



**AIN SHAMS UNIVERSITY**  
**FACULTY OF ENGINEERING**  
Electronics Engineering and Electrical Communications

## **Integrated Systems for Land Vehicle Navigation**

A Thesis submitted in partial fulfillment of the requirements of the degree of  
Doctor of Philosophy in Electrical Engineering  
(Electronics Engineering and Electrical Communications )

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# Statement

**This thesis is submitted as a partial fulfillment of Doctor of Philosophy in Electrical Engineering (Electronics and Communications Engineering), Faculty of Engineering, Ain Shams University.**

**The author carried out the work included in this thesis, and no part of it has been submitted for a degree or a qualification at any other scientific entity.**

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## **ABSTRACT**

Low-cost, Micro Electrical Mechanical Systems (MEMS) based inertial sensors have gained an increasing interest with the growing dependence on unmanned systems and small guided aerial vehicles. Building an Inertial Navigation Systems (INS) based on this technology is a challenging task due to the associated degraded accuracy and noisy measurements. That led a lot of researchers to work in this interesting area and to focus in the issue of enhancing the localization and navigation performance. MEMS based navigation systems are used in unmanned aerial vehicles (UAVs), guided, autonomous and land vehicles because of their low weight, low size and low power consumption compared with the previous systems which are heavy and are characterized by their high cost, high consumption of energy. The requirements of any used INS are to provide high rate and accuracy information about the position, velocity and attitude over a certain period of time. Some problems related to MEMS usage is the deviation of the accuracy of the readings over time. Global Positioning System (GPS) provides more accurate and continuous position and velocity calculations, but with a lower measurements rate. Furthermore, satellite signals are not always available in different conditions such as urban canyons, tunnels, and even indoor situations such as parking lots. GPS/INS integration based on Kalman filter (KF) has proven to be a reliable solution to overcome on the drawbacks of both of them.

The research objective presented in this thesis is to use an extremely low-cost and grade inertial sensors and one of the cheapest microcontroller and processor modules available in the market to achieve a real-time localization solution for land vehicle application. The challenges of verifying the proposed algorithm that can handle the above hardware is tackled through the following steps. Firstly; to provide an accurate estimation of navigation states, the errors from the MEMS Inertial Measuring Unit (IMU) must be appropriately treated in order to turn the observations

into useful data for object position determination. The used IMU deterministic errors such as scale factor and bias have been experimentally calculated with the aid of turntable and fixed positions tests for gyros accelerometers respectively. On other hand, the random errors such as Velocity/Angular random walk (V/ARW), bias instability, rate random walk, etc. have been estimated using Allan Variance (AV) which is the one of common methods used to estimate the stochastic errors to have a good result for the low cost sensors. These errors values can be used further in the KF for improved navigation accuracy. Secondly; the mechanization model has been implemented using the calibrated data to form the INS based on MEMS, which offers continuous navigation information (attitude, velocity and position) of the vehicle. Thirdly; due to accumulated integration errors, using a standalone INS leads to a huge navigation deviation from the real path. Therefore, the estimated pitch and roll from INS are fed to a Complementary Filter (CF), to improve the estimated solution of pitch and roll angles. Through this step, the CF algorithm has been implemented and the navigation performance is investigated. Fourthly; the heading observation angle obtained from an integrated magnetometer and the vehicle speed received from the odometer are fused to KF as extra measurements. Fifthly; a novel Multi Sensors Data Fusion (MSDF) algorithm is designed and assessed in both post processing and real time domains. The designed algorithm is based on cascaded CF and KF. A loosely coupled GPS/INS integration algorithm has been implemented to help in estimating the errors in velocity and position of INS and improve its accuracy. Both Extended Kalman Filter (EKF) and Unscented Kalman Filter (UKF) have been adopted and implemented in a cascade with CF in order to achieve the optimal state estimation and to enhance the integrated navigation system performance under different operating conditions and GPS availability. If the GPS solution is available, the position and velocity from GPS receiver are fed to the KF as an observation measurement to correct the state estimation which is fed back to the INS algorithm. In addition,

if the GPS solution is not available in case of denied environments, then the velocity received from the odometer is fed KF as an observation measurement for state estimation correction. The raw measurements have been logged for further post processing under MATLAB for system tuning and offline integration evaluation that helps in testing and upgrade of the sensor performance. Finally, the experimental results show that the implementation of the ultra-low cost real time (MSDF) based on the cascaded CF-UKF can achieve good level of accuracy and a continuous localization of a land vehicle in different environmental cases. In addition to the above experimental results it is founds that, the accuracy of UKF based algorithm solution is slightly more accurate than the EKF based solution due to the low-dynamics of the land vehicle.

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