ISSN 2348 – 7968

Combined Information Processing of GPS and IMU Sensor using Kalman Filtering

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Abstract

Navigation system technology is a subject of great interest today. Computation of an accurate position data is the key task in a navigation system. Commercial navigation systems currently in use have reduced position error, but are quite expensive. GPS (Global Positioning System) alone is incapable of providing continuous and reliable positioning, because of its inherent dependency on external electromagnetic signals. Inertial sensors are used to obtain the position information, but these sensors are prone to accuracy degradation over the time period. The main framework of this project is to fuse low cost GPS with an inertial sensors using kalman filtering in order to improve the accuracy of navigation information. GPS and inertial sensors individually exhibit large errors but they do complement each other by maximizing the advantages of both. It is illustrated by all the tests that GPS plays a dominant role in determining the absolute positioning of the system when GPS is fully available. The fusion of inertial sensors can improve the positioning accuracy during GPS outages.

Keywords: IMU, Microcontroller, GPS receiver, Kalman Filtering.

1. Introduction

The accurate measurement of orientation plays a very important role in many applications. With the advanced research and development, it is becoming a necessity factor to utilize smaller and less expensive components. This has lead to the use of cheap measurement unit called Inertial Measurement Unit (IMU) which includes accelerometer, gyroscope and magnetometer which measures orientation based on number of sensor inputs, known as Degrees of Freedom (DOF). Micro-Electrical-Mechanical Systems (MEMS) based IMU's are preferred due to its small size and less cost, thus providing less accurate readings. These MEMS sensors can be affected by many factors such as stability, drifts etc. Each sensor includes both advantages and disadvantages. In this paper sensor fusion has been employed in order to combine the advantages of each sensor and compensate for the individual errors. Accelerometers are sensitive to vibrations and external forces including gravity, where as gyroscopes are prone to drifts from integration over time and finally the magnetometers are prone to corruption from ferrous materials in the environment. Inertial measurement unit senses accelerations, angular rates and heading references along three axes. With respect to the adequate computations, the IMU creates inertial navigation system (INS), which results in biased and noisy position data, assuring relatively high short term accuracy. On the other hand, GPS receiver provides relatively less accurate position data with long term accuracy and it is not affected by the time drifts. Hence, both the devices are complement to each other. It is possible to fuse both sources of data's in order to gain the advantages and reduce or even eliminate disadvantages by means of kalman filtering. Apart from the position, orientation and heading reference is also obtained by the use of three different sensors namely accelerometer, gyroscope and magnetometer. An IMU carries a key navigation data during the loss of GPS signals and then enables fast re-acquisition of the signals when they are once again available.

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2. Existing Methodologies

[a] In the past olden days Dead reckoning was one of the technology employed with navigation to calculate one's current position by using a previously determined position, and advancing that particular position based upon known or estimated speeds over elapsed time and course. The basic formula for working out dead reckoning is shown below:

DR = distance * time

At the first glance Dead reckoning seems to be more robust method for navigation. This method was subjected to significant errors due to many factors, such that speed and direction must be accurately known at all instants of time to determine position accurately.

[b] For indoor and outdoor localization there exist many solutions, one among the solution for the outdoor localization is the use of GPS. The major challenge is that, GPS signals can be blocked or reflected by buildings, terrain and other structures or even intentionally jammed or spoofed with readily available and affordable jamming technology.

[c] Some systems used IMU's, which take the measurement values provided by the sensors accelerometers, gyroscopes and magnetometers to track the position and orientation of an object relative to known starting point, orientation and velocity. The major challenge is that, the IMU data's were prone to accuracy degradation over time period.

[d] There are some other systems which fuse GPS and IMU data's in order to find an accurate positioning data using complementary filters. In this approach there exists orientation, position and attitude estimation problem with respect to sensor. The computational complexity is more with this algorithm.

3. Proposed Methodology

The proposed methodology uses kalman filtering to fuse GPS and IMU sensor data's in order to find an accurate positioning. The IMU which is used here is MPU-9150 breakout board, which includes accelerometer, gyroscope and magnetometer. As a GPS module L76 is used. In this framework, only the accelerometer sensor data is considered. In order to read the sensor data's, Arduino Due microcontroller and the IMU (accelerometer sensor) is interfaced. Inter integrated circuits has been used for the communication between Arduino Due and IMU. The accelerometer raw data's which are obtained are more prone to errors. These errors are reduced by removing their offsets. For the real time computations, the IMU (accelerometer sensor) data's are calibrated and scaled in order to convert in to meter per second squared. The velocity, distance values are calculated for further computations. The latitude and longitude values are obtained with respect to the starting reference latitude and longitude values and the distance values. The Fig.1 shows the interfacing of IMU and Arduino Due to obtain the raw data's from accelerometer sensor.

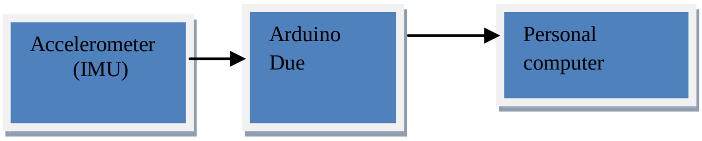

Fig. 1.Block diagram of Interfacing IMU and Arduino Due

Once the Latitude and Longitude values obtained from the GPS receiver, the GPS and IMU (accelerometer sensor) data's are fused using kalman filtering. The Fig.2 shows the block diagram of GPS and IMU (accelerometer sensor) data fusion using kalman filter.

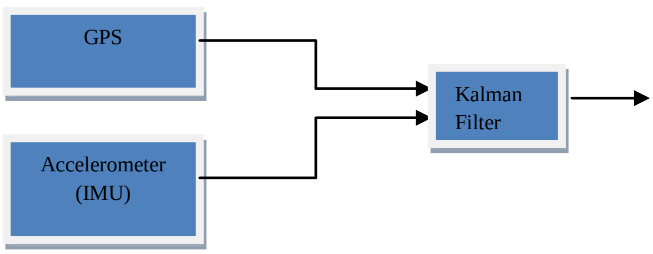

Fig. 2 Block diagram of GPS and IMU Data Fusion

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4. Kalman Filter

Kalman filter is over 50 years old and it is one of the most important and common data fusion algorithm which is used in today's information processing in the presence of uncertainty. The filter was named after Rudolf E. Kalman, the great success of this filter is due to its small computational requirement and elegant recursive properties. Kalman filter is commonly used in smoothing noisy data and providing estimates of parameters of interest. The most famous early use of Kalman filter was in the Apollo navigation computer that took Neil Armstrong to the moon and brought him back. Today, Kalman filters are used in every satellite navigation devices, every smart phone's and many computer games.

The kalman filter works in a two-step process:

- Prediction
- Update

In prediction step, the Kalman filter produces the estimates of current state variables, along with their uncertainties. Once the outcome of the next measurement is observed, these estimates are updated using a weighted average, with more weight being given to estimates with higher certainty. The kalman filter is recursive in nature. It can run in real time using only the present input measurements and the previously calculated state and its uncertainty matrix, with no additional past information.

Kalman filter is used where there is an uncertain information about some system. This filter is ideal for systems which are changing continuously.

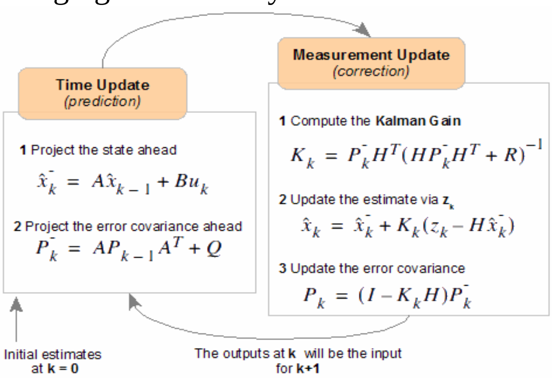

Fig. 3 Kalman Filter

5. Results

Once the raw data's from accelerometer sensor are signal conditioned, scaled and converted in to its particular units. The data's are then ready for the further computation. The below screenshots shows latitude and longitude values plotted along x, y axis, which are obtained by python application program for the calibrated accelerometer's input data's.

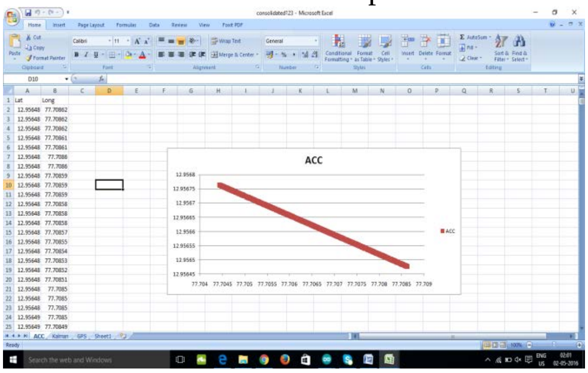

Fig. 4 Screenshot of Latitude and Longitude values from Accelerometer Calibrated Data's

The GPS data's i.e. latitude and longitude values are collected simultaneously with respect to the accelerometer sensor data's. The below figure shows the screenshot of plotting GPS data's along x and y axis.

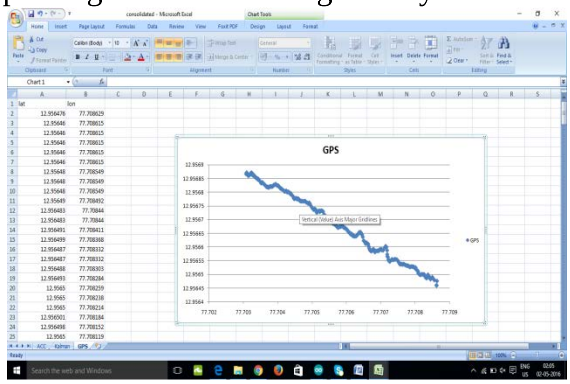

Fig. 5 Screenshot of Latitude and Longitude Values obtained from GPS

The below screenshot shows the kalman filter output graph which fuses data's of GPS (blue) and accelerometer (red) and produces the best position data estimate (green).

ISSN 2348 – 7968

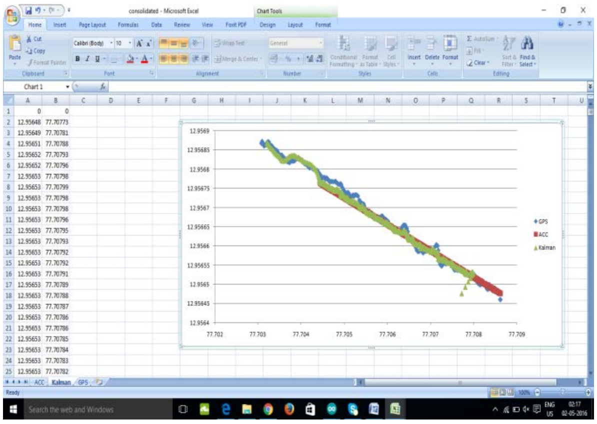

Fig. 6 Screenshot of Kalman Filter Output

6. Conclusion & Future Enhancements

It can be concluded that GPS and accelerometer data's (IMU) are fused for providing an accurate position has been demonstrated successfully. An experimental result from the fusing of GPS and accelerometer was done through kalman filter estimation technique which is an optimal way for improving sensory data's. Future enhancement of the work includes addition of other sensors like magnetometer, gyroscope, barometer, temperature and odometer for obtaining the best accurate position of any object. Secondly, not only GPS data's can be taken, GLONASS data's can also be taken together to find the exact position of any objects. Thirdly, modelling of nonlinear systems using better estimation techniques like: Extended Kalman filter, Particle filter etc. to further reduce estimation error and enhance predictability of nonlinear systems as well.

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