AN INTEGRATED SYSTEM OF DIGITAL VIDEO CAPTURING SYSTEM, GPS AND GIS FOR RADAR CLUTTER ANALYSIS

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ABSTRACT:

Radar clutter is very complicated signal, because it is a kind of random process and invisible to human. As a result, besides instrumental parameters, environmental parameters will play a critical role in later data analyses. At present, the research about radar clutter has become a special field, which greatly affects the development and application of radar. This paper presents an innovative and creative method to support this research. It makes use of 3S (RS, GPS, GIS) integrated technique to provide visual background information for radar signal processing.
This paper proposes several applicative solutions, which can be used to realize 3S integrated system. Its opinion and method about multi-sensor cooperation lay a foundation for 3S data integration. It implements a kind of video capture system in Visual C++6.0 and video for window (VFW) technology. It is used in vehicle-borne experiment and solves the problem about automatically recording captured video. It also implements reading position data from GPS and synchronizing the three kinds of equipments (camera, GPS and radar). In addition, an algorithm is given to calculate coordinates of the radar antenna and video camera or the ground center of radar echo and the image according to coordinates of GPS antenna on airplane or vehicle.

1. INTRODUCTION

Radar clutter is a very complicated signal, because it is a kind of random process and invisible to human. As a result, besides instrumental parameters (band of frequency, angle of incidence. and mode of polarization), environmental parameters or spatial information (size of object, ground vegetation, soil moisture data and terrain, etc) will play a critical role in later data analyses. Environment clutter, or background clutter, such as that from ground, sea or weather, is the main factor affecting radar detection (Ding Lufei, 2000). At present, the research about radar clutter has become a special field, which greatly affects the development and application of radar.

The paper provides an innovative visual method to support this research by an adoptable integrated system of digital video capturing system (belong to Remote Sensing, RS), Global Positioning System (GPS), Geographical Information Systems (GIS). The integrated system can provides clear and visible and quantitative background information for radar clutter collection and signal analysis, and increase the relation between radar clutter analysis and environment or background information.. With 3S integrated technology to distinguish, analyze and classify all the collected data, we can find out the radar clutter character in various environment to aid clutter analysis, create clutter model, improve radar design and measurement precision. That is to say, it can also provide the foundation for radar design, application and simulation.

This paper is based on both the experiment of vehicle-borne system and several investigations of airborne experiments. Several applicative solutions, which can be used to realize 3S integrated system, are proposed. The opinion and method about multi-sensor cooperation lay a foundation for 3S data integration. A class of digital video capture system has been implemented in Visual C++6.0 and video for window (VFW) technology. It is used in the vehicle-borne experiment and solves the problem about automatically recording captured video. Collecting position data from GPS and synchronizing the three kinds of equipments (camera, GPS and radar) have also been implemented. An algorithm is given to calculate coordinates of the radar antenna and video camera or the center of radar clutter and the image with the coordinate of GPS antenna on airplane or vehicle, which is the key to integrate GPS and digital video capturing system into GIS. Finally, some conclusions are presented.

2. 3S INTEGRATED SYSTEM PRINCIPLE AND IMPLEMENTATION

2.1 The Principle of 3S Integrated System

The 3S integrated system for radar background clutter collection and analysis is composed of radar clutter collecting system, RS digital video capturing system, Differential Global

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Positioning System (DGPS) or DGPS integrated Inertial Navigation System (INS), and GIS of the experiment area. The basic configuration of the system is shown in Figure 1.

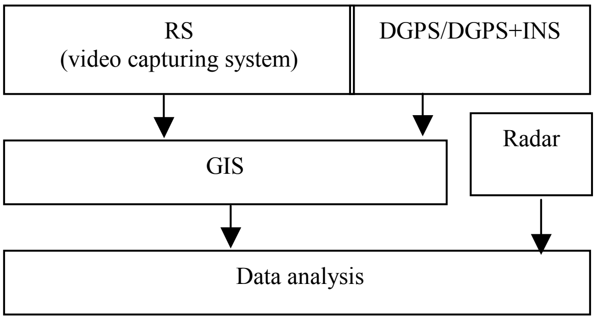

Figure 1. 3S integrated system configuration

The digital video capturing system records the images of the center ground that radar beam covers. These ground images can be used as texture data for 3D scene and update the earth's surface information. The GIS provides a database management platform to integrate, display, and analyse the data collected from GPS and digital video capturing system. Digital elevation model (DEM), 3D scene and other information about the experiment area can be obtained from GIS. GPS can acquire the coordinates and attitude data of the experiment platform in real time, and the ground center coordinates and range of a radar clutter or an image can be calculated through coordinates transformation. Of course, the INS is a better instrument to obtain the attitude data of the experiment platform. With these coordinates, spatial information about the area generating radar clutter can be retrieved from GIS. All of these is helpful to analyse radar clutter.

2.2 Key Technologies of Implementing 3S Integration

In a 3S integrated system, GIS is a subsystem to manage and analyse data, while others are the parts of data collection that based on sensors. These sensors include microwave sensor (radar), positioning sensor (GPS receiver) and image sensor (CCD camera). So, to implement an organic 3S integration is to make the multi-sensors integrated.

Radar clutter data, video data and GPS positioning data are collected automatically in real time. But radar, GPS receiver and digital video capturing system belong to different parts respectively. In order to integrate the system and support radar clutter collection, an internal contact, or a common frame of reference must be created among radar, GPS receiver and digital video capturing system. For example, a synchronizing sign from one of these sensors or a special instrument can be provided to the other sensors, and make them cooperate with each other and confirm the relation of their data flows. With a clear matching relation in space-time, these multi-sensors data can be input, managed and analyzed in GIS, and provide detailed background information for radar clutter analysis.

Therefore, In order to implement the integration application of Digital Video Capturing System, GPS and GIS, some key technologies must be realized. They include communication of sync signal between multi-sensors, controllable video capturing, calculating coordinates of the radar antenna and video camera or the ground center of radar beam and image.

2.3 Solutions to Multi-sensors Cooperation

2.3.1 Principle

In vehicle-borne or airborne experiment, GPS receiver, radar and digital video capturing system run in respective instrument and in respective rhythm, or non-synchronization. In order to achieve the integration of radar, GPS receiver and digital video capturing system and make them cooperate with each other, two principles must be used. First, three parts must obey a common order or dating pulse to start up or end work. The drive pulse which triggers radar transmits electromagnetic wave is exported as the dating pulse to others. Second, every point's instantaneous coordinates of the radar antenna and video camera on the experiment platform's track must be naturalised into the GPS epoch of GPS receiver's antenna. Afterwards, their coordinates can be obtained by interpolating the natural position data of GPS receiver.

2.3.2 Multi-sensors Cooperation Solutions

There are four solutions to be able to implement multi-sensors cooperation in terms of experiment devices.

1. **GPS receiver as the master synchronization controller.**

   In this solution, GPS receiver must have more than two ports of Event Marker input. In the experiment, radar outputs a TTL synchronization signal pulse while microwave is transmitted. At the same time, the pulse is input into GPS receiver's Event Marker input, and triggers the video capturing system. Then, the synchronization signal pulse is input into GPS receiver in regular intervals so that the coordinates of radar antenna are naturalized with the GPS epoch of the GPS receiver antenna. Similarly, While digital video capturing system is running, it output a pulse to GPS receiver's Event Marker input in regular intervals so that the coordinates of CCD camera is naturalized with the GPS epoch of the GPS receiver antenna. See Figure2

2. **Multi-sensors associated with each other**

   This solution is divided into two kinds of solutions due to GPS receiver.

   a) If GPS receiver has only one Event Marker input, Radar still works in the same way as No. 1 solution. The digital video capturing system begins to capture video automatically as soon as it receives the first dating pulse from radar. Meantime, the time code from the GPS receiver, the highly accurate one-pulse-per-second output (PPS pulse), is imported and stored along with the time of each captured frame image in the file that can be used to synchronize the video and positioning data. See Figure2 (2a).

   b) If GPS receiver hasn't Event Marker input (such as GPS OEM card), the time code (PPS pulse) or position data from the GPS receiver must be imported in the radar data flow in regular intervals. Digital video capturing system works as No. 1). See Figure2 (2b).

3. Using special host computer

A special host computer is used to work as a master controller. All the information, both positioning information from GPS receiver and marker data from radar and digital video capturing system, is collected into the host computer and stored in synchronization file. See Figure2 (3).

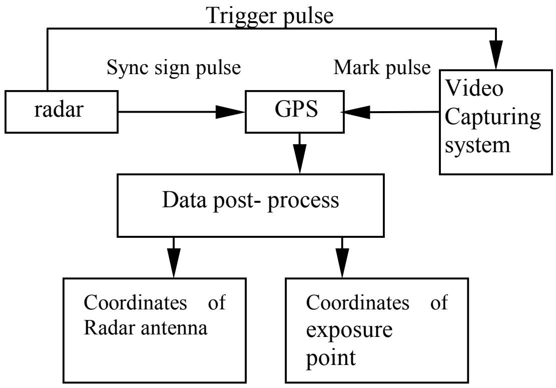

Figure 2 (1)

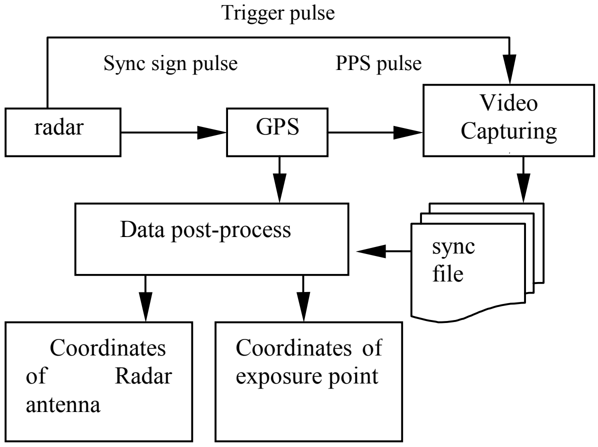

Figure 2 (2a)

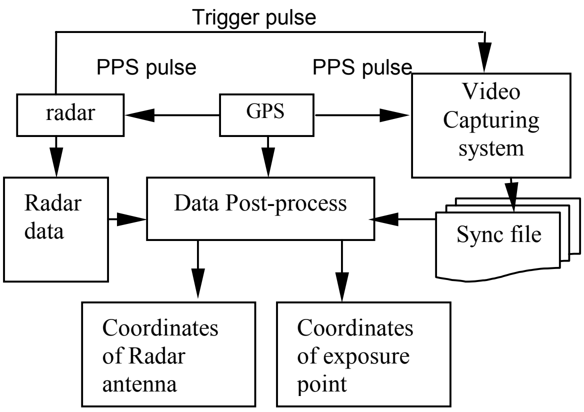

Figure 2 (2b)

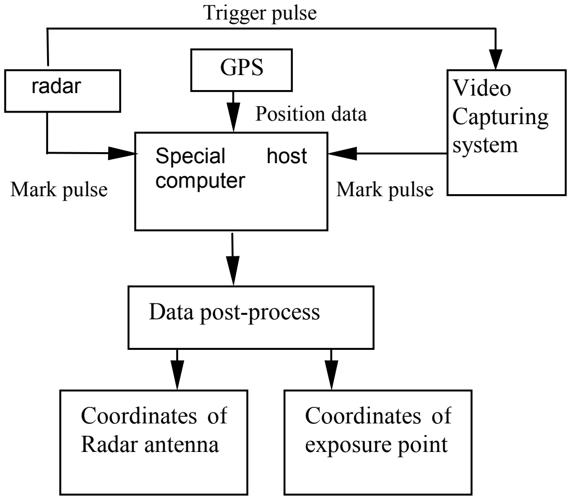

Figure 2 (3)

Figure 2. The multi-sensor cooperation solutions

2.4 Implementation of Multi-sensors Cooperation

2.4.1 Synchronization Signals Communication Between Multi-sensors

According to the multi-sensors cooperation solutions, the communication between multi-sensors relates to the following contents.

- **Serial Communication between computer and GPS receiver.** It includes serial communication between their serial ports or computer's serial port and GPS receiver National Marine Electronics Association (NMEA) output port.
- **Communication between serial port and TTL pulse I/O port.** It includes communication between computer serial port and Even Marker port or PPS output port of GPS receiver, and communication between computer and radar synchronization signal pulse output port.
- **Communication between TTL pulse I/O ports.** It is the communication between radar synchronization signal pulse output port and Event Marker port of GPS receiver.

Therefore, it is clearly that serial communication between computer serial port and the other sensor's serial port or pulse I/O port, together with level switch between different ports are the key to make multi-sensors cooperate with each other.

When a computer communicates with a GPS receiver in serial port, asynchronous communication mode and hardware handshake protocol are used. A ' D' type RS-232C cable tie-in is often used to connect their serial ports. In addition, after level converted, a computer serial port can also collect data from a NMEA port of GPS receivers.

In windows9x, two programming models can be adopted to implement the serial communication. They are port-inquired programming model and event-driven programming model (Chen Jian and Sun Ziyue, 1999). We adopt event-driven programming model due to greatly saving cost-effective of system resources and CPU time.

There are two kinds of format codes for output data from GPS receiver. One is NMEA-0183 format code, another is binary format code. Different manufacturer's GPS receivers provide the same NMEA-0183 data, but there are some differences in binary data. For this reason, the detailed data output format codes must be known before programming.

All the level of pulse signals, from radar and PPS output port, need to be converted from TTL level to RS-232C level before inputting into serial port. Similarly, the mark pulse signal from serial port need to be converted from RS-232C level to TTL level before sending to Event Marker port.

Communication between TTL pulse I/O ports, radar synchronization signal pulse output port and Event Marker port of a GPS receiver is easy to be implemented by direct cable connection.

2.4.2 Signal Level Converted Between Different Ports

Radar synchronization signal pulse output port, Event Marker port and NMEA port of GPS receiver are all TTL logic level, namely, a voltage level of 0~ +0.8 volt corresponds to a logic 0 (the high or true state), and +2~+5 volts corresponds to a logic 1 (the low or false state). On the other hand, computer serial port obeys RS-232C electric criterion. RS-232C electric criterion is a kind of negative logic level criterion, viz. logic 1 corresponds to a voltage level of +12 volts and logic 0 corresponds to a voltage level -12 volts. Thus, when a computer sends marker signal pulse to Event Marker port of a GPS receiver or collects data from a NMEA port, all signals level need to be converted. The level converter unit can use a MAX233 chip.

3. DESIGN AND IMPLEMENTATION OF DIGITAL VIDEO CAPTURING SYSTEM

3.1 Configuration and Principle

The digital video capturing system, which helps to generate the 3D scene of the experiment area, is an automatic subsystem to record the instant image on the ground, which is covered by the radar beam. It consists of various elements including a video capturing software and hardware system. The hardware system is comprised of a CCD video camera, a video amplifier, a video display, and a video capturing board, a video tape recorder and a computer. See Figure3. The model (black-and-white or colour) and image resolution of the CCD camera and the video capturing board are determined by the spatial resolution in response to GIS. The CCD camera's angle of view is not less than the aerial beam width of radar altimeter. The capturing rate of the video capturing board is no less than 25 frames per second. The computer needs a 64M or above memory, a Pentium III or above CPU and a 20G or above high-speed hard disk. If the CCD video camera uses a higher resolution digital video camera with a longer lens, the digital video capturing system can be used to some actual applications of remote sensing data collection.

The image signal from the CCD video camera is divided into two parts. One is input into video tape recorder and recorded as backup data. The other is imported into the video capturing board. After sampling, coding and A/D converting, it becomes a digital video flow. Finally, the digital video flow is captured in sequential frame and stored into the computer's hard disk in AVI file format. These AVI files can be separated offline into individual frame and still image by an image process program.

The digital video capturing system begins to capture video automatically as soon as it receives the first radar synchronization signal pulse from the computer's serial port. From then on, the time code from the GPS receiver, the highly accurate one-pulse-per-second output, is imported via another serial port and stored along with the time of each captured frame image in the file which can be used to synchronize the video and positioning data. On the other hand, each radar synchronization signal pulse is also input into the GPS receiver's mask port to synchronize the radar clutter data and positioning data. The highly accurate GPS receiver's clock is used as a standard for timing clocks of video camera and all computers.

3.2 Digital Video Capturing System Program Design

The digital video capturing system needs to execute several tasks synchronously. While it is capturing video images, it needs to communicate with GPS receiver for multi-sensors cooperation. Windows 9x is a multitask and multithreading operating system, and Visual C++ supports multithreading programmed (David. J, 1997). Therefore, the digital video capturing system program, a multi-task program, can be implemented by multithreading mechanism.

Video for windows (VFW) provides Multimedia Control Interface (MCI) and AVICap window class. By means of sending messages and setting attributes, programmers can easily

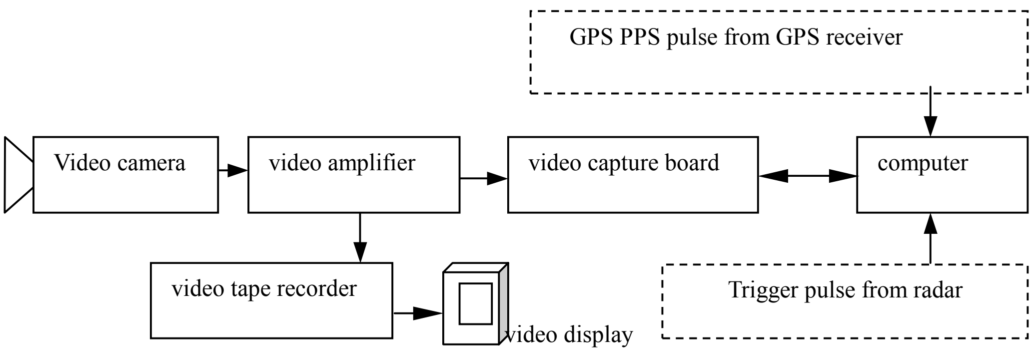

Figure 3. The configuration of digital video capturing system

use all of them to access video and waveform-audio acquisition hardware, to control the process of streaming video capture to hard disk and to reduce the number of frames dropped during capturing. Figure 4 is the program flowchart of the digital video capturing system.

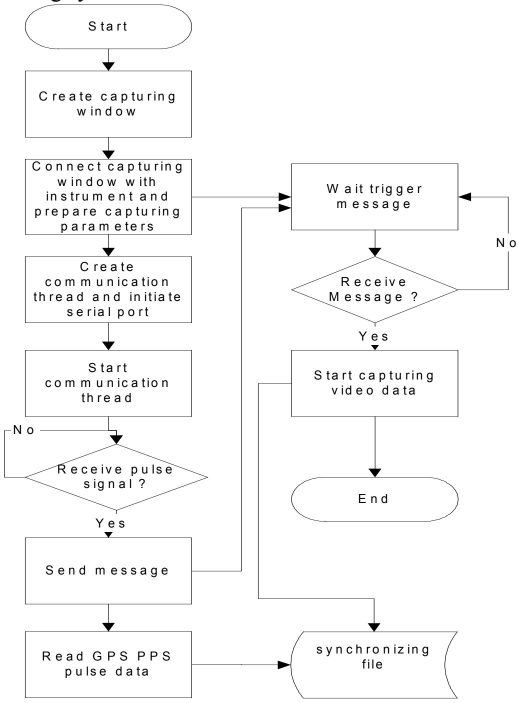

Figure4. The program flowchart of the digital video capturing system

3.3 Vehicle-borne Experiment

During the end of 1998 to March 1999, five times vehicle-borne experiments for 3S integrated system supporting radar clutter collection ware completed. In these experiments, the radar antenna, the video camera and the GPS receiver are all fixed on a swinging arm of a personnel hoist truck. The arm can be rotated 360 degrees. In vehicle-borne experiment, the CCD video camera is an ordinary CCD video camera, JVC GR-AXII. Three Trimble 4000SSI receivers are used to make up of a DGPS. Parts of captured images are shown in Figure 5. The dynamic trajectory of the experiment platform is shown in Figure 6 (Liu Xianlin, 1999).

Figure 5. Parts of captured images in the vehicle-borne experiment

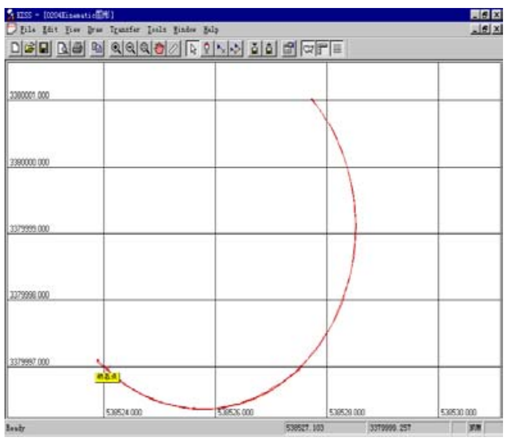

Figure 6. The dynamic trajectory of the experiment platform

4. COORDINATES TRANSFORM AND CALCULATION

4.1 Coordinate System of 3S Integrated System

In the experiment, three-dimensional coordinate of the experiment platform obtained by a GPS receiver must be transformed from the WGS-84 coordinate system into the Beijing ground coordinate system, the O-XYZ coordinates system as shown in Figure 7. On the other hand, radar antenna,video camera and GPS receiver antenna construct an experiment platform coordinate system due to their different installed position. In addition, there is a photograph coordinate system, See Figure 7.

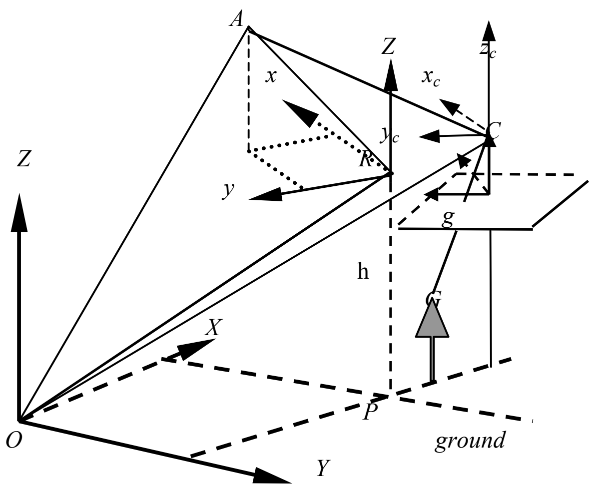

Figure 7. Coordinate system of 3S integrated system

The radar antenna, GPS receiver antenna and video camera are all fixed on a plane's body. The GPS receiver antenna is installed on the back of the plane, while the radar antenna and video camera are fixed under the plane and point ground vertically. In the coordinate system of the experiment platform, the phase center of the radar antenna (the point R) is selected as the origin of coordinates. The x-axis parallels the horizontal center axes with its positive direction same as the direction of the platform motion. The *z*-axis perpendicular to the level ground, and its positive direction is upward. The y-axis, x-axis and z-axis create a right hand x-y-z system, *R-xyz* coordinate system.

In the photograph coordinate system, the exposure point of video camera (the point C) is selected as the origin of coordinates. The x_c-axis parallels the x-axis with its positive direction same as the direction of the platform motion. The z_c-axis is perpendicular to the level ground, and its positive direction is downward. The y_c-axis, the x_c-axis and the z_c-axis create a right hand XYZ system, C- x_c y_c z_c coordinate system.

By all appearances, the phase center of the GPS receiver antenna (the point A) does not coincide with the video camera, and has a fixed amount of deviation (ξ_x, ξ_y, ξ_z). This amount of deviation can be determined by the close range photogrammetry or the theodolite measurement with a precision of centimetresized (Xu Shaoquan, 1998). Similarly, the fixed amount of deviation (δ_x, δ_y, δ_z), the phase center of the GPS receiver antenna (the point A) in respect of the phase center of the radar, can also be acquired accurately.

4.2 Calculating the Ground Coordinates of a Radar Clutter

As is shown in Figure6, we suppose that the center axis of the radar antenna intersects the level ground at the point P, and the h is the distance between the point R and point P. So, in the platform coordinate system, the phase center coordinate vectors of the GPS receiver antenna is $x_g = (\delta_x, \delta_y, \delta_z)^T$, and the coordinate vectors of the point P is $x_p=(0, 0, -h)^T$.

Considering the coordinate vectors of the point A, the point R and the point P are $X_{G\,t}=(X_{At}, Y_{At}, Z_{At})^T$, $X_{R\,t}=(X_{Rt}, Y_{Rt}, Z_{R\,i})^T$, $X_{P\,t}=(X_{Pt}, Y_{P\,t}, Z_{P\,t})^T$, respectively, following formulas can be obtain(Liu Jiyu, Li Zhenghang, 1993).

$$x_g=M(X_{At} — X_{Rt}) \quad (1)$$
$$x_p=M(X_{Pt} — X_{Rt}) \quad (2)$$

Where, M is a matrix rotating the Beijing ground coordinate system into the experiment platform coordinate system, and given $M= R(\psi)R(\omega)R(\kappa)$. Where,

$$R(\kappa) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\kappa & \sin\kappa \\ 0 & -\sin\kappa & \cos\kappa \end{bmatrix}$$
$$R(\omega) = \begin{bmatrix} \cos\omega & 0 & -\sin\omega \\ 0 & 1 & 0 \\ \sin\omega & 0 & \cos\omega \end{bmatrix}$$
$$R(\psi) = \begin{bmatrix} \cos\psi & \sin\psi & 0 \\ -\sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

with ψ, ω and κ being the rotating angles of the the Beijing ground coordinate system plane in respect of the experiment platform coordinate system, respectively.

It can be proved that $M^TM=I$. Where, M^T is the transpose matrix of *M, I* is an identity matrix. Subtracting Eq. 2 from Eq. 1, we obtain:

$$x_g—x_p=M(X_{At} — X_{Pt}) \quad (3)$$

After left multiplying both sides by M^T, transposing and simplifying, we have the WGS-84 coordinate of the point P.

$$X_{Pt}=X_{At}—M^T(x_g—x_p) \quad (4)$$

Namely,

$$\begin{bmatrix} X_{Pt} \\ Y_{Pt} \\ Z_{Pt} \end{bmatrix} = \begin{bmatrix} X_{At} \\ Y_{At} \\ Z_{At} \end{bmatrix} - M^T \begin{bmatrix} \delta_x \\ \delta_y \\ \delta_z + h \end{bmatrix} \quad (5)$$

4.3 The Coordinate of the Exposure Point and the Ground Point

Using the same method as 5.2, the the Beijing ground coordinates of the exposure point C can be gotten:

$$X_{Ct}=X_{At}—M^T x^c_g \quad (6)$$

Namely,

$$\begin{bmatrix} X_{ct} \\ Y_{ct} \\ Z_{ct} \end{bmatrix} = \begin{bmatrix} X_{At} \\ Y_{At} \\ Z_{At} \end{bmatrix} - M^T \begin{bmatrix} \xi_x \\ \xi_y \\ \xi_z \end{bmatrix} \tag{7}$$

Where, $X_{C\,t}=(X_{C\,t}, Y_{C\,t}, Z_{C\,t})^T$ is the Beijing ground coordinates of the exposure point C, and $x^c{}_g = (\xi_x, \xi_y, \xi_z)^T$ is the coordinate of the phase center of the GPS receiver antenna in the photograph coordinate system. $(\xi_x, \xi_y, \xi_z)^T$, $X_{A\,t}$ and M^T have the same meaning as the previous statements.

According to the direct georeferencing model (Mostafa, Schwarz, 2001), we can get the ground coordinate of an arbitrary image point g as :

$$X_{Gt}=X_{C\,t}+S_g MR^c{}_{gt} \tag{8}$$

Where X_{Gt} is the georeferenced 3D vector of coordinates of an arbitrary ground point G in the WGS-84 frame. $X_{C\,t}$ is the 3D vector of the instant coordinates of the exposure station C in WGS-84 frame; S_g is a scale factor per point per image for the imaging sensor, implicitly derived during the 3D photogrammetric reconstruction of objects using image stereo pairs and therefore not explicitly computed in practice; M is a matrix rotating the imaging sensor camera frame (c-frame) into the Beijing ground coordinate frame utilizing the three photogrammetric rotation angle ψ, ω and κ (cf. Moffit and Mikhail, 1980); and $R^c{}_{gt}$ is the 3D vector of coordinates of the image point g in the c-frame, expressed by:

$$\mathrm{R}^{\mathrm{c}}_{\mathrm{gt}} = \left(x^c_g - x^c_{pp}; \frac{y^c_g - y^c_{pp}}{k}; -f \right) \tag{9}$$

Where x^c_g and y^c_g are the image coordinates of the point g corresponding to the object point G; x^c_{pp} and y^c_{pp} are the principal point offsets from the CCD format center; k is a scale factor accounting for the non-squareness of the CCD pixels; f is the calibrated focal length of the lens in use.

4.4 Discussion

The instant height of an experiment platform is important for this system to support radar clutter analysis. In vehicle-borne experiments, it can be acquired easy. But it may be a more difficult thing to collect radar clutter and measure heights of the in airborne. We are ready to use radar altimeter to do the two missions.

The height provided by a radar altimeter is not the real distance between a plane and a ground point, but an average height within a definite area (Zhu Qiming, 1992). It is followed by the error of survey of the radar altimeter. The ground is considered as a level ground in the foregoing coordinate calculation. So, when the ground is an undulant terrain, the result of the foregoing ground coordinate of a radar beam center may have calculation error, too. Therefore, the height is not accurate. However, there is a determinate relation for the ground center point of a radar beam and an image due to their rigid connection with the experiment platform. So, a rather accurate height of the platform above the ground can be obtained easily in terms of the ground coordinate of the exposure point and attitude data so that the rather accurate ground coordinate of a radar beam center can still be obtained. 3S integrated system can support the radar altimeter collecting environment clutter.

Although many studies have been made for the realization and data correlation of the multi-sensors cooperation, the calculation approach to implementing automatically multi-sensors data fusion demands further hard study.

5. CONCLUSION

By an adoptable 3S integrated system of a digital video capturing system, GPS and GIS, an innovative visual analysis method for the research of radar environment clutter collection and analysis, together with a powerful support for design, application and emulation of radars are provided. This integrated system provides a simple and effective solution for a radar altimeter to increase its precision of measure and calibration. The integration idea about multi-sensor cooperation can lay a foundation for 3S data integration. The digital video capturing technology based on 3S integration can provide a support for the popular application of 3S integration technology.

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