MEDWIN PUBLISHERS
Committed to Create Value for Researchers

Advances in Robotic Technology

Hybrid 5G Positioning Systems with Applications to Mobile Robot Technology

Chen HY*

Center for Digital Technology Innovation and Entrepreneurship, Zhejiang University, China

***Corresponding author:** Hsin-Yuan Chen, Center for Digital Technology Innovation and Entrepreneurship, Zhejiang University, China, Email: hychen0925@gmail.com

Short Communication
Volume 1 Issue 1
Received Date: October 25, 2023
Published Date: November 09, 2023
DOI: 10.23880/art-16000106

Abstract

A new concept of 5G/INS integration of artificial intelligence-based systems is proposed, namely the Recurrent Neural Network-based Fuzzy Inference System (RNNFIS). The 5G system with fuzzy logic was used as a reference during its availability. Data from the 5G system and the inertial navigation system (INS) are used to build a structured knowledge base consisting of the behavior of the INS system in some special scenarios of robotic technology. Using the same data, the proposed fuzzy system is trained to obtain corrected navigation data. In the absence of 5G system information, the system will only utilize data from the INS system and blur correction algorithms to perform its tasks.

Keywords: RNNFIS; Fuzzy Correction; 5G/INS system

Introduction

Vulnerabilities in 5G are related to intentional interruption of service, loss of subsurface accuracy, poor Geometric Dilution of Precision (GDOP) factors, and multipath reflections. The presence of noise in 5G signals forces the use of narrow bandwidth filters [1,2], which also limits vehicle dynamics [3]. Since wireless navigation systems are not autonomous, it is suitable to integrate this type of navigation system with different systems, which should gain greater autonomy. From this perspective, an inertial navigation system (INS) is ideal. As opposed to receiving signals from base stations, in the case of 5G the autonomy of the INS is provided through its functional principle, which is based on the measurement of vehicle inertia, linear acceleration and angular velocity.

The main interest is the position determination, which is possible after a double integration of the acceleration to obtain the linear displacement and a single integration of the angular velocity to obtain the rotation angle. Using this integration process means that small uncertainties in measurement deviations turn into position errors that grow over time [4]. The integration between 5G and INS systems is based on the use of KF, exploiting the synergy of various methods, aiming to mitigate short-term errors for 5G and long-term errors for INS [5].

The resulting device is an integrated navigation system that performs better than a 5G positioning system or INS (which is considered a stand-alone navigation system). The properties of KF are well understood and analytically proven, and the purpose of this article is not to restate how KF works. However, we must emphasize that in order to calculate estimates of INS system errors; KF continuously requires information from both sources: INS and 5G systems. Based on the autonomy of the INS system, we assume that it will always be able to provide data to the KF. To prevent or at least reduce the impact of accuracy degradation when 5G systems are unavailable, we use RNNFIS) [6], built and trained using data from independent INS systems on the one hand, and from the most accurate available navigation systems on the other refer to. The problem is to demonstrate that, by choosing appropriate parameters, RNNFIS can be built and trained while a reference system is available. We will show in the next few pages that passing INS system data through RNNFIS results in better accuracy when the reference source is lost. Analyze system error and resilience.

5G Positioning System

There are many methods to determine the user's location, such as the time it takes for the signal to travel from the user to the base station, signal strength, etc. In this article, we're taking the time-killing approach. Time difference of arrival (TDOA) systems determines the location of a mobile phone based on the hyperbolic characteristics shown in Figure 1. This system uses time difference measurements rather than absolute time measurements like TOA. TDOA measurements determine that the MS must lie on a hyperbola with a constant distance difference between two base stations.

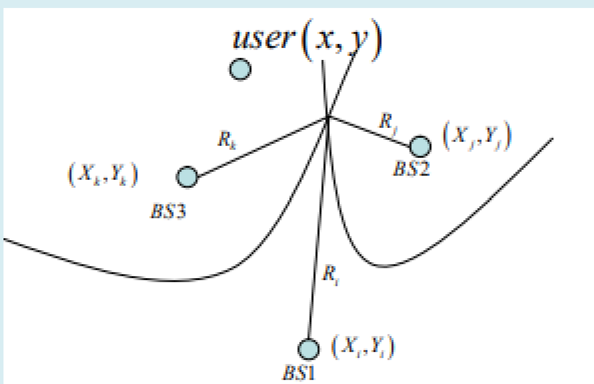

Figure 1: Method of TDOA location.

We assume two base stations are i and j respectively and the difference time with receive signal from i and j is $\tau_{i,j}$. Hence, the difference distance can be represented as follow:

$$R_{i,j} = c\tau_{i,j} = c\left(\tau_i - \tau_j\right) = R_i - R_j \quad (1)$$

Where c is velocity of light. According to principle of hyperbolic, we replace to following equation that shown in.

$$R_{i,j} = \sqrt{\left(X_i - x\right)^2 + \left(Y_i - y\right)^2} - \sqrt{\left(X_j - x\right)^2 + \left(Y_j - y\right)^2}$$

(2)

Where $\left(X_i, Y_i\right)$ $\left(X_j, Y_j\right)$ are position of i and j base stations. If there are three base stations, we can obtain two TDOA equations as follow:

$$\begin{cases} R_{i,j} = \sqrt{\left(X_i - x\right)^2 + \left(Y_i - y\right)^2} - \sqrt{\left(X_j - x\right)^2 + \left(Y_j - y\right)^2} \\ R_{i,k} = \sqrt{\left(X_i - x\right)^2 + \left(Y_i - y\right)^2} - \sqrt{\left(X_k - x\right)^2 + \left(Y_k - y\right)^2} \end{cases}$$

(3)

For this reason, the estimate position with TDOA method has two steps. First, we use time delay estimation technique to measure signal difference between two base stations, and transform time delay into distance. Second, we can solve the user position(x, y) by equation (3).

In this paper, we use two-step Least Squared Method to estimate user position. This method provides high accuracy with low complicated Calculation.

When there are more base stations, this algorithm has better accuracy. In this, we assume the base station position is X_i, Y_i where i = ⋯ 1, 2, 3..., and (x, y) is the user position. Hence, the distance between user and base station 1 is

$$R_{i,1} = cd_{i,1} = R_i - R_1 = \sqrt{\left(X_i - x\right)^2 + \left(Y_i - y\right)^2} - \sqrt{\left(X_1 - x\right)^2 + \left(Y_1 - y\right)^2}$$

(4)

Where c is velocity of light. From equation (4), we get Ri as follow:

$$R_i^2 = \left(X_i - x\right)^2 + \left(Y_i - y\right)^2 = K_i - 2X_i x - 2Y_i y + x^2 + y^2, i = 1, 2, \ldots$$

(5)

Where $K_i = X_i^2 + Y_i^2$ From, $R_i^2 = \left(R_{i,1} + R_1\right)^2$ so that (5) can be rewritten as follow:

$$R_{i,1}^2 + 2R_{i,1}R_1 + R_1^2 = K_i - 2X_i x - 2Y_i y + x^2 + y^2 \quad (6)$$

To subtract (5) at i = 1from (6,), we can get

$$R_{i,1}^2 + 2R_{i,1}R_1 = -2X_{i,1}x - 2Y_{i,1}y + K_i - K_1 \quad (7)$$

The equation (7) can be rewritten as follow:

$$X_{i,1}x + Y_{i,1}y + R_{i,1}R_1 = \frac{K_i - K_1 - R_{i,1}^2}{2} \quad (8)$$

Where $R_{i,1}, X_{i,1}$ and $Y_{i,1}$ represent $R_i - R_1, X_i - X_1$ and $Y_i - Y_1$ respectively and $i = 1, 2 \ldots M$.

Hence, the matrix can be obtained from equation (8) as follow:

$$\begin{bmatrix} X_2 - X_1 & Y_2 - Y_1 & R_{2,1} \\ X_3 - X_1 & Y_3 - Y_1 & R_{3,1} \\ M & M & M \\ X_M - X_1 & Y_M - Y_1 & R_{M,1} \end{bmatrix} \begin{bmatrix} x \\ y \\ R_1 \end{bmatrix} = \begin{bmatrix} \frac{\left(K_2 - K_1 - R_{2,1}^2\right)}{2} \\ \frac{\left(K_3 - K_1 - R_{3,1}^2\right)}{2} \\ M \\ \frac{\left(K_M - K_1 - R_{M,1}^2\right)}{2} \end{bmatrix}$$

(9)

A so-called Two-Step LS method can be used here to estimate the MS location. In the first step, we use x and y in terms of R1 that shown as follow:

$$R_1^2 = \left(X_i - x\right)^2 + \left(Y_i - y\right)^2 \quad (10)$$

In the second step, equation (10) inserted back to (8). Therefore, we can solve these unknown variable x, y and R1 by equation (9).

Fuzzy Processing on 5G Data

This article proposes a new application of fuzzy logic theory in improving the accuracy of 5G positioning systems. We employ obfuscation to improve the accuracy of 5G systems. The units input to Fuzzy processing include the number of base stations, GDOP and SNR. The fuzzy system output is defined as the reliability factor. Based on the reliability factor value, a more accurate location is selected. We can choose a more accurate location based on the value of Reliable Factors. Figure 2 shows the process of how to improve positioning accuracy. First, we select raw data through a fuzzy processing unit with reliable factors. Secondly, the user position is calculated using the TDOA method.

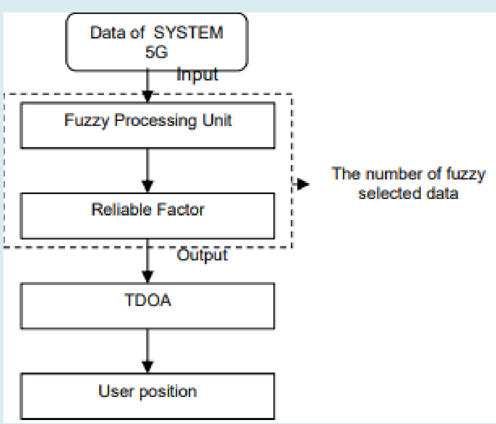

Figure 2: Block diagram of the structure with fuzzy logic theory.

Unit of Fuzzy Processing

The signals we received were from the main base station and six neighboring base stations. However, the number of base stations we need to locate is at least three. To improve accuracy, we use four base stations to calculate user location. Therefore, when the number of base stations is less than four, we define it as insufficient; when the number of base stations exceeds four, we define it as sufficient. The membership function is shown in Figure 3. The geometry of the base station is an important factor in the positioning accuracy of 5G system.

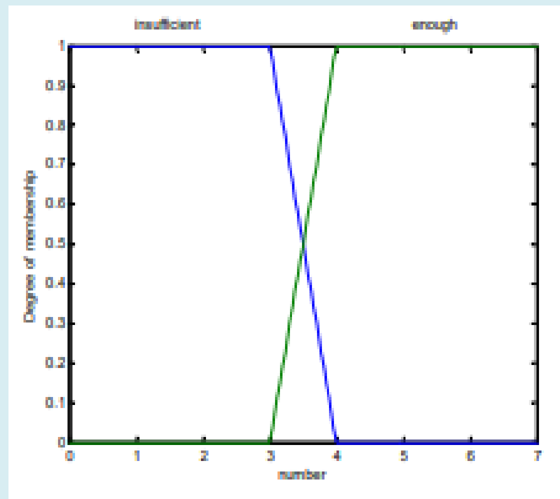

Figure 3: Membership function of the number of base stations.

We calculate GDOP to determine the user's relative position to neighboring cells. Poor GDOP results in larger position errors. On the contrary, good GDOP results in small position errors. Therefore, we want GDPOP to be as small as possible. GDOP changes over time and across different users and locations. In these systems, position accuracy depends on the geometry of the four base stations. GDOP is defined by a matrix as follows:

$$GDOP = \sqrt{tr\left(HH^T\right)^{-1}} \quad Where\ H = \begin{bmatrix} e_{1x} & e_{1y} & 1 \\ e_{2x} & e_{2y} & 1 \\ e_{3x} & e_{3y} & 1 \\ e_{4x} & e_{4y} & 1 \end{bmatrix} \quad (11)$$

Here $e_{ix}\, e_{jy}\, \left(i, j = 1, \ldots, 4\right)$ denote the direction cosines from the user to the base stations. Among these we can find the main base station and six neighboring ones. Through the relative position relationship between the user and any base station, these base stations can be selected in various combinations. However, users try to select the four best base stations with the smallest GDOP to reduce errors. Because the smaller the GDOP, the more accurate the location. The fuzzy sets we defined are divided into good, medium and poor, and the membership functions are shown in Figure 4.

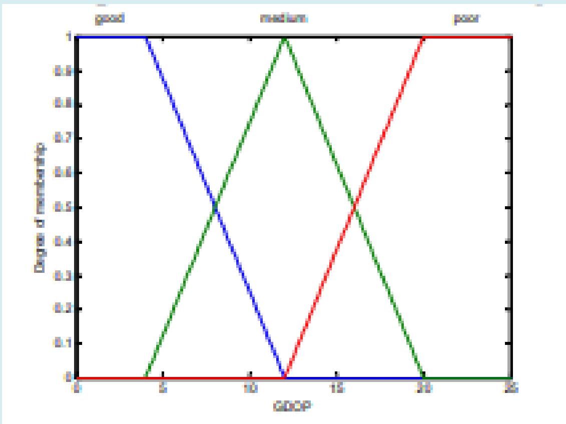

Figure 4: Membership function of GDOP.

The SNR is defined by the ratio of signal and noise as follows:

$$SNR = \frac{signal}{noise}$$

When the user is in different places, the signal strength value from the user to the base station will be different. We can get different SNR values under different environments. Therefore, we want the SNR to be as large as possible, because the larger the SNR, the greater the signal strength, and the smaller the SNR, the greater the error. The fuzzy sets we define include small, medium and large, and the membership functions are shown in Figure 5.

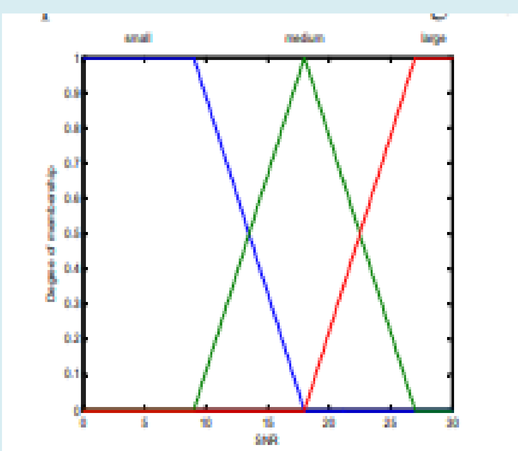

Figure 5: Membership function of SNR.

The output unit of the fuzzy processing is defined as the reliability factor. We use reliability factors to determine signal level. The greater the reliability coefficient, the more accurate the signal. The fuzzy sets we define include zero, small, medium and large, and the membership functions are shown in Figure 6.

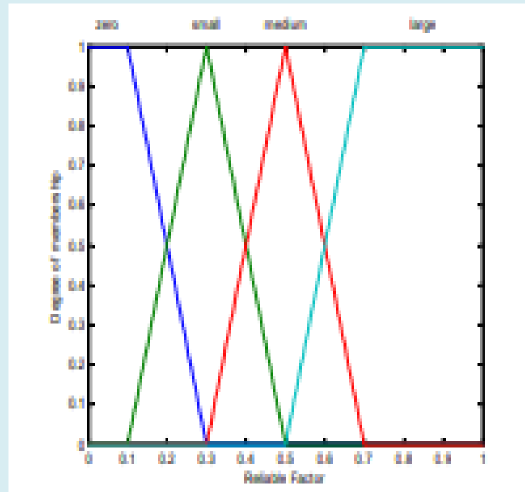

Figure 6: Membership function of Reliable Factor.

Based on the above discussion, we designed 4 rules to simulate this hybrid system. It can be seen from Figure 7 that there is no signal deletion, the reliability coefficient is zero, and the position error is 374m. As the reliability factor increases, the number of ambiguously chosen positions decreases. The better the selected signal, the smaller the position error. Therefore, as the reliability coefficient increases by 0.5, the position error decreases to 131m. Figure 7 shows the performance comparison between different reliability factors. Obviously, we have better performance with a reliability coefficient of 0.5.

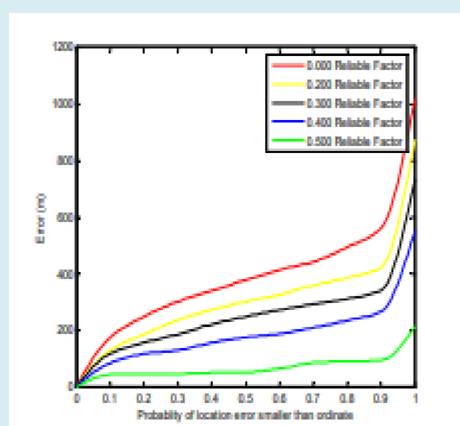

Figure 7: Performance comparisons for different Reliable Factor.

Fuzzy Integrated Navigation System

Accelerometers and gyroscopes produce two main types of errors. The first type is a high-frequency stochastic process that follows a Gaussian distribution with zero mean and variation. The second type is slowly changing (low frequency) deviations. However, data from the sensors are integrated into the inertial navigation algorithm and can significantly reduce high-frequency noise (Type 1 errors). The second error integrates over time and is the main reason for the increase in INS position error. If this deviation is small and changes slowly, artificial intelligence techniques can be used to compensate. In this section, the approach using RNNFIS [6] as an inertial navigation training technique is described. Current data fusion methods include: extended Kalman filter, model-based method, wavelet decomposition, artificial neural network and fuzzy logic. Methods developed in the field of artificial intelligence include: common sense reasoning, no monotonic logic, caution, algorithms used in neural networks, and extensions of Bayesian calculus. Further research and development are needed to develop reasoning skills in the face of uncertainty and the ability to integrate information from different sources. When the 5G system is available and has good GDOP coefficients, the 5G location information is used to form the output vector of the fuzzy subsystem. The two inputs will be formed from INS position data and delayed variants of these data respectively.

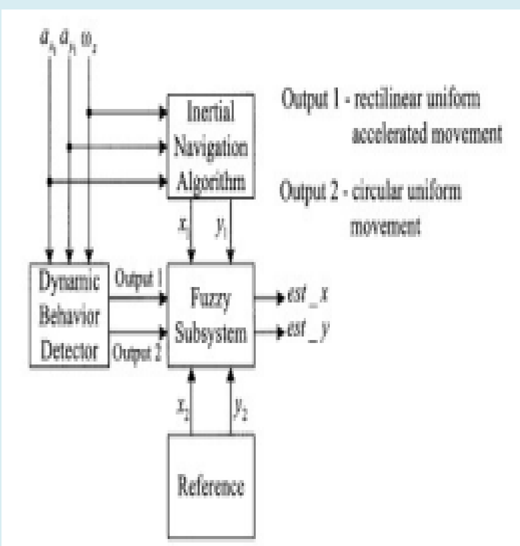

Figure 8: Schematics of fuzzy integrated navigation system.

Therefore, the input-output training pairs are: the position reported by the independent INS system (first input), the same data delayed by one step (second input), and the position reported by the reference navigation system (when data from that system are not available, RNNFIS training and goals). In this way, we consider INS data, changes in these data, and data from 5G systems. Training targets the parameters of the membership function and is done using the back propagation algorithm alone or in combination with the least squares method. In our hypothesis, the training objective is to minimize the absolute position error, defined as the difference between the reference position and the position reported by the independent INS system. During the training process, the fuzzy subsystem learns the evolution of the INS system error under different scenarios. The resulting model is heuristic and, as we mentioned before, is based on trial and error as Figure 8.

Conclusion

A new concept of 5G/INS integration based on artificial intelligence is proposed, namely the Recurrent Neural Network-based Fuzzy Inference System (RNNFIS). For the 5G positioning system, we apply fuzzy logic theory and two-step LS method to reduce positioning errors. For the INS positioning system, we have long applied RNNFIS theory to solve positioning errors. We only use 4 rules in the RNNFIS system.

References

1. Chan YT, Ho KC (1994) A simple and efficient estimator for Hyperbolic Location. IEEE transaction on Signal Processing 42(8): 1905-1915.
2. Wann CD, Lin, MH (2004) Location estimation with data fusion for wireless location systems. IEEE transaction on Networking, Sensing and Control 40(1): 327-332.
3. Zhu J (1992) Calculation of Geometric Dilution of Precision IEEE Trans. Aerospace and Electronic Systems 28(2): 893-895.
4. Chen HY, Liu CH (2008) Hybrid GPS/GSM Positioning Systems Design with Fuzzy Logic. J Adv Comput Intell Informatics 12(3): 254-262.
5. Chen JHY (2014) Solar system GSM/INS positioning system with fuzzy control. CACS International Automatic Control Conference.
6. Goldman A, Espinosa C, Patel S, Cavuoti F, Chen J, et al. (2022) QuAD: Deep-Learning Assisted Qualitative Data Analysis with Affinity Diagrams. CHI Conference on Human Factors in Computing Systems, pp: 1-7.