to also be a consideration

Early pioneers saw limitations within the digital charged coupled device (CCD) chip, the equivalent of the film media. Small-format size and huge data handling together present a major hindrance to mainstream user acceptance. Small-format digital cameras have caused data collection methodologies to be modified as compared to typical large-format film aerial imagery procedures. Modifications include, flying height, lower flying speed, and target photography versus strip photography (Compass Informatic, 2000). This is based on the image size, collection process and data handling procedure.

Compass Informatics (2000) used an airborne digital camera system for fisher habitat designation for the Salmon Research Agency of Ireland. The project's objective was to assess the suitability of small-format aerial digital imagery as a complement to ground-based river habitat surveys in generating a GIS of in-stream, riverbank and riparian habitat conditions in freshwater fisheries. The system was designed to mosaicked imagery, format and correct images for terrain-induced distortion. A Kodak DC460 digital camera, Trimble ProXL GPS and a laptop computer are used in the project. The *auto* process is still a post-processing method that requires recording all information for later analysis. A ground-processing segment was used to georeference the imagery to the Irish National Grid coordinates, mosaicked, correct distortion, and use DEM (Compass Informatic, 2000).

The USDA Forest Service evaluated a Kodak DCS 2000 color digital camera for use in natural resource interpretation and mapping. The camera resolution is 1524 by 1012 pixels at two frames per second. Software was developed that was used to navigate, capture images and create an index footprint by applying autonomous GPS exposure positions. Data were all post-processed and showed positive results. Based on the digital source of the images, the window of turn-around was near real-time, but still demanded post-processing by experienced aerial surveying personnel. It was also noted that near infrared (NIR) spectral resolution was achieved by removing the 'blue-blocker' lens and replacing it with a 'hot-mirror' filter, which displayed NIR (USDA FS, 1996).

Another usage of small-format digital cameras involved a color digital camera for quantitative remote sensing analysis of vegetation by West Virginia University, Department of Geology and Geography (Dean *et al.*, 2000). In this research a Kodak DCS460c digital camera and high-resolution color imagery were used to identify species of deciduous vegetation. This research's main objectives were to focus on the image spectral characteristics. The flight characteristics of the project are single exposures at 450 meters above the site. It was concluded that the digital camera produced more spectral consistency for multiple image acquisition of similar targets (Dean et al, 2000). Use by the USDA in interpretation and classification of crop types is possible with a digital camera capable of NIR image collection.

Accuracy of the spatial resolution of small-format cameras for mapping applications has been addressed in several publications. A Kodak DCS460 was used in Cape Town, South Africa as a viable alternative to analogue cameras in mapping settlements. Images yielded spatial accuracies on the order of 0.2 meters horizontally and 0.6 meters vertically at a scale of 1:18,500 (Mason, et al, 1997). The characteristics of the Kodak DCS460 include large image files of 18.6 Mb, slow recording rates of eight seconds for two images and a small field of view or image size. An analysis of the image resolution in terms of modulation transfer function of the lens and system was conducted (Mason *et al.*, 1997). To achieve 39 mm line-pair (lpr), an average for large-format photography at a 25-micron scan level, a digital image must achieve a 13-micron level. That 13-micron level is close to the 9-micron pixel size of the Kodak DCS460.

Conclusively, four times the number of digital images are needed to acquire the same area as a scanned film product. This same prediction was discussed earlier by the USDA analysis of small-format digital imagery (Davis, 2002c). Images from large-format cameras such as the Leica-Wild RC-30, Zeiss Top-15, or LMK-2000 have an estimated resolution of 39 lpr/mm and would require an 11-micron scan size (Light, 1996). For a 9 by 9 inch photo would need to have a CCD with an sizes of 28,000 by 28,000 pixels, with each pixel being 11-microns to be equivalent to the metric film product (ASPRS, 2000).

Image comparisons between film and digital images can best be summarized by the ASPRS Calibration Final Report that states "the resolution of some digital cameras is equal to film cameras, the dynamic range, yielding about, 4096 shades of gray, is superior to the 180 shades of gray typical of film systems" (ASPRS, 2000 p.6). Digital camera systems are quickly maturing, and digital camera technology appears to be concurrent with computer technology's rapid growth.

Some methodologies, such as the camera calibration process, remain constant between small-format and large-format imagery (Fraser, 1997). Fraser (1997) determined a small format digital camera self-calibration method. It was found that other potential problems existed such as movement in the CCD chip, image plane warp, and in-plane image distortion. This self-calibration method showed potential for photogrammetric applications with a small-format digital camera.

However, camera calibrations in digital cameras have different parameters; such as the CCD chip distortion and exposure write time. Many of these errors are discounted based on the GIS application accuracy requirements (Kersten and Haering, 1997). Kersten and Haering (1997) used scanned photographic film to analyze the interior orientation of digital aerial images. It was found that the intensive determination of the interior orientation was not necessary for all application, but for photogrammetric applications the orientation took about 40 seconds per image to automatically calculate.

Interior parameters of small-format camera have been evaluated with commercial image processing software such as ERDAS Imagine or R-Wel Digital Mapping System (Twiss *et al.*, 2000). This application was used to estimate the gray seal length, width and body mass with a small-format camera. The images were 5- by 4-inch format film. The images were scanned at 4096 by 6144 pixels.

Results showed that some distortion (0.096 mm) existed in the bore sight of the camera to the principal point. This research concluded that if an application requires high accuracy such as species quantification, then very accurate GCP's are needed for georeferencing and digital elevation models (DEM's) should be used to remove orthographic distortion.

These procedures are similar to small-format film camera techniques. The exterior calibration remains constant and is addressed later, as it becomes the main emphasis of this dissertation. Investigations into the spectral resolution of the digital sensors have had a gradual history. CCD's have increased in size and complexity within the consumer product range.

Pixel interpolation within a Bayer Matrix and brightness fall-off with smaller view angle have been addressed within different applications and research (King 1992a; King 1992b; King 1993; and Dean *et al.*, 2000). The small-format digital frame camera has the advantages of higher resolution and radiometric quality compared to NTSC-video systems and offers better geometric quality compared to line scanners. These advantages indicate a need for investigation for use in crop compliance monitoring (King *et al.*, 1994).

King (1995) found that acceptance of videography has been based on the low cost of sensor components. Kings (1995) research showed digital video sensors are non-interlaced and are considered full digital frame sensors. Instead of a line scan method of analog video the sensor grabs and writes the entire frame. A calibration method of aligning the camera in a lab based on relative orientation method of photogrammetry was performed. Multiple frame grabber digital video cameras with pass filters were developed for this research. The cameras were associated to computer hardware and software system. GPS was utilized in the research, but not presented. Conclusions were drawn that demonstrated multiple applications in which the system could be utilized.

King *et al.*, (1994) pervious work had focused on elevation determination with digital frame images. The research showed that digital frame video cameras has advantage of high resolution and radiometric quality compared to NTSC analog video systems. The results produced indicated that digital frame video cameras can be used to determine elevations and are suitable for applications of rural and municipal mapping projects for integration with a GIS framework (King *et al.*, 1994).

Currently the remote sensing industry uses moving line or scanner sensor systems in a large-format satellite and airborne system. For example, the Leica Geosystems AD40 airborne digital sensor is capable of collecting large-area and large format datasets with moving line scanning (Fricker *et al.*, 2000). These large-format systems are considerably more expensive and require more processing then a small-format digital camera. Small-format digital cameras typically use digital frame or digital frame video sensor systems. Digital frame video is the newest system currently being investigated. Airborne digital frame video has data capturing advantages over digital frame sensors such as the ability to capture high volumes of imagery.

Menges *et al.*, (1998) further demonstrated how high-resolution airborne video data could be used to assess and map land cover types in northern Australia. Digital frame video has the ability to capture continuous high-resolution digital video data (Menges *et al.* 1998). These digital frame video cameras were used to obtain ground 15-centimeter resolution. It was found for this application that the optimal resolution for remote sensing of the vegetation communities required spatial resolution of 20-27 meters. To obtain this resolution the canopy cover image was filtered to 5, 10,20,30, and 40 meter pixel resolution. The digital video camera was mounted in a helicopter and flown at a flying height of 500m. The imagery was rectified before resampling using differential GPS (DGPS) in the order of 1-3 meter GCP's.

Multiple digital frame video cameras can be used to provide different spectral images concurrently by aligning and calibrating the individual images into a composite single image solution (Cramer 2000b; and Kulkarni *et al.*, 2002). This is demonstrated in a phase one of this dissertation where the digital frame video was used to capture images of urban highway area in Corpus Christi, Texas (Kulkarni *et al.*, 2002). Here GCP's were used to georectify a series of images to mosaic a composite of the highway. The GCP's were obtained using DGPS were a minimum of six points per image were obtained. Each image was extracted from the video were a 60 % overlap was collected. Once georectified it was found that the images, based on their format of digital frames, showed stereo characteristics. Elevation data could be extracted from the imagery. The images showed potential for utilization of the spectral values to analyze the sediment within the water areas around the coastal area (Kulkarni *et al.*, 2002).

Videography with analog video film has been shown to be relatively inexpensive to initiate and operate in studies of GIS land cover classification applications (Smith *et al.*, 2003). Integration of the digital frame video sensors to a PC will also allow for collection of large data volumes. The results of these studies show that adapting more digital videography to land cover classification is less expensive, and more continuous data sets are acquired.

Smith *et al.*, (2003) described how difference between analog videography and digital camera systems. Georeferencing the imagery was a concern with synchronizing the GPS to the camera. Results showed that the digital camera could be used for land cover classification over the use of Landsat Thematic Mapper (TM) satellite imagery. Targets with similar spectral signatures such as different type of deciduous vegetation were more easily distinguishable with digital imagery.

A review of literature has demonstrated the use of small-format digital camera for multiple applications. Limitations and advantages of the camera characteristics has been provided. A more in depth look at small-format digital camera systems is need to select the proper camera system.

USDA Small-Format Digital Camera

The USDA FSA seeing the shortfalls of their methodologies with 35 slide film and has attempted to improve the process. Small-format digital sensors or digital cameras for remote sensing have been investigated by FSA for several applications. As of 1987, the current method of image acquisition has generated 50,000 rolls of 35 mm film and 1,250,000 slides for 2,800 counties with in the United States for crop compliance and other applications.

Three small-format digital cameras were evaluated; (i) Nikon D1X, (ii) Kodak DCS760, and (iii) Contax N1D. Over 100 hundred small-format digital cameras were researched (Davis, 2002c). The three evaluated cameras represented the best resolution and configuration that matched the 35 mm slide film. Conclusions were made that suggest that no small-format camera existed that could have the quality of the 35 mm slide film camera. It was stated that an eight mega-pixel digital image would be needed to meet the resolution of a scanned 35 mm slide at 1,200 dots-per-inch (dpi). Current high-end digital cameras are capable of six mega-pixel images with a 1/1000 second shutter speed. Data are captured locally on a flash memory card or with a USB or IEEE 1394 firewire connection to a laptop computer. A one-gigabyte (Gb) micro-drive cartridge can be used internally on most digital cameras. Logging images locally into a laptop computer with a 32 Gb drive was found to be the best solution (Davis, 2002c). Data capture software has been developed allowing for planning and post processing of images for the USDA. The software focus was to index the photos based on stand-alone GPS positions.

It was mentioned that third party software could be used to georectify the images. Stand-alone GPS data, previously georeferenced DOQQ or USGS 7.5 minute quadrangles can be used to georeference the digital images. Image georeferencing is addressed in terms of using ground control to "rubber-sheet" or georectify the small-format digital frame. The conclusion is "orthorectification of the images would far surpass the necessary accuracy level and would be much more expensive and time consuming" (Davis, 2002c p.9).

These conclusions strengthen the position within this dissertation that research into a direct georeferencing solution with minimal human intervention is necessary. GPS solutions still hold the best option for initiation in an aerial platform. Long-range differential GPS solutions have been shown to support real-time imagery at the level of accuracy needed without post processing (Lyle and Wood, 2002). With the advancing technology of digital frame (DF) and digital frame video (DFV) taken into consideration the main focus of this research was a method that would allow direct georeferencing.

USDA FSA GIS with Small-Format Digital Imagery

Within this section digital imagery storage in an aerial platform is discussed, data analysis for the establishment of GIS is defined, and the GIS for crop compliance analysis is the final element is established. Integration of GIS data layers that allow mapping of agriculture resources is an effort the USDA has initiated. The CLU contains a geospatial component that is ideal for the construction of a GIS.

The LIS is typically referred to as a land management system in which decisions about the land and its resources, such as crops, are supported (Lo and Yeung, 2002). For this research LIS is identified directly as a GIS. Decisions for the USDA include property ownership, water resources, land erodability, crop type, support level, insurance, and other values needed to formulate agriculture support and fines to meet the laws set forth in the US Farm Acts. GIS is the tool and process that will be used by the USDA FSA in future resource management. The transition from an analog to a digital method of data capture and storage is the procedure deemed by the USDA to be the future methodology (Davis, 2002c).

The problems addressed in this research are the investigation and automation of a small-format digital camera for remotely sensed aerial images used by the USDA and FSA for crop compliance and boundary digitizing, replacing the current manual method and utilizing 35 mm slide film solution. The research contribution to science is the development of a new methodology for aerial crop compliance checking and processing for developing the GIS of the CLU layer. Improvements will be addressed for the current temporal scale of gathering, processing, and analyzing aerial images.

Compliance, as defined by FSA, is the assessment of agriculture crops to determine if performance requirements for those receiving benefits for crop support are maintained (Bailey and Meador, 2002). To determine if participants are in compliance, random inspections are made to ensure that provisions are being met. Compliance encompasses all assistance programs administered by FSA. Inspection is often done by two methods. The first is ground truthing with field inspections, and the second is aerial compliance photography flown each summer with 35 mm slide film (Bailey and Meador, 2002). Producers voluntarily report farm crop history and acreage. These reports are the criteria used to develop future farm programs (USDA OK FSA, 2001).

Aerial photographs also aid the offices and farmers in determining new crop-lines for crop rotations, seed corn and plots, irrigation pivots, specialty crop acreage, tiling, conservation work, and crop insurance (Bailey and Meador, 2002). The Food Service Act of 1985, as amended by the Federal Agriculture Conservation and Trade Act of 1990, and the Federal Agriculture Improvement Act of 1996, discourages overproduction of highly erodible soils; therefore compliance is often conducted to ensure producers' follow a conservation plan in susceptible areas (USDA OK FSA, 2001).

The month of May is typically when compliance checking for small grains is completed. All other crops are usually reported by August (USDA OK FSA, 2001). Improvements in the process of crop compliance measurements can assist the agricultural industry by providing fast, viable information that can be used universally between farmers and agencies. Improvements in the final results of time to final product can also assist farmers and agencies in improving crop performance, which is related to precision farming. GIS is a tool used in precision farming and can be of assistance because it organizes the entire agriculture process.

GIS is a spatial information database science providing an organized collection of computer, hardware, software, geographic data, aerial imagery, maps, and personnel. It is designed to efficiently capture, store, update, manipulate, analyze and display all forms of geographically referenced information (Clark, 1997). GIS implementation by the USDA for aerial compliance is now a standard. The 35 mm slide images must be scanned and entered into a GIS. The slide must be rectified using existing USGS DOQQ's as seen in Figure 2.1. To improve this process, the use of digital imagery has been suggested.

The CLU data layers are a critical component for the FSA implementation of GIS. FSA seeks to survey and map all farm fields in the country to delineate agricultural and non-agricultural farm areas. FSA seeks to use GIS to assist in many other projects, such as addressing geospatial time-series information of security, privacy, production, and natural disaster relief programs.

The proposed current method for the development of the CLU includes transfer of data from the hard-copy maps using on-screen digitizing. Mosaicked DOQQ and DOQ imagery will be used as the base layer for developing the CLU. Current imagery in many areas is not available. It has been proposed that the 35 mm slide film be used in those areas (Heald, 2002). The need for more modern methodologies to obtain the imagery is the focus of this research in order to produce a rectified digital product reducing the need for the manual 35 mm slide film procedure.

Figure 2.1: USDA FSA Scanned Georeferenced 35 mm Slide of Nueces County, Texas.

From the USDA FSA (1996) handbook it was determined that the replacement system must be simplistic in nature in order to accommodate the inexperienced end user. Heald (2002) suggests that the solution will be a combination of different products, such as small-format digital imagery and satellite imagery. Research in the development of GIS from small-format digital images has been broad in application.

The review of literature shows the new USDA FSA (1998) handbook for the state and county offices depict the procedures and methodologies to develop the GIS of CLU. Rules are defined for delineating the boundary within the CLU. No information is given on the process of entering the digital imagery into the GIS. Davis (2002a) has investigated a comparison of compressed imagery accuracy within the CLU and found that the MrSID format from LizardTech adequate for CLU digitizing.

Training sections for the field offices have been performed to update the users in the process of utilization of ESRI's ArcView 3.2. GIS software. This training included the use of field GPS data collection. No training was given in the process of georeferencing or georectification. The USDA FSA offices have continued to use the older method of crop compliance area measurement in most of the United States for the 2002 program.

Those states that have successfully transitioned to a digital compliance method have employed scanned 35 mm slide film, satellite imagery, or high altitude airborne imagery. A correlation is evident between the states that have seen successful transition and the cadastral system of the Public Land States. This has been accredited to the large land section and quarter section land tracts. The use of Landsat imagery is successful based on the large area of coverage. It has been found to be easier to detect the crop and even crop type utilizing photo interpretation with large land areas (Avery and Berlin, 1985). Detection and identification of crop types with the satellite and high altitude airborne imagery is more problematic in states that have a metes and bounds systems with irregular shaped land parcels.

The small-format digital cameras directly georeferenced images proposed in this dissertation will have some error in the final product based on the tilt, platform orientation, camera distortion, image scale and other errors. Procedures to consider the extent of this error and the means to correct it with supporting GIS image and mapping resources are proposed. A complete error–budget analysis is performed on a flight-by-flight mission. Cumulative error of orientation components might exceed the GPS direct position, but is more overly adjusted using the other supporting imagery.

Chapter Summary

In this chapter a critical review of literature was presented to offer a definition of the thesis being addressed. The USDA FSA has actively searched for cost effective solutions for these crop monitoring problems. This review offers other methodologies and procedures for using a small-format digital camera imagery for GIS applications. The findings and conclusions within the literature point to small-format digital camera imagery meeting the prediction and recommendation set forth in this dissertation. A new paradigm of eRTK-GPS for direct georeferencing of the exterior position of the digital image is the projected outcome. A suggested new framework for the USDA FSA has been presented that addresses the strengths and weaknesses of other small-format digital camera GIS applications.

CHAPTER 3

RESEARCH METHODOLOGIES AND CONCEPTS

Introduction

This chapter deals with the current trends and common technologies critical to the achievement of the objectives within this research. Unlike the literature review, this section deals with the specifics of extracting conceptual information in the creation of this solution. Described are the procedures and concepts used to illustrate the dissertation components. Connections between the variations in prior research guide the methodology of this dissertation. Details as to the research methods are provided in the three peer-review papers. This section will provide brief overview of technologies, methodologies and concepts as they pertain to this research dissertation.

Defining Geometric Concepts of Aerial Photography

A review of the geometric concepts of aerial photography is provided to illustrate how the direct georeferencing methodology is produced. Duplication of standard principles are provided to set the stage of the conceptual framework to which the concepts of direct georeferencing.

The American Society for Photogrammetry and Remote Sensing (ASPRS), defines *photogrammetry* as the art, science, and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring and interpreting photographic images and patterns of recorded reflected electromagnetic energy and other phenomena (Wolf and Dewitt, 2000). For this research the principles of photogrammetry are applied to remotely sensed images from a small-format digital camera. This section will define some of the basic principles of photogrammetry as they relate to the georeferencing of small-format digital images.

In GIS, remote sensing and photo imagery are typically the base layers to establish structure to the spatial database. For the context of this research, the terminology and methodology of remote sensing with digital imaging will be used. The digital images from this research have the properties photogrammetric and remote sensing image, with the usage of the images more representative of a remote sensing system.

Commonly, aerial perspectives can be obtained in a photographic record or a digital image record. Analog photographic records utilize a film medium to collect a composite image of the reflectance of natural energy from the sun via a *photographic film camera*.

Aerial images employ the science of vertical photography and geometric optics. The fundamentals of the *central perspective* photography are used in this research. This includes the concepts that rays of light pass through *a central perspective point* (central point or focal-point) and then are re-projected as emergent rays onto a focal-plane to produce a photographic image. The recorded reflectance passes through the central perspective point at the lens and proportionally displays the image on a focal-plane (film or digital frame) (Ackermann and Schade, 1993). The object distance from the focal point is then proportional to the focal-plane distance from the central perspective point. This is a key theory of photogrammetry utilized within this research.

Digital cameras can exhibit photogrammetric properties when used in aerial platform. Aerial photography is considered vertical or near vertical when the aerial platform is oriented within 2 degrees from a plumb line towards the Earth. The platform is flown in accordance with a predetermined (nadir) flight path and aircraft elevation to acquire a series of overlapped photographs cable of stereoscopic viewing.

Equipment used to capture aerial photography and remote sensing data is divided into photographic and non-photographic (Lo and Yeung, 2002). Photographic data are collected with a conventional camera (analog or digital) in the visible electromagnetic and near-infrared spectrum. Non-photographic data (imagery) are acquired with electronic detectors that can obtain the invisible portion of the electromagnetic spectrum, such as thermal, radar, lidar, or microwave sensors.

The film-based product is typically placed at the focal-plane location and records the light intensity and spectral values. Digital cameras replace the film-based product at the focal-plane location with a charged coupled device (CCD) or complementary metal oxide semiconductor (CMOS) chips with light sensors. These pictures represent a real-world perspective of existing features.

Defining Small-format Digital Sensors

This section will discuss the principal concepts of the small-format digital sensors. This is pertinent developing the assumptions that are made when using small-format digital sensors in a GIS application.

A small-format digital camera has similar geometric characteristics to a single-lens frame camera that uses film (Wolf and Dewitt, 2000). The digital camera system is a key element in the proposed research. It should be noted that increasing advances in technology would rapidly evolve this component of the proposed system. The selection of a proper digital sensor should be made to meet the objectives of the application. The recording device, contrary to the film medium, is a CCD or CMOS. CCD is most prevalent and offers the best solution for aerial photography because CMOS requires more light than a CCD. Improvements in the CCD technology will increase the capabilities of the proposed methodologies, but the scientific process and cognitive procedure will remain the base for assisting the USDA and FSA in generating a GIS to assist in crop production. Selecting the correct digital sensor is based on the technical specifications of each individual sensor.

The CCD chip is considerably smaller than typical 35 mm or 9 by 9 inch film. Common chips are 1/4-inch, 1/3-inch, or 1/2 inch square. CCD chips consist of solid-state array chips that absorb incident photons into their internal structure. Digital cameras utilize an in-camera analog-to-digital converter to transfer photons to digital signals. The CCD array is in the typical raster format that is commonly used in remote sensing. Therefore, each detector of the CCD array proportional to each pixel in a digital image (Usery, 1985). It is proposed in this research, as well as in discussion from a series of research papers, that a digital aerial small-format digital camera be used to replace the existing methodology to improve the process for building the GIS.

The science of photogrammetry often is divided into the photographic process and the analysis and application of the aerial photograph or image product. Regardless of the sensor, key specifications and operation define capability to collect the desired imagery.

Table 3.2 outlines the specifications that are the standard of consideration when selecting the correct sensor for this research project.

For this research several possible photographic digital sensors were analyzed for use as a remote sensing device. A small-format digital frame (DF) camera and digital frame video (DFV) camera, with similar geometric characteristics to a single-lens frame camera that uses film, are the sensors being researched. Both systems use a CCD or CMOS to record the reflected sun energy into solid-state array chips that absorb incident photons into their structure. A discussion of the DF and DFV camera is presented later in the review of information pertinent to the USDA FSA agriculture application.

A digital frame (DF) camera operates with a trigger, typically by pressing a button or triggering with an IEEE 1394 firewire communication cable to mechanically open a shutter and captures the reflected light that passes through the lens and filters onto the CCD chip. A typical CCD array is comprised of a checkerboard of a three band color spectrum pattern of red, green, and blue (RGB) cells, also known as a Bayer filter.
The color is interpolated from a series of RGB cells in the checkerboard pattern as seen in

Figure 3.1. Each cell in a Bayer filter is adjacent to a two by two matrix of two green cells for every red and blue cell. The adjacent pixel color interpolation technique assures that the cell is adjacent to the possible color cell. The interpolation algorithm looks at the strength of the missing colors recorded by adjacent pixels and makes a qualified interpolation of the two missing colors on a pixel-by-pixel basis (Graham and Koh, 2002).

Table 3.1: Considered During Selection of the Proper Sensor for the Application.

Image Standard Specifications	
Specification	**Description**
Field of View	Area of coverage that is sensed in single temporal representation.
Spectral Resolution	Electromagnetic spectral resolution the sensor is capable of sensing. This could include its limits and radiometric sampling value.
Spatial Resolution	Often defined to the modulation transfer unit. It represents what is visibly discernable on the photo or image. In digital imagery it is often referred to as the total area or linear measurement of a single pixel.
Temporal Resolution	The frequency of coverage. This is the time value from image to image in the same perspective. For example, if an area of the same perspective is captured every year, the temporal resolution is better then one where the same perspective is captured every five years.

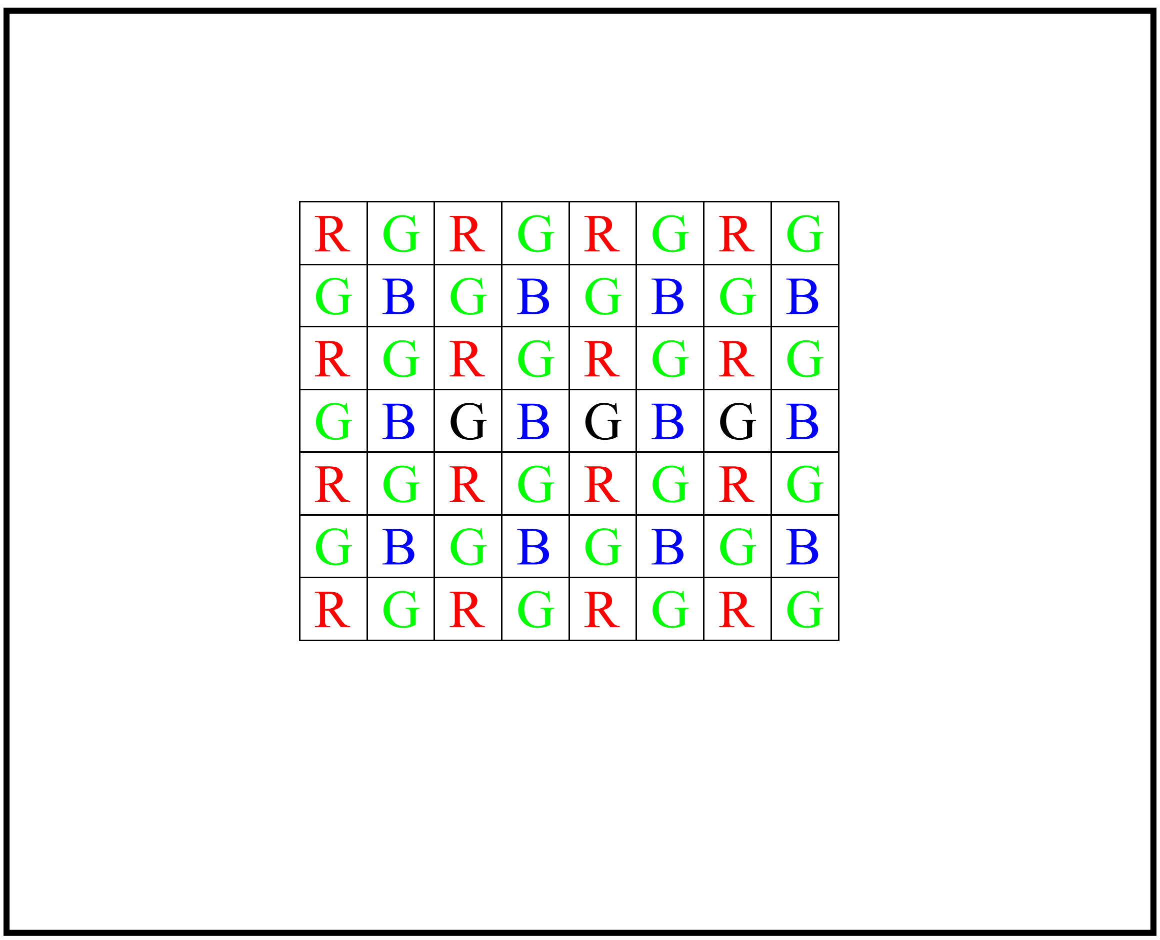

Figure 3.1: Typical Bayer Matrix used in a CCD Chip.

Each cell is covered with a single color RGB filter, allowing each cell to see only one color. The light shines on a sensitive photodiode, which absorbs the reflected energy and generates charged electrons that are recorded. This color is recorded as a *digital number* representing the spectral gray-scale of each of the RGB color bands Once recorded, the image becomes the raster image needed for remote sensing and GIS applications.

New technology, called *Foevon*, is entering the market which stacks the RGB matrix with a configuration similar to film that allows the longer wavelengths to pass through to the other chips (Foevon, 2002). A Foevon chip could improve image quality, but the remaining methodology and process presented in this research will remain constant.

The number of pixel rows to pixel columns often defines the two-dimensional (2D) coordinate system of a CCD chip, where the upper left corner is the origin. Often, a coordinate system other than a digital frame coordinate system is required. To obtain new coordinate values, a linear mathematical transformation must be performed utilizing an *affine transformation* equation and known coordinates in the projected system. An affine transformation maintains line linearity, but will distort shapes. This process of converting digital frame arrays to terrestrial coordinate systems is often known as *referencing* or *geo-referencing* (Lo and Yeung, 2002). Ground control points that have known coordinates are matched with digital frame coordinates to compute the transformation parameters.

Digital images from a small-format DFV camera operate similarly to a DF with essentially the same recording procedures and geometric principles. The shutter of a DFV remains open and the CCD array binary code is recorded on digital tape media. Digital tape media are capable of recording 60 to 90 minutes of digital frame video, which equates to approximately 200,000 total frames. Typical analog video and television display are defined in horizontal lines of resolution. DFV is recorded in frames, but often considered in lines of resolutions to be consistent with current analog video. When using an IEEE 1394 firewire port on a computer, digital video can be captured in a compressed movie or by individual frames maintaining the CCD raster matrix. This can occur on-the-fly (in real-time) or in playback mode. The main difference between DF and DFV is the CCD image resolution that depends on the CCD chip size. A large-area CCD chip DFV camera will actually produce a better picture than a small-area CCD chip DF camera. This is a direct correlation between the write speed of the digital image and the ability to capture imagery with efficient overlap for mosaicking.

This section defined two small-format digital camera image types. Both DF and DFV have distinct advantages and disadvantages that will be presented in this dissertation.

Defining Global Positioning Systems

The following section reviews the Global Positioning System (GPS) in reference to its use in this research. A review of the terms and methodologies is presented that directly relates to the research objective of testing GPS in an aerial platform.

GPS is a simplified acronym for the NAVigation System with Time And Ranging Global Positioning System (NAV STAR GPS), which is comprised of a Space, Control System, and User Segments. The space segment is comprised of 24 satellite systems orbiting Earth every 11 hours and 58 minutes at approximately 20,200 kilometers from the earth's surface (more satellites are in orbit, but 24 satellites is considered a full constellation). Satellites are set in six orbital planes with 55 degrees of inclination from the equator. Each satellite broadcasts two carrier frequencies. These frequencies carry digital data and information on the L-Band of the electromagnetic spectrum. The L1 carrier is 1575.42 Mhz at 19 cm long wavelength and the L2 carrier is 1227.60 Mhz at 24 cm long wavelength. The L1 carries two binary coded strings, the Course/Acquisition Code (C/A Code) and the Precision Code (L1 P-Code) and the L2 carries only the Precision Code (L2 P-Code) (Hatch *et al.*, 1997).

These codes are used to determine the range of the satellites to the other Control Segment and the User Segment. Currently, the second generation of GPS satellites called the GPSIIf is scheduled to launch in 2004. It should be noted that with the launch of the GPSIIf, a new civilian code is added to the L2, as well as a new L5 frequency. This newly proposed code and frequency aid in the tracking, acquisition and GPS positional accuracy for the civilian User Segment.

The GPS orbital ephemeris is used to calculate the radial location of the satellite in reference to the World Geodetic System 1984 (WGS 84) ellipsoid. This is used in combination with ranges calculated by using Newton's Law of Motion to compute the time of the wavelength travel from the satellite to the user. The User Segment utilizes the satellites C/A Code and P-Code binary signal which is based on the time given by an acutely accurate atomic clock determining the delay or time taken for a signal to reach a receiver. The User Segment GPS satellite receiver is able to correlate the incoming satellite C/A or P-code to the receiver generated C/A or P-code (Leica, 1999). Multiple satellites are used to determine spatial position by performing a range intersection, or trilateration, of the viewed satellites. At least three satellites are required for X, Y position and for two-dimensional navigation. Four satellites are needed for 3D navigation for X, Y, Z and a time correction range.

Spatial positional tolerance for GPS users is based on several factors. Geometrically, the orientation of satellites in space will provide the best position. Positional solution is optimal when satellites are observed in an equal geometry in which the Geometric Dilutions Of Precision (GDOP) are minimized. GDOP is based on the geometric strength of the satellites at the time of positional fix. An individual GPS unit is capable of an accuracy of 10 meters autonomously (Leica, 1999). Several errors can work to degrade the GPS position, including ionosphere and atmosphere delays, satellite and receiver clock errors, signal multiple-path (multipath) from satellite to receiver, GDOP, US Department of Defense ‘dithering’ to dampen the accuracy of GPS with Selective Availability, and Anti-Spoofing the encrypting of the P-code with a W-Code to produce a Y-Code signal.

To remove or reduce these errors, a simple differential analysis can be performed with the incoming signals based on known positional information on reference tracking stations. The User Segment of GPS establishes its own reference receiver or base station by placing a known World Geodetic System 1984 (WGS 84) coordinate to generate range correction for rovers within one to hundreds of kilometers away (Lyle *et al.*, 1998). This Differential GPS (DGPS) correction can be applied in a post-process or a real-time configuration. Post-processing requires that data at the base station and rover receiver(s) are collected simultaneously and processed together within DGPS software. Real-time solution requires data to be sent via a radio modem from the base station to the rover receiver(s) and processed by the rover receiver's DGPS software. Improvements to DGPS have been seen with the discontinuation of Selective Availability. It has been shown that accuracies of 3.119 meters, 4.080 meters, and 4.369 meters RMSE in Northing, Easting, and Elevation respectively are possible with an autonomous uncorrected GPS sensor (Lyle and Wilson, 2000a). DGPS is not adequate for some spatial applications when precise positioning is required. To improve the accuracy range, measurements from satellites must be improved.

Another method for measuring range from satellites is to count the number of full wavelengths and the small wave shifts from the satellite to the receiver at any given moment. This is called Differential Phase GPS. The total number of wavelengths is unknown and ambiguous. To determine the unknown number or solve the ambiguity differential, a base station GPS and rover receiver simultaneously collects data. A series of least-squares analysis solves the ambiguity.

This method is also possible in real-time, called Real-time Kinematic GPS (RTK-GPS). An in-depth description of RTK-GPS is addressed in a later section. It is proposed that when utilizing multiple tracking stations in a networked solution, a least squares adjustment can be calculated on each individual epoch with a rover GPS within the solution. This is done by sending a network matrix every 15 seconds to the rover where a networked solution is extrapolated by *virtualizing* each base station's corrections. This allows the GPS to generate a networked least squares adjusted solution in three dimensions for each RTK GPS solution (Lyle and Woods, 2002).

A summary of GPS technology and terms has been presented. An explanation of how RTK is generated for standard computation is provided. The next section will define how GPS is utilized with in an aerial platform in similar airborne systems.

Defining GPS Interfaced to Aerial Cameras

This section discusses the use of GPS to assist in solving the exterior orientation of aerial images. In the pervious section details on how each application or research project of those who attempted to utilize digital cameras and GPS was presented. The availability of GPS has advanced the ability to deliver fast and accurate ground control for georectification and georeferencing of aerial images. GPS has also been implemented into aircraft in order to reduce the extent of ground control necessary in the photogrammetric process (Ackermann, and Schade 1993; Merchant, 1993; Ackermann 1996; Gao, 2001; LeSiege 2001; Rees, 2001; and Gao, 2002).

Use of GPS in its native form generates an accuracy of approximately ten meters (Lyle and Wilson, 2000a). The low cost/low accuracy GPS receivers have been shown to obtain coordinates that are not accurate to georeference images (Rees, 2001). This is more evident when ground control can be obtained with existing DOQQ products. Implementation of differential GPS (DGPS) or sub-meter GPS as a means of collecting control points is a current viable solution for many photogrammetric images utilized in GIS (Greening *et al.*, 1998, and Lyle and Woods, 2002). GPS solutions that involve real-time have not been fully investigated in an aerial platform. Limitations in the ability to supply the real-time differential GPS corrections to an airborne platform are difficult (Auerbach, 1999). Satellites and wide area corrections have been attempted with varying results (Ambrosia *et al.*, 1998). The USDA FSA tested the DGPS in an aircraft with control taken from maps or previously georeferenced images such as DOQQ's or MDOQ's and found the results to be sufficient for aerial compliance mapping (Davis, 2002c).

To improve this procedure and reduce the need for ground control of any type an extended Real-Time Kinematic- GPS (eRTK-GPS) solution is suggested. The eRTK-GPS solution has been found to be robust over distances of 35 kilometers from a base station with accuracies in the centimeter range (Lyle and Woods, 2002). Investigation into the ability to receive the eRTK-GPS solution and directly apply it to the georeferencing process will be the overall emphasis of this dissertation.

Current methods of aerial solutions require a spatial placement typically consisting of four ground control points (GCP's) with known X, Y, and Z coordinates in each photo. The use of an *aero-triangulation* method assists in the reduction of needed GCP's, passing coordinates from one photo to another via *pass points*. Aero-triangulation with DGPS in an airborne platform provides the coordinates (indirectly) of the camera exposure station at the instant each photograph is exposed and, in theory, eliminates the need for ground control entirely (Wolf and Dewitt 2000). The concept of collecting the exposure station using airborne DGPS to aid in reducing the need for GCP's has been described in many publications (Ackermann & Schade, 1993; Merchant, 1993; Schenk, 1997; Greening *et al.*, 1998; ASPRS, 2000(p6); Mostafa and Schwarz, 2000; and Skloud, 2002). As discussed earlier the USDA FSA recognizes the viability of aerial GPS for navigation to assist in image georeferencing and image indexing (Davis, 2002c).

Using GPS for aerial exposure station position, two main concepts have evolved. The University of Stuttgart in Germany supported the concept that GPS instability with current methodologies (1990's) made it difficult to model all carrier phase errors to maintain the ambiguity solution through a flight path. Also, single ambiguity solutions are computed from a single base station that drifts. There is no possibility for a networked solution with local control along the flight path. The station must be within ten kilometers for a proper kinematic ambiguity solution. Other errors, such as the GPS antenna offset between the GPS recordings and actual exposure of the camera are difficult to resolve.

These accumulated errors, according to Ackermann and Schade (1993), are systematic and form a linear model. Systematic linear errors can be adjusted via least squares. It can also be said that selection of an incorrect carrier phase ambiguity solution via a C/A-code correlation would cause a small and uniform linear error that is easily adjusted as a block of all the photos in the flight strips. Selection of an incorrect carrier phase ambiguity solution would allow the placement of the base station at a distance of 500 kilometers away. Block adjustment applies linear drift correction per strip. Data reduction with this method is intense, but allows all systematic errors to be adjusted (Ackermann and Schade, 1993).

The other method of GPS in aerial photogrammetry is Merchant's (1993) concept suggesting that an overall aerial calibration be performed to decouple the interior parameters from the exterior parameters. The aerial calibration is similar to a self-calibration, but it uses GPS and GCP's to assess the systematic errors for the system. In this scenario, GPS carrier phase ambiguity must be resolved correctly. This method is most difficult and requires that absolute position accuracy be achieved by the GPS

(Merchant, 1991). Wolf and Dewitt (2000) describe the block bundled adjustment of the Ackerman and Schade concept, but conclude that an aerial system adjustment, or self-calibration, might be necessary.

Utilization of the GPS aero-triangulation in reducing the number of GCP's is now a standard practice with many commercial applications in photogrammetry. One application conducted by Measurement Science in Englewood, Colorado showed GPS-assisted photogrammetry to be viable over a wide range of photogrammetric mapping applications (Greening *et al.*, 1998). Tests were conducted to compare the standard method of using GCP's and typical aero-triangulation to airborne GPS aero-triangulation. The exposure station coordinates positioned with GPS aero-triangulation resulted in a standard deviation of 0.2 meters in X and Y and 0.3 meters in Z. The remaining control point values (29), included in the initial adjustment as independent check points, resulted in RMSE values of 0.25, 0.24 and 0.38 meters in Northing, Easting and Elevation respectively. Improvements to the robustness of on-the-fly (OTF) DGPS algorithms use of geoidal model and rigorous aircraft attitude determination is needed to improve the efficiency of GPS aero-triangulation (Greening *et al.*, 1998).

Results from tests conducted by the Maine Department of Transportation showed 0.218, 0.161, and 0.377 meters maximum and a RMSE of 0.06, 0.08 and 0.05 meters in Northing, Easting and Elevation respectively, using 42 targets as check points (LeSiege, 2001). The typical aero-triangulation is still a manual process of matching pass or conjugate points on two or more partially overlapping photographs.

Krupnik and Schenk (1997) have suggested that an automated process be used where image matching is done after tie points are developed. The image matching will allow a multiple-patch matching for accurately locating conjugate points. Data in raw digital format are the next challenge in projecting new methods for photogrammetry. According to Schenk (1997) digital photogrammetry and computer vision are seen as technology that will change the shape of aerial triangulation as dramatically as analytical photogrammetry did during the past 30 years. Digital photogrammetry deals with digital imagery and the goal is to capture, store and process images automatically (Schenk, 1997).

The desired outcomes of this concept of automation are to reduce the need for ground control and reduce operator involvement. To achieve an automated process, it was assumed that some improvement in GPS and Inertial Navigation Systems (INS) information in relation to exterior orientation was needed, as well as, searching and matching algorithms. Others have suggested direct georeferencing as a method to improve this underlying problem of determining the exterior orientation.

Direct georectification of the image with coupled small-format digital cameras, Global Positioning Systems (GPS) and Inertial Navigation Systems (INS) has been proposed (Maas, 1997b; Škaloud, 1999; Cramer *et al.*, 2000a; Škaloud, 2002; and Kinn, 2002). These methods, which have initiated commercially available units, are post processing procedures. This intensive post process solution is not adequate to meet the USDA FSA crop compliance field office requirements. The complexity of such an implementation would require a more intense solution and increase the cost function that a small-format digital camera would attempt to pre-empt.

Improvement to GPS/INS solutions has been forthcoming with new concepts of direct georeferencing or locating the exact exposure station. Concepts of bridging INS and GPS by means of Kalman Filters, Kalman published his famous paper describing a recursive solution to the discrete-data linear filtering problem, have been discussed widely (Skaloud et at., 1999; Mostafa and Schwarz, 2000; Cramer *et al.*, 2000b; and Skaloud, 2002). This solution allows the INS to aid in the ambiguity solution and extend the range from base station to rover without concern for the carrier-phase ambiguity cycle count. Direct georeferencing utilizes GPS for position and INS for attitude determination at the time of image exposure.

Position and attitude are the unknown parameters of the exterior orientation (Crammer *et al.*, 1999). The accuracy of the exterior orientation is directly relevant to the ground accuracy of the pixels. At a 1:10,000-scale mapping standard, INS/DGPS of 0.6meter position and 130 seconds attitude equate to one meter mapping accuracy. For many GIS applications this will suffice, but for more accurate mapping it is not adequate (Skaloud, 1999).

Direct georeferencing is better suited for a digital sensor system based on the ability to process the images concurrent to the post-processing of the GPS/INS. Cramer *et al.*, (2000a) tested a GPS/INS solution with varying baseline lengths up to 380 kilometers from the DGPS base station and found at 1:6,000 scale the exposure position of 13.5, 8.6, and 6.1 meters in X, Y and Z position respectively, with 3.0, 2.0 and 4.4 10^{-3} degrees in ω,φ, and κ rotations respectively resulted in a RMSE 0.113, 0.150 and 0.246 meters in Easting, Northing and Elevation respectively of 126 check points.

Conclusively, direct georeferencing for some photogrammetric applications is possible. Limitation of the field of view of digital sensors, the need to post process sterilized GPS/INS data, and the process of bundled block aero-triangulation have slowly hindered the progress of direct georeferencing with GPS/INS.

The use of these methodologies for GIS applications has multiple merits. Considering applications such as crop compliance and the development of the GIS of CLU, a direct georeferencing solution could greatly reduce the hours needed to rectify and process the imagery. Based on the existing results, an automatic solution to achieve results in collecting crop compliance and land boundary information is possible.

Defining extended RTK-GPS

In order to produce the position of exposure station economically, eRTK-GPS is suggested. This section details the use eRTK-GPS to resolve the procedures of data collection.

The use of real-time positions in an aircraft has been attempted for navigation purposes only because of the limitation of the baseline length from base station to rover. Unless a more expensive GPS/INS coupled solution is attempted, aerial RTK is limited to less than 10 kilometers. New technology in extending RTK to 35 kilometers is now available with the use of long distance communication, wireless networks and error modeling software (Lyle and Wilson, 2000b; Euler and Ziegler, 2000; and Euler *et al.*, 2001).

Current methods of GPS positional post-processing involve logging data to a base and rover and then combining the data to produce a post-processing solution. Real-time surveying systems provide centimeter accuracy based on a rapid search to determine the carrier-phase ambiguity. Both the L1 and L2 carrier-phase observations from the base station are transmitted to the rover unit where the real-time algorithm is used to remove systematic errors and reduce the carrier-phase ambiguity. To resolve longer baseline solutions, the errors must be totally modeled. Errors are caused by the ionosphere activity that directly affects the cycle count. Delay propagation through the ionosphere is random and difficult to model. With new models from hundreds of GPS tracking stations monitoring the total electron content of the ionosphere, removal of the errors can be quickly accomplished.

Other errors, including multiple signals from reflectance (called multi-path), can be reduced with new seeding algorithms by showing multi-path patterns with very long wavelength signals from nearby reflectance. These improved algorithms allow for a real-time ambiguity to take place within less than one-minute of beginning observations (Euler and Ziegler, 2000). Results of rapid real-time solutions show that at 30 kilometers, an accuracy of two centimeters in Easting and Northing is possible (Euler and Ziegler, 2000).

Long-range or extended RTK (eRTK) have difficulty in receiving base-station information in a dynamic mode. Modems and standard land communication methods currently are the only means of testing eRTK. Typical UHF and Spread Spectrum radios have not been usable at high communication rates based on the overland obstruction. Use of wireless cellular communication has allowed for sharing of data at high rates with little to no signal loss. With this communication solution of permanent reference station arrays, longer-range positions can be determined. GPS positions can be obtained as far as 35 kilometer and still maintain carrier-phase ambiguity of 2 cm horizontally and twice that vertically. Tests show that at 35 kilometer from the base station results are obtained within two minutes of being observed resulting in RMS of 1 cm horizontally and 2 cm vertically (Lyle and Wood, 2002).

With this accuracy a eRTK position could be directly used in computing the exterior location of the exposure station of a digital frame camera. Testing this concept will be a key element in developing an automatic georeferencing system for the USDA FSA crop compliance GIS application.

In summary, the RTK algorithms are attempting to determine the total number of full wavelengths between each satellite and the rover antenna. Once this number of full wavelengths is known, it is possible to compute the rover coordinates to centimeter accuracy. Many different solutions to the total number of whole wavelengths exist. New extended RTK algorithms and advanced hardware to assist in improving possible solution acquisition is presently available and proven.

A newer method of transforming digital frame coordinates to terrestrial coordinates is direct georeferencing. The current method of georeferencing requires using multiple GCP's to locate the exposure station. Direct georeferencing utilizes multiple sensors to acquire the georeferenced exterior position at the time of image collection. Utilizing differential Global Positioning Systems (DGPS) and Inertial Navigation Systems (INS) to acquire the spatial location and the attitude (angular orientation) would theoretically allow for the removal of GCP's. Advanced algorithms have been developed to tightly couple these sensors together to form a more exact orientation (Mostafa *et al.*, 1997; Mostafa *et al.*, 1998; and Skaloud, 2002).

Geometric Concepts of Direct Georeferencing

The geometry of a digital image is a scaled equivalent of the real-world phenomenon in a map plane surface. The central principal point is defined as the *external nodal point* (front or rear) or *exposure station* (Ackermann and Schade, 1993). For the context of this document it will be referred to as the exposure station.

A line passing through the exposure station and intersecting perpendicular to the focal-plane is defined as the *principal point,* as seen in Figure 3.2. The scale of an image may be expressed by proportionality of the focal length of the camera to the height above ground for the exposure station. This is illustrated in the similar triangles in Figure 3.2 and in Equation 3.1.

The scale factor is computed using the focal-length to the average flying height or the photo distance to the ground distance where:

$$\frac{f}{H_a} = \frac{d_a}{D_a} = \frac{1}{SF} \qquad \textbf{Equation 3.1}$$

f	= Focal length of the camera
Ha	= Average flying height above the ground
da	= Photo distance
Da	= Ground distance
SF	= Scale Factor, of dimensionless ratio

The geometry of a photo is further defined by its mathematical spatial orientation (Förstner and Gülch, 1999). The DF and DFV exterior, or outer orientation, is defined as spatial location in X, Y and Z, or the equivalent of E, N, and Height in a grid system.

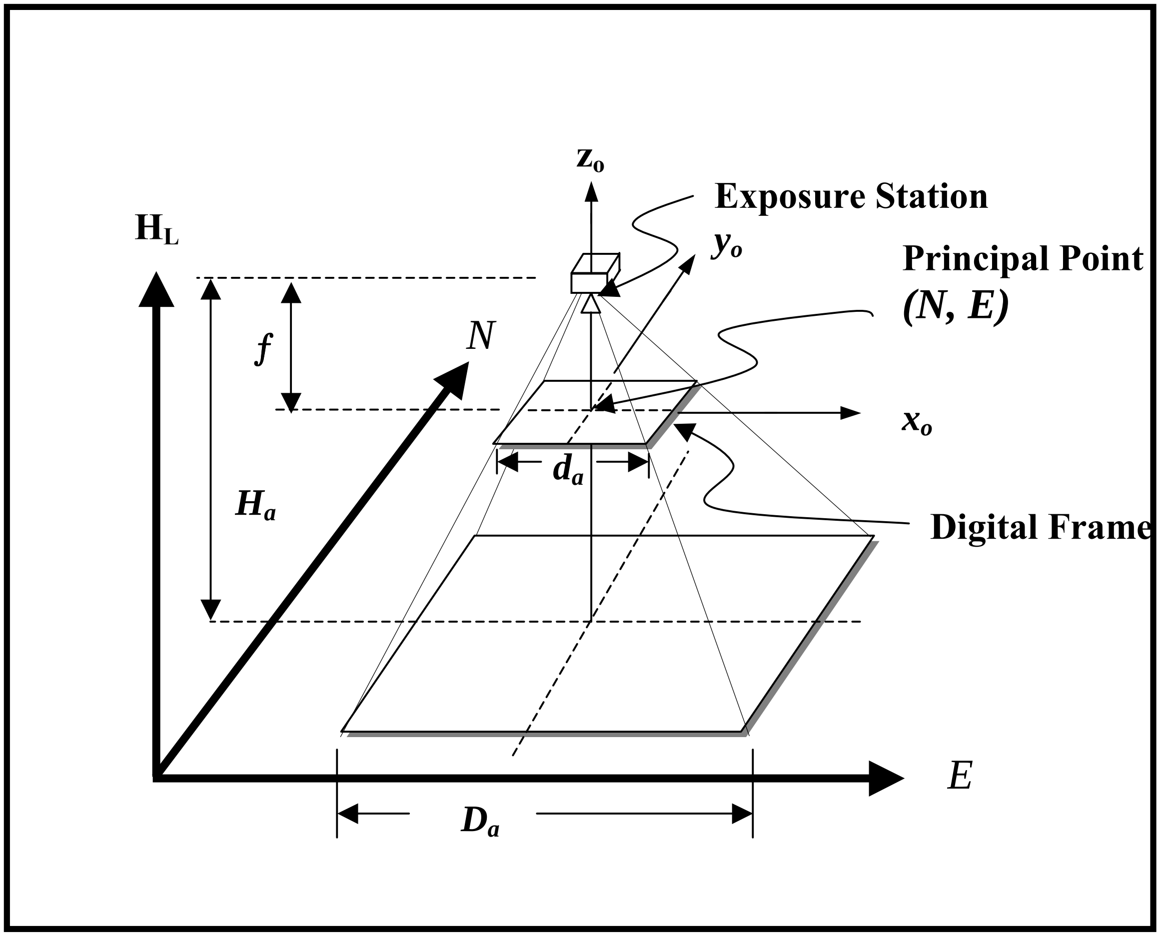

Figure 3.2: Geometric Properties of Aerial Photograph.

The angular rotations of pitch ϕ (phi), roll ω (omega) and yaw κ (kappa) of the camera are about the X, Y and Z-axes, respectively. The interior, or inner orientation, is based on the lens focal point distance to the focal-plane or digital frame (CCD/CMOS). This is referred to as the focal distance or principal focal line perpendicular to the focal-plane. This terminology is further defined in the specifications of the small-format digital cameras employed.

Geometric proportional properties of the scale based on flying height to focal length can also be determined for ground to image distance. Based on the instability of the aerial platform, tilt often occurs making the camera no longer perpendicular to the Earth. A vertical line still exists that is perpendicular or nadir to Earth. This line passes through the focal plane and can be used to calculate and ultimately remove tilts caused in the image by a method of rectification. Distortion error caused by the relief of the Earth can be removed using orthometric corrections.

Once an image has been collected, it is rectified or georeferenced using ground control points (GCP's) to triangulate the position of the exposure station with a terrestrial reference coordinate system such as the Universal Transverse Mercator (UTM), State Plane, or a local system. In this procedure GCP coordinates are obtained on visible targets on the airphoto. These GCP's are used in the transformation to compute rotation, shift, and scale in order to georeference the image. Coordinate transformation is a mathematical process of determining the relationship between two sets of coordinates.

Points are matched between two coordinates systems to determine rotation, shift, and scale. The parameters generated from a transformation can be directly applied to an image on a pixel-by-pixel basis for rectification and resampling.

The raw file can be maintained and an associated *world file* can be created that includes the six-parameter affine transformation in the following:

$$X1 = Ax + By + C \qquad \textbf{Equation 3.2a}$$

$$Y1 = Dx + Ey + F \qquad \textbf{Equation 3.2b}$$

where,

X1 = Calculated x-coordinate of the pixel on the map

Y1 = Calculated y-coordinate of the pixel on the map

x = Column number of a pixel in the image

y = Row number of a pixel in the image

A = X-scale; dimension of a pixel in map units in X direction

B = Rotation term for X

C = Shift terms; X map coordinates of the center of the upper-left pixel

D = Y-scale; dimension of a pixel in map units in Y direction

E = Rotation term for Y

F = Shift terms; Y map coordinates of the center of the upper-left pixel

The y-scale (E) is negative because the direction of increasing values of the y-coordinate and the image is opposite to the direction of y-reference in the map coordinate system. The origin of an image is located in the upper-left corner; whereas, the origin of the map coordinates system is located in the lower-left corner. Row values in the image increase from the origin downward, while y-coordinate values in the map increase from the origin upward (ESRI, 2003). Table 3.3 demonstrates example values in a typical world file.

Table 3.2. Sample of World File with Transformation Parameters with TFW File Extensions Associated with the TIF Image File (ESRI, 2003).

Example World File Parameters		
A	5.000000000000	(size of pixel in x direction)
B	0.000000000000	(rotation term for row)
E	0.000000000000	(rotation term for column)
D	-5.000000000000	(size of pixel in y direction)
C	492169.690845528910	(x coordinate of center of upper left pixel in map units)
F	5426523.318065105000	(y coordinate of center of upper left pixel in map units).

Direct Georeferencing Computation

The section will describe the computation equations need to computer the affine transformation values for the world file. The values will be derived from the GPS and ground elevation of the target site.

Direct Georeferencing Affine Transformation Equations:

$$E_i = SF_x + R_{Ey} + E_{GPSo/s} \qquad \textbf{Equation 3.3a}$$

$$N_i = SF_x + R_{Ny} + N_{GPSo/s} \qquad \textbf{Equation 3.3b}$$

From the above Equations 3.3 (a) and (b) the parameters are computed and placed in an associated world file with the image. The individual values within the equation must be computed using other orientation equations. Table 3.4 defines Equation 3.3 (a) and (b) parameters measured and computed from the eRTK-GPS and elevation values. Figure 3.3 shows the DF coordinate system with y-coordinate increasing from the origin downward. Figure 3.4 shows the image in the ground coordinate system.

To compute the parameters several computations must be taken to extract the information needed for the world file. The steps are provided that offered procedures and equations necessary for the computations.

Step 1: Standard Scale Factor

$$\frac{f}{H_a} = \frac{d_a}{D_a} = \frac{1}{SF} \qquad \text{Equation 3.1}$$

Table 3.3. World File with Transformation Parameters with Direct Georeferenced Parameters.

World File Parameters	
Ei	Calculated X-coordinate of the pixel on the map
Ni	Calculated Y-coordinate of the pixel on the map
SF_x	X-scale; dimension of a pixel in map units in x direction = focal length/ U_{GPS}- H_{AVG} or U_{GPS}- DEM
R_{Ey}	Rotation terms in X direction
$E_{GPSo/s}$	Translation terms; X, map coordinates of the center of the upper-left pixel
SF_y	Negative of y-scale; dimension of a pixel in map units in y direction = focal length/ U_{GPS}- H_{AVG} or U_{GPS}- DEM
R_{Ny}	Rotation terms in y direction
$E_{GPSo/s}$	Translation terms; X, map coordinates of the center of the upper-left pixel

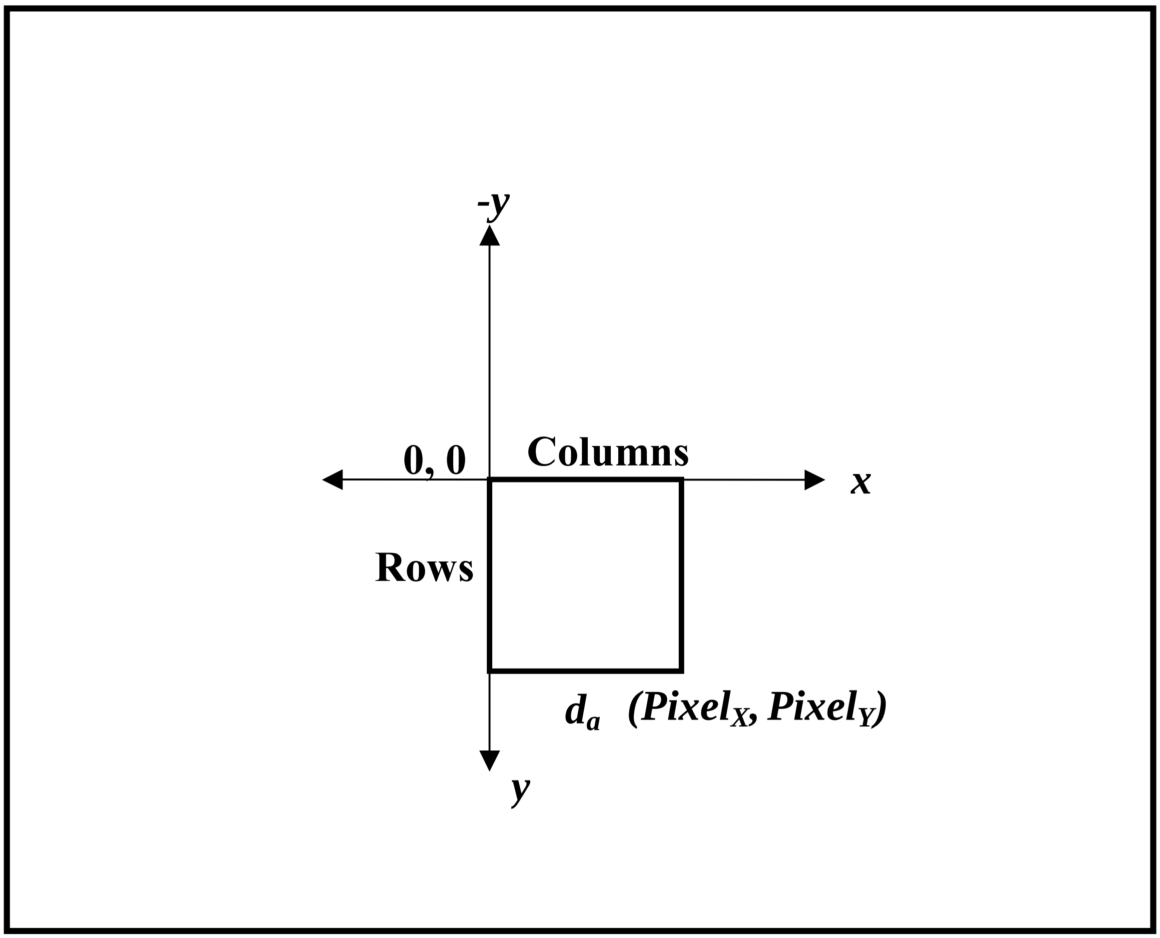

Figure 3.3: Digital Frame Image Coordinate System.

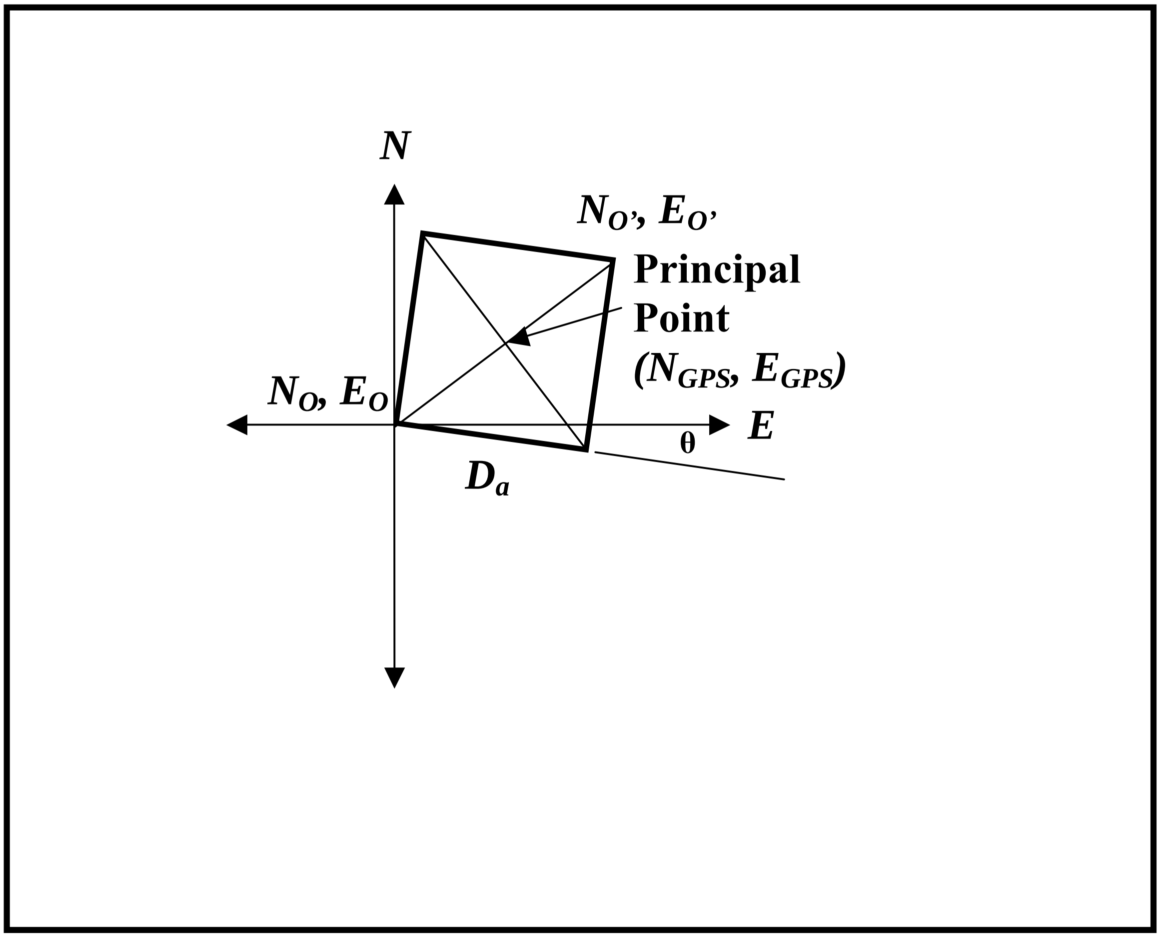

Figure 3.4: Digital Frame in Ground Coordinate System.

A precise focal length f of the camera is needed in computing the scale factor of all images. This is done with a laboratory calibration. The flying height above ground H_a is needed for the proportional equation of the focal length to the flying height. Flying height above ground is computed by using the orthometric height H from the GPS less the average ground elevation H_L from DEM's or DRG's of the image coverage.

Step 2: Direct Georeferenced Scale Factor

$$SF = d_X / D_X$$

$$d_X = Pixel_X * (Pixel\ Size)$$

$$D_X = Pixel_X * (Pixel\ Size) / SF$$

$$SF_X = \frac{\sin\theta\ D_X}{Pixel_X} \qquad \text{Equation 3.2}$$

$$SF_X = A\ (\text{Affine Transformation})$$

$$SF = d_Y / D_Y$$

$$d_y = Pixel_Y * (Pixel\ Size)$$

$$D_Y = Pixel_Y * (Pixel\ Size) / SF$$

$$SF_Y = \frac{\sin\theta\ D_Y}{Pixel_Y} \qquad \text{Equation 3.3}$$

$$SF_Y = -E\ (\text{Affine Transformation})$$

Step 3: Rotation Angle

$$\text{Tan}(\theta + 90) * (SF_X) = R_X = D_Y / \text{Pixel}_X \qquad \text{Equation 3.4}$$

$$\text{Tan}(\theta + 90) * (SF_Y) = R_Y = D_X / \text{Pixel}_Y \qquad \text{Equation 3.5}$$

Step 4: Offset from Central Perspective to Digital Frame upper-left pixel

Where,

$$\beta = 90 - \theta - \gamma$$

$$\frac{d_y}{2} / \frac{d_x}{2} = \frac{1/2\,Pixel_Y}{1/2\,Pixel_X} = Tan\beta \qquad \text{Equation 3.6}$$

The distance to the point of rotation from the central perspective is computed by utilizing the angular standard of the digital frame image and ground computed distance.

$$Pxy = \sqrt{\left(\left(\frac{Dy}{2}\right)^2 + \left(\frac{Dx}{2}\right)^2\right)}$$

$$Y_{O/S} = P_{XY} \sin\beta$$

$$X_{O/S} = P_{XY} \cos\beta$$

Shift in X in the Affine Transformation can be computed by applying the offset equation

$$C = E_{GPS} - X_{O/S} \qquad \text{Equation 3.7}$$

$$F = N_{GPS} - Y_{O/S} \qquad \text{Equation 3.8}$$

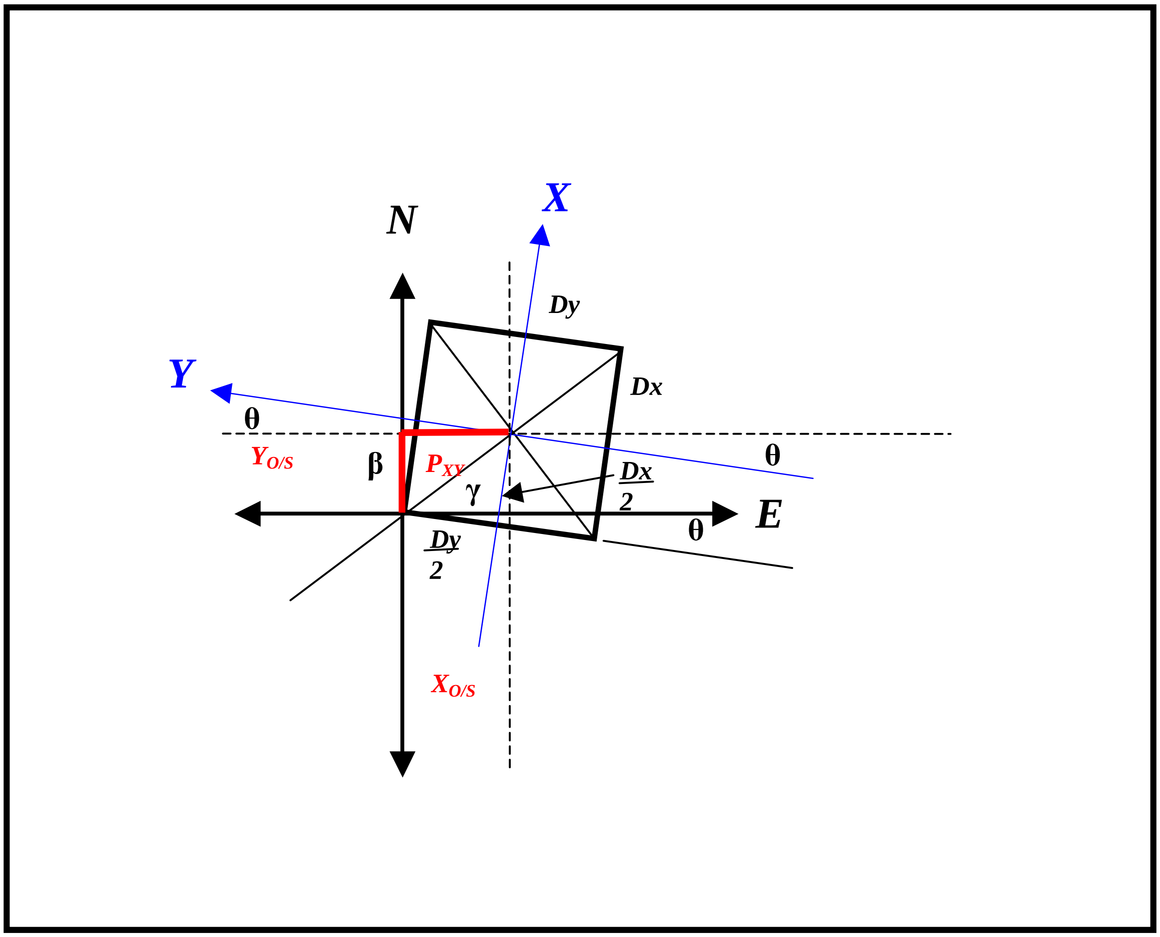

Figure 3.5: Computation Between Coordinate Systems.

Example of Direct Georeferenced Computation

This section is provided to demonstrate the procedure and equations applied to an image. The image is from the Kodak DC290 small-format DF camera. This example is provided within the methodology section to present quantitative results between direct georeferencing and typical georectification.

Know variables are:

Image Size:	$Pixel_X = 1792$ $Pixel_Y = 1200$
Focal Length:	$f = 0.008$ meters
Pixel Size:	4.2 micron
Average Elevation:	HL = 272 meters
From GPS:	EGPS = 728809 meters NGPS = 3686349 meters
Average Ground Elevation:	Ha = 634 m
Heading:	277.125º

Step 1: Standard Scale Factor

$$\frac{f}{H_a} = \frac{d_a}{D_a} = SF$$

$$\frac{f}{\boldsymbol{H_a}} = \frac{0.008}{634-272} = \frac{\boldsymbol{d_a}}{\boldsymbol{D_a}} = \frac{1}{45{,}265}$$

Figure 3.6: Raw Small-Format Digital Image from Kodak DC 290.

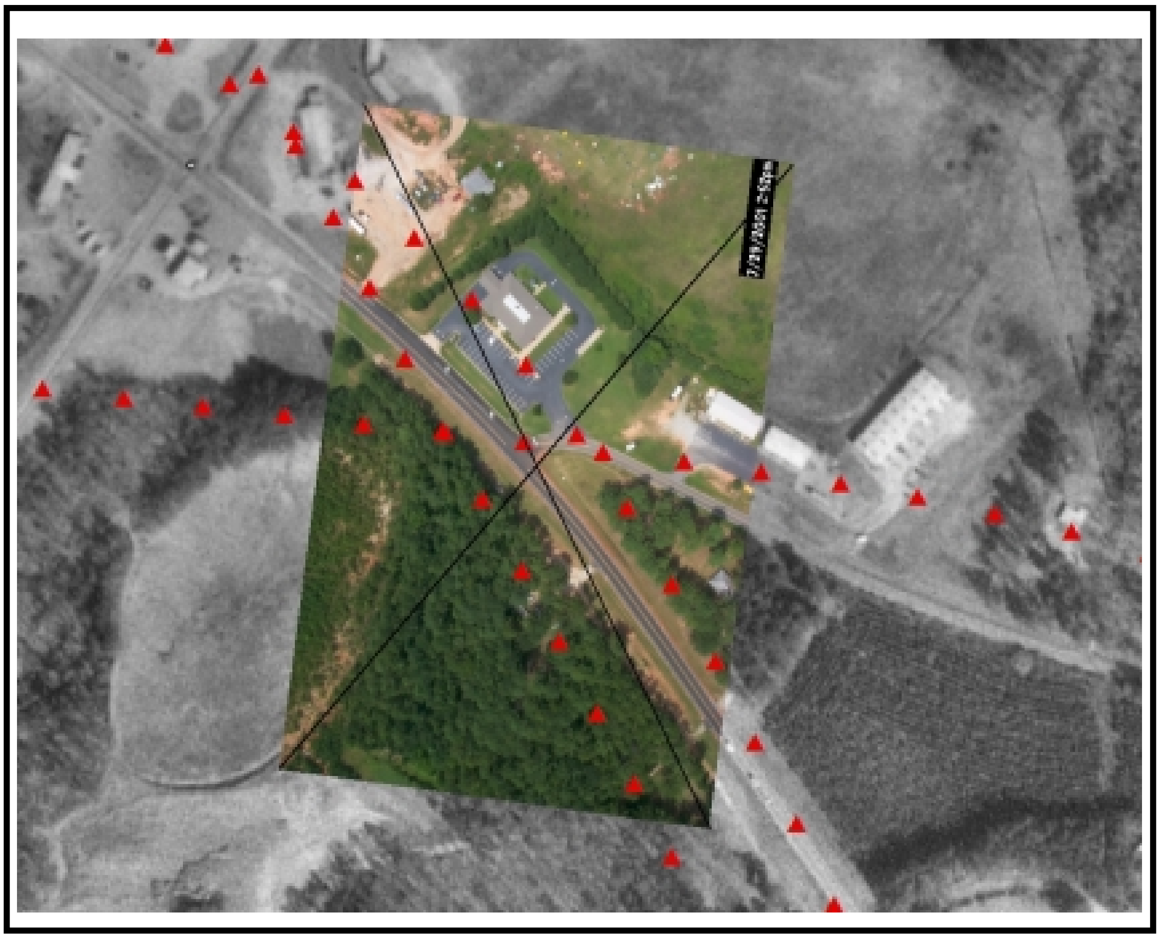

Figure 3.7: Georeferenced Image using DOQQ with eRTK-GPS Flight Path Overlay.

Step 2: Direct Georeferenced Scale Factor

$$SF= d_X / D_X$$

$$d_X = Pixel_X * (Pixel\ Size) = 1792 * 4.2x\ 10^{-6} = \underline{0.007562}$$

$$D_X = Pixel_X * (Pixel\ Size) / SF = (0.007562)/(1/45{,}265) = 340.68\ m$$

$$SF_X = \frac{\sin\theta\ D_X}{Pixel_X} = \sin 7.125 * 340.68/1792 = \underline{0.023580}$$

$$SF_X = A\ (Affine\ Transformation)$$

$$A= 0.023580$$

$$SF= d_Y / D_Y$$

$$d_Y = Pixel_Y * (Pixel\ Size) = 1200 * 4.2x\ 10^{-6} = \underline{0.005040}$$

$$D_Y = Pixel_Y * (Pixel\ Size) / SF = (0.005040)/(1/45{,}265) = 228.14\ m$$

$$SF_Y = \frac{\sin\theta\ D_Y}{Pixel_Y} = \underline{-0.02356}$$

$$SF_Y = -\ E\ (Affine\ Transformation)$$

$$E = \underline{-\ 0.023580}$$

Step 3: Rotation Angle

$$Tan\ (\theta +90) * (SF_X) = R_X = D_Y / Pixel_X$$

$$Tan\ (\theta +90) * (SF_Y) = R_Y = D_X / Pixel_Y$$

$$Tan\ 97.125 * 0.023580 = \underline{0.188640}$$

$$Tan\ 97.125 * 0.023580 = \underline{0.188640}$$

Step 4: Offset from Central Perspective to Digital Frame upper-left pixel

$$\beta = 90 - \theta - \gamma = 90- 33.808- 7.125 = 49.067^{o}$$

$$\frac{d_y}{2} / \frac{d_x}{2} = \frac{1/2\,Pixel_Y}{1/2\,Pixel_X} = Tan\beta = 33.808^o$$

$$Pxy = \sqrt{\left(\left(\frac{Dy}{2}\right)^2 + \left(\frac{Dx}{2}\right)^2\right)}$$

$$Pxy = \sqrt{\left((170)^2 + (114)^2\right)}$$

$$Pxy = 204.69$$

$$Y_{O/S} = P_{XY} \sin \beta$$

$$= 204.69 * \sin 49.067 = \underline{154.64 \text{ m}}$$

$$X_{O/S} = P_{XY} \cos \beta$$

$$= 204.69 * \cos 49.067 = \underline{134.11 \text{ m}}$$

Shift in X in the Affine Transformation can be computed by applying the offset equation

$$C = E_{GPS} – X_{O/S}$$

$$C = 3686349 - 154.64$$

$$C = \underline{3686194}$$

$$F= N_{GPS} – Y_{O/S}$$

$$F = 728809- 134.11$$

$$F = \underline{728675}$$

The final results will be a world file with the six parameters. The results are compared to the same image georectified using six GCP's as seen in Table 3.5.

Table 3.4: Comparison of Georectified and Direct Georeferenced Affine Transformation Parameters.

Comparison of Georectified to Direct Georeferenced		
Parameter	**Georectified RMSE = 3.57207**	**Direct Georeferenced**
A	0.0241780507561330060	0.023580
E	0.187888943187361050	0.188640
B	0.180873292638056770	0.188640
D	-0.0249782993028029620	-0.023580
C	728685.31672634801	728675
F	3686183.1259230524	3686194

Figure 3.8: Direct Georeferenced Digital Frame Image with eRTK GPS Solution.

At this point, the image is transformed and the positions of the original grid cells in the raster layer may be reoriented. The digital values are resampled into their new locations to interpolate values for each cell. Three methods of resampling commonly used include (i) nearest-neighbor, (ii) bilinear interpolation, and (iii) cubic convolution (Lo and Yeung, 2002). For this research, the affine transformation parameters are written to a world file related to the raw image file. Resampling is not used in this research to restructure the image at the time of image capture; this saves computation time in processing and recording the large number of images obtained in the real-time small-format DF or DFV. When an image is imported an affine transformation, a resample method is used by most software packages to display the image. The USDA FSA will have the option to resample or utilize orthographic rectification to remove tilt and ground relief errors.

Conclusions

Unlike metric cameras, small-format cameras have limitations; specifically, an unstable interior orientation (Fraser, 1997). Movement in the CCD chip, image plane warp, and in-plane image distortion can cause instability in the orientation. Both a system calibration made in post-operation test fields and an in-situ self-calibration were explored. This system was best calibrated using a concept from Merchant (1993). A typical GCP procedure was preformed to geo-rectify the imagery. GPS was used to obtain the GCP and a post processing method was implemented. Format size and download times of the camera during post processing were presented that followed consistent trends. Cost trends tend to still support a small-format camera solution.

Summary of Objectives

The purpose of this research is to investigate the use of an aerial small-format digital camera-imaging sensor by the United States Department of Agriculture Farm Service Agency in the development of a GIS of CLU for crop compliance under support programs. This research seeks to establish new technologies and mythologies to improve the current system.

CHAPTER 4

NEW APPROACH IN USING eRTK-GPS FOR DIRECT GEOREFERENCING OF AERIAL IMAGES IN A GIS APPLICATION [1]

[1]Lyle, S., 2003. Accepted by Surveying and Land Information Science. American Congress on Surveying and Mapping. Reprinted here with permission of publisher.

Abstract

The purpose of this paper is to describe the research conducted in the development and preliminary testing of a real-time georeferencing method for a small-format digital aerial camera system using new methodologies in extended Real-Time Kinematic Global Positioning System (eRTK-GPS) solutions. This system is being developed to supply the U.S. Department of Agriculture Farm Service Agency (USDA FSA) with aerial digital images to replace the current 35 mm slide film method and for the development of a geographic information system (GIS) for crop compliance support. The system was developed by the University of Georgia and Texas A&M University-Corpus Christi in fulfillment of the National Aeronautical Space Agency's (NASA) contract for developing new technologies and methodologies in remote sensing. The methods employed include the development of eRTK-GPS in an aerial platform where differential solutions 35 kilometers from the base-station generate two-centimeter and five-centimeter accuracy horizontally and vertically from the digital camera exposure station's location. A real-time georeferencing system results in a world file with affine transformation parameters without the need for post-processing GPS or ground control points. Flight tests were conducted in Georgia and Texas with different wireless communication systems to assess the robustness of the solutions in an aerial platform.

Introduction

The U.S. Department of Agriculture Farm Service Agency (USDA FSA) seeks to implement a geographic information system (GIS) to connect and manage crops for crop compliance monitoring under crop support programs. The USDA has determined that the current 35 mm film slides traditionally used for aerial compliance are no longer compatible with the digital format needed to establish a GIS for land ownership. This research suggests that a small-format digital camera system be utilized for acquiring new compliance imagery (Davis, 2002c). This new methodology creates the ability to maintain the image completely in a digital format.

The USDA looks to efficiently convert line data extracted from aerial photography into a digital format by developing a GIS. The line data are boundaries of common land units (CLU) of common owner, tenant, and producer association. This GIS provides a framework for linking tabular data to the spatial dimension. The overall function of the CLU is to define the farmer and land relationship spatially (USDA FSA, 1998). Seven digitizing centers have been established in several states to begin this process of developing the CLU.

According to USDA FSA the CLU represents various combinations of land cover and land-use. Determining the boundaries and placement of these lines in a GIS is based on these combinations. The lines must also coincide with the ownership lines defined according to the rules for the cadastral layers. Aerial images are used to visually delineate boundaries by digitizing USDA FSA cadastral layers.

The current method of data collection is with a standard, fixed-focus 35 mm film camera mounted in a small aircraft. When flying predetermined heights and flight lines, aerial images are collected. The wait time for film development is approximately two weeks. The slides are indexed into a slide projector that is oriented to a flat-table digitizer (Figure 4.1). Personnel using Farm Unit Maps locate the targeted area by sorting manually through the slides in the projector. A calibration rectification is performed to change scale and tilt by adjusting the projector. A measurement of the ground area is made to verify the reported crop acres submitted by the growers who receive crop support under the USDA FSA program. Digitizing ownership into a GIS is then completed by interpretation of land boundaries visually. The labor and effort in gathering this information is lost after the task is completed. Future efforts of temporal analysis to study trends require repeating the process. A digital GIS solution would allow for the capture and correlation of all efforts.

The objective of this research is to develop a system that utilizes the capture of digital data for direct georeferencing in real-time based on the extended Real-time Kinematic Global Positioning System (eRTK-GPS) solutions with on-the-fly image georeferencing. According to Wolf and Dewitt (2000 p. 189) georeferencing is often referred to as rectification; however "the term rectification is reserved for the process of removing effects of tilt from an aerial photograph." Direct georeferencing up until now has focused on a direct rectification. For the context of this research direct georeferencing will refer to the use of an orthogonal transformation account for shift, scale and rotation.

This system is being developed to analyze the possibility of such a solution for use with the USDA and FSA and county aid offices and farmers in determining new crop lines for crop rotations, seed corn and plots, irrigation pivot management, specialty crop acreage, conservation work, and crop insurance (Bailey and Meador, 2002). GIS is a tool of precision farming and it assists in organizing the entire farming process. GIS is a spatial information database that is an organized collection of computer, hardware, software, geographic data, aerial imagery, maps and personnel designed to efficiently capture, store, update, manipulate, analyze and display all forms of geographically referenced information (Clark, 1997).

Other methods have been deployed that utilize a combination of GPS and Inertial Navigation System (INS). Improvements to GPS/INS solutions have been forthcoming with new concepts of direct georeferencing. Concepts of bridging INS and GPS by means of Kalman Filters, Kalman published his famous paper describing a recursive solution to the discrete-data linear filtering problem, have been discussed widely (Skaloud, et at., 1999; Mostafa and Schwarz, 1998; Cramer and Haala., 1999; and Skaloud, 2002). This solution allows the INS to aid in the ambiguity solution; therefore, extending the range from base-station to rover without concern for lost carrier-phase ambiguity cycle count. Direct georeferencing uses GPS for position and INS for attitude determination at the time of image exposure. The position and attitude are correlated to the parameters of the exterior orientation.

The Photography Field office of the USDA FSA evaluated a number of digital camera systems for use by area offices (Davis, 2002c). Digital systems currently being reviewed still demand post processing GPS, but it offers the ability to shorten the time to produce the final product. This research proposes to extend the current concepts determined by the USDA and FSA to a real-time data processing of the GPS solution by reducing the need for some post-processing steps.

Figure 4.1 35 mm Color Slide Projector at USDA FSA Office.

To meet the objectives of this research several key technologies and methodologies must be developed. Utilizing eRTK-GPS in an aerial platform requires an advanced communication system. The accuracy achieved with eRTK-GPS in an aerial platform must be evaluated. The exterior orientation parameters such as tilt and heading must be analyzed for this application. An algorithm was developed to directly georeference an image by writing a georeference world file with affine transformation parameters (Equation 4.1a,b).

$$E_i = SF_x + R_{Ey} + E_{GPSo/s} \qquad \textbf{Equation 4.1a}$$

$$N_i = SF_x + R_{Ny} + N_{GPSo/s} \qquad \textbf{Equation 4.1b}$$

A world file is an associated file with image files that contain affine transformation parameters to georeference an image into a desired coordinate system. A quantitative analysis is made to compare the results of aerial eRTK-GPS to the method of post-processing GPS.

With the current growth in available technology, the advancement of small-format cameras is continuous. The conception of direct georeferencing of exposure station will remain consistent regardless of the digital camera system. The formats of the digital image remain consistent with this evolution. The camera formats and specifications play a critical role in determining if this solution is adequate for development of the base-layer with aerial imagery.

Table 4.1: World File with Transformation Parameters with Direct Georeferenced Parameters.

World File Parameters	
Ei	Calculated X-coordinate of the pixel on the map
Ni	Calculated Y-coordinate of the pixel on the map
SF_x	X-scale; dimension of a pixel in map units in x direction = focal length/ U_{GPS}- H_{AVG} or U_{GPS}- DEM
R_{Ey}	Rotation terms in X direction
$E_{GPSo/s}$	Translation terms; X, map coordinates of the center of the upper-left pixel
SF_y	Negative of y-scale; dimension of a pixel in map units in y direction = focal length/ U_{GPS}- H_{AVG} or U_{GPS}- DEM
R_{Ny}	Rotation terms in y direction
$E_{GPSo/s}$	Translation terms; X, map coordinates of the center of the upper-left pixel

USDA FSA states “georeferencing (rubber-sheeting, warping) is sufficient for the accuracy level needed for the aerial compliance program” (Davis, 2002c p.9). Therefore, orthorectification of images would far surpass the necessary accuracy level according to the USDA FSA report. For this research a georeference method in which only the scale, position and yaw is taken into consideration.

The camera was mounted on a leveling device to reduce the tilt. Tilt from roll and tip was found to cause only a slight increase in the positional accuracy. At 2000-meter flying height with 10 minutes of tilt the 1/4" CCD was found to have six meters of positional error. A six-meter by six-meter error would equate to 0.009-acre error that is well below the +/- 0.1-acre measure limit of the USDA FSA GIS application (Williams, 2002)

<u>eRTK-GPS for Direct Georeferencing</u>

Basic GPS receivers with selective availability discontinued are capable of ten-meter autonomous position with a single frequency L1 C/A coded receiver. At least four satellites in a good geometry generating a low dilution of precision (DOP) must be tracked to obtain a 3-D solution. This can be achieved easily without the need for differential corrections. Stand-alone positional GPS has been investigated as a means to collect ground control points (GCP’s) for use in rectification of aerial images. Use of autonomous GPS in aircraft has been attempted in several applications where ground control cannot be obtained. The GCP’s are correlated to pixels. The pixel size is based on the digital charged couple device (CCD) chip and flying height. As seen in Figure 4.2, the ground resolution of each pixel decreases with flying height for a ¼” CCD digital camera.

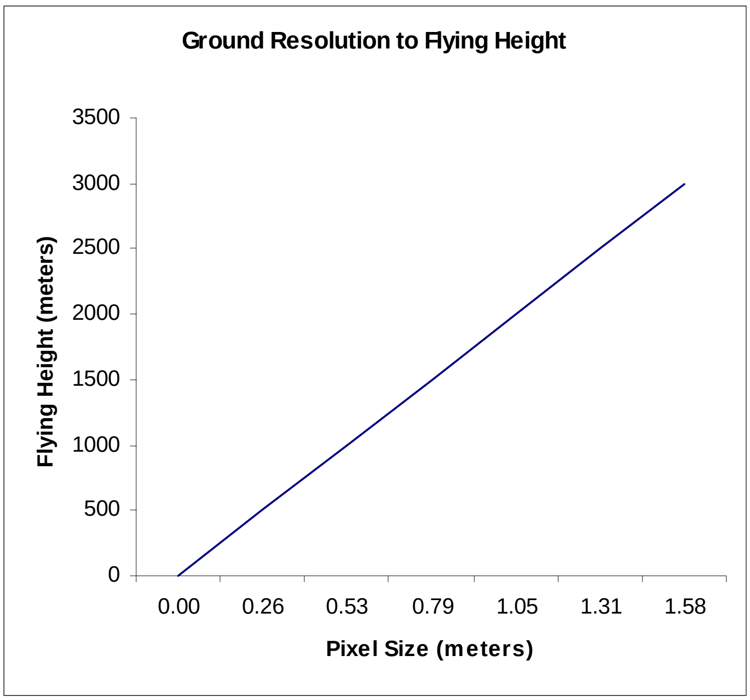

Figure 4.2: Spatial Resolution for a 1/4" CCD Digital Camera.

The developments of the GIS are completed with verification and digitization using USGS 7.5 Minute Digital Ortho Quarter-Quadrangles (DOQQ) images. These can be used to further improve the georeferencing by warping the image with the DOQQ, as currently proposed by the USDA FSA (Davis, 2002c).

Differential GPS uses two types of methods to improve GPS positional tolerance. The first method is a code or pseudo-range solution. Differential-code solutions utilize base stations placed on known GPS coordinates locations to remove systematic and random errors from satellite signals. Differential code receivers have the capability of generating sub-meter positional accuracy at one standard deviation based on the course/acquisition code or the precise code of the GPS. This accuracy can be achieved with both single and dual frequency receivers tracking the L1 and L2 frequency signals of the GPS. The process of differential GPS requires that the base-station and rover-station data be post-processed together to determine the errors and generate corrections.

This method is successful and is employed by the USDA Forest Service in tree acreage determination (USDA FS, 1996). However, there are two disadvantages to using post processing differential code solutions for direct georeferencing. One is that it is not possible to determine sub-meter positional tolerance until after the flight is completed and data are post-processed. While this can be amended with utilizing real-time differential GPS, there still remains the possibility that a two or three standard deviation solution could be generated setting the linear accuracy above the requirement of the GIS. For many applications and GIS work in agriculture, sub-meter GPS accuracy is adequate for mapping and georeferencing data.

The second method of differential GPS is called differential carrier-phase. Carrier-phase differential GPS surveying systems provide centimeter accuracy based on a rapid search to determine the carrier-phase ambiguity or total number of unknowns, from the satellite to the receiver. This can be done in a kinematic process where a static base-station collects data concurrent to a kinematic rover. The data are post-processed by combining the base and rover data and generating a centimeter solution.

Solutions using eRTK-GPS solutions receive base-station information in a dynamic mode. To date, modems and standard land communication methods pose a challenge in testing the eRTK-GPS. Typical UHF and Spread Spectrum radios have not been usable at high communication rates because of overland obstruction propagation. Use of wireless cellular communication such as GSM, CDMA and G3 have allowed for the sharing of data at high rates with little to no signal loss. With wireless technology, communication solutions and permanent reference station array solutions can reach as far as 35 kilometers while maintaining carrier-phase ambiguity of two centimeters horizontal and twice that vertical. Tests show that at 35 kilometers from the base-station results are obtained within two minutes of being observed and result in root-mean-square error (RMSE) of one centimeters horizontally and two centimeter vertically at two sigma (Lyle and Woods, 2002).

The ability to obtain long-range solution is vital to the FSA GIS application based on the need to acquire images over large areas in remote agricultural counties for the development of the CLU.

With these types of results an eRTK-GPS position could be directly used in computing the exterior location of the exposure station of a digital frame camera. Testing this concept will be a key element in developing an automatic georeferencing system for the USDA FSA crop compliance GIS application (Davis, 2002c).

The use of eRTK-GPS solutions are seeing a broader move to wide area spatial reference frame networks, like Texas Department of Transportation, to support multiple uses. Precision agriculture and construction are utilizing eRTK-GPS solutions to automate machinery by controlling steering, harvesting, earth movement and real-time mapping activities. This technology growth in the commercial market and the opportunities to receive correction from wide area networks free of charge from state providers will generate more available resources for the USDA FSA utilization of this methodology.

Equipment Configuration

Small-format digital camera systems use CCD's to record the reflectance values with small light energy sensors. Most commercial chips are 1/3"-1/4" in size. A CCD has a standard pixel array that makes converting into raster format straightforward. Several small-format digital camera systems were evaluated and tested for this research. The Kodak DC290 that has a digital frame of a 1901 by 1212 pixel array or 2.3 mega-pixel generating a uncompressed file of 6 Mb was selected. Figure 4.3 shows an example of an aerial image shot with the Kodak DC290.

Figure 4.3: Kodak DC 290 Digital Frame Camera.

The pixel size is approximately 4.2 microns or 4.2 x 10^{-6} m. Therefore the CCD array is 0.0080 meters by 0.0051 meters. Data flowed from the camera to a laptop computer with an USB version 2.0 port on the notebook. As a backup, images were also left on the flash card memory of the camera.

Communication between the PC and the digital video camera can use IEEE 1394 standard often referred to as Firewire Technology. It is defined as a serial data transfer protocol and interconnection system that provides the same services as modern IEEE-standard parallel buses, but at a much lower cost (Kulkarne *et al.*, 2002). IEEE 1394 was created to allow universal interconnectivity, eliminating the need for many different input/output connectors. With IEEE 1394, one can connect 63 devices. Digital camcorders, scanners, printers, hard disk audio recorders, videoconferencing cameras and disk drives all share a common bus connection, not only to an optional host computer, but to each other as well. The IEEE 1394 standard defines three signaling rates, which, in precise terms, are: 98.304, 196.608 and 393.216 Mbps (megabits per second). These rates are referred to in the 1394 standard as S100, S200 and S400. In addition, the IEEE 1394 is ‘hot-pluggable’ meaning that devices can be added and removed without restarting the connected devices or PC. Table 4.2 illustrates the comparison chart between USB and IEEE 1394 standard (Kulkarne, *et al.*, 2002).

The eRTK-GPS system is a Leica SR530 receiver with a Micro-Pulse airborne antenna in a Cessna 152. A Leica SR530 was used for the base station with an AT302 chock-ring antenna to reduce multi-path. Data were broadcast from the base to the rover eRTK-GPS unit.

Table 4.2: Comparisons between USB and IEEE 1394.

	USB 2.0	**IEEE 1394 Firewire**
Speed	1 Mbits/sec to 12 Mbits/sec	100 Mbits/sec to 400 Mbits/sec
Topology	HIIR w/PC in center	Peer-to-Peer
Hot-Pluggable	No	Yes

Several communication systems were tested for the eRTK-GPS solution. A ground test was made previously with Sprint PCS wireless web at 19,200-baud rate. Airborne tests with the Sprint PCS were inconclusive based on the move from PCS to G3 format resulting in communication connection difficulties. The aircraft and base would connect but only stay locked for short periods.

An airborne system test was made with Verizon wireless communications system and the system was unable to maintain a lock for longer periods of time. It was hypothesized that this could be caused from the cellular link jumping from tower to tower based on the rover location above multiple visible towers. For final tests, a UHF 35 Watt Pacific Crest radio was used. The aircraft location above the radio antenna allowed for long-range data communications. Concurrent to the real-time data collection, the raw data were logged for post-process verification along with other base stations for multiple baseline calculations.

The digital camera was mounted on the wing strut of the aircraft and the antenna was mounted directly above on the wing. An offset calculation of eccentricity was made from the antenna to the exterior body frame of the camera. The point was previously located on the camera in a laboratory calibration and the phase center of the antenna was determined from published information from Leica Geosystems. After the aircraft was manually leveled a reflectorless total-station was used to measure the offset eccentricity in 3-D. These values were directly entered into the GPS unit and applied to the offset computation. Based on previous tests by the USDA FSA on small-format digital cameras, it was determined that no tilt sensor would be utilized for this GIS application. Using a 2-D affine transformation, a world file was concurrently written for each image.

Use of the digital image for GIS application in this methodology will allow for a speedier rectification process without the need for complex tilt sensors. A tilt sensor could be directly attached to the camera and linked to the GPS sensor and a binary string of the Easting, Northing, Othrometric Elevation, swing/yaw (kappa) from GPS, and roll (omega) with pitch (phi) from the digital tilt sensor can be recorded and applied. The USDA FSA transformed the Easting and Northing coordinates into a grid coordinate system that matched the CLU layer in the GIS. The Elevation values were an orthometric elevation derived from a geoidal model loaded in the eRTK-GPS unit and applied on-the-fly. All eRTK-GPS positional data flowed to the computer using a National Marine Electronics Association (NMEA) LLK format string. A laptop computer with Windows 2000 and the control software was utilized.

A system calibration of the GPS and the small-frame digital camera were needed to assess systematic errors. Based on direct georeferencing of the exposure station for rectification, no aero-triangulation or block adjustment was performed. Latency between image grab, or exposure, and GPS logged time was noted and applied. Figure 4.4 illustrates the eRTK-GPS exposure station positions with a single directly georeferenced image on a DOQQ.

<u>System Results of Aerial eRTK-GPS</u>

The results show a comparison of post processing to eRTK-GPS. Once directly georeferenced, the image captured 26-kilometers from the base-station was compared to six GCP's from ground GPS survey. Results showed that the small-format digital image RMSE was 12 meters to that of the GCP's.

Figure 4.4: Digital Frame Georeferenced on DOQQ with eRTK-Exposure Stations 26-kilometer Baseline.

Table 4.3 shows a comparison of the direct georeference affine transformation as compared to the georectified solution using the six GCP's. This could be attributed to measurement where taken at full one second measurement and the camera could have exposed between GPS measurements or the positional error in the DOQQ. This positional error would not effect the acreage calculation. Shifting the image to the proper location would not change the acreage of the tract. The direct georeferencing is ideal for placing the image on the spatial location of the tract being checked under compliance. USDA FSA most difficult aspect of aerial compliance is the spatial orientation of the aerial images to the landowner or tenant under crop support.

A base station was set approximately 30-kilometers from the airport and within approximately 26-kilometers of the target area. Raw carrier-phase and code data were recorded at a one second epoch rate in the aircraft and at the eRTK-GPS base-station. Concurrently, a National Geodetic Survey (NGS) Continuously Operating Reference Station (CORS) at Southern Polytechnic State University Surveying Research Center in Marietta, Georgia, was set to collect data at a one-second rate 40-kilometers north of the target area for the post processing comparison. Results are shown in Table 4.4 and Figures 4.5 illustrate the flight path using eRTK-GPS as compared to a multi-station GPS networked solution. Results at a ten-kilometer long baseline are approximately three centimeters in position and nine centimeters in height. The accuracy at the longest baseline (27,154 meters) resulted in a real-time positional error of three-centimeters in position and elevation as compared to the networked solution from two independent base stations.

Table 4.3: Comparison of Georectified and Direct Georeferenced Affine Transformation Parameters.

Comparison of Georectified to Direct Georeferenced		
Parameter	**Georectified RMSE = 3.57207**	**Direct Georeferenced**
A	0.0241780507561330060	0.023580
E	0.187888943187361050	0.188640
B	0.180873292638056770	0.188640
D	-0.0249782993028029620	-0.023580
C	728685.31672634801	728675
F	3686183.1259230524	3686194

Figure 4.7 shows the distance of the baseline in reference to time, and Figures 4.8-4.10 provide the residuals of the eRTK-GPS versus the post-processing multiple baseline solution. The post-processing solution is considered the most probable value to which the residual of the eRTK-GPS is computed.

The quality of the results offers promising usage for direct georeferencing of the exposure station with the small-format digital camera, and the eRTK-GPS. No loss of carrier phase ambiguity was encountered during flight. The maximum error occurred as the aircraft was making its descent to land and radio communication was lost. Some increased error of less-than 0.5 meters occurred when the aircraft banked over the target area. The images that were collected and georeferenced suffered from vibration from the mounting of the camera on the wing. Overall, the results show that based on the GIS application of crop compliance, an eRTK-GPS solution of the exposure station can meet the minimum tolerance set by the USDA FSA. This new approach of direct georeferencing with eRTK-GPS would remove the time-consuming task necessary to post-process the GPS data, transform coordinates to a grid system and apply a geoidal model.

Table 4.4: Exposure Station Positional Error between eRTK-GPS and Post Processing in Aerial Platform.

Aerial eRTK-GPS Results

Baseline Length Kilometers	RMSE(N) Meters	RMSE(E) Meters	RMSE ELEV Meters	Max N Meters	Max E Meters	Max ELEV Meters
<10	0.011	0.025	0.089	0.037	0.025	0.401
10-20	0.023	0.014	0.036	0.051	0.037	0.130
20-30	0.538	0.327	0.261	1.240	1.140	0.839

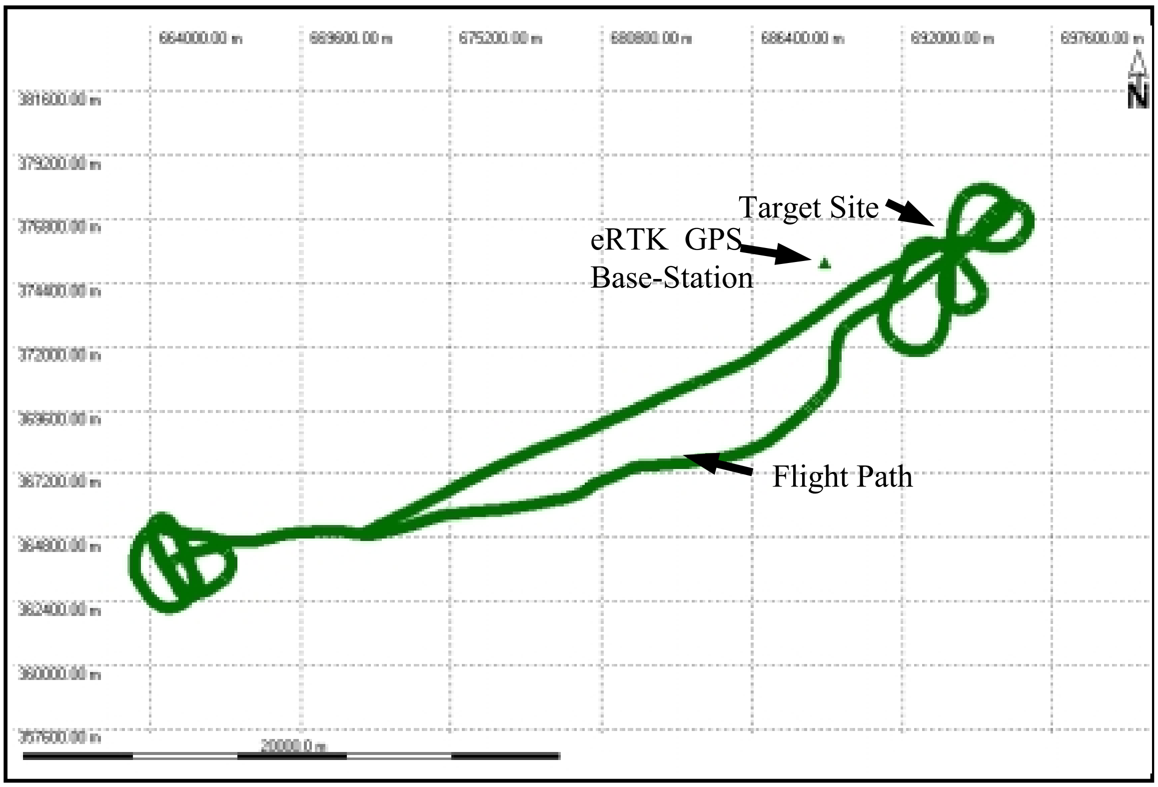

Figure 4.5: Aircraft Path from Airport to Target Site.

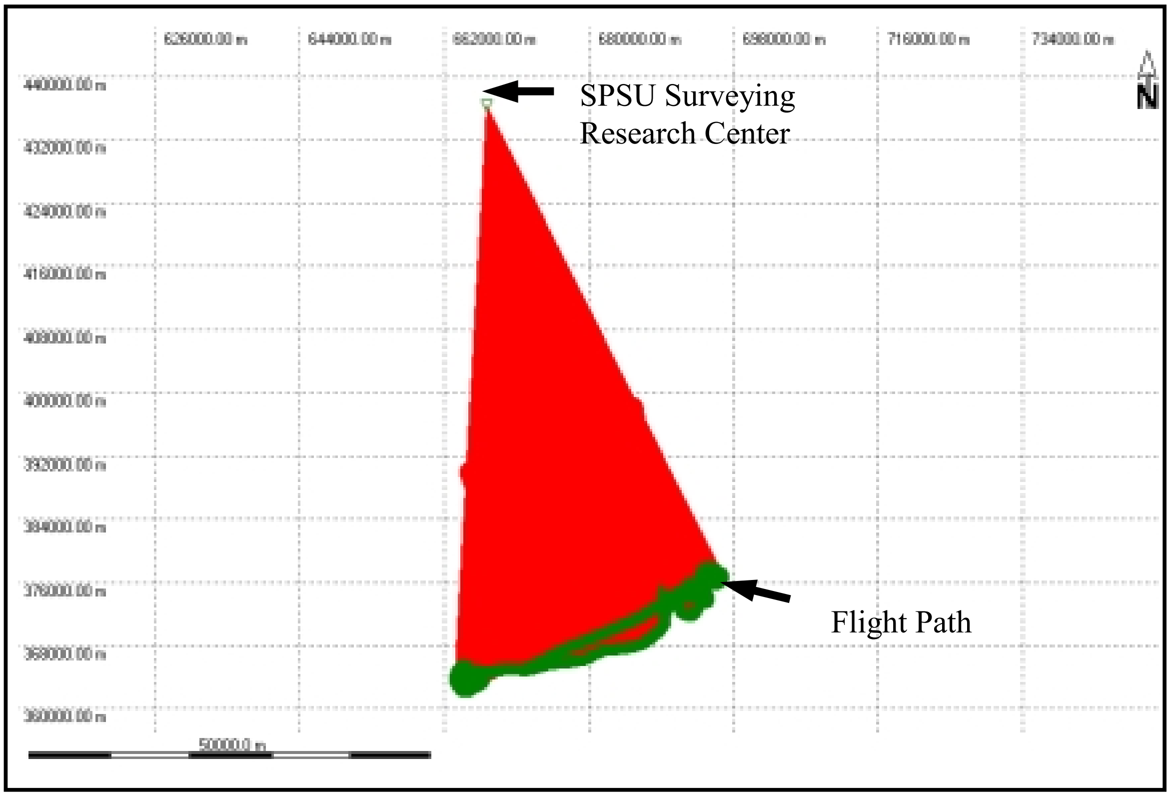

Figure 4.6: Aircraft Path and Post Processing Base-Station.

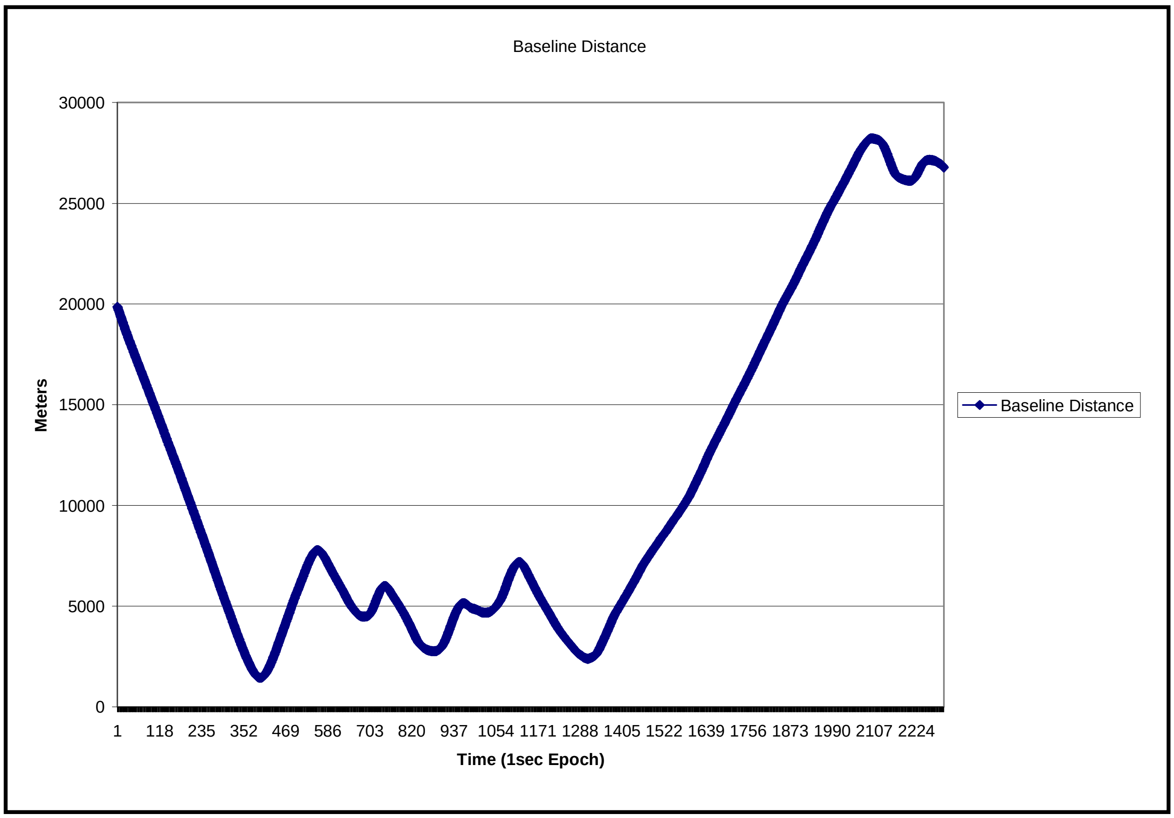

Figure 4.7: Baseline Distance from GPS Base-Station to Aircraft.

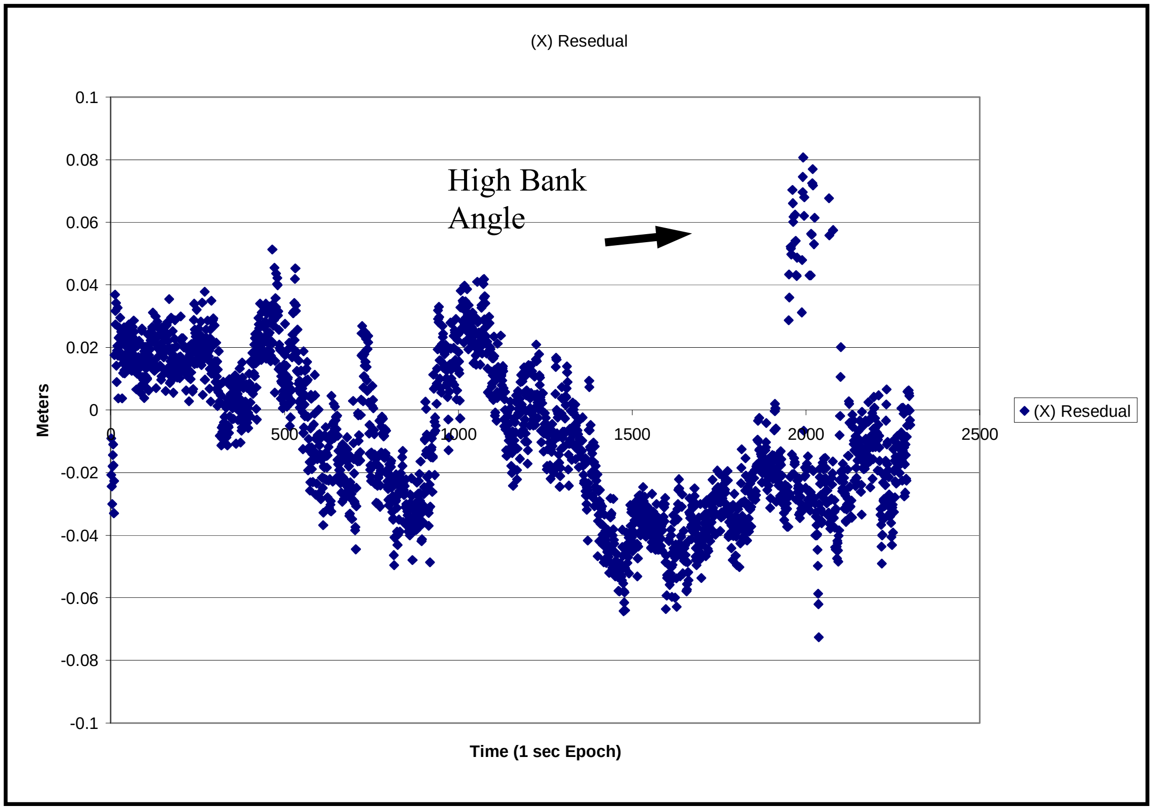

Figure 4.8: Baseline Residual Error in X Direction (Easting).

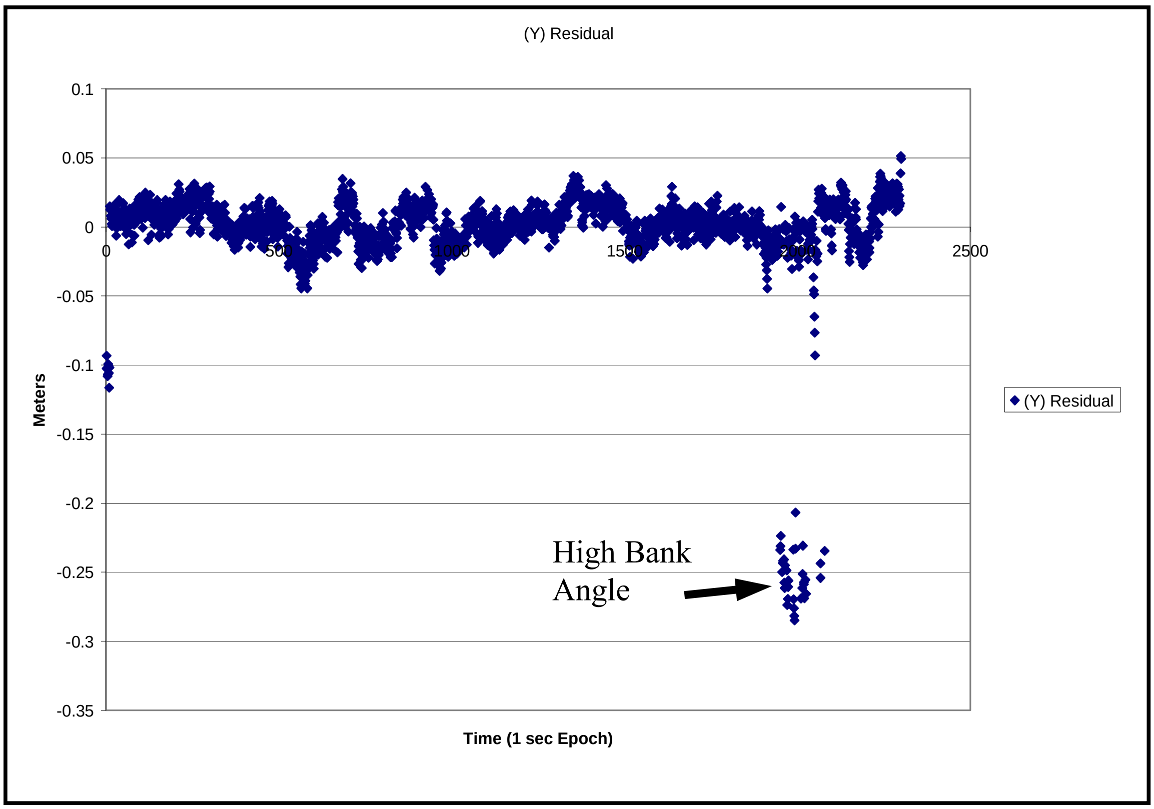

Figure 4.9: Baseline Residual Error in Y Direction (Northing).

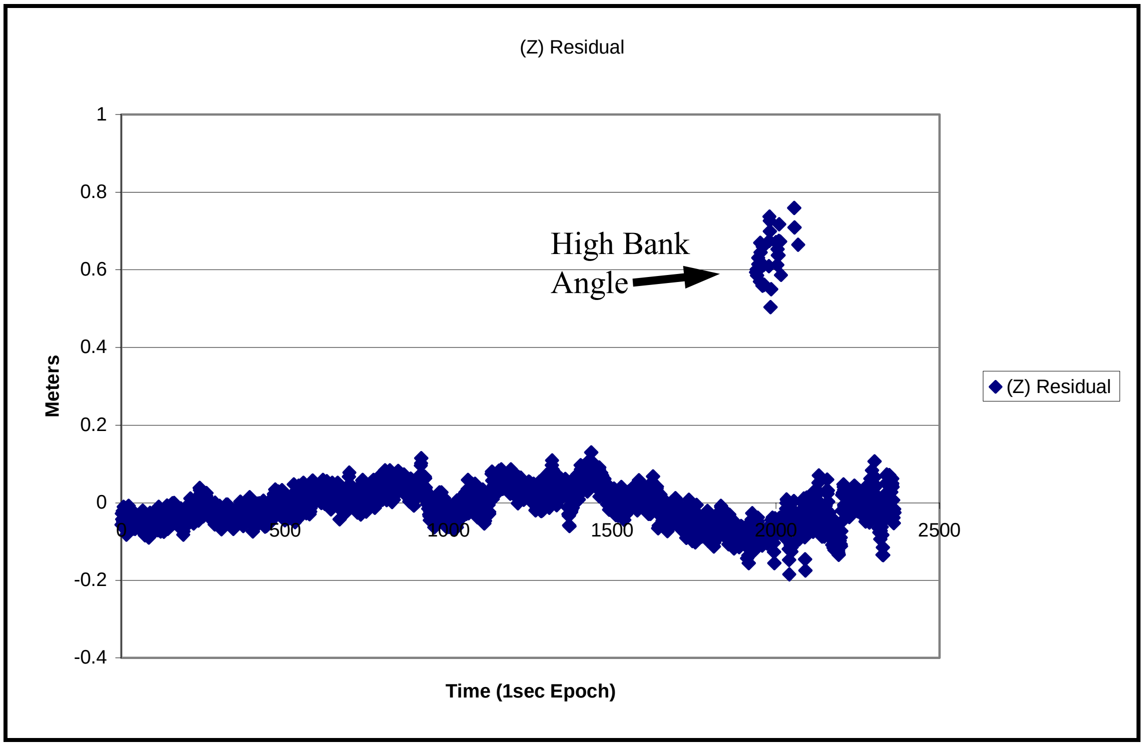

Figure 4.10: Baseline Residual Error in Z direction (Elevation).

Application

The current method of utilizing 35 mm slide film requires a considerable amount of time to process and rectify, measure acreage, and digitize the land ownership. Images of target areas are often shot with smaller scales to capture the target site in one slide because the navigation of targeting areas is often performed from chart navigation methods. Digital navigation could provide an instant improvement with supported over-site verification of the target area within the aircraft at approach. Distance cross-course values as well as height correction from eRTK-GPS can improve target image capture. Having GIS overlay functionality in the navigation software will allow the CLU to instantly be integrated with the image to determine if the correct crop area was collected.

Conclusion

This research discusses a new approach to direct georeferencing small-format digital camera systems with eRTK-GPS solutions for USDA FSA crop compliance monitoring. The approach using the small-format digital camera is suggested to improve the time of obtaining digital data to support USDA FSA GIS implementation and increase the accuracy and quality over the digitizing method with 35 mm slide film. The system was expected to, and did, achieve centimeter level spatial accuracy in a real-time aerial platform of the exposure station as compared to post processing DGPS. Future publications and research will discuss improvements in mounting and image capturing. With the strong results shown in this application, more investigation for increased accuracy of application should be sought.

CHAPTER 5

INVESTIGATION INTO SMALL-FORMAT DIGITAL CAMERA SENSORS FOR DEVELOPMENT OF USDA GIS OF CROP COMPLIANCE [1]

[1] Lyle, S., 2003. Accepted by Surveying and Land Information Science. American Congress on Surveying and Mapping. Reprinted here with permission of publisher.

Abstract

The purpose of this research is to investigate the use of a small-format digital camera sensor for crop compliance monitoring in the establishment of a geographic information system (GIS) for crop compliance replacing the 35 mm slide film format system. To meet this objective an analysis and evaluation of digital frame (DF) and digital frame video (DFV) small-format digital sensors was conducted. DF offers higher spatial resolution with larger image size, but requires longer image write times. DFV offers faster write speed, but typically has smaller image size. Evaluation and comparison of the two types of sensors were completed in this research for replacing the current 35 mm slide film. A discussion of previous small-format aerial photography is included with the principal objective of defining the parameters of the small-format digital aerial imagery. The focus of this research is to determine the extent of the digital cameras' limitations, and to determine the ability to quickly georeference and insert data into a GIS. The results show that DFV is adequate for collecting the desired images for interpretation of crops and digitizing the boundaries to determine land areas based on advancing communication connections and larger image sizes.

Introduction

The use of a small-format digital camera for aerial crop compliance has been investigated by the U.S. Department of Agriculture Farm Service Agency (USDA FSA) based on the digital camera low cost data capture logistics, total digital format delivered and ability to support their initiative to move to a geographic information system (GIS) compatible format (Davis, 2002c). Small-format digital cameras for aerial mapping for

GIS have been well established by others (King el al., 1994; Mason *et al.*, 1997; and Mostafa and Schwarz, 2000). New technology in off-the-shelf high-resolution digital camera systems is now more available for use in scientific applications. Small-format digital camera systems can be grouped into digital frame (DF) and digital frame video (DFV) formats. The formats are similar in nature, but have unique characteristics for use in aerial imaging that will be discussed in this research. The Kodak DC290 digital frame (Figure 5.1) and the Sony PC1 digital frame video (Figure 5.2) were evaluated.

A solution was developed that included the communication, mounting, and processing of the DF and DFV. Comparisons were completed between the two sensor formats for evaluation in use of crop compliance aerial photography. DFV's largest benefit is its ability to capture and write high-speed digital frames in consecutive frame format. The disadvantage to current DF and DFV technology is the size of the charged coupled device (CCD) chip. As seen in Figure 5.3, a comparison of the image size to standard photogrammetry products show the CCD image format to be considerably smaller. Digital sensor systems are capable of collecting images more ergonomically and so that the USDA FSA can use the digital data in other applications.

This new technology of digital sensors allows fast acquisition of data that can be used in a GIS to calculate the area of crops receiving support and the delineation of the boundary for the common land units (CLU). To automate the system, previous research of direct georeferencing of the exposure station can be used to reduce the extent of ground control typically needed in rectifying the imagery to remove tilt and place the image in a coordinate system.

Figure 5.1. Kodak DC 290 Digital Frame Evaluated and Mounted on the Aircraft.

Figure 5.2: SONY PC1 Digital Frame Video Evaluated and Mounted on the Aircraft.

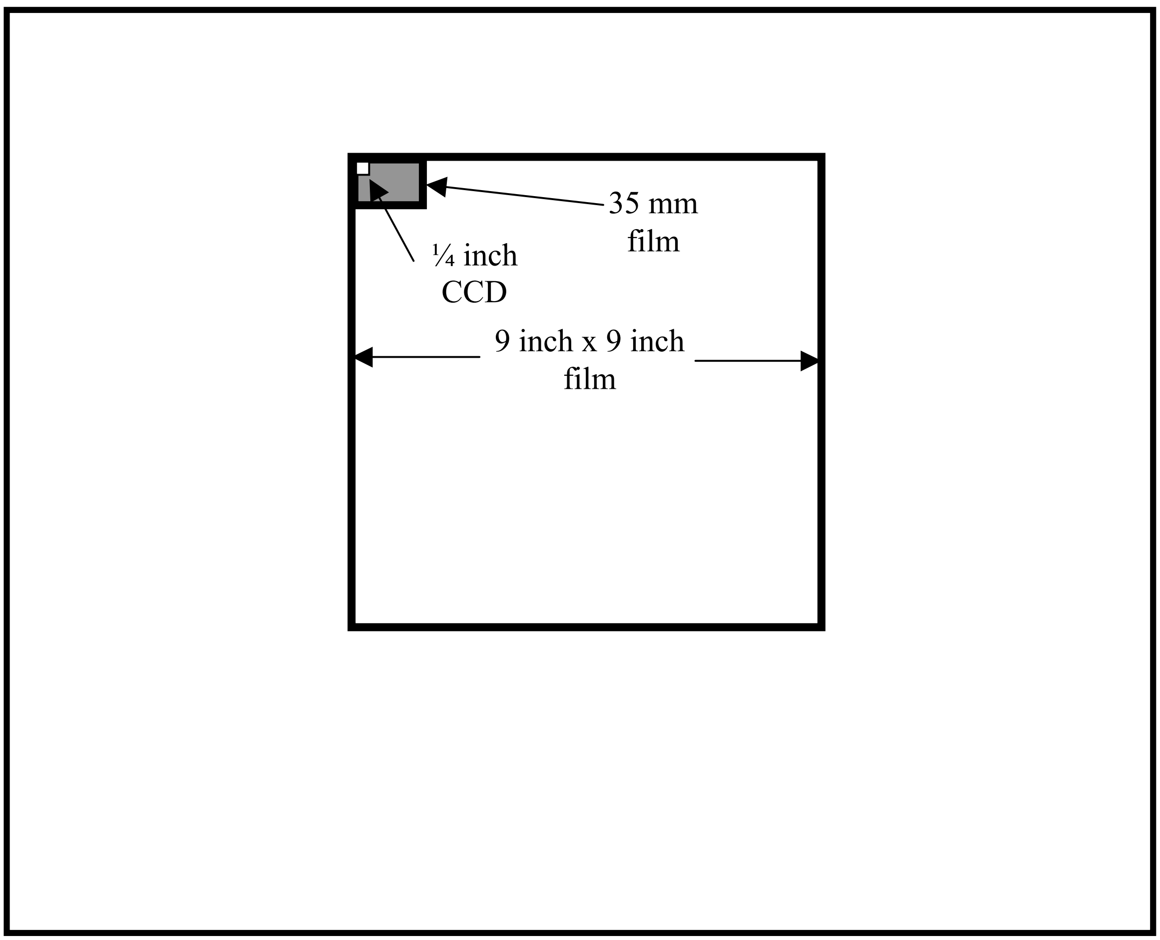

Figure 5.3: Comparison of a CCD chip, 35 mm slide film and 9” x 9” Format Film.

The current 35 mm slide film method involves image rectification using slide projectors and table digitizers. This method is time consuming. This time delay dilutes the time to the final product that is manageable for GIS precision agriculture applications. An advantage to a film product is the higher spatial resolution based on the grain size in the film and the scanner utilized. A review of this process demonstrates that a film product for the small-format digital camera in crop compliance can achieve eight-mega pixel resolution once scanned (Davis, 2002c).

In this research, geometric correction is applied both in real-time and through a post processing method to the DF and DFV. Geometric corrections are conducted to remove error due to tilt or terrain relief and georeference the image to a desired coordinate system by using existing U.S. Geological Survey Digital Orthophoto Quarter Quadrangle (DOQQ) images and Digital Elevation Models (DEM's). An extended Real-time Kinematic Global Positioning System (eRTK-GPS) solution is employed to georeference the images by composing an approximate world file (a file containing affine transformation parameters) for each image based on the real-time position of the digital camera exposure station location. This discussion will focus on the application of using a DF or DFV for acquiring aerial images in the GIS CLU process. The focus of this research is an evaluation of the camera systems and the results of the imagery. A potential use in other applications is discussed. Conclusions are drawn on the best method of using small-format digital sensors for other applications within the USDA FSA.

Small-format Digital Camera Systems

A small-format camera with a DF, has similar geometric characteristics to a single-lens camera that uses film (Wolf and Dewitt, 2000). The recording device, contrary to the film medium, is a CCD. The CCD chip is considerably smaller than typical 35 mm or 9 by 9 inch film. Common chips are 1/4-inch or 1/3-inch square. CCD chips consist of solid-state array chips that absorb incident photons into their internal structure (Usery, 1985). Digital cameras employ an in-camera analog-to-digital converter to transfer photons to digital signals. The CCD array is then in the typical raster format that is commonly used in remote sensing. Therefore, each digital detector in an array is proportional to each pixel (picture element) in a digital image.

The discrete pixel (X,Y) coordinates in the array allow for a uniform measurement of the spectral reflectance of each individual pixel. Tight arrays experience problems in registration errors from the X,Y movement of the scene or the detector. The CCD of a DF is an area scanner chip in which the X,Y array of detectors are structured so that the entire image can be captured with one exposure, eliminating the need for any movement by the detector or the scene. This area array is capable of producing the highest frame rates with the greatest registration accuracy between pixels. Bleed over, or blooming from a fuzzy pixel's high reflectance requires lower signal-to-noise digital amplifiers. The process of data collection begins with the chip's exposure, which coverts the reflected light in the form of photons sensed into an electronic charge at each element. Now charged, the element moves the packets of charge particles within the silicon substrate. A conversion of charge to voltage value based on output amplification is recorded. The photons' penetration into the depths of silicon determines the charge or wavelength reflectance value (Kodak, 2002).

The color is interpolated from a series of Red-Green-Blue (RGB) cells in the checkerboard pattern, or Bayer filter, as seen in Figure 5.4. Each cell in a Bayer filter is adjacent to a two-by-two matrix of two green cells for every red and blue cell. The adjacent pixel color interpolation technique assures that the cell is adjacent to the possible color cell or each cell is in contact with a cell color of the possible color to be recorded. The interpolation algorithm looks at the strength of the missing colors recorded by adjacent pixels and makes a qualified interpolation of the two missing colors on a pixel-by-pixel basis (Graham and Koh, 2002). Figure 5.4 illustrates a standard chip in the DC290 camera used in this research with the Bayer Filter.

Another method uses a Dichroic Prism to split the light into three primary colors and channel them to dedicated CCD chips for red, green and blue (Kodak, 2002). New technology, called Foevon, is entering the market. Foevon stacks the RGB matrix with a configuration similar to film. The Foevon chip allows the longer wavelengths to pass through to the other chips (Foevon, 2002). Foevon technology could improve image quality, but the remaining methodology and process presented in this paper will remain consistent for DF versus DFV and the georeferencing process.

DFV uses an area-scanned array, but is often specified to the horizontal line resolution of the chip based on the output ability for National Television Standards Committee (NTSC) or Phase Alternation by Line (PAL) broadcast formats.

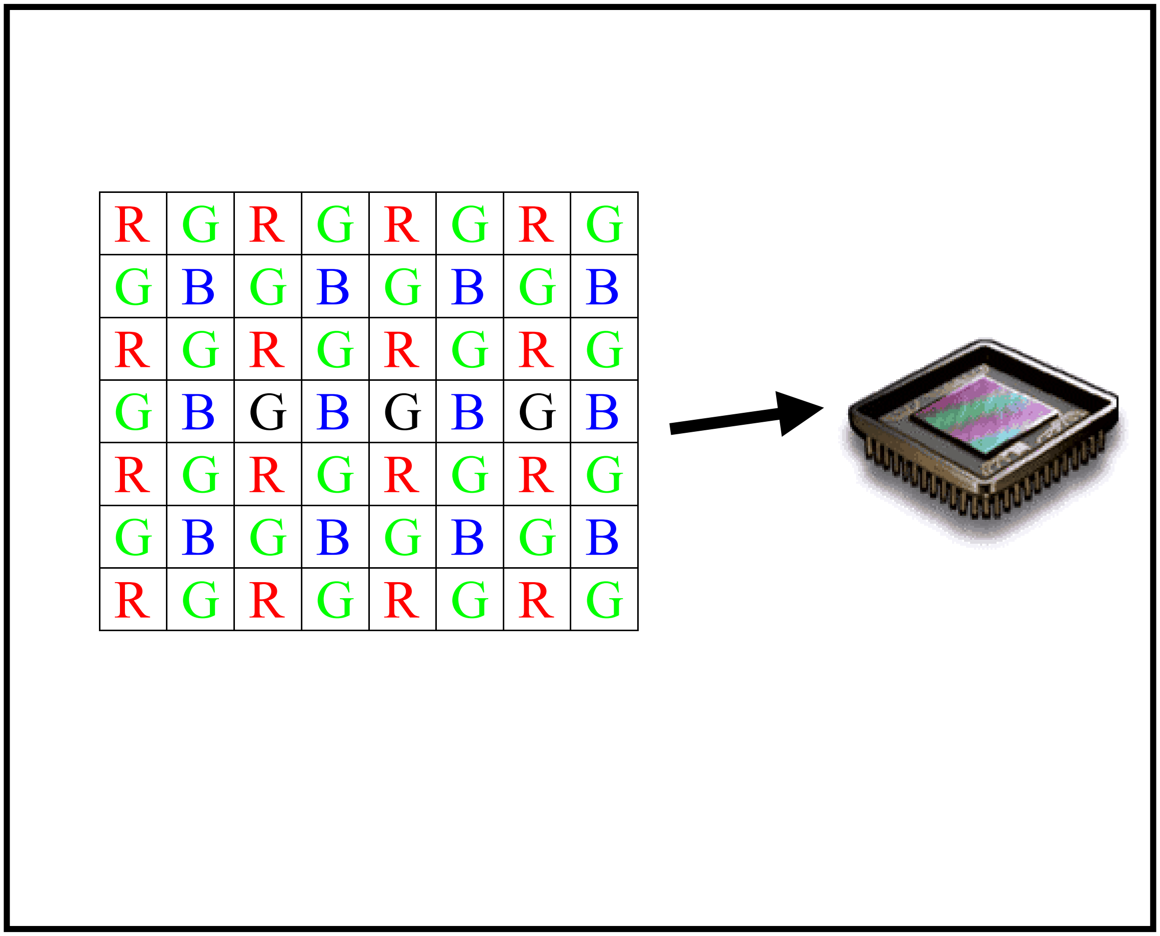

Figure 5.4: Kodak CCD Chip for the DC290 Digital Frame Camera and Bayer Filter.

The DFV has the ability to capture full frames from the digital video and obtain a full scanned-area output of the actual CCD array, less approximately 30 percent of the total pixels on the chip. The DFV horizontal scan rate for digital cameras uses the Kell factor 0.7 of the vertical pixel from the 1950's to represent the horizontal resolution.

Each of the smallest detail of the a scanned scene should be represented by one pixel, that is, each scanning line would be available for one pixel along any vertical line in the image. In practice, however, some of the details in the scene fall between scanning lines, so two scanning lines are required for such details that are one scan line high. Thus some vertical resolution is lost (Benson and Fink, 1991).

For example, the 480-pixel vertical or Y-scan length has 336-lines of vertical resolution in video output. It should also be noted that most DFV have a time-code for each frame maintaining approximately 30 frames per second to concur with NTSC format. This is important when synchronizing the image to its spatial exposure location.

Sensor Specifications

Both cameras were evaluated to test the advantages and disadvantages. The Kodak DC 290 is a DF totally contained within its own operating system and communication format. The DC 290 has a 4.2-micron square pixel CCD image sensor with an array of 1901 by 1212 pixels with 24-bit color radiometric value; thus, suggesting an 8.0 millimeter by 5.1 millimeter actual chip size. The image resolution can be set to several levels: Ultra (2240 by 1500 interpolated), High (1792 by 1200), Medium (1440 by 960), and Standard (720 by 480). For this research, High (1792 by 1200) was selected to give the best resolution without using an interpolated solution that could give mixed pixel problems in the interpolation of the pixels. The stored images can be saved in an uncompressed TIFF or a JPG format. To maintain as high a quality as possible, uncompressed TIFF was used in this research and images were stored on a 48 MB compact flash card with 6.3 MB per image. The camera has selectable auto-focus mode with focal lengths of 8-24 millimeter. For this research the focal length was set at manual focus infinity, or 8 millimeter. Shutter speed is variable at 1/360 to 1/2 second in auto exposure. Again, to maximize the functionality, 1/360 was set. Real-time communication was achieved through the Universal Serial Bus (USB 2.0) interface cable (Kodak, 2002).

Communication to the Kodak Camera with the USB was made using the Kodak Software Development Kit (SDK) and ActiveX control functions. Control software was developed in Microsoft Visual Basic to operate the camera remotely for setting configuration parameters, capturing images, and managing memory. Data were coordinated between eRTK-GPS for spatial coordinates and the exposure station location using a real-time georeferencing algorithm.

The Sony DCR-PC1 DFV camera was selected based on its compatibility and compact size. The CCD chip’s physical size is stated as a standard 1/4-inch (6.8 millimeters) CCD. It has been noted in this research that the recorded size is different from the output size in real-time. The output size via an IEEE 1394 firewire communication format equates to 720 by 480 array compared to 680 by 480. With a focal length of 4.3 millimeters zoomed at infinity and shutter speed set at 1/10,000 auto exposure, the images were collected in TIFF format directly onto a laptop computer.

The Sony PC-1 was also fitted with an advanced Hole Accumulation Diode CCD imaging device that provided reduced noise in the video signal-to-noise-ratio, or a 6 dB gain from a standard CCD chip. This allowed darker images or images in shadows to be seen with more clarity. An added advantage seen in DFV is the stabilization function standard in most camcorders. The stabilization system uses motion sensors and a floating lens and chip to compensate for unwanted camera movement. This process acts like a gyro mount to reduce the tilt and vibration at high-frequency oscillation, but does not remove gross tilt created in pitch and yaw. Another benefit is the Carl Zeiss spherical lens that provided small lens distortion.

Communication was performed utilizing an IEEE 1394 firewire for bi-directional digital communication interface between the laptop PC and the Sony PC1. To substantiate the specification offered by the manufactures and analyze the interior orientation parameters, a camera calibration was conducted. This calibration is discussed later as the overall system was calibrated based on the concept that orientation parameters could vary with different configurations.

Evaluation

Advancements in CCD chip technology have led to increased investigation. Research has been conducted on the camera system's interior characteristics and the use in direct georeferencing applications (Deng and Faig, 2001). Conclusions reveal that the main disadvantages in utilizing a small-format digital camera for photogrammetry applications are image size, the write speed of the camera, and spatial resolution. In GIS applications, where less strenuous accuracies are required, the small-format digital camera can be utilized based on the ground area size and spatial resolution based on adjusting the flying height to meet the coverage. If more spatial accuracy is needed lower flying heights are required and a mosaicking of the images could be employed. In this configuration the write speed of the DF camera cannot be maintained to acquire a continuous data stream based on the data format and size. The use of DFV offers the ability to collect images continuously, but at a smaller frame rate. The continuous pattern of DFV with mosaicking gives an image of a standard photogrammetry strip. It is possible to obtain stereo pairs to acquire elevation models, if a good base-height ratio is maintained.

The Kodak DC290 produced excellent spatial resolution offering 7.6 centimeter per pixel at a 600 meter flying height (Figure 5.5). A burst rate could be used to capture four continuous JPG frames, but it was found that at the approximate 0.4 megabytes (MB) size per photo the write time for the burst was as much as 75.3 seconds. Increased card size would not resolve the write speed, but would allow for more data collection. Therefore, a 128 MB Flash card would only be able to store approximately 90 images. The images can be removed from the Flash card to the laptop computer through the USB port accessing the Flash as a standard hard drive. A routine was developed that performed this task, but it was found that conflict existed if a move command was used while the camera was accessing the card.

The Sony DCR-PC1 camera collected approximately 30 centimeter resolution at a 600 meter flying height (Figure 5.6). With DFV it is possible to record 200,000 frames on a 60-minute tape. Video in MPEG or AVI format can be collected directly to a laptop PC, where 17 minutes of video equates to approximately 1500 MB of memory.

Both the Kodak and the Sony digital sensors would meet the spatial requirements needed to obtain ground areas needed by the USDA FSA in the GIS for crop compliance at this flying height.

The chip area is directly proportionate to the field-of-view (FOV) of the image. For the Kodak DC290 the CCD chip area is 40.80 mm^2 and would cover approximately 15.0 acres at a flying height of 600 meters. The Sony DCR-PC1 CCD chip area is 26.88 mm^2 and would cover 85 acres at a flying height of 600 meters, which is greater based on the smaller focal length (4.3 millimeters) utilized in the Sony DCR- PC1 compared to the 8.0 millimeter focal length of the Kodak DC290. Figure 5.7 illustrates that at 600 meter flying height, the DFV is capable of capturing continuous area frames.

According to the USDA, a 35 mm slide film would meet the desired accuracy based on flying height to area covered. Pixel quality degradation caused by vibration is evident in the DF imagery. DFV in commercial digital camcorders include motion stabilizers that can assist removing the smearing from vibration. The qualitative evaluation demonstrates that the small-format digital imagery would support the USDA's needs.

Application Configuration

Price support is offered to farms for the equitable delivery of benefits and services in improving and promoting the economic stability of agriculture. These services use aerial photographic images to monitor the compliance of the farmers by monitoring the crops for land use productivity. Approximately 15 percent of the total farm area under compliance is randomly checked using the 35 mm slide film aerial images

Figure 5.5: Digital Frame Image Example of Agricultural Site.

Figure 5.6: Digital Frame Video Image Example of Agricultural Site.

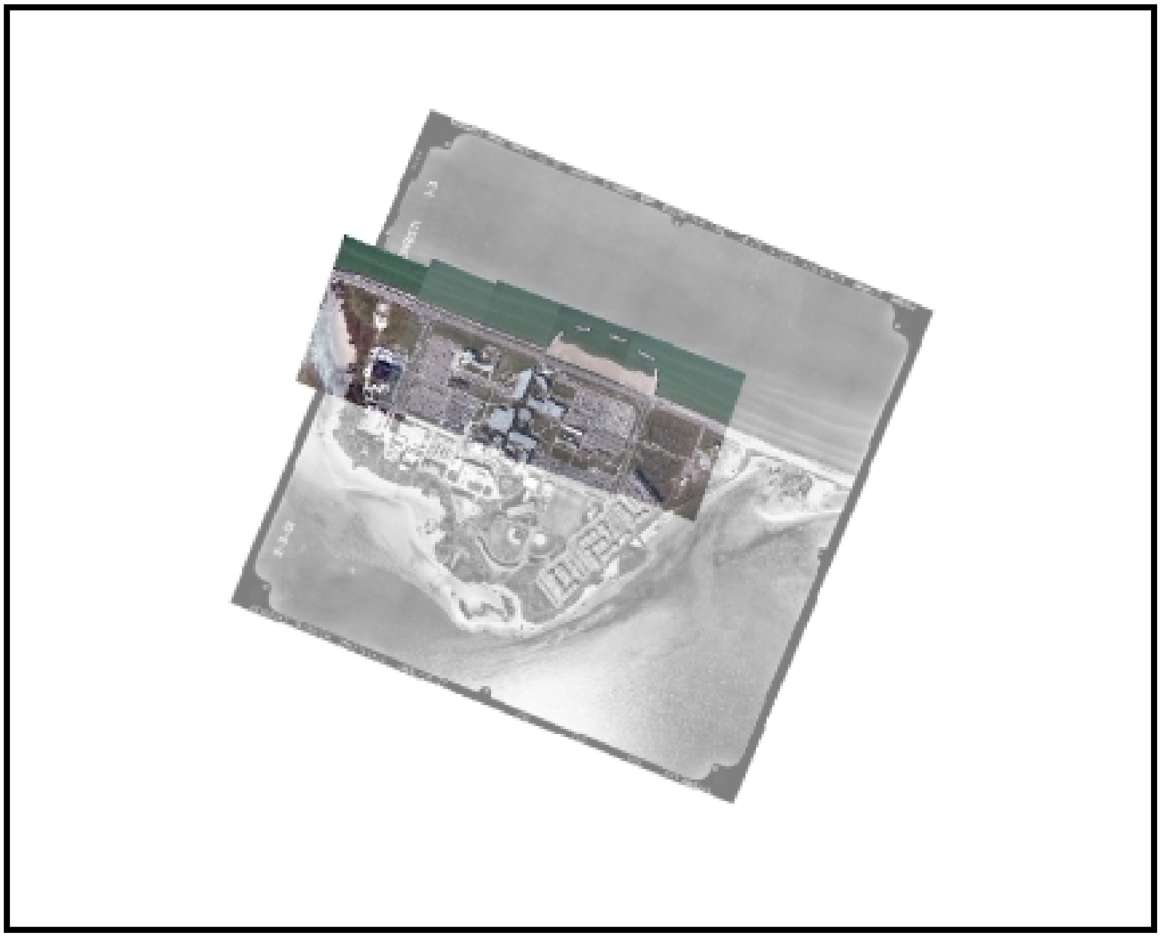

Figure 5.7: Digital Frame Video of Texas A&M University-Corpus Christi Campus.

The 35 mm slide film is used to digitize the area and identify the crop type. The information is also used to assist the USDA FSA field service office in supporting the grower in crop decisions, such as erodability, crop rotation, and planting. The USDA FSA plans to develop a digital solution that GIS can use to assist the growers. **A**dvancements in improved crop production can be directly linked to the use of GIS and remote sensing (Usery *et al.*, 1995; Clark, 1997; Perry *et al.*, 2000). The demand for more reliable and affordable images is high by the agricultural industry.

Although satellite imagery (e.g. Landsat, TM, MSS, etc.) is available at a low spatial resolution (typically, 10 to 30 meters) it is difficult to interpret and extract information at a reliable accuracy for use within a GIS (Mostafa and Schwarz, 2000). Having available images that focus on a specific area is not always readily possible due to cloud cover. Film-based airborne imagery systems can improve spatial resolution and time to final product. The cost of film-based airborne imagery systems is typically quite expensive. Digital aerial photograph imagery, on the other hand, solves both the spatial and time to produce a final product in a financially feasible manner.

The USDA FSA is now required to complete the crop inspection for crop support with a GIS solution (Heald, 2002). Offices are scanning and rectifying all the 35 mm slide film currently available. The proposed method of utilizing the DFV would remove the need for scanning and rigorous rectification. The solution proposed in this discussion has the ability to directly georeference the extracted images from the DFV by utilizing the recorded eRTK-GPS locations. A DFV is selected over the DF based on the image writing and collection format.

System Configuration

The Sony DCR PC1 was mounted internally in a fixed frame system and was calibrated to the eRTK GPS system with an in situ self-calibration. The Sony DCR PC1 was mounted into a custom designed camera mount that allowed the operator to level and rotate to remove tilt (Figure 5.8).

Software was developed to collect the images in real-time for post processing. The software used the IEEE 1394 firewire port for bi-directional communication. This allowed for the triggering and recording of images. Data were captured on both the internal memory of the small-format digital sensor and the laptop computer within the aircraft. In a real-time configuration the TIFF encoder was used on the laptop computer to compress the image for better storage.

An image index model was built to assist with future mosaicking processes that are done in a post processing methodology. The images were maintained in their raw format and an accompanying World File was written for each image extracted from the video. Equation 5.1 and 5.2(a)(b) demonstrate the process of generating the world file, which is recorded with each associated image based on the GPS information as illustrated in Figure 5.9. This equation is the standard affine transformation equation derived from computed elements taken from the flight parameters and the eRTK-GPS solution recorded in a text file in National Marine Electronics Association (NMEA) LLK format. NMEA is a standard that defines electrical signals, data transmissions protocol, timing, and sentence formats for communicating navigation data among marine navigation instruments.

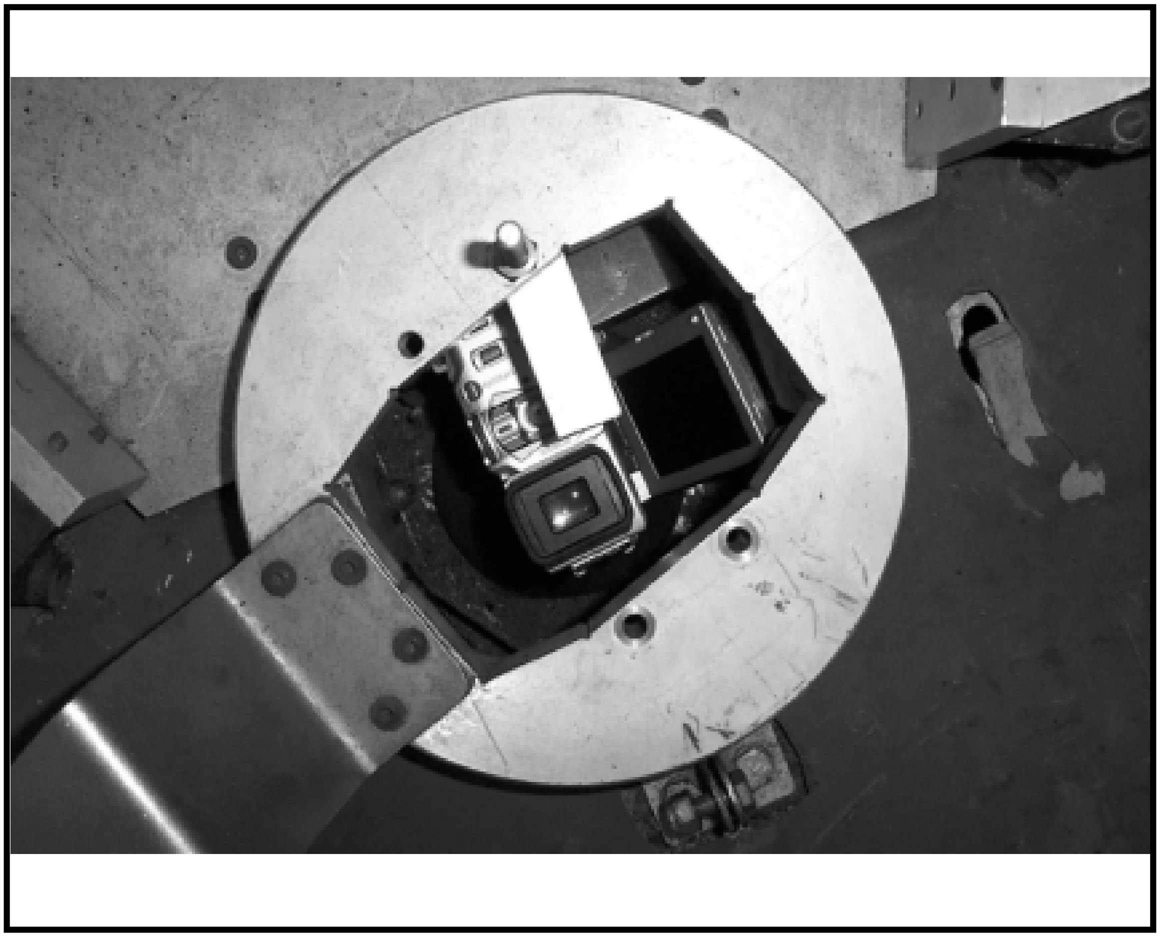

Figure 5.8: SONY PC 1 Digital Frame Video Mounting in Aircraft.

$$\frac{f}{H_a} = \frac{d_a}{D_a} = \frac{1}{SF}$$ Equation 5.1.

$$E_i = SF_X + R_Y + E_{GPSo/s}$$ Equation 5.2a

$$N_i = R_X + SF_Y + N_{GPSo/s}$$ Equation 5.2b

The y-scale (E) is negative because the direction of increasing values of the y-coordinate and the image is opposite to the direction of y-reference in the map coordinate system. The origin of an image is located in the upper-left corner; whereas, the origin of the map coordinates system is located in the lower-left corner. Row values (Y) in the image increase from the origin downward, while y-coordinate values in the map increase from the origin upward (ESRI, 2003). This system is composed of the digital camera system, eRTK-GPS for georeferencing, laptop computer for data collection and a separate GPS for navigation. This system requires minimal interaction and processing from the operators.

Table 5.1: World File and Affine Transformation Equations

Direct Georeference Equation	
Ei	calculated x-coordinate of the pixel on the map
Ni	calculated y-coordinate of the pixel on the map
SF_X	x-scale; dimension of a pixel in map units in x direction = focal length/ U_{GPS}- H_{AVG} or U_{GPS}- DEM
R_X	rotation terms in x direction
R_Y	rotation terms in y direction
$E_{GPSo/s}$, $N_{GPSo/s}$	translation terms; x,y map coordinates of the center of the upper-left pixel
SF_Y	negative of y-scale; dimension of a pixel in map units in y direction = focal length/ U_{GPS}- H_{AVG} or U_{GPS}- DEM

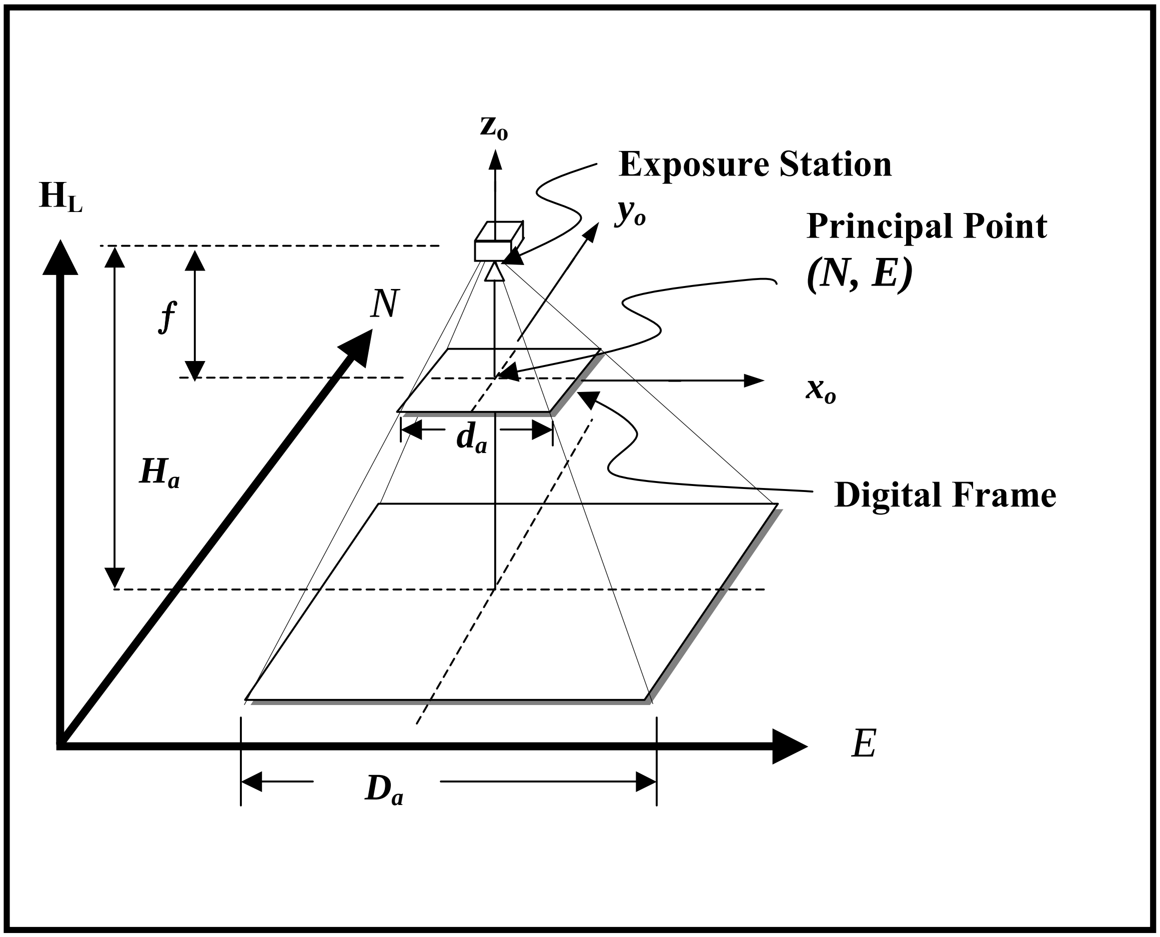

Figure 5.9: Geometric Properties of Aerial Photograph.

Conclusion

Potential applications for crop compliance and other GIS applications are possible with a small-format digital camera. Refinement of this methodology using a digital sensor results in images that can be collected and utilized quickly and uniquely. The USDA FSA's new directive builds the compliance into a GIS of CLU and can be completed and achieved with a small-format digital camera.

A small-format digital camera can be used to collect images along the USDA flight lines typically collected with the 35 mm slide film. The difference between the DFV/DF and 35 mm film is the format size. However, increasing flight lines or adjusting the flying height can correct these differences. The method discussed in this paper demonstrates that DFV/DF for GIS of CLU is possible. The image format is equivalent to the raster format, making it easy to import into a GIS. Another topic for future research is defining procedures for the USDA FSA to implement the GIS with the digital camera. It is important to note that increasing technology advancements in the digital sensors will assist in improving image format. DF offers the advantage of larger array size with disadvantage of write speed and DFV offers the advantage of quantity with disadvantage of array size. DFV should the best potential for fitting the USDA FSA needs in collecting more information for crop compliance monitoring.

CHAPTER 6

US DEPARTMENT OF AGRICULTURE AND FARM SERVICE AGENCY CROP COMPLIANCE MONITORING GIS [1]

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Abstract

Small-format digital aerial imagery is becoming an important source of data for crop compliance monitoring by the US Department of Agriculture (USDA) Farm Service Agency (FSA). The objective of this article is to discuss the procedures to establish a geographic information system (GIS) of common land units (CLU) as determined by the small-format digital aerial images. The CLU is used by the USDA FSA for crop compliance verification to determine the performance of producers participating in program provisions to receive financial benefits, insurance or emergency management funds. An examination of the spatial and spectral resolution for mapping and identification of crop types and land classification with digital imagery is discussed. The procedures employed in this research defined using small-format digital images for the development of land boundary lines. Procedures for using digital imagery in delineating areas utilizing heads-up digitizing and automatic methods are discussed. Results demonstrate that small-format digital imagery can be used to assist in delineating land boundaries of land use for agricultural applications.

Introduction

Current methods of aerial compliance checking by the US Department of Agriculture (USDA) Farm Service Agency (FSA) are accomplished by the use of 35 mm slide-film. The images are projected with a standard slide projector on a paper film product and areas are manually digitized. These polygon areas are recorded manually and digital area polygon information is not retained. To capture this digital compliance area polygon and associate it with the producer requesting price support, a geographic information system (GIS) of common land units (CLU) was used. The crop compliance is a polygon GIS layer that contains a database of information. The compliance area is a GIS of landowners, tract number, crop type planned, crop area planted, crop type reported and crop area reported. An important aspect of the operations of the USDA FSA is the timely delivery of a final product (USDA FSA, 1998).

The use of small-format digital frame and digital frame video in an airborne platform is reliable and widely used as a form of remote sensing imagery, based on the low cost and high spatial resolution as compared to a satellite product. Digital frame video has further been demonstrated to meet the spatial needs with the ability to capture continuous data. A Landsat Thematic Mapper product has a resolution of 30 meters and a repeat cycle of 16 days. Cloud cover and the timing of crop harvesting make the satellite imagery unreliable. Higher resolution imagery such as Ikonos or Quickbird has been suggested, but again, cost and cloud cover considerable problems (Heald, 2002). The success of these products has occurred mostly in public land states with large tracts. In the states with metes and bounds cadastral boundaries, satellite imagery is not adequate. This based on the ability to simply digitize the acreage of the public land states with a minimal number of vertices. Metes and bounds areas require a large number of vertices and thereby increasing the amount of error in computing the acreage. The crop types of public land tracts are easily interpreted with the satellite image and the area is very consistent. The crop types of metes and bounds are easily interpreted with satellite images, but the areas are not consistent.

Airborne imagery from a small-format digital frame or digital frame video offers a more versatile solution in capturing imagery than film products. One demonstrated advantage is the ability to gather image rectification parameters in near real-time to aid in the mapping process (Mostafa and Schwarz, 2000). This low cost near real-time approximate rectification procedure can assist in the computer processing and product delivery to the crop compliance GIS.

For compliance checking, the specifications on the spatial resolution are not as critical as the temporal resolution. It is desired that the area be digitized to within 0.1 of an acre. This number is not always achievable, but the USDA FSA will report acreage to 0.1 acre. The detailed information needed for crop compliance includes the crop type and area. The goal of the CLU in the initial stages is to determine land boundary locations and ownership. To establish the CLU, the USDA FSA is utilizing older DOQQ products (USDA FSA, 1998). Changes in land use and land cover temporally mandate that the most recent imagery be used to establish the database.

A proposed methodology of using small-format digital frame video and GPS to orientate the image would aid in improving the time to a final product. Integrating remote sensing, GPS and GIS to solve time consuming problems shows economic benefit (GEO, 1997). The objective of this article is to discuss the procedures involved to demonstrate that small-format digital images can be utilized to develop GIS of crop compliance monitoring.

The methods of research used to meet the objectives include: (i) analysis of the data flow; (ii) development of new procedures of image rectification from near real-time approximate imagery; and (iii) qualitative analysis of the interpretability of the small-format digital frame video imagery. Presentation of current method of crop compliance and CLU is presented.

Defining the Purpose of the CLU

Decisions for the USDA include property ownership, water resources, land erodability, crop type, support level, insurance, and other values. These are needed to formulate agriculture support and fines to meet the laws established by the US Farm Acts. The CLU is a standardized GIS layer that contains land ownership with related crop production information. Every growing season producers report their crop type and acreages. Crops are routinely monitored for verification using a System36 legacy database farm selection process. Approximately ten percent of the total farms under the program are checked (Heald, 2002).

Compliance, as defined by FSA, is the assessment of agriculture crops to determine if performance requirements for those receiving benefits for crop support are maintained (Bailey and Meador, 2002). Compliance encompasses all programs administered by FSA for assistance. Inspection is often accomplished by two methods. (1) ground truthing with field inspections, and (2) aerial compliance photography flown each summer with 35 mm slide film (Bailey and Meador, 2002). Producers voluntarily report farm crop history and acreage. These reports are the criteria used to develop future farm programs (USDA OK FSA, 2001). Aerial photographs also aid the offices and producers in determining new crop-lines for crop rotations, seed corn and plots, irrigation pivots, specialty crop acreage, tiling, conservation work, and crop insurance (Bailey and Meador, 2002). The Food Service Act of 1985, as amended by the Federal Agriculture Conservation and Trade Act of 1990, and the Federal Agriculture Improvement Act of 1996, discourage overproduction on highly erodible soils; therefore, compliance is often conducted to ensure that producers follow a conservation plan in susceptible areas (USDA OK FSA, 2001).

May is often the month for compliance checking for small grains. All others are usually reported by August (USDA OK FSA, 2001). Improvements in the process of crop compliance measurements can assist the agricultural industry by providing fast, viable information that can be used universally among farmers and agencies. Improvements to the ability to obtain imagery sooner and more frequently can also assist farmers and agencies in improving crop performance, which is related to precision farming. The CLU data layers are a critical component for the FSA implementation of the GIS. The FSA seeks to digitize all farm fields in the country to delineate agricultural and non-agricultural farm areas. GIS has been used to assist in many other projects such as addressing geospatial time-series information of security, privacy, production, and natural disaster relief programs (Sun, 2000). The move to a digital product will allow the integration of multi-layered information and the changes in land boundaries and ownership can be quickly addressed. Figure 6.1 demonstrates the typical fields within the CLU GIS.

CLU Data Extraction.

Polygons digitized for the CLU are usually obtained from the DOQQ or MDOQ. Ikonos imagery, where available, will supplement areas where DOQQ images are outdated. The objective of the development of the CLU is to: (i) identify a common term, (ii) identify boundary and definition for land units, and (iii) have all the data on that land unit accessible to all Service Center Agencies.

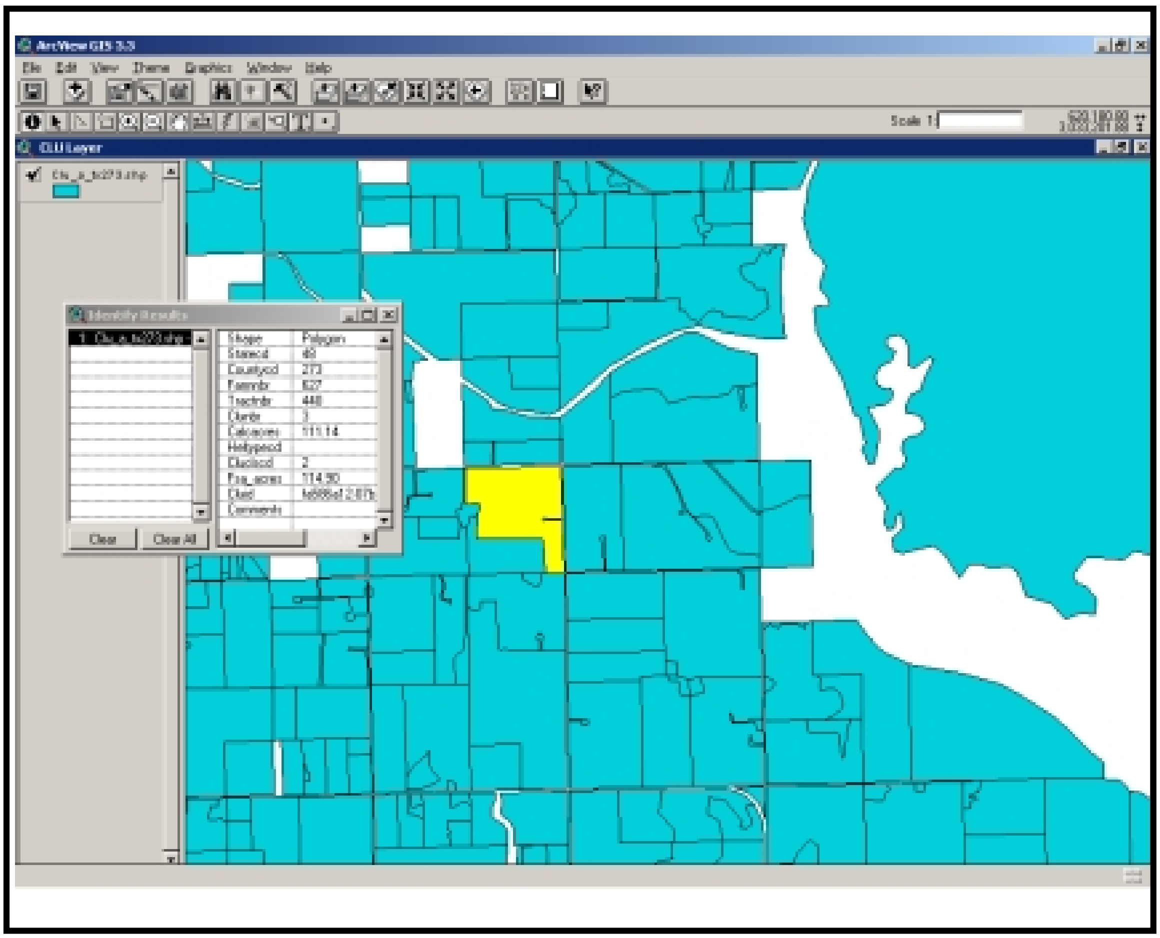

Figure 6.1: CLU Layer and Table of Attributes within the CLU.

The CLU will provide a GIS which includes a permanent, contiguous boundary, common land cover management, common owner, and common producers association (USDA FSA CLU, 1998). The rules of delineation can be summarized in three boundary types: (i) visible delineation of physical boundary, (ii) management crop lines and classification boundary, and (iii) cadastral of ownership or growing association in terms of crop property. The CLU boundaries will be determined by ground cover of physical boundaries, such as fences, timberlines, roads, and waterways from the DOQQ or annual 35 mm slides. The boundaries can be entered in conjunction to concurrent datasets, such as the existing track/field lines from the 24 by 24 inch aerial photography and cadastral GIS layers. The land classification will be established by interpretation of the scanned 35 mm slides by the delineation rules for that land category set by the USDA FSA 2-CP manual (USDA FSA, 1996). Land ownership lines or "tracts" divide the CLU's with an assigned user number or code for each area. This is the key value between the CLU and the crop compliance GIS tables.

Current Method of Crop Compliance

The USDA FSA has used the 35 mm slide film products to update the current database system. The current method of data capture from 35 mm slide film is one in which the slides that cover the area of interest must be sorted and organized so that the correct data can be extracted. The procedure begins with a search for the correct slide by analyzing the index map generated by the aerial photography company. Often, the index map is a relative location and the slide must be viewed and searched to find the exact imagery. Next, the slide is inserted into a slide projector and projected onto a paper film product. The county agents are sent paper film products that are 24 by 24 inch enlargements at a scale of 600 feet per inch. Field boundaries are drawn directly on the prints. The projector is then adjusted for scale and tilt. Once the target area is visually rectified, the area is digitized and the photo is interpreted for crop type. The paper film products are often outdated. For example, the images used by Nueces County, Texas date back five to ten years.

The information is recorded and compared to the numbers submitted by the crop producer. If a target area is between slides, the values are computed for each slide and then combined and reported. This method involves a considerable amount of personnel time to produce a final product. If an image needs to be re-verified, the entire procedure of rectification and measurement must be repeated.

Under the digital requirement of the new GIS, the USDA FSA has utilized satellite images to assist in compliance checking. The CLU has been digitized standard 9 by 9 inch aerial photographs and Ikonos images. The digitizing centers and individual FSA offices have completed a quality check of the CLU. Compliance checking can be done by photo interpretation to determine the crop type. The area reported by the grower is compared to previously digitized areas. States that have large tracts can use Landsat images to determine crops planted. States that have a metes and bounds cadastral system with irregular tracts require images with a higher spatial resolution. Figure 6.2 shows a CLU overlaid on a Landsat image demonstrating the digitized area.

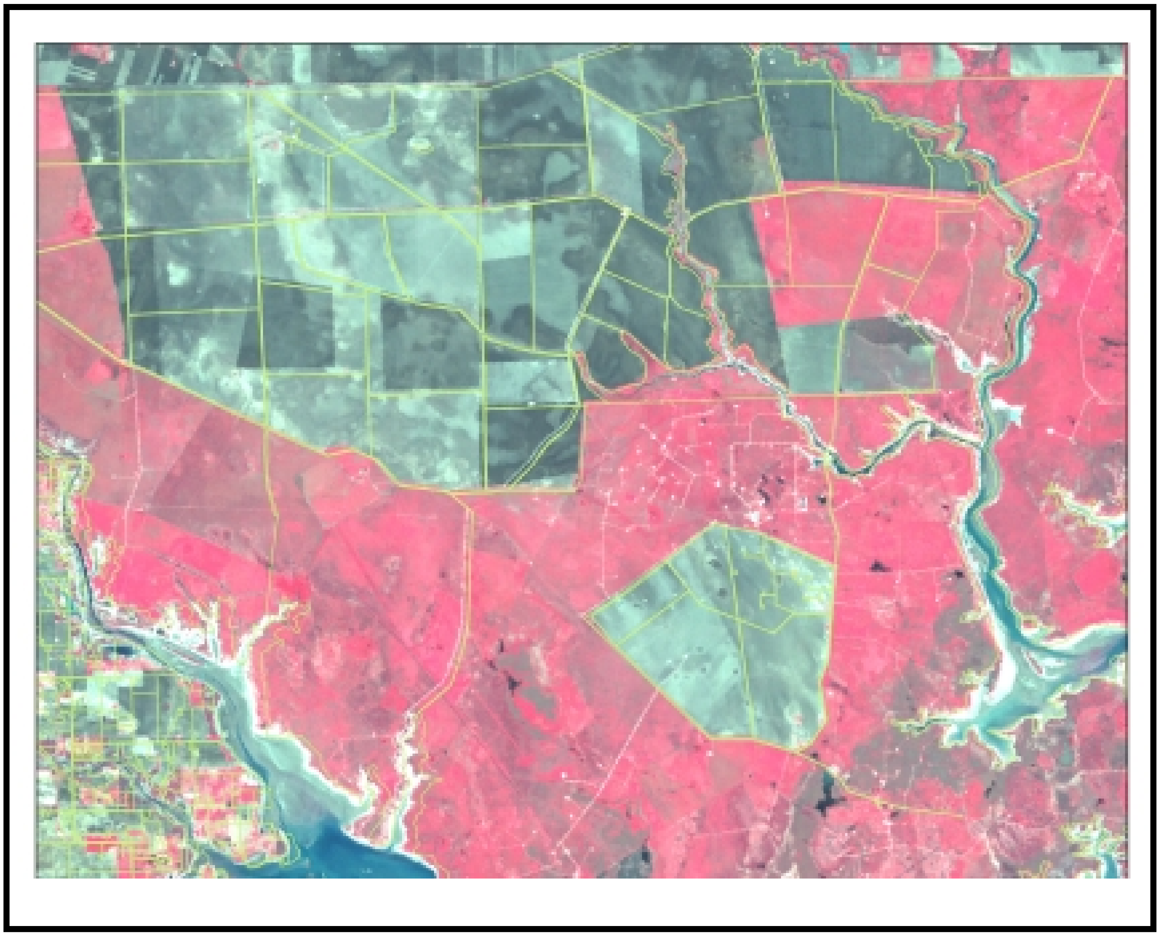

Figure 6.2: Landsat Image with a CLU of Kelburg County, Texas.

GIS Development

The GIS that the USDA FSA will need to establish for crop compliance monitoring includes the utilization of the CLU and development of a new spatial dataset and metadata. The datasets of the CLU and the crop compliance is joined spatially by the common land “tract” code. The CLU contains the tract code assigned to that property and the landowner and/or land tenant. The CLU is constantly updated or changed. For the GIS project of crop compliance it is suggested that the entire CLU be copied into the crop compliance GIS project separate from the CLU server, versus linked, this is needed so that a static reference of the existing CLU as of compliance checking is maintained. Further it is suggested that a new dataset with the attributes seen in Table 6.1 is joined with the CLU for each landowner or tenant being checked. Landowners might own several tracts that will represent individual polygons of areas being checked.

The purpose of the GIS is to assist the USDA FSA office in collecting the information necessary to verify the crops planted and reported by those landowners receiving support. To perform this several values must be input into the GIS. The reported attributes as seen in Table 6.1 are compared to the measured values. To obtain measured values such as the crop type, crop use, or row pattern the aerial images have to be interpreted. The USDA FSA agent in charge of compliance checking often does this interpretation of the aerial images. Ground-truthing is often the method used by the USDA FSA agent to check the values reported. Some agents use knowledge and experience to determine the crop type information. Cotton, corn, wheat and other crops have distinctive patterns and tones that are easily discernable. Crop usage between similar wheat crops for example, might not be extractable from the aerial images.

Therefore, expert knowledge is needed from the USDA FSA agent. This could be automated with image classification algorithms from existing knowledge datasets.

Once the crop type is defined it must be measured to compute the acreage. This value might not be the current tract acreage, based on multiple factors. For example, the crop might run over into an irrigation or right-of-way area not considered in the tract area. Some field areas might be to wet at time of planting and therefore are not planted or considered. The area is digitized from the small-format digital images using head-up digitizing as seen in Figure 6.4. The GIS software will automatically compute the area and prompt the operator for the crop attribute information. A query can be made that compares the reported values to the measured values. The information input into the USDA FSA Legacy system where the owner is then paid for crop support or contacted if not within compliance. The compliance checking GIS is maintained for future comparison. This could be beneficial to the USDA and grower in forecasting or trend analysis.

Proposed Methods

The USDA has identified the concepts of geographic information systems and science as a means to efficiently manage data and make data more assessable to the public and other entities (Harrison *et al.*, 2002). The abilities of a GIS to maintain the information in a structured format constitute a more reliable product. Combinations of multiple layers of information within the generation of the CLU diversify the information complexity. For example, the raster layer from the base of the digitized crop areas and a cadastral layer can be used to assign land ownership. The updating and maintenance of the GIS then becomes a viable concept.

Table 6.1: Example Crop Compliance GIS Database Fields.

Possible Attributes Assigned to Crop Compliance Data Layer	
Tractnbr	*Landowner Track Code*
Cropcode	*Code for each crop type- Identified by agent*
Croptype	*Name of crop- Identified by agent*
Cropuse	*Crop Use*
Irrigationprct	*Crop Irrigation Method*
Calcarea	*Computed area of digitized polygon*
ReportName	*Landowner Name*
ReportType	*Reported Name of crop*
Reportarea	*Reported crop area*
ReportIrr	*Reported Irrigation Method*
RowPattern	*Reported Row Pattern*

Photos from a small-format digital frame video in conjunction with DOQQ produce a final product that can be used in maintenance of the CLU. As seen in the flowchart (Figure 6.3) of the suggested procedure, the exact georectification of the image can later be completed to improve the image registration. This is done with a method of utilizing ground control points (GCP's) from an image-to-image rectification or by a method of human interaction rectification.

The GIS developed by the USDA FSA will be completed using ESRI ArcView 3.2 GIS software. Tools previously developed under the CLU GIS project by the USDA FSA will be used. The crop compliance GIS project will include a database of the DOQQ, DEM, DRG, CLU and the compliance imagery. The digitized area polygons will reside in the GIS project, but also exported to the main compliance database with associated metadata. The compliance-checking project database will be archived with the associated data.

The purpose of this procedure is to maintain the temporal static context of the project, as the DOQQ, DEM, DRG, CLU and compliance imagery will continue to evolve and grow. The existing CLU and DOQQ that are current spatially orientated to data are imported into the GIS. If the small-format digital camera data is not in the correct spatial coordinate system it must be reprojected. Next, the small-format camera data can be searched based on spatial location of the world file upper left corner coordinate to match the targeted compliance area. Once the tract is identified the spatial information can be extracted. This data extraction and information is spatially based, therefore supporting the need for the project to be developed under a GIS.

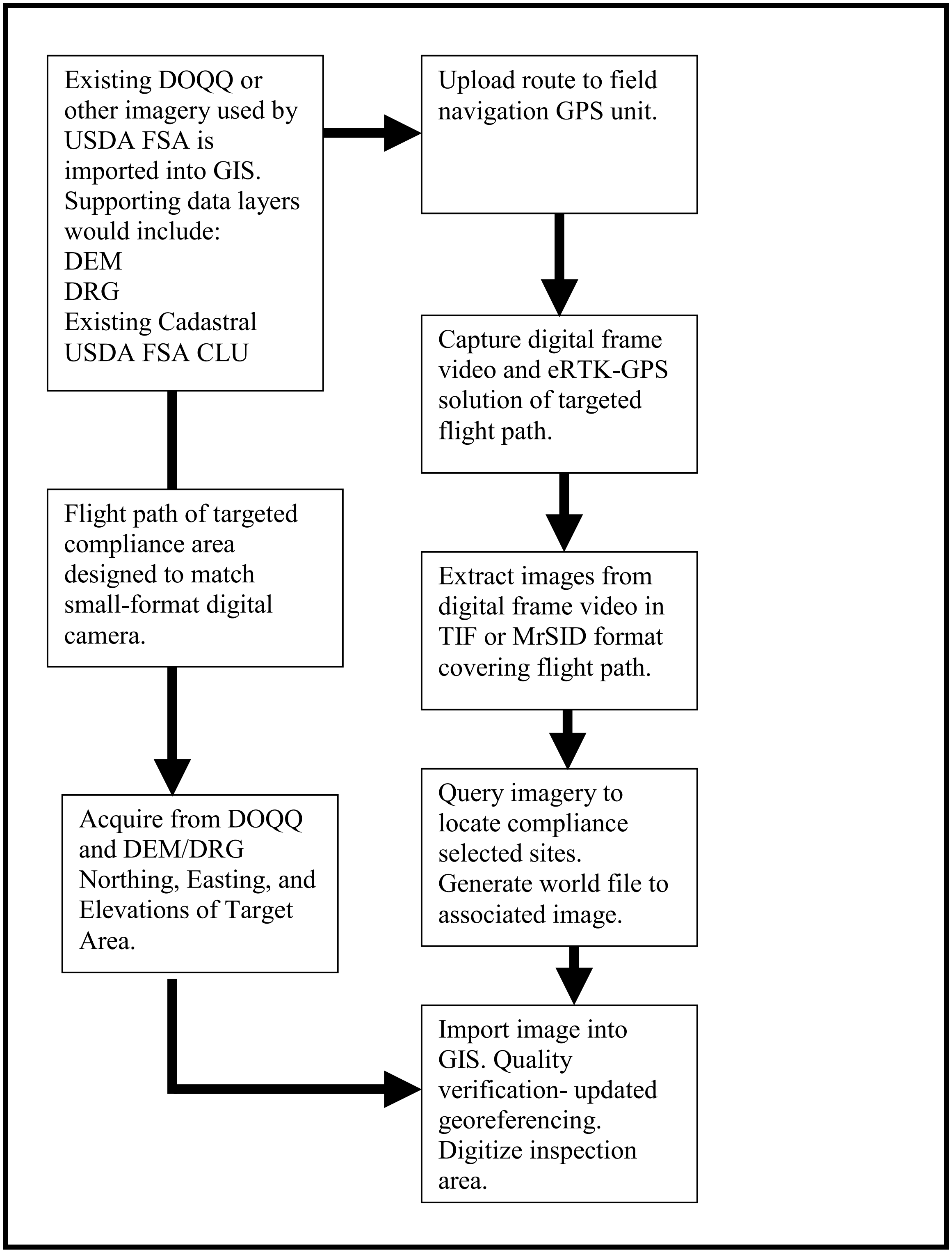

Figure 6.3: Flowchart of Proposed Method.

All captured imagery data that are not used in the compliance-checking phase will be attached to the GIS and can later be used by other GIS applications. The MDOQ or DOQQ foundation base imagery will remain as the primary layer within the GIS. GIS projects for each individual compliance checking process will be generated. Figure 6.4 shows a digital frame image extracted and overlaid on the DOQQ, and then overlaid with the CLU.

Results

As seen from Figure 6.4 the georeferenced small-format digital frame video image provided an image that could be digitized. From the image the USDA FSA agent can identify the crop type and digitize the area. The spatial resolutions of these images were around 23 centimeters. This allows the USDA FSA agent to distinguish crop types and rows. The area that was computed in the georeferenced images matched the ground survey using GPS within 0.1 acre as required. Future test on other crops and areas are suggested.

Conclusion

It was demonstrated that a small-format digital frame video image could be used to create the crop compliance GIS. The Farm Service Agency Aerial Photography Field Office is collecting and establishing a National Aerial Image Program NAIP of film and digital imagery. NAIP goals are to acquire and deliver digital imagery at one and two meter spatial resolution on an annual basis. This process will be supported and maintained by small-format digital sensors (NAIP, 2002).

Figure 6.4: Digital Frame Video within a CLU and DOQQ.

A new methodology was demonstrated using new tools to help support the crop compliance GIS. The new procedure could be utilized by the USDA FSA to help improve the quality and time to the final product. The importance and significance of this research in the investigation of new initiatives for the USDA FSA for verification of crop compliance was addressed.

CHAPTER 7

SUMMARY AND CONCLUSION

Summary

The objectives of this dissertation research were to: (i) test extended Real-time Kinematic –Global Positioning System (eRTK-GPS) in an aerial platform; (ii) investigate new methodologies of digital images with small-format digital camera; (iii) investigate image crop identification for digitizing and establishing a geographic information system/ land information system of common land units for crop compliance by the United States Department of Agriculture Farm Service Agency (USDA-FSA). The resulting research established three peer-reviewed articles that published the achievements of the objectives met. The methodology and techniques of utilizing a small-format digital camera for a GIS were presented. A summary of the overall methodology is described in this section. The remaining section demonstrates conclusive results and research details

The USDA FSA is working to develop a seamless GIS layer of land information for use in crop compliance under price support programs. To establish this layer, manual digitizing of aerial imagery of land boundaries and photo interpretation of crop type is performed. A small-format digital camera system was developed, calibrated, and tested that allowed for the collection of the digital imagery. An alternative method of using the existing 35 mm slide film scanned was also investigated. Methodologies and procedures for implementing either system were established for the USDA FSA.

The eRTK GPS aerial camera position solution was tested and implemented on all flights. Post processing methods and multiple GPS base stations were used to determine positional values. Proposed national eRTK-GPS networks by the National Geodetic Survey Continuous Operation Reference System would support the utilization of this technique in a wide area network. Each county flown would require a base station to be established where the digital imagery is collected. Placing a base at one of the Federal Base Network stations located at most county airports accomplishes this objective. Resulting translations of the direct georeferencing position of the eRTK GPS solution to the body frame or bore-sight of the digital camera is critical and flexible.

The imagery is typically used to investigate and substantiate the submitted USDA FSA crop compliance request. The accuracy of determining the crop type and area is variable based on ties to existing digital imagery of the DOQQ or MDOQ obtained by the USDA FSA. Any inaccuracy that exists due to tilt or terrain relief can be differentially corrected, and the resulting correction would not result in a substantial distortion difference in the imagery for the interpretation process.

Distortions such as tilt and terrain relief can be corrected with the existing digital imagery during the digitization process. GCP’s can be located from an image-to-image rectification. With the proposed near real-time direct georeferencing, the images are close to their actual scaled spatial location. A generated world file versus a resampled image would inhance the data interpretation process. Lower altitude imagery with large-scale imagery would reduce the overall pixel size and allow for more accurate digitization.

Obtaining the small-format digital imagery with the most common sensors was an evolving variable within this research. New charged coupled device (CCD) chips and larger arrays are continuously being developed. Current technologies have size and write speed limitations. Digital frame sensors that capture a single array require data buffering and write time. Digital frame video has smaller array and allows for continuous data collection of the total area array. The images can then be mosaicked into longer strips. Each sensor has advantages and disadvantages that are improving constantly. Both solutions offer a temporal resolution above existing high-resolution satellite systems such as Ikonos or Quickbird. The small-format digital camera system can be deployed in breaks in weather or at specific time periods to capture information from events as they occur.

A small-format digital image was found to be adequate for updating the GIS CLU layer and for the compliance checking aspect of the USDA FSA activities. The system formed was a complete solution that could easily replace the existing 35 mm slide film solution providing enchased spatial information and economic efficiencies

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Techniques Used to Meet Objectives

The following summary and synopsis is provided to recap the overall research techniques. These techniques included the development of new methodologies and technologies in data collection in aerial platforms, utilization of new small-format digital sensors and production of a GIS with digital images.

The following conclusions are presented in more detail to illustrate the techniques used in this research to meet the objectives. A quantitative analysis was made from the use of eRTK-GPS in an aerial platform. Results showed that the positional accuracy of long-range real-time position generated standard deviations of less than five centimeters horizontally and eight centimeters vertically with base line lengths less than 35 kilometers. To complete this task, a method was developed for providing differential corrections to the aircraft position. Quantitative testing and results were gathered that demonstrated the possibility of eRTK-GPS in an aerial platform. The accuracy of the placement of the images into real world space based on direct georeferencing had varying results with errors of up to 12 meters in ground position, these results were adequate for interpretation of the production area for USDA FSA crop compliance. Performing image-to-image rectification and differential orthographic rectification with DOQQ's and DEM's produced more accurate small-format digital images. This would allow the digitizing of the area of the compliance crop.

A comparative evaluation of digital frame and digital frame video was conducted in the development of the GIS CLU. The digital frame video was found to produce the greatest extent of coverage with minimal temporal delay. The positive quality of the digital frame video was visible in the digitization and image crop identification. Techniques of field-testing and sensor calibration were conducted to evaluate the two different sensors types. The photographic data of the test areas demonstrates that the digital frame produced higher spatial resolution. The digital frame video produced similar equivalent spatial resolution, but was able to capture more continuous coverage. Improvements in small-format digital frame camera data collection technology for continuous data collection have advanced in a more complex and costly manner compared to digital frame video.

The GIS of common land units developed by the USDA is a definitive vector layer with the land acreage and owner information. When crop compliance activity is initiated with a digital image or 35 mm slide film comparison of the digitized area, the existing CLU area, and reported growers area is undertaken. The digital image must be adequate to within +/- 0.1 acre. This number is achievable with imagery that has a spatial resolution of one to two meters. It is noted that if the image had a positional tolerance that is larger due to direct georeferencing, the area will not vary by any significant number for smaller tracks. The USDA FSA maintains that the CLU is commonly used as the definitive value of acreage. The USDA FSA has used Landsat images and other high altitude images. These images generate a larger error of +/- 0.1 acre in compliance checking, but maintain a reasonable temporal resolution. Methods used in this research-involved comparison of an existing crop location with the reported acreage and the digitized acreage.

Step by Step Investigation Method

The following is a step-by-step description of the investigation methodology developed in this research. The steps were conducted to answer the following thesis statement:

How can a small-format digital camera system be used with direct georeferencing to improve and replace the current 35 mm color slide film methods used by the United States Department of Agriculture Farm Service Agency in developing a geographic information system of crop compliance?

This research involved a number of individuals and organizations. It was proposed and directed under current research done by this author, the University of Georgia and Texas A&M University-Corpus Christi. The initial investigation was the determination of the thesis as it relates to utilizing small-format digital cameras in a GIS. A literature review of the process of direct georeferencing of aerial images with GPS was conducted. Research into the methods of direct georeferencing was performed. A review was made with the USDA FSA offices in Georgia and Texas to determine the current system in place. Next, a combination of different configurations and components were researched to select the best configuration, thereby reducing the need to repeat research completed by other institutions or organizations.

It was found that the USDA FSA has investigated the concepts of utilizing small-format digital cameras, but the USDA FSA has not investigated the direct georeferencing methodology. Other work has focused on the combination of Inertial Navigation Systems and Global Position System to reduce the need for ground control and base stations. It was determined that this research would focus on the concept of extended Real-time Kinematic Global Positions Systems previously researched by the author.

The investigation began by developing and testing the eRTK-GPS solution in an aerial platform. Positive results were presented, indicating that direct georeferencing with the small-format digital camera is adequate for economically replacing the USDA FSA's current 35 mm color slide film method for compliance checking. The next step was to evaluate the small-format camera solution. It was decided that a comparison of digital frame and digital frame video format would be conducted. The procedure was to develop, calibrate and test both systems in an aerial platform. This step was completed, with the results demonstrating that the digital frame video had two main advantages: (i) the large volume of data that digital frame video could collect, and (ii) collection of data in a more ergonomic and less-costly methodology.

The final step was to discuss the usage of the small-format digital camera for the development of the crop compliance GIS. A comparison of the 35 mm slide film imaged using a projector and the small-format digital camera image was made. A similar quality of spatial resolution was visibly evident.

Conclusion

It has been demonstrated that eRTK-GPS has a potential in direct georeferencing. The eRTK-GPS limitation of 35 kilometers from a base station is one drawback. Further investigation into the use of a lower accuracy satellite based differential GPS solution could be considered. The GIS CLU can be obtained economically from a small-format digital camera. The final conclusion is that eRTK-GPS and small-format digital cameras can be used in combination to develop and compute areas for the USDA FSA crop compliance checking GIS database.

Future research includes the utilization of different cameras with larger CCD chips. Integration of INS to record tilt is the direction of further investigation. Attempts to obtain eRTK-GPS at longer range can also be investigated. To finalize the research a more complete solution made for general distribution should be developed. This would include software operational manuals, system installation manuals, equipment and supplier standards, and training material. Testing and utilization of the system by a USDA FSA currently involved in a GIS should thoroughly apply the solution within an actual crop compliance checking operation.

References

Abd-Elrahman, A., L. Pearistine, B.A. Dewitt, and S.E. Smith, 2001. Detection of positional errors in systems utilizing small-format digital aerial imagery and navigation sensors using area-based matching techniques, *Photogrammetric Engineering & Remote Sensing*, 67(7), July 2001, pp. 825-831.

Ambrosia., V.G., Buechel, S.W., Brass, J.A., Davies, R.H., Kane, J.R., and Spain, S., 1998. An Integration of Remote Sensing, GIS and Information Distribution for Wildfire Detection and Management, *Photogrammetric Engineering & Remote Sensing*, 64(10): Oct. 1998, pp. 977-985.

Anderson, J.E., Fishcer, R.L., and Deloach, S.R., 1999. Remote Sensing and Precision Agriculture: Ready for Harvest or Still Maturing, *Photogrammetric Engineering & Remote Sensing*, Highlight, (10), Oct, 1999.

Ackermann, F., 1996. Photogrammetry today, *ITC Journal*, (3/4) pp. 230-237.

Ackermann, F., and H. Schade, 1993. Application of GPS for aerial triangulation, *Photogrammetric Engineering & Remote Sensing*, 59(11), Nov. 1993, pp. 1625-1632.

ASPRS, 2000 p. 6. Camera calibration panel report, prepared by ASPRS - The Imaging and Geospatial Information Society, sponsored by U.S. Geological Society, Jan. 2000.

Auerbach, Jon G., 1999. Airlines ban cell phones - why?, *Wall Street Journal Interactive Edition*, Oct. 5, 1999. Retrieved from http://www.mercola.com/1999/oct/10/ airlines_ban_cell_phones_but_why.htm. on October, 01, 2000.

Avery, T.E., and G.L. Berlin, 1985, Fundamentals of Remote Sensing and Airphoto Interpretation, 5th Edition, Prentice Hall, Upper Saddle River, New Jersey.

Bailey, D., and Meador, L., 2002. Compliance, USDA FSA Illinois. Retrieved from http://www.fsa.usda.gov/il/page9.html on March 06, 2002.

Bensen and Fink, 1991 “HDTV Advanced Television for the 1990's”, 1st Edition, Intertext Publication, McGraw- Hill, McGraw Hill, NY.

Clark, R., 1997, Practices and Potential, Assessing an Agriculture Revolution in Progress, Retrieved from http://www.precisionfarming/features/0497Clark.html, on June 05, 200.1

Compass Informatic, 2000. An assessment of the cost effectiveness and applicability of an Airborne Digital Camera System for Fishery Habitat Designation, Remote Sensing Service. Retrieved from http://compass.ie/rs/maint.html on February,24 2001.

Cramer, M. and N. Haala, 1999. Direct exterior orientation of airborne sensors, *Journal GIM International*, Sept. 1999, Vol. 13, pp. 46-49.

Cramer, M., D. Stallmann, and N. Haala, 2000a. Direct georeferencing using GPS/Inertial exterior orientations for photogrammetric applications, *IAPRS*, Vol. XXXIII, Amsterdam, 2000.

Cramer, M., D. Stallmann, and N. Haala, 2000b. Sensor integration and calibration of digital airborne three-line camera systems, Institute for Photogrammetry, University of Stuttgart. Unpublished results

Davis, D., 2002a. CLU Digitizing on MrSID Compressed Imagery, USDA FSA Whitepaper, February 2001, Retrieved from http://www.apfo.usda.gov/whitepapers.html on February 16, 2003

Davis, D., 2002b. 35 mm Aerial Compliance Slide Scanning, Recommendation for the scanning and naming of aerial compliance 35 mm slides, USDA FSA Whitepaper, August 2001,Retrieved from http://www.apfo.usda.gov/whitepapers.html on February 16, 2003

Davis, D., 2002c. Using 35 mm Digital Cameras in the Aerial Compliance Program, USDA FSA, Aerial Photography Field Office Internal Whitepaper. http://www.apfo.usda.gov/whitepapers.html, on May 5,2002

Dean, C., T. Warner, and J.B. McGraw, 2000. "Suitability of the DCS460c colour digital camera for quantitative remote sensing analysis of vegetation," *ISPRS Journal of Photogrammetry & Remote Sensing*, 55(2): June 2000, pp. 105-118.

Deng, G., and Faig, W., 2001. An Evaluation of an Off-Shelf Digital Close Range Photogrammetric Software Package, *Photogrammetric Engineering & Remote Sensing*, 67(2), Feb 2001, pp. 227-233.

ESRI, 2003. Environmental Systems Research Institute ArcView 3.3 Help, ArcView 3.3, Retrieved January 2003.

Euler, H.J., Keenan, R., Zebhauser, B., and Wubbena, G., 2001. Study of a Simplified Approach in Utilizing Information from Permanent Reference Station Arrays, *The Institute of Navigation* GPS 2001.Salt Lake City, Utah, Sept 11-14, 2001.

Euler, H.J., and Ziegler, C., 2000, Advances in Ambigutiy Resolution for Surveying Type Applications, The Institute of Navigation GPS 2001., Salt Lake City, Utah, Sept 19-22, 2000.

Förstner, W. and E. Gülch, 1999. Automatic orientation and recognition in highly structured scenes, ISPRS Journal of Photogrammetry & Remote Sensing, 54(1): Feb. 1999, pp. 23-34.

Fraser, C.S., 1997. Digital camera self-calibration, *ISPRS Journal of Photogrammetry & Remote Sensing*, 52(3), pp. 149-159.

Fricker, Peter, Rainer Sandau A., and Stewart Walker, 2000. Development of an airborne digital sensor for photogrammetric and remote sensing applications, *LH Systems*, Heinrich-Wild-Strasse. CH-9435, Heerbrug, Switzerland.

Foevon, 2002. The Worlds First Full-Color Image Sensor, Retrieved from http://www.foveon.com/X3_tech.html on March 6, 2002.

Gao, J., 2001. Non-Differential GPS as an Alternative Source of Planimetric Control for Rectifying Satellite Imagery, *Photogrammetric Engineering & Remote Sensing*, 67(1), Jan 2001, pp. 49-55.

Gao, J., 2002. Integration of GPS with Remote Sensing and GIS: Reality and Prospect, *Photogrammetric Engineering & Remote Sensing*, 68(5), May 2002, pp. 447-453.

Graham, R., and Koh, A., 2001, Training for digital aerial survey and mapping, GeoEurope, Nov 2001, Adams Business Media, Chicago, Illinois.

Gravel C.; C. Larouche; and P.A. Gagnon, 1999. Integration of total station and digital camera. Surveying with Images, *Geomatics Info Magazine*, 13(9): pp. 6-7.

Greening,T., Chapli, B.A., Sutherland, D.G. and Deshoche, E. D., 1998. Commercial Application of GIS Assisted Photogrammetry, Retrieved from http://www.odysseymaine.edu/gisweb/spatdb/gis-lisgi94048.html on 11/13/2000

GEO, 1997. Intergrating remote sensing GIS and GPS: the rise of a 3S technology, *Geomatics Info Magazine*, 11(8): pp. 46-47.

Hatch, R.R., Keegan, R.G., and Stansell, T.A., 1997. Leica's Code and Phase Multipath Mitigation Techniques, Leica Geosystems, 1004-Letter-10/97.

Harrison, D., St. John, R., Tesky, J., Urie; W., and Alvin K., 2002. Automating an Inventory Collection and Coordination Site with Digital Imagery, Image Processing and Geographic Information System Technology, Natural Resources Conservation Service, Retrieved from http://www.mt.nrcs.usda.gov/rigis/techrpt/techrpt.html, on March 6, 2002.

Heald, J., 2002. USDA Establishes a Common Land Unit, *ArcUser*, April-June 2002, 5(2). pp 14-15.

Kersten, T. and S., Haering., 1997. Automatic interior orientation of digital aerial images, *Photogrammetric Engineering & Remote Sensing*, 63(8): Aug. 1997, pp. 1007-1011.

King, D.J., Walsh, P., and Cluffreda, F., 1994. Airborne digital frame camera imaging for elevation determination, *Photogrammetric Engineering & Remote Sensing*, 60(11): Nov. 1994, pp. 1321-1326.

King, D.J. and A. Chichagov, 1993. The potential of digital frame camera imaging in digital elevation modeling, Proc. 5th Can. Conf. on GIS, Ottawa, Ont., March 20-26, (Can. Inst. of Geomatics, Ottawa Ont.), p. 758-766.

King, D.J. 1995. Airborne multispectral digital camera and video sensors: a critical review of system designs and applications. Canadian Journal of Remote Sensing, Special Issue on Aerial Optical Remote Sensing 21 (3): 245-273.

King, D.J. 1993. Digital frame cameras: characteristics related to remote sensing. Proc. International Forum on Airborne Multispectral Scanning in Forestry (with Emphasis on MEIS), Val Morin, Quebec, April 13-16, 1992, (Forestry Canada Information Report PI-X-113, Petawawa National Forest Institute, Chalk River, Ont., p. 31-35.

King, D.J. 1992a. Evaluation of radiometric quality, statistical characteristics and spatial resolution of multispectral videography, Journal of Imaging Science and Technology, Vol. 36, p. 394-404.

King, D.J. 1992b. Development and application of an airborne multispectral digital frame camera sensor. Proc. XVII Congress of the Int. Soc. *Photogramm. and Rem. Sens. (ISPRS) Commission I*, Washington D.C., August 2-14, (Am. Soc. Photogramm. and Rem. Sens., Bethesda MD), p. 190-192.

Kinn, G., 2002. Direct Georeference in Digital Image Practice, *Photogrammetric Engineering & Remote Sensing*,68(5), May 2002, pp. 399-402.

Krupnik, Amnon and Toni Schenk, 1997. Experiments with matching in the object space for aerotriangulation, *ISPRS Journal of Photogrammetry & Remote Sensing*, Vol. 52, pp. 160-168.

Kodak, (2002). Digital Learning Center, Retrieved from http://www.kodak.com/US/en/digital/dlc/index.jhtml on March 6, 2002.

Kulkarne, R., Bachnak, R. Lyle, S., Steidley, C., 2002. Design and Development of an Airborne Multi-Spectral Imaging System, *Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery VII.* Vol 3425, 540-546.

Leica, 1999. Introduction to GPS, Leica Geosystems Publication 713282-1.0.en, Leica Geosystems-AG, Heerbrugg Switzerland, CH 9435.

LeSiege, Timothy E., 2001. Airborne GPS controlled photogrammetry - the Maine experience, Maine Department of Transportation. Retrieved from www.state.me.us/ mdot/survey/airborne.htm on 2/6/01.

Light, Donald L., 1996. Film cameras or digital sensors? The challenge ahead for aerial imaging, *Photogrammetric Engineering & Remote Sensing*, 62(3): Mar. 1996, pp. 285-291.

Lo, C. P., and Albert K. W. Yueng, C., 2002 Concepts and techniques of geographical information systems. Prentice Hall Series in Geographic Information Science, Prentice Hall, Upper Saddle River.

Lyle, S., Eckels, R., Bartline, H., and Carlson, B., 1998. A High-Performance, High-Accuracy RTK GPS Machine Guidance System. *The Institute of Navigation GPS 55th Annual Meeting Proceedings,* June 28-30, 1999 pp. 789-796.

Lyle, S. and Wilson. M., 2000a. Performance Benchmark of IBM Receiver, *The Institute of Navigation GPS 2001, Salt Lake City*, Utah, Sept 11-14, 2001.

Lyle, S. and Wilson. M., 2000b. Agriculture Equipment Tracking and Monitoring System, *The Institute of Navigation GPS 2001, Salt Lake City*, Utah, Sept 11-14, 2001.

Lyle, S. and Woods, L., 2002. "Texas Department of Transportation Real-time DGPS Spatial Reference Frame.", *The Institute of Navigation GPS 2002,* Portland Oregon, Oct. 24-27, 2002.

Maas, H.G., 1997a. Aerotriangulation and DEM Orthophoto generation High Resolution Still Video Imagery *Photogrammetric Engineering & Remote Sensing*, 63(9), Sept. 1997, pp. 1079-1084.

Maas, H.G., 1997b. Concepts of real-time photogrammetry, *Human Movement Science*, Vol. 16, pp. 189-199.

Mason, Scott; Heinz Rüther; and Julian Smit, 1997. Investigation of the Kodak DCS460 digital camera for small-area mapping, *ISPRS Journal of Photogrammetry & Remote Sensing*, Vol. 52, pp. 202-214.

Menges, C.H., Hill, G.J.E., and Ahmad W., 1998. Use of airborne video data for the characterization of tropical savannas in northern Austrialia: the optimal spatial resolution for remote sensing application, *The international Journal of Remote Sensing*, 22(5), pp. 727-740

Merchant, Dean C., 1993. GPS controlled aerial photogrammetry, *Photogrammetric Engineering & Remote Sensing*, 59(11), Nov. 1993, pp. 1633-1636.

Mostafa, M.M.; K.P. Schwarz; and P. Gong, 1997. A fully digital System for Airborne Mapping, Proceedings of the International Symposium on Kinematic System in Geodesy, *Geomatics and Navigation*, 03-06 Jun, Banff, Alberta, Canada, pp. 463-471.

Mostafa, M.M.; K.P., Schwarz; and P. Gong, 1998. GPS/INS Integrated Navigation System in Support of Digital Image Georeferencing, *Proceeding, Institute of Navigation 54th Annual Meeting*, 01-03 June, Denver Colorado, pp. 435-444.

Mostafa, M.M., and Schwarz, K. P., 2000. Multi-Sensor for Airborne Image Capture Georeferencing, *Photogrammetric Engineering & Remote Sensing*, 66(12), Dec. 2000, pp. 1417-1423.

NAIP, 2002. The Farm Service Agency's National Agriculture Imagery Program NAIP. Presentation for the US Geological Survey Easter Region Geography State Cooperators Form 2002 Nov. 12-14, 2002 Reston, Virginia retrieved from http://www.apfo.usda.gov/whitepapers.html February 3, 2003

Perry, C. D., Velldis, G., Wells, N., and Kvien, C. 2000. Simultaneous evaluation of Multiple Commercial Yield Monitors in Georgia, Retrieved from http://nespal.cpes.peachnet.edu/PrecAg/2001BeltWide.pdf on March 23, 2003.

Rees, W. G., 2001. Improving the accuracy of low-cost GPS measurement for remote sensing applications, *The International Journal of Remote Sensing*, 22(5), pp. 871-881.

Schenk, T., 1997. "Towards automatic aerial triangulation," *ISPRS Journal of Photogrammetry & Remote Sensing*, Vol. 52, pp. 110-121.

Škaloud, Jan, 1999. Optimizing georeferencing of airborne survey systems by INS/DGPS, (Ph.D. dissertation., University of Calgary, 1999).

Škaloud, Jan, 2002. Direct Georeferencing in a Photogrammetry, *Photogrammetric Engineering & Remote Sensing*, 68(3), May. 2002, pp. 207-210.

Smith, S.E., Pearlstine, and L., Stenberg, 2003. Comparison of Aerial Videography and Digital Camera Imagery for Improving Land Cover Classification, *Surveying and Land Information Science*, Vol 62, No3, 2002, pp163-170.

Sun, J., 2000. Dynamic Monitoring and Yield Estimation of Crops by Mainly Using the Remote Sensing Technique in China, *Photogrammetric Engineering & Remote Sensing*, 66(5), May. 2000, pp. 645-650.

Toth, C., and D.A. Grejner-Brzezinska, (1998). Performance Analysis of the Airborne Integrated Mapping System (AIMS(tm)), *International Archives of Photogrammetry and Remote Sensing*, 32(2):320-326.

Twiss, S.D.; P.P. Pomeroy; C.J. Thomas; and J.P. Mills, 2000. Remote estimation of grey seal length, width, and body mass from aerial photography, *Photogrammetric Engineering & Remote Sensing*, 66(7): July 2000, pp. 859-866.

Usery, E.L. ,1985, "A Raster Database Approach to Topographic Map Revisions", Published Dissertation, University of Georgia, pp16-21.

Usery, E.L., Pocknee, S., and Boydell, B., (1995), "Precision Farming Data Management Using geographic information systems", *Photogrammetric Engineering & Remote Sensing*, 61(11), Nov. 1995, pp. 1383-1391.

USDA FS, 1996. "Summary Report on FHP's 1996 Aerial Photo Missions using the Kodak CIR Digital Still Camera", US Forestery Web Site, Retrieved March, 3, 2002, Retrieved from http://www.fs.fed.us/foresthealth/technology/publications/96cirdigcam_rpt/cirpaper.htm

USDA FSA, 1998. Common Land Unit, *FSA Handbook, 8-CM*, United States Department of Agriculture, Farm Service Agency, Washington DC 20250.

USDA FSA, 1996. Acreage Compliance Determinations, *FSA Handbook, 2-CP*, United States Department of Agriculture, Farm Service Agency, Washington DC 20013-2415.

USDA OK FSA, 2001, FSA Compliance, Oklahoma FSA Web Site, Retrieved http://www.ok.fsa.gov/, published April, 2001 on March, 2002.

Welch, R. and TB. Jordan. 1996. *Using scanned aerial photographs.* In: Morain, Stan and Shirley Lopez Baros (eds.). 1996. Raster Imagery in Geographic Information Systems. High Mountain Press, Inc., Santa Fe, NM. pp. 55-70

Wiliams, K., 2002. United States Department of Agriculture, Facts, Price Support, White Paper Publication, Retrieved from http://www.apfo.usda.gov/whitepapers/fsa_imagery.pdf, on May 5,2002

Wolf, P.R. and B.A, Dewitt, 2000. Elements of Photogrammetry, with Application in GIS, 3rd Edition McGraw Hill, Boston, MA.

Yany, C. Everitt, J.H., Bradford, J.M. and Escobar, D. E. 2000, Mapping Grain Sorghum Growth and Yield Variations Using Airborne Multispectral Digital Imagery, *ASAC* 2000, Vol43(6) pp 1927-1938