UNIVERSITI PUTRA MALAYSIA

INERTIAL NAVIGATION SYSTEM DATA PROCESSING FOR POSITION DETERMINATION

KHURRAM NIAZ SHAIKH

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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DEDICATION

I dedicate this research to my parents especially my mother who bore the absence of her beloved son and prayed all the time for my success and accomplishment due to which it became possible for me to write this thesis.

Abstract of thesis presented to the Senate of University Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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Chairman: Associate Professor Abdul Rashid Mohammad Shariff, PhD

Faculty: Engineering

Locating the positions and mapping the spatial information is of critical significance in the field of Precision Farming. Global Positioning System (GPS) is the main tool being utilized for this purpose but it is dependent on the satellite signals. Unfortunately these signals may get lost due to the blockage by canopy of the orchards or plantation. Inertial Navigation System (INS) can address this problem and support the non-availability of GPS signal for a short time. INS is capable of individually calculating the vehicle's position without any external references. However, its high cost and time dependent errors are its major drawbacks.

The research focuses on the mapping solution by INS only so that it can provide solution in the absence of GPS signal. Low cost inertial sensor (Xbow RGA300CA) was used for data collection and processing. Data Processing was done in Matlab/Simulink environment. A Simulink processing model is presented in detail to give an insight of the Strapdown INS Mechanization. Low pass filter and wavelet denoising model was used to assess the margin of improvement for noise filtering. Accurate GPS information was used as a reference of comparison.

The model was tested in the lab as well as in the field for its validity. Before going to the field the Inertial sensor was tested in the lab for yaw rate drift and for stationary drift. For kinematic field testing, inertial sensor with GPS was mounted on the vehicle to get the positions for straight trajectories up to 100 meters.

Results obtained are presented in detail. A gradual error growth was observed in the INS data and the sensor was found to be stable for short term only. Wavelet denoising was found to be better over short distances up to 40 meters while low pass filtering showed better performance over longer distances up to 100 meters.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

PEMPROSESAN DATA SISTEM NAVIGASI INERSIA BAGI PENENTUAN KEDUDUKAN

Oleh

KHURRAM NIAZ SHAIKH

Mac 2005

Pengerusi: Profesor Madya Abdul Rashid Mohammad Shariff, PhD

Fakulti: Kejuruteraan

Menentukan kedudukan dan memetakan maklumat spatial sangat kritikal dalam bidang Pertanian Presisi. Sistem Posisi Global (GPS) ialah sistem utama yang digunakan untuk tujuan ini, tetapi ia bergantung kepada isyarat daripada satelit, sedangkan isyarat-isyarat tersebut mungkin hilang akibat halangan kanopi pokok di dalam ladang. Sistem Navigasi Inersia (INS) boleh mengatasi masalah ini dan boleh menampung ketiadaan isyarat GPS bagi masa yang singkat. INS mampu mengira kedudukan kenderaan tanpa rujukan luaran. Tetapi kosnya yang tinggi dan ralatnya yang bergantung pada masa adalah kelemahan sistem ini.

Oleh itu penyelidikan ini tertumpu kepada penyelesaian pemetaan menggunakan INS agar ia dapat menghasilkan penyelesaian tanpa isyarat GPS. Penderiaan Inersia berkos rendah (Xbow RGA300CA) digunakan untuk pengumpulan dan pemprosesan data. Permprosesan data dibuat di dalam Matlab/Simulink. Sebuah model pemprosesan Simulink dipersembahkan dengan terperinci untuk menjelaskan Mekanisasi INS

“Strapdown model”. Tapisan laluan rendah dan “wavelet denoising” telah digunakan untuk menilai tahap pembaikan bagi “noise filtering”. Maklumat GPS yang jitu telah digunakan sebagai rujukan bandingan.

Model ini telah diuji di dalam makmal dan juga di lapangan bagi menentukan keberkesananya. Sebelum deria inersia dibawa ke lapangan, ianya terlebih dulu diuji didalam makmal bagi menentukan kadar halaju pecutan dan kadar pemberhentian. Bagi tujuan ujian kinematik, deria inersia dan GPS diletakkan di atas kenderaan untuk mendapatkan posisi bagi projector laluan lurus sehingga 100 meter.

Keputusan yang didapati daripada ujikaji ini telah diterangkan dengan lengkap. Peningkatan ralat yang biasa telah diperhatikan di dalam data INS dan deria inersia itu didapati stabil dalam jangka waktu yang pendek sahaja. “Wavelet denoising” telah dedapati lebih berkesan bagi jarak dekat, sehingga 40 meter, manakala tapisan aluan rendah menampakkan performasi yang lebih baik bagi jarak melebihi 100 meter.

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I am also grateful to Mr. Zakaria Ghazali (Technical Officer at Department of Civil Engineering) for his help and sharing of experience in the use of survey equipments.

I certify that an Examination Committee met on **date of viva** to conduct the final examination of **Khurram Niaz Shaikh** on his **Master of Science** thesis entitled "**Inertial Navigation System Data Processing For Position Determination**" in accordance with Universiti Putra Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the Degree of Master of Science. The members of the Supervisory Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

KHURRAM NIAZ SHIAKH

Date:

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LIST OF ABBREVIATIONS

DCM	Direction Cosine Matrix
DTG	Dynamically Tuned Gyro
EU	European Union
FOG	Fiber Optic Gyro
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IFOG	Interferometric Fiber Optic Gyro
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
JUPEM	Jabatan Ukur Pemetaan Malaysia (Department of Survey and Mapping Malaysia)
MEMS	Micro-Electro-Mechanical Systems
MMS	Mobile Mapping System
MPOB	Malaysian Palm Oil Board
RGA	Rate Gyro Accelerometer
RLG	Ring Laser Gyro
SINS	Strapdown Inertial Navigation System
WGS	World Geodetic System

CHAPTER 1

INTRODUCTION

1.1 Background

Humans have been trying to figure out the position on earth since stone age so that we can use that information to know where we are and where we are going. Today, the strife has brought us to the technological advancement that has made things much easier and with the help of innovative technology and computing power we have been working hard to achieve accuracy with higher precision. Today, there is a wide range of navigation sensors available that not only can pin point the location on earth but also can keep track of the navigation information with velocity. In geomatics engineering sense, navigation is understood as quasi-continuous positioning of a moving object. Thus, we often encounter expressions such as "GPS-navigation". In fact, the task of navigation is much more complex than just positioning as it includes the decision making as well as steering of the moving vehicle (OmarBashich, 1998).

Global Positioning System (GPS) is the most popular navigation system in use today. But its limitations open doors for an autonomous navigation system such as Inertial Navigation System (INS). A decade ago inertial sensors were only limited to aerospace and military applications due to their high cost and restrictions by the government but now due to the reducing cost they are finding their way in civil applications such as mobile tracking, precision surveying, and precision farming.

INS (Inertial Navigation System) was originally developed by the military about 20 - 25 years ago when they sought a self-contained system that didn't rely on outside contact. Other systems at that time needed land-based beacons and transmitter stations. It is the most complex and expensive navigational aid. INS has been the system of choice for many years by the military and commercial airlines. It is extremely accurate, not affected by external factors and being independent of outside communication, it can operate worldwide. INS uses a sophisticated form of dead reckoning. It starts from a known position and calculates further positions from the acceleration of the aircraft. This gives accurate data on speed and change of direction to determine a new position. To detect changes in velocity, the INS uses accelerometers (3 of them, mounted east-west, north-south and vertically) (Education Queensland, 2005).

The difference between the INS for land vehicles (low dynamics) and high dynamics is that high dynamics platforms such as Aircraft, satellites etc need to have angles measured at all three angles accurately to give three-dimensional accuracy. The navigation accuracy and reliability requirements for a ballistic missile and that of an autonomous vehicle are not that different. Both require high precision navigation solutions, in some cases that of the autonomous vehicle is down to centimeters, and both require the system to provide this data reliably. The major difference is the duration requirement to which the INS is allowed to function without any external aiding, a function of the accuracy required. For civilian applications this is quite short, in the order of seconds, because some sort of external aiding can be used. The goal however is to provide the navigation solution from the INS for as long as possible without external aiding. This is due to two main reasons: 1) aiding information cannot be guaranteed to come in at fixed intervals, and 2) in any autonomous vehicle navigation fault detection is paramount and this requires accurate navigation solutions from individual systems. The cost of an Inertial Measurement Unit (IMU) governs its accuracy (an IMU is a sensor package which provides the raw vehicle dynamic data from which the final navigation solution is determined). In general, civilian applications require low cost IMUs. These units however pose significant errors, which in turn cause navigation solutions to drift significantly with time (Sukkarieh, 2000).

1.2 Research Problems

No one denies the accuracy of GPS with the increased constellation of satellites and improved methods of data processing but GPS is still dependent on the satellite signal. Today, the surveyors are having problems of accuracy in places where the signal gets lost due to blockage by buildings, canopy, and other obstructions. Many of the studies are being carried out to address the issue of signal loss. Inertial Navigation System (INS) is one of the most popular navigation systems that can provide an autonomous solution in case of signal loss.

Accurate and high performance inertial sensors are still not feasible for use in land applications due to high cost constraints and restrictions by the government. This research strives to utilize a low cost inertial sensor in an optimum manner to get the position information. These low cost inertial sensors can experience large positioning errors over short time due to low quality of gyros and accelerometers. The software (Gyroview) that comes with these inertial sensors only logs the raw accelerations. These raw accelerations can not be used for mapping unless converted to positions. The sensor used in this research is a low cost inertial sensor (RGA300CA) that outputs raw accelerations with lots of noise in it that need to be filtered to get accurate position information. Therefore an approach was initiated to build a simulation algorithm do the processing of INS raw accelerations and angles by removing the noise and converting them to positions.

1.3 Goal and Objectives

The major goal of this research was to get accurate coordinate trajectory information from low-cost strapdown inertial navigation systems so that it can be used as a standalone navigation system to support the short GPS outages during mobile mapping by land vehicle.

The specific objectives to achieve this goal were:

1. To develop INS data processing algorithm in Simulink (Matlab) to get output in terms of positions.

2. To remove the Noise from the output by testing and comparing two filtering techniques, viz. Low Pass Filtering and Wavelet Denoising.

3. To investigate the navigation accuracy of the RGA Inertial Sensor with accurate GPS information.

1.4 Summary of Methodology

Inertial sensors output accelerations and angles but the mapping information needs positions. Therefore, the output given by inertial sensors need to be processed to get the information in terms of positions. A low cost inertial sensor (RGA300CA) from Xbow Inc. USA was used to collect and process the data. To attain the objective of INS data processing Matlab/Simulink software was used because of its strong computing capabilities and ease of use due to built-in blocks in the Simulink library. The output given by the RGA inertial sensor contains substantial noise that needs to be filtered. The software used to log the accelerations from RGA inertial sensor is Gyroview version 2.4 that comes with the RGA Inertial Sensor but it is not capable of processing the accelerations to convert them to positions. The data is saved in text format that was later loaded in Matlab workspace as individual variables of three accelerations and three axis angular information. By integrating the accelerations once gives velocities and integrating again gives positions.

These accelerations multiplied by the angular information give attitude corrections. However, the noise in the RGA inertial sensor data makes output inaccurate and requires a proper noise filtering technique. Two noise filtering techniques: Low pass filtering and Wavelet denoising were tested and compared for accuracy.

The simulink processing model was tested for validity by conducting tests in the lab as well as in the field. Stationary lab testing and yaw rate lab testing was conducted to check the error growth with respect to time. Kinematic testing was conducted by mounting the inertial sensor over the vehicle and taking the measurements from the distances of 10 to 100 meters. These measurement once processed were compared with accurate DGPS information. Chapter three on methodology discusses the research approach in detail comprising the data processing method and testing setup.

1.5 Scope of Study

The research focuses on the processing of INS data using RGA300CA inertial sensor (Figure 3.3) from Xbow Inc. USA and to develop an algorithm (model) to convert the INS output (accelerations and angles) to obtain position information. The term 'INS data model' is used to refer INS data processing simulation algorithm in Simulink (Matlab). This model gets the coordinates (positions) from the inertial sensor output (accelerations and angles). The model includes the noise filtering algorithms (Low Pass filter and Wavelet denoising), however this research does not focus on noise filtering, perse It is beyond the scope of this research to go into the details of the noise filtering, noise filtering is itself a big area and needs focused research to improve the results. It is the noise found in the INS data that led us to do the noise filtering and we tried two techniques to suppress the noise to get the meaningful result from INS data. Filtering algorithms were 'taken' from Matlab help manuals and were used in the model, and the 'INS data processing model' was developed. This research does not go into the details of hardware design and configuration. It also does not deal with the details of GPS/INS integration. Field surveys were limited to the distances of up to 100