UNIVERSITI PUTRA MALAYSIA

IMPROVEMENT OF AN INTEGRATED GLOBAL POSITIONING SYSTEM AND INERTIAL NAVIGATION SYSTEM FOR LAND NAVIGATION APPLICATION

AHMED MUDHEHER HASAN

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By

AHMED MUDHEHER HASAN

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

April 2012

DEDICATION

I dedicate this work

to

My dearest Mother and Father,

My Sisters,

Marwa, Zainab, and Sara

and

My Friends

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chairman: Khairulmizam Samsudin, PhD

Faculty : Engineering

Global positioning system (GPS) has been extensively used for land vehicle navigation systems. However, GPS is incapable of providing permanent and reliable navigation solutions in the presence of signal attenuation or blockage. On the other hand, navigation systems, in particular, inertial navigation systems (INS), have become important components in different military and civil applications due to the recent advent of micro-electro-mechanical systems (MEMS). Both INS and GPS are not so far apart and they are often paired together to provide a reliable navigation solution by integrating the long-term GPS accuracy with the short-term INS accuracy. Therefore, this work is concerned to presents an alternative method to integrate GPS and INS systems and provide a robust navigation solution with trusted position and velocity information.

Cascaded de-noising method based on discrete wavelet transform (DWT) is exploited in this work to filter out the MEMS inertial sensors. In addition, in this work a GPS

predictor is developed to incorporate information from the accelerometers and gyroscopes at high rates and information from GPS measurements at low rates to improve the vehicle strapdown inertial navigation system (SDINS) with the aid of GPS.

This work also presents a new method for de-noising the GPS and INS data and estimate the INS error using wavelet multi-resolution analysis algorithm (WMRA) based particle swarm optimization (PSO) with a well designed structure appropriate for practical and real time implementations due to its very short optimizing time and elevated accuracy. The proposed hybrid method is simple, easy to implement and can be used to automate the INS-error estimation step used in the proposed integrated GPS/INS navigator.

Moreover, three alternative GPS/INS integration structures have been proposed. The developed navigators utilize artificial intelligence (AI) based on adaptive neuro-fuzzy inference system (ANFIS), to fuse data from both systems and estimate position and velocity errors. Most integration systems based on Kalman filter (KF) which is usually criticized for working only under predefined models and for its observability problem of hidden state variables, sensor error models, immunity to noise, sensor dependency, and linearization dependency. The proposed GPS/INS integration has been evaluated during various GPS signal conditions including continuous and non-continuous satellites signals.

Finally, performance evaluation for the proposed integrated GPS/INS navigator provides a reliable navigation solution including position and velocity information. A comparative study using different structures for GPS/INS integrations are conducted to test the performance in terms of accuracy and time required for training mode. The experimental results using real field test data show also the improvements in predicting the INS error for both position and velocity. The integrated GPS/INS system is able to maintain satisfactory accuracy with the maximum error less than 0.82, 0.78, and 0.83 m for position and 0.0414, 0.0273, and 0.0415 m/s for velocity in all directions during maximum GPS outages of 200 second while it requires less than 9 and 5 seconds for learning mode in position and velocity respectively.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENAMBAHBAIKAN DARIPADA SATU SISTEM KEDUDUKAN GLOBAL BERSEPADU DAN SISTEM NAVIGASI INERSIA BAGI APLIKASI NAVIGASI TANAH

Oleh

AHMED MUDHEHER HASAN

April 2012

Chairman: Khairulmizam Samsudin, PhD

Faculty : Kejuruteraan

Sistem kedudukan global (GPS) telah digunakan secara meluas untuk sistem navigasi kenderaan darat. Walau bagaimanapun, GPS tidak mampu menyediakan penyelesaian navigasi secara berterusan dan tidak boleh dipercayai dalam kehadiran kehilangan isyarat atau halangan. Sebaliknya, sistem navigasi tertentu seperti sistem navigasi inersia (INS), telah menjadi komponen penting dalam aplikasi ketenteraan dan awam yang tertentu kerana perkembangan terkini seperti mikro-elektro-mekanikal sistem (MEMS). Kedua-dua INS dan GPS tidak begitu ketara dan mereka sering dipasangkan bersama untuk menyediakan satu penyelesaian navigasi yang dipercayai dengan mengintegrasikan ketepatan jangka panjang GPS dan ketepatan jangka pendek INS. Oleh itu, tesis ini memperkenalkan kaedah alternatif untuk menyatukan GPS dan sistem INS serta menyediakan satu penyelesaian navigasi yang mantap dengan kedudukan yang dapat dipercayai dan maklumat halaju.

Kaedah lata “de-noising” berdasarkan diskret ubahan wavelet (DWT) dieksploitasi dalam kerja ini untuk menapis sensor inersia MEMS. Di samping itu, peramal untuk GPS direka untuk menggabungkan maklumat daripada "accelerometer" dan "gyroscope" pada kadar yang tinggi dan maklumat ukuran dari GPS pada kadar yang rendah untuk meningkatkan sistem navigasi inersia strapdown (SDINS) dengan bantuan GPS.

Kerja ini juga membentangkan kaedah baru “de-noising” GPS dan data INS serta menganggar ralat INS menggunakan wavelet pelbagai resolusi analisis algoritma (WMRA) berdasarkan zarah meluru turun optimization (PSO) dengan struktur yang direka dengan baik, sesuai untuk pengunaan praktikal dan masa sebenar yang disebabkan sangat pendek dan ketepatan yang lebih jitu. Kaedah hibrid yang dicadangkan adalah senang, mudah untuk dilaksanakan dan boleh digunakan untuk mengautomasikan langkah daripada anggaran ralat INS yang digunakan dalam cadangan sistem bersepadu GPS/INS.

Tambahan pula , tiga alternatif struktur integrasi GPS/INS telah dicadangkan. navigator yang telah dibangunkan menggunakan tiruan risikan (AI) yang berdasarkan penyesuaian neuro-kabur inferens sistem (ANFIS), untuk menggabungkan data dari kedua-dua sistem serta menganggar kedudukan dan kesilapan halaju. Kebanyakan sistem berintegrasi berdasarkan Kalman menapis (KF) biasanya dikritik kerana hanya dapat berfungsi di bawah model pratentu serta masalah-masalah pemerhatian pemboleh ubah dalam keadaan tersembunyi, model kesilapan sensor, imuniti kepada bunyi bising, pergantungan terhadap sensor, dan pergantungan terhadap pelinearan. cadangan

Integrasi GPS/INS telah dinilai dalam pelbagai keadaan isyarat GPS termasuk isyarat satelit berterusan dan tidak berterusan.

Akhir sekali, penilaian prestasi untuk sistem navigasi GPS/INS bersepadu dicadangkan dapat menyediakan penyelesaian navigasi yang boleh dipercayai termasuk kedudukan dan halaju. Satu kajian perbandingan yang menggunakan struktur yang berlainan bagi integrasi GPS/INS dijalankan untuk menguji prestasi dari segi ketepatan dan masa yang diperlukan untuk mod latihan. Keputusan uji kaji menggunakan data ujian lapangan yang sebenar juga menunjukkan peningkatan dalam meramal kesilapan INS untuk kedua-dua.

Kedudukan dan halaju. Sistem GPS/INS bersepadu mampu untuk mengekalkan ketepatan yang memuaskan dengan maksimum ralat kurang daripada 0.82, 0.78 dan 0.83 m untuk kedudukan halaju pada 0.0414, 0.0273 dan 0.0415 m/s pada semua arah semasa kehilangan GPS maksima 200 saat sementara ia memerlukan 9 dan 5 saat masing-masing untuk mod latihan kedudukan dan halaju.

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LIST OF ABBREVIATIONS AND NOTATIONS

AI	Artificial Intelligence
AHRS	Attitude and Heading Reference Systems
ANN	Artificial Neural Network
ANFIS	Adaptive Neuro fuzzy Inference System
AR	Autoregressive
ANS	Astronavigation system
BANFIS	Back propagation Neuro Fuzzy Inference System
Bior	Biorthogonal filters
BP	Back Propagation
CNSS	COMPASS Navigation Satellite System
Coif	Coiflets filters
Db	Daubechies filters
DCM	Direction Cosine Matrix
DGPS	Differential Global Positioning System
DR	Dead Reckoning
DWT	Discrete Wavelet Transform
EA	Evolutionary Algorithms
ECEF	Earth Center Earth Fixed
EKF	Extended Kalman Filter
ES	Expert Systems
6DOF	Six Degree of Freedom
FL	Fuzzy Logic
FOS	Fast Orthogonal Search
GA	Genetic Algorithm
GANFIS	Genetic Neuro Fuzzy Inference System
GLONASS	GLObal NAvigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HEPF	Hybrid Extended Particle Filter
HNN	Hopfield Neural Network
HSWM	Hybrid Swarm Wavelet Method
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
KF	Kalman Filter
LKF	Linearized Kalman Filter
LM	Levenberg-Marquardt
LOD	Level of Decomposition
LOS	Line of Sight
MEMS	Micro-Electro-Mechanical Systems
MLP	Multi Layer Perceptron
MRA	Multi-Resolution Analysis
MSE	Mean Square Error
PANFIS	Particle-Swarm Neuro Fuzzy Inference System

PF	Particle Filter
PSO	Particle Swarm Optimization
PVUA	Position and Velocity Update Architecture
RBF	Radial Basis Function
RLSL	Recursive Least Squares Lattice
RMS	Root Mean Square
RMSE	Root Mean Square Error
RNN	Recurrent Neural Network
SDINS	Strapdown Inertial Navigation System
SNR	Signal to Noise Ratio
SPP	Single Point Positioning
STD	Standard deviation
SURE	Stein's Unbiased Risk Estimate
Sym	Symlets filters
Thrv	Threshold value
TSR	Threshold Selection Rule
UAV	Unmanned Aerial Vehicle
UKF	Unscented Kalman Filter
UPF	Unscented Particle Filter
WMRA	Wavelet Multi-Resolution Analysis
WPT	Wavelet Packet Transform
WT	Wavelet Transform
A_E	Difference between the GPS and INS approximations
A_x, A_y, A_z	Acceleration measured in body frame
A_{GPS}	Approximation coefficient of the GPS
A_{INS}	Approximation coefficient of the INS
C_a^b	Transformation matrix from a-frame to b-frame
$C_{s,k}$	Approximation coefficients
D_E	Difference between the GPS and INS Details
D_{GPS}	GPS details part
D_{INS}	INS details part
$d_{s,k}$	Detail coefficients
$d_j(k)$	Desired output at time (k)
e	Earth eccentricity (0.0818 m)
$E(k)$	Error between desired and actual output at time (k)
f_{j}	Fuzzy set
F'	Wavelet filters type
F_{i}	Linguistic label assigned to fuzzy set
$f(x)$	Fuzzy logic system
f^b	Force vector measured in body frame (N)
f'	Derivation of the activation function
G_{best}	Global best position
g_s	Detail part
$g(.)$	Activation function
g_o	Initial gravity (m/s^2)
g_e	Gravity acceleration (m/s^2)
h	Altitude (m)

H_0	Initial vehicle height above the ground (m)
$iter_{max}$	Maximum iteration in swarm evolution process
K_c	Constriction factor
k	Shifting coefficients
L_{best}	Local best position
L	Latitude (rad)
L_o	Initial Latitude (rad)
l	Longitude (rad)
l_0	Initial Longitude (rad)
mln	Multi-level noise
M	Number of fuzzy IF-THEN rules
$m_{i,}\ \sigma_i$	Center and width of bell-shaped function of i^{th} input variable, respectively
$m_{ij},\ \sigma_{ij,}$	Center and width of bell-shaped function of the i^{th} input of the j^{th} rule, respectively
N^l	Estimation noise level
n	Number of input linguistic variables
N	Signal length
N, E, D	North, East, and Down directions
P	Number of outputs of the fuzzy system
$rand()$	Uniformly distributed random function in [0, 1]
R_E	Radii of curvature in East direction (m)
$r_{1,} r_2$	Random numbers in the range between [0, 1]
r_e	Semi-major axis length of the earth (6378137.0 m)
R_N	Radii of curvature in North direction (m)
sln	Single level noise
S_s^{th}	Difference between GPS and INS details at S^{th} level
S_i	Second derivative for the predicted point
s	Scaling coefficients
Th	Hard Thresholding
t_o	Time for initial reading
t_p	Prediction time
Ts	Soft thresholding
T^f	Threshold function type
u	Quaternion vector $[u_0\ u_1\ u_2\ u_3]^T$
V	Universe of discourse
$\vec{v_i}$	Specific particle velocity vector
V^N	Geodetic velocity vector $[V_N\ V_E\ V_D]^T$
W	Temporal Window size
W^P	Vector of wavelet parameters of the HSWM
w	Inertia coefficient
w_{max}	Maximum value of inertia weight
w_{min}	Minimum value of inertia weight
w_{ie}	Earth angular velocity (7.2921×10^{-5} rad/s)
w_R, w_P, w_Y	Vehicle angular velocities in body frame (roll, pitch, and yaw)
w_N, w_E, w_D	Vehicle angular velocities in inertial frame (Latitude, Longitude, Height)
$X(n)$	Original signal

$\hat{X}(n)$	De-noised signal
x_s	Approximation part
$X(k)$	Actual output
$\vec{x}_i$	Current particle position vector
X_i^1	Inputs to the first layer
X_i^2	Input to node i in layer 2
X_{ij}^3	i^{th} input to node j in layer 3
X^e, Y^e, Z^e	Position in ECEF frame
y_j	Center of fuzzy set f_j
$\mu_{Fi}(y)$	Membership function
φ_1	Cognitive coefficients
φ_2	Society coefficients
η	Learning rate
$\Phi_{s,k}(n)$	Scale function (basis function)
$\Psi_{s,k}(n)$	Wavelet function
$\Phi(2^s n\text{-}k)$	Scaled version of $\Phi_{s,k}(n)$
$\Psi(2^s n\text{-}k)$	Shifted version of $\Psi_{s,k}(n)$
ΔL_o	Forward difference reading
Δt	Time interval (sec)
Φ, θ, Ψ	Euler angles (*rad*)
σ_x	Standard deviation for the details coefficients
σ^2	Noise power for noisy signal
Ω_{in}^b, Ω_{ib}^b	Angular velocity skew-symmetric matrix

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Land navigation systems have an astonishingly protracted history. From the time when the life first started on earth, human beings had the penchant to travel from one place to another in order to investigate and discover new lands and territories. Oldest navigation tools in history use fixed celestial bodies like the sun and stars to locate positions on earth. Furthermore, surveillance of fixed objects, such as mountains, hills, and rivers, can also be used for location purpose during navigation mission as shown in Figure 1.1. Those fixed objects navigation techniques are known as position fixed systems.

Most essential tasks of a vehicular navigation system are to incessantly preserve precise track of vehicle position. There are two types of navigation technology: dead reckoning (DR) and position fixing (e.g. GPS). Both of them are used widely for position determination. The fundamentals of DR depend on the knowledge of vehicle initial position, traveling speed and time interval until the current position (e.g. the end mission). In view of the fact that the average speed and time elapsed are measured, the speed can be resolved into the east and north directions. However, at current position, both velocity components can be utilized to calculate the distance traveled by multiplying them with the elapsed time in both directions in order to get the new location of the moving vehicle.

The popular three DR sensors used are inertial measurement unit (IMU), magnetic compass, and odometer. These sensors are dependent on operational environments; however, sensor errors result in unreliable position while velocity errors increase with time.

Figure 1.1: Position Fixed Systems are used as Aiding Positioning Tools during Navigation

At the beginning of the last century, a highly developed technique, called position fixing technology based on radio signals, can provide navigation solution with accepted precision. Global positioning system (GPS) is one of the most accepted technologies used in position fixing technology, which has been mainly used in vehicular navigation systems due to its low cost and high performance in certain environments. Besides, GPS provides an acceptable accuracy when receiving signals from at least four satellites with a good geometry. Not far behind, global navigation satellite system (GLONASS) is another navigation satellite system to provide position operated by Russian Federation. In addition, there are other new navigation satellites, such as the COMPASS navigation satellite system (CNSS) from China, and the Galileo navigation satellite system from the European Union. Notably one weakness of the global navigation satellite systems (GNSS) is requiring a direct line of sight (LOS) to at least four or more satellites simultaneously with the receivers. Furthermore, its accuracy deteriorates due to poor geometry, multipath, and signal loss especially in urban areas [1, 2].

In general, there are four main factors considered to assess the act of any navigation system [3, 4]:

a. Accuracy: The identity between the calculated and real positions at a certain time.
b. Integrity: The reliability of the navigation system to provide a complete navigation solution such as attitude, velocity and position.
c. Continuity: The ability of the navigation system to provide a continuous navigation solution without any intermission.
d. Availability: The proportion of the provided service to be available during the time by taking into consideration all the interruption sources; in other words, the service is considered available if the three previous factors are all satisfied.

Unfortunately, both DR and position fixing technologies (e.g. GPS) have failed to satisfy these requirements as a stand-alone mode. DR sensors are not reliant on external signals for their operation, and also it has the ability to provide a continuous navigation solution. Furthermore, they are highly prone to short and long-term errors that can reduce the required accuracy. On the other, although GPS has the ability to provide a continuous navigation solution, it suffers from discontinuity and availability. In addition, even though high sensitivity technologies have been used to improve the availability of GPS, it is still unreliable and experiences unbounded errors especially in signal degraded environments such as canyons, tunnels and between large buildings inside the city. Therefore, the integration between GPS and DR sensors, such as the inertial navigation system (INS), is mandatory to realize the required navigation performance factors mentioned previously. Precisely, the GPS and INS integration has become more widely used as a common tactic in land vehicle navigation since the integration can provide a complete navigation solution. Due to the complementary characteristics of both systems, the integrated system can offer a better solution than if only one of them is used.

Advances in inertial navigation technology, microelectronics and microprocessors have experienced a rapid development since the last two decades. As a result, the continual development of micro machinery technology has provided low-cost inertial sensors. Furthermore, a single point positioning (SPP) has also become one of the most suitable navigation systems in land vehicles. Integrating MEMS INS with a single-point GPS necessitate robust navigation algorithms that can handle large sensor errors existing in both systems. At present, low-cost MEMS sensors are being extensively used in numerous civil applications, for instance, auto cars crash, antenna stabilization and hard disk vibration protection [5, 6].

1.2 Problem Statement and Motivation

The majority of the current land vehicle navigation apparatus depend mostly on GPS as an essential source to provide the required navigation solution. No one contradicts the accuracy of GPS after the huge improved in satellites navigation system and enhanced techniques of data receiving and processing that give GPS the ability to supply an accurate navigation solution to infinity numbers of users anywhere on earth when receiving signals from at least four satellites. However, the downside of GPS is that, it relies on the satellite signals and the accuracy decay due to several reasons, such as weak satellite geometry, signal losses and cycle slips. Because of this drawback, GPS users are having troubles in urban areas due to signal obstruction by high buildings, canopies, and further obstacles. Following this, several researches are conducted to address the signal outages problems. On the other hand, inertial navigation system (INS) is a mechanical and independent instrument that can provide position, velocity and attitude through continuously measures three angular velocities and three linear accelerations along the body frame to provide the position, velocity, and attitude to the moving vehicle. The main limitation is that, INS can not be used as a stand-alone navigation system.

Drift and residual bias errors with random noise and vehicle vibration in both the accelerations and angular rates measurements may deteriorate the long-term navigation solution precision. Most errors in inertial systems are mainly emerged from the inertial sensors itself or from computation and integration operations inherent in the INS mechanization equations. Continuous updates are necessary to restrict the quickly increasing in position and velocity errors. For that reason, augmenting the GPS with the INS will maximize their advantages and minimize their disadvantages since GPS can be utilized as a position and velocity calibration for the inertial sensors during long-term operations while INS can be used for bridging the GPS outages during GPS signal loss.

Currently, the GPS with INS integration is realized using Kalman filter (KF) to optimally estimate the errors associated with both systems [7, 8]. Unfortunately, KF-based GPS/INS integration suffers from more than a few shortcomings as have been reported by other researchers. In fact, KF requires a well-defined model for the GPS and INS error models in order to perform appropriately [5, 9, 10].

KF estimates relay on the quality of the dynamic model, in addition to the quality of the measurements from the IMU. Hence if the Kalman filter is exposed to a new input data that does not fit its prior defined model, it will produce unreliable estimates for the model. In general, the dynamic model is based on nine error states including position, velocity, and attitude error states in all components together with sensor errors including both accelerometer bias and gyroscope drifts. In fact, inertial sensors are affected by several random errors.

For instance, several noise types contribute in typical gyroscope sensors may comprise of white noise, correlated random noise, bias instability and angle random walk [11, 12].

Therefore, setting a certain stochastic model for each inertial sensor that work proficiently in all environments and imitates the long-term behavior of sensors is not a straight forward process. Weak observability of some error states for the inertial sensor reduces the capability of KF, which may lead to unstable estimation error. Moreover, the need to re-design KF algorithm to obtain satisfactory and reliable error estimations whenever using a new platform or different IMU grades (e.g. MEMS, tactical, and navigation grade IMUs) can be very expensive and impractical for real time implementations. Therefore, a model-less approach that can map the vehicle dynamics under all conditions is thus highly required. The inadequacies of KF provoked researchers to develop unconventional methods mainly based on artificial intelligence (AI) [10, 11, 13-15]. Last decade show growing attention to use AI in integrating the GPS/INS systems as an alternative method, which considered an effective method to deal with uncertainty, imprecision, and vagueness in the input data in dynamic environments. Adaptive neuro fuzzy inference system (ANFIS) is employed in this study to be the core of the proposed alternative GPS/INS navigator to provide an enhanced navigation system for land navigation applications.

1.3 Objectives of the Study

The primary aim of the present study is to design an alternative GPS/INS navigation system which integrates the GPS with INS based on hybrid swarm wavelet-ANFIS techniques. The proposed GPS/INS navigator must estimate the INS errors, and hence, correct the raw INS output and connect the GPS outages during the GPS signal loss. To achieve this aim, the following specific objectives are to be accomplished:

1- To apply a strapdown inertial navigation system (SDINS) to mechanize the IMU output and provide full navigation solutions including position and velocity information for the moving vehicle.
2- To predict the missing GPS data. For this purpose, three techniques will be tested using the data generated from a developed package of six degrees of freedom.
3- To automate the wavelet parameters selection in order to de-noise the GPS and INS outputs and estimate the INS errors required for the integrated GPS/INS system.
4- To integrate the GPS with the INS systems in order to estimate the required INS errors and hence, correct the raw INS outputs including the position and velocity.

1.4 Contributions of the Study

This study is dedicated to develop an alternative integration algorithm between GPS and low-cost MEMS INS navigation system for land navigation applications, which works in all environments and provides a complete navigation solution, such as velocity and position. Therefore, to attain these objectives, this study has considered different techniques, such as the artificial intelligence (AI), wavelet analysis (WA) and evolutionary algorithm (EA), in order to build up a reliable GPS/INS navigation system. AI is widely used in different applications such as classification, estimations, mapping and decision making [16-19]. Thus, the AI methods can provide a robust navigation system utilizing the MEMS inertial sensors and single-point positioning GPS systems.

The main contributions of this study to the field of navigation systems can be elaborated as follows:

1- A new design for INS error estimation is proposed through fusing certain characteristics from the GPS and INS signals using wavelet multi-resolution analysis (WMRA) based particle swarm optimization (PSO) in order to optimize the best possible wavelet parameters. This design is appropriate for practical and real time implementation due to its very short optimizing time and elevated accuracy.

2- A new method is proposed for predicting the missing GPS data in order to be synchronized with INS data based on numerical and ANFIS with PSO techniques.

3- An optimal design of an integrated GPS/INS navigation system is presented. The ANFIS technique has been utilized as an alternative method to integrate the GPS and INS systems and produce the corrected navigation solution. The learning parameters of the proposed navigation system is optimized using three learning methods (BP, GA, and PSO) and an effective sliding windowing strategy has been employed to guarantee efficient learning and mimic the navigation knowledge to be used in predicting mode during the GPS signal loss.

4- A new structure for the GPS/INS integration is proposed utilizing the current and previous INS data as the inputs to the ANFIS module to increase the prediction reliability during long GPS signal loss.

5- Another new structure for integrating GPS with INS is proposed utilizing the inertial measurements as the raw inputs to the ANFIS module in order to model the sensor errors to be used during GPS signal loss to predict the INS errors in prediction mode.

1.5 Scope of the Study

The ultimate aim of this study is to present a reliable and low-cost navigation system. The proposed integration and algorithms in this study are applied to solve different inadequacies in the current navigation systems, such as predicting the missing GPS data by providing continuous navigation solutions through bridging the GPS outages during signal losses. This is achieved through proposing techniques toward improving the performance of the integration between the low-cost MEMS-based IMU and GPS to provide a navigation solution with the previously mentioned attributes. The provided navigation solution is suitable for a land vehicle only (e.g. automobile and mobile robot).

The experimental work done in this study utilizes two different data types:

1- A hypothetical 6DOF simulink package is developed specifically to generate the required data for training the ANFIS during the learning mode for the GPS prediction since large data sets are required to train the proposed GPS predictor (a total of 20 data sets are used that divided into 13 data sets for training and 7 for testing).

2- A data collected using the MotionPakII MEMS IMU sensor with a NovAtel OEM4 GPS is used in the GPS/INS integration to evaluate and compare the results with the previous works that use the same IMU grade (using 8 field data sets, 4 used for training and 4 for testing).

Navigation systems are utilized by diverse applications that are different in the required accuracy. However, for land vehicle applications a meter level accuracy is adequate (e.g. 2-5 m) is quite sufficient while for a mobile robot applications then a centimeter level accuracy is necessary (e.g. 0.1-0.9 m) and there are numerious applications required different accuracy resolution such as vehicle control, precision agricultural and unmanned ground vehicle (UGV).

The accuracy of the proposed navigation system and especially the INS with GPS integration is vastly reliant on the length of the GPS outages. In this study, a maximum of 200 second outages have been tested for all the GPS/INS structures that show an acceptable accuracy, since outages more than this period is not practical. Moreover, the training mode for the proposed integrations requires continuous data from both GPS and INS that cannot be accomplished if any of them is missing.

The work presented in this study is limited to land navigation applications. Therefore, it is not suitable for airplanes or any unmanned aerial vehicles (UAVs) since a terrestrial strapdown INS algorithm is used.

As already mentioned, the neuro fuzzy applied in this study is the adaptive neuro fuzzy inference system (ANFIS) network. Therefore, other types of neuro-fuzzy systems are not covered in this study.

As exposed in Figure 1.2, the research scope can be divided into two main blocks namely GPS prediction and INS/GPS integration.

1.6 Thesis Organization

This thesis is divided into five chapters, as follows:

Chapter One comprises a concise historical background of land navigation systems and their development followed by the problem statement, the research objectives and the thesis contributions.

Chapter Two explains in detail the literature that supports this research; this includes an overview of both GPS and INS as stand-alone systems and their associated errors. Different applications that use GPS and INS are also reported and different methods used in order to solve the synchronization between GPS and INS data are illustrated. This chapter also presents a basic concept of fuzzy inference system (FIS) with a special emphasis on ANFIS. ANFIS modeling, including its structure and parameters optimization, is also covered. In addition, a detailed survey on integration strategies used to integrate both the GPS and INS systems focusing on the most used integration algorithms, such as Kalman filter (KF), particle filter (PF) and artificial intelligence (AI) is also given in this chapter.

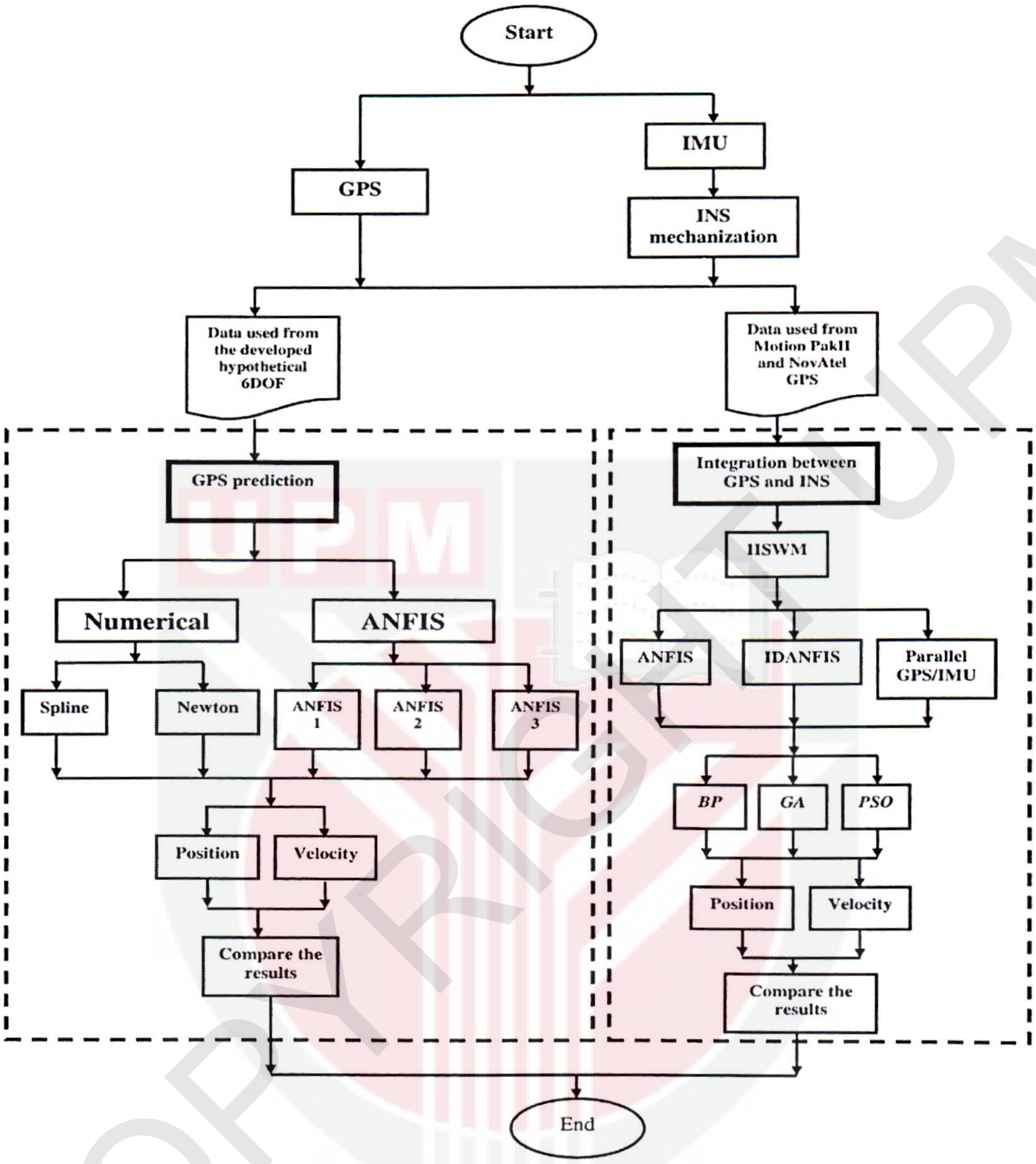

Figure 1.2: Study Scheme Shows the Proposed Work

Chapter Three presents the general and detailed methods that have been adopted to achieve the objectives of the present work. Strapdown mechanization equations algorithm computation is first presented in this chapter, then the proposed three methods for predicting the mislead GPS data are explained. This chapter also introduces a well-structured hybrid swarm wavelet method (HSWM) designed to estimate the INS errors followed by the proposed three structures to integrate the GPS with the INS navigation systems based on ANFIS. Finally, their learning modes utilize the windowing method and their ability testing to connect the GPS outages for different lengths is compared.

Chapter Four presents the results of evaluating the wavelet de-noising algorithm on the inertial measurements unit readings. In this chapter, the prediction performance of GPS data is evaluated and compared using the Newton, Spline and ANFIS methods in terms of prediction accuracy and time required for prediction. Moreover, the estimation for INS errors using the proposed HSWM is also presented. In addition, the performance of the proposed integrated system is tested during GPS blockage. Performance comparison of the three GPS/INS structures using three different learning methods, in particular, back propagation, genetic algorithm and particle swarm optimization, is presented. Lastly, a comparative study between the three GPS/INS structures in terms of maximum errors obtained during different outages length and time required for learning mode is also presented in this chapter with illustrating the improvement percentage for the proposed GPS/INS structures.

Finally, Chapter Five summarizes the objectives addressed in this thesis. The most important findings and performance analysis evaluation are presented. Suggestions and recommendations for future development are also offered in this final chapter.

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