

## A Framework for Sensor Fusing Using Fuzzy Logic for Navigation Systems

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**Abstract** - Navigational sensors are evolving both on a commercial and research level. However, the limitation still lies in the accuracy of the respective sensors. For a navigation system to reach a certain accuracy, multi sensors or fusion sensors are used. In this paper, a framework of fuzzy sensor data fusing is proposed to obtain an optimised navigational system. Different types of sensors without a known state of inaccuracy can be fused using the same method proposed. This is demonstrated by fusing compass/accelerometer and GPS signal. GPS has evolved as a choice of navigation method for outdoor autonomous system. Despite it emerging trend and application, one problem remains is that it is still prone to inaccuracies due to environmental factors. These factors are available and evaluated in the GPS receiver architecture. These inaccuracies are available in the extracted NMEA(National Maritime Electronics Association) protocols as SNR (Signal to noise ratio) and HDOP (Horizontal Dillusion of Precision). Dead reckoning sensors on the other hand does not depend on external radio signal coverage and can be used in areas with low coverage. Unfortunately, the errors are unbounded and has an accumulative effect over time.

### I. Related works

The emergence of maritime, aeronautical technologies and autonomous system has led to a more demanding and accurate navigational system. Standalone navigational systems such as GPS (global positioning systems) and INS (Inertial measurement systems) has its respective limitations in application. Global positioning system works on constant updates from the GPS satellites. The faint

signals that are received by the receivers are often reflected by buildings causing a multi-path effect. Moreover, in an urban environment, the LOS (Line of sight) of receivers and satellites are often blocked by skyscrapers and other concrete obstacles. This causes varying level of accuracies over time.

Inertial measurements units (IMU) are an alternative to the GPS system which works on acquiring the dynamics and acceleration of the platform to calculate the displacement of the platform. Unlike the GPS system, it doesn't receive any signals from external source and are prone to hardware errors that build up over a period of usage. Moreover, the displacement calculated might not be as accurate in low velocities.

Due to the limitations of both systems, many researchers were focused on fusing the several types of sensors. Many researcher are working on sensor fusion methods.

One classical approach is by using Kalman filter. One example is cited in [1] which uses the classical kalman filter for GPS/INS data fusing. In [2] and [3], several other data fusing methods were cited, among others using artificial intelligence algorithm such as fuzzy logic and neural network. On the application level, many UAV projects employs fusion techniques for a more accurate UAV system and can be found both in [8] and [4]. In these research works, the frame fixed coordinate is converted into earth fixed coordinate using DCM (Direction Cosine Matrix). For navigation that involves a wheeled platform, the odometry system were also included in the navigation

system and fused together with the GPS/INS system. This method is applied in [9] using kalman filters. Several other navigation methods that involves image flow to estimate the velocity, and gyroscopic telemetry data are currently being developed for UAV and other autonomous systems.

## II. Quick view on GPS and INS system

Navigation can be defined as the method of locating and tracking a certain coordinate. In order for a system to perform navigation, it has to be able to accurately determine its own position. Currently, two systems were widely used for navigation. Both system have have their own limitations and advantages in terms of applications. GPS (Global Positioning System) receives constant radio signals from orbiting satellites. From these signals, the GPS receiver figures out its position by comparing its distance from the satellites. This provides constant updates from the GPS satellites. However the GPS system has fluctuating quality of receiving data which is referred to as GPS 'outages.' The faint radio signals needs a line of sight from the satellites for an acceptable signal. Similar to radio signals, the atmospheric condition can greatly impact the signal quality. This degradation of signal quality due to atmospheric conditions is known as the the Signal to noise ratio(SNR). Apart from the SNR, the quality of the the GPS data can also be effected by the geometry of the position of satellites. The satellites forms a tetrahedron shape that enables the receiver to have a three dimensional position tracking (latitude, longitude and attitude). Angle and geometry of this tetraheron also effects the accuracy. This element is known as Dilution of Precision (DOP). Lastly, the number of detectable Sattelites can also effect the GPS reading. The more detectable Satellites within line of sight range, the more accurate the GPS reading. GPS Coordinates given are Earth fix coordinate system which means that the coordinates given follow the axes that rotate with the earth rotation. Information on GPS data validity and the respective outages are explained in detailed in [6] and [7].INS navigation system (INS) are also known as dead reckoning navigations. This navigation system doesn't receive any updates from external sources. INS

navigation system measures the acceleration of the frame fixed axis and calculates the displacement by intergating the acceleration values. Unlike the GPS navigation system, the INS navigation system have unbounded errors which means that the error in position is accumulated over time. Moreover the errors are also intergrated hence creating a amplified errors in navigation. The advantage of the INS navigation system is that it can be operated in covered area where there is no line of sight range to the satellites.

Hence,the fusion of these two navigation systems complement the respective weaknesses. In area where there is low GPS signal, the INS can serve as the prime navigation system whereas in areas with acceptable GPS signal, the GPS can serve as the primary navigation update and also recalibrate the accelerometer systems.

Fuzzy Logic was developed by Lofti A. Zadeh in [5]. The concept of fuzzy logic uses vague verbal expressions for processing. The crisp value are converted to a heuristic value . In contrast to the conventional model based systems, the heuristic values are processed using a set of If –Then Logics.

## III. Hardware development

The application of fuzzy logic in fusing sensors is demonstrated by fusing the accelerometers and GPS. This is a classical approach that has been in many comercial smartphones using kalman filter.The hardware for this hybrid navigation system consist of a GPS receiver ,three axis accelerometers and a digital compass. The. Figure 1 shows the block diagram of the hardware system. All the sensors are intergrated to a single microcontroller via ADC interface and transmitted to the processor via serial interface and evaluated using matlab fuzzy logic toolbox. Figure 1 shows the block diagram of the hardware setup and figure 2 shows the prototype of the hardware.

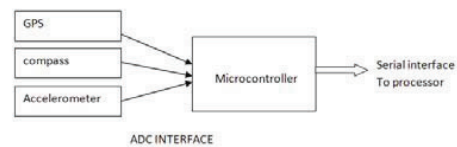


Figure 1: Hardware development for the hybrid system



Figure 2 :GPS receiver intergrated to a microcontroller based circuit.

**IV. Sensor fusing with GPS/Accelerometers**  
The overall system of the hybrid GPS/INS can be seen from figure 2. The section highlighted in the 'blue' boundary- GPS receivers provide the GPS latitude and longitude which are the earth axis fixed coordinate (not to be confused with Earth cartesian coordinate system). The Compass provide the angle of the velocity and the accelerometers provides the forward velocity  $Vf$  from equation (1)

$$Vf = \sqrt{v_x^2 + v_y^2 + v_z^2} \tag{1}$$

where  $v_x, v_y, v_z$  are the component velocity along the x,y and z axis on the frame fixed axis.

The  $Vf$  is an approximation of the actual forward velocity by neglecting the tilt angle. The accelerometer navigation block converts the accelerometer to travelled distances via a double intergration of the measured acceleration as shown in the equation in (2)

$$D = \iint_{t=0}^{t=k} a \, da \, dv \tag{2}$$

where D is the distance traveled and a is acceleration values.

In many circumstances, the accelerometer requires recalibration when it is at static mode. Examples of these was mentioned in [7] and [8]. The speed of the accelerometers are constantly updated using the acceleration from the GPS while the bearing is constantly updated from the Compass. The distance travelled is given by the angle of heading multiplied

by the distance travelled over the bounded period as shown in (3) and (4).

$$\text{Latitudinal distances } (D_{lat}) = \sin \phi \times \int_{t=k-1}^{t=k} Vf + c \, dD \tag{3}$$

$$\text{Longitudinal distances } (D_{lon}) = \cos \phi \times \int_{t=k-1}^{t=k} Vf + c \, dD \tag{4}$$

where D is the distance traveled,  $\phi$  is the angle bearing and  $Vf$  is the forward velocity, c is the previous calculated velocity.

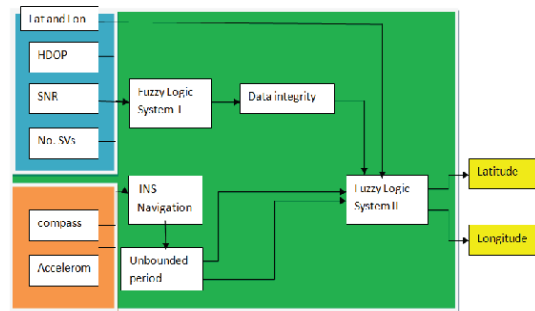


Figure 3: Block diagram of navigation architecture

The fuzzy logic system I (refer to Figure 1) to evaluate the GPS coordinates returns a value of data integrity for evaluation. As can be seen from figure 3, The respective value that shows the outages of the GPS are the HDOP (Horizontal dilution of precision), SNR (Signal to noise ratio) and no. of SVs (no. Detectable satellites in range). These values are 'fuzzified' into verbal values are shown in the membership function shown in figure 4,5, and 6.

Generally if the input function shows a high level of GPS outages at any of the input membership function, an overall 'low quality' will be output at the output membership function. If all the input membership displays an average level of GPS outages, the output membership function will consequently give an average quality of the GPS data.

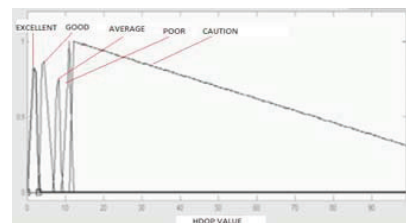


Figure 4 : Membership function for the HDOP Values

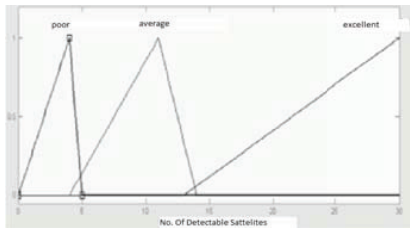


Figure 5: Membership function for the no. of SVs Values

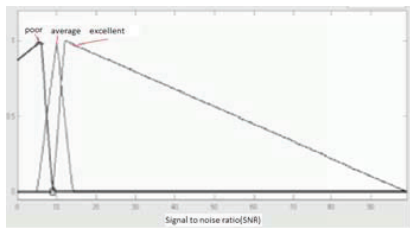


Figure 6 : Membership function for the SNR Values

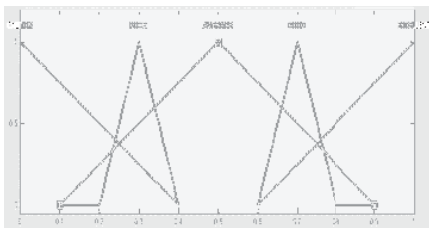


Figure 7 : Output Membership function for the SNR Values

The fuzzy logic II module (refer to figure 3) evaluates and decides the sensor that will give the input to predict the Position. The input membership functions are the Evaluated GPS data quality and period of dead reckoning without update from validated GPS data. The output membership function is the decision to use the data from GPS or accelerometer/compass. The block diagram for the fuzzy system is shown in figure 8.

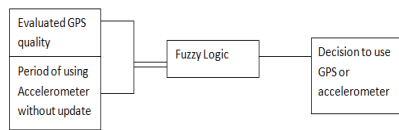


Figure 8: Block diagram of the fuzzy system

The rule base of the fuzzy system is as below:

**If** GPS data is not valid, **then** Accelerometers data are used

**If** GPS data is valid, **then** GPS data are used

**If** period of using accelerometer is long without update from GPS and GPS Data is invalid, **then** accelerometer reading is used

As can be seen from the rule base, the accelerometer data is still preferable despite long period without update in the presence of low data validity of GPS data. The output membership is a sliding value from 0 to 1. A value nearer to 0 meaning the accelerometer is more preferable and value nearer to 1 meaning the GPS is more preferable. A scenario of a certain navigation and localization process can be seen from figure 9, showing the time frame of operation in seconds.

At  $t=0$ , The GPS gives a valid data input. The first fuzzy logic would output a low GPS validity hence validating the information given. Based on this, the second fuzzy logic outputs a 1 – Meaning that the GPS data should be used. At  $t=1$  to  $t=5$ , the platform passes through an area with dense concrete coverage hence causing the GPS receiver to have high level of GPS outages/low level of validity. From this, the second fuzzy logic will give an output of less than 0.5 meaning the accelerometers are the preferable navigation sensor over GPS receiver. The period of absence without valid GPS update is 5 seconds.

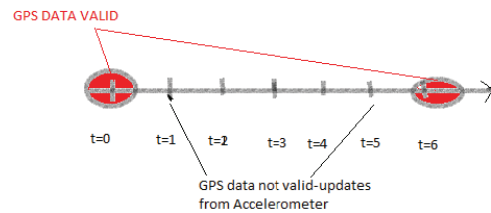


Figure 9:Time line of navigation

## V. Preliminary results.

The GPS/INS system is tested on a tunnel as shown in figure 10. The concrete covering blocks any LOS to the GPS satellite causing absence of GPS signal in position 2 and position 3. (Refer to figure 11) Result show that the GPS/INS fusion system shows the updating of navigation coordinates using accelerometer despite the absence of GPS signal. The LLS (Lat Lon Altitude) coordinates are converted to earth measurements in order to synchronize both accelerometer and GPS data. The methods are explained in [11]. In future phases of the research, more readings will be carried in venues with varying degrees of GPS data validity.



Figure 10: Tunnel used for preliminary testing

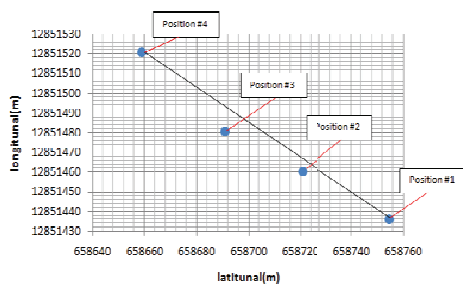


Figure 11 :Path of tracked points

The fuzzy logic Accelerometer/compass hybrid have demonstrated the the application of fusing sensors with known states of inaccuracy. These hybrids systems can be applied in autonomous systems that require navigations in places with low GPS satellite coverage. Thus far, the hybrid system can only be used in areas with level plane. In the future, the system will be intergrated with a tiltmeter. Hence, the accelerometers can be compensated with the tilt angle.

$$\text{Actual velocity} = Vf \cos \phi \quad (15)$$

where  $\phi$  is the tilt angle and  $Vf$  is the forward velocity.

## VI. Conclusion and future works.

With the fuzzy logic system, countless navigational devices can be fuzed together for a more comprehensive navigation. For example vision flow system which has been developed in [10] way back in 1996 which enables the estimate of velocity in a certain platform. This can be fused together with the GPS/INS system for a more accurate navigation system.

In conclusion, we are constantly having new types of navigation sensors with known varying degree of accuracy. With the method proposed, these data can be fused for a more accurate navigation. The application of fuzzy logic controls

presents an 'knowledge based alternative' to fuse these sensors with varying degree of inaccuracies as shown in the block diagram in figure 12.

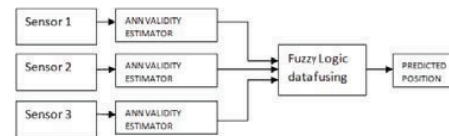


Figure 12: Block diagram of data fusing

For the GPS/INS system, the data is validated from the GPS data itself and the fuzzy logic. However, a neural network can be trained to predict the level of validity of respective sensors by considering the states that effect the accuracy of the sensors. The fuzzy logic system decides the sensor that has the highest level of validity for coordinate prediction. In the future phases of this research, sensors with high level of validity fluctuations can be intergrated together as long as the states that effect the inaccuracy of the sensors are known.

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