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Indoor Child Tracking in Wireless Sensor Network using Fuzzy Logic Technique

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ABSTRACT

Recent advances in telecommunication technology has led to the development of sensor networks. The sensor networks have become part of everyday lives for people. There are many applications that have been developed using these networks. There are many localization techniques available for use but the use of these applications depends on the requirements of the application. This study chooses the localization technique to be used in Child Tracking application. The localization is divided into two steps: signal measurement and position computation. Signal measurement step requires the sensors to measure some signal properties. And then the measurements of the signal are used in the computation of the location in the 2nd step, position computation. Two of the most widely used methods, triangulation and trilateration, are described in the study, as well as, few newer methods. In this study, fuzzy logic is proposed to be used as a technique for the localization of the target node. Fuzzy logic does not require the complex calculations that other methods do. The steps for the localization using fuzzy logic are described.

Key words: Child tracking, child abduction, wireless sensor networks, positioning, localization, fuzzy logic

INTRODUCTION

Advances in telecommunication technology in recent years have lead to the rapid development of sensor networks where the sensors are low in cost and power consumption and can perform multiple functions. Being small in size the sensors can still acquire and process data and communicate to the other sensors, usually, through radio frequency channel. The sensors are easy to deploy and cost-effective which have revolutionized the applications of remote monitoring (Ilyas and Mahgoub, 2006; Wu, 2006).

Since the first introduction of Wireless Sensor Networks (WSN), growing research and commercial interest, that followed it, brought many applications of WSN. These applications were created for military, health and civilian purposes (Callaway, 2004).

Applications using localization information are on demand by people more and more each day. These applications are used to determine the location of the target in the given environment. There are many localization methods developed in the past, each of them have different use for each particular application (Li *et al.*, 2010). The localization applications are developed to be used indoors and/or outdoors.

Most of the localization applications for outdoors use Global Positioning System (GPS) to locate the target (Subhan *et al.*, 2011). Cell phones are also often used as an alternative to GPS to track the location of a person. Using Cell-ID is the easiest way of positioning with cell phones but the accuracy of such systems might vary from hundreds of meters to few kilometers. This depends on the size of the cell. However, both of these systems, GPS and cell phone, are not very useful in indoor environments. This is because the accuracy of cell phone positioning technology is not sufficient and GPS systems can't penetrate the buildings and other obstacles.

One of the applications which require the localization information is Child tracking. Tracking applications have been developed rapidly. People want to track everything important for them. Child kidnapping is one of the widespread types of crime now-a-days in Malaysia and other countries. Many kidnapping cases end with rape and/or murder. And many cases go unsolved. In most of the cases the children are abducted in places with specific perimeter, like shopping malls, markets and playgrounds. Sometimes parents are unsure whether the child just got out of sight and is still within the perimeter of the place or the child has been abducted. The problem is that this causes the delay in the search, because when the related authorities are notified, the search is first concentrated on the inside of the area. A good tracking system that is able to detect the child's presence in the area and notify the authorities when the child goes out will be very useful. The direction where the child was taken could be known and the search could speed up.

This study explains the process of positioning and describes the techniques which could be used for child tracking. Fuzzy logic, as a positioning technique for Child tracking, will be described.

LOCALIZATION TECHNIQUES

The typical scenario for the indoor localization system is that the target walks among the sensor nodes in the Wireless Sensor Network (WSN). The sensor node of WSN which detects the presence of the target node, sends the signal to the target and receives the reply confirming that it is the target node (Vossiek *et al.*, 2003). When the reply is received, the sensor node can calculate the time it took the signal to travel to the target and back and/or the signal strength of the signal received from the target. These measurements are then used to estimate the distance between the sensor node and the target node. Then with the estimated distance between the target and few sensor nodes in WSN, the location of the target can be calculated.

As can be seen in Fig. 1, the basic of the localization techniques is divided into two steps: First step is to measure the signal related parameters, like time and signal strength; Second step is to calculate the actual position of the target.

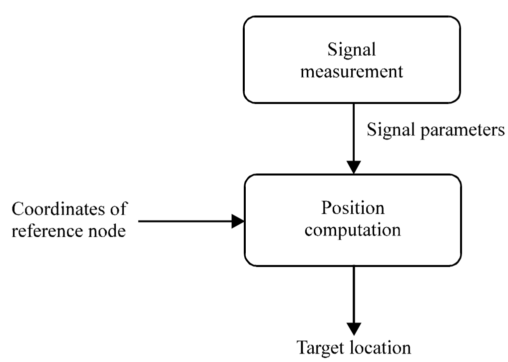

Fig. 1: Steps of localization

In the first step of localization, the sensor node measures the properties of the signal between itself and the target node. The most common signal properties measured are the time, signal strength and angle of the signal (Liu *et al.*, 2007).

In the second step, the signal parameters measured in the first step will be used to calculate the location of the target. The calculation usually uses the geometric methods of calculating the location of a point with known coordinates of the neighboring points and the distances between them. The two widely used methods are: Triangulation and Trilateration. These methods are often used with some other techniques, i.e. statistical, to improve the accuracy of the result, because the measurements in real-life are not ideal (Koyuncu and Yang, 2010).

Signal measurement: As has been described in the previous section, the signal measurement is the first step of localization of an object. In this step, the sensor nodes measure some defined parameters of the signal that it sends to the target node. The signal measurements can be taken from any type of signal used in the communication between the sensor nodes. It can be Radio Frequency (RF), Infrared (IR), Bluetooth and etc. The most commonly used parameters measure the time and signal propagation strength (Patwari *et al.*, 2005). When measuring the time parameters, one or more of the following are measured: Time of Arrival (TOA), Time Difference of Arrival (TDOA) and Round-trip Time of Flight (RTOF). Angle of Arrival (AOA) and Received Signal Strength (RSS) are the parameters of the signal (Subhan and Hasbullah, 2009) which measure the angle at which the signal is received and the strength of the signal, respectively.

Time of Arrival (TOA): TOA is the measure of a time it takes the signal to arrive from the transmitter to the receiver (Fig. 2). To find the distance between the two nodes, the transmission time delay (TOA) is multiplied by the propagation speed:

$$d_{ij} = t_{ij} \times v_p \tag{1}$$

where, d_{ij} is the distance between the two nodes, t_{ij} is the transmission time delay and v_p is the propagation speed of the signal.

The main issue in TOA is the clock synchronization. If the nodes are not synchronized, the calculation results will not be accurate. One way to solve the synchronization problem is to install the synchronized clocks at the receiver and the transmitter nodes or attach GPS to the nodes. However, this solution is very costly to install and maintain (Li *et al.*, 2009; Zhang *et al.*, 2010).

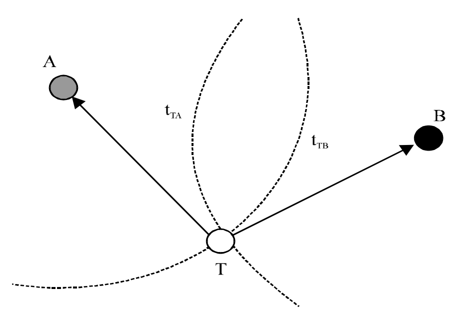

Fig. 2: TOA where t_{TA} and t_{TB} are the measured one way times, from the target, T, to reference points A and B, respectively

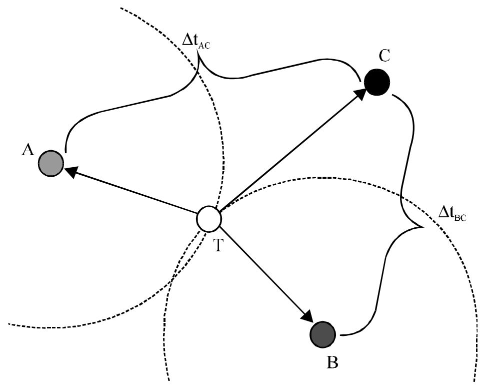

Fig. 3: TDOA where, Δt_{AC} and Δt_{BC} are the differences in time measurements from sensor A and C (reference sensor) and B and C, respectively

Time Difference of Arrival (TDOA): TDOA is very similar to TOA, in a way that it also measures the time delay of the transmission between the two nodes (Fig. 3). Instead of measuring it only once, it measures the time delay of the transmission using two different signals.

The difference of time delay of two signals is used to calculate the distance between the nodes. So, the distance between the two nodes is calculated by the following equation:

$$\frac{d_{ij}}{v_{p1}} - \frac{d_{ij}}{v_{p2}} = t_{ij1} - t_{ij2} \tag{2}$$

where, d_{ij} is the calculated distance between the two nodes, v_{p1} and v_{p2} are the propagation speed of the signal one and signal two, respectively, t_{ij1} and t_{ij2} are the recorded time delays of the two transmissions.

Round-trip Time of Flight (RTOF): The issue of clock synchronization in TOA is addressed with RTOF. RTOF tries to solve the problem of synchronization with TOA to some extent. By measuring the RTOF, the distance between the two nodes is calculated as follows:

$$d_{ij} = \frac{(t_{RT} - \Delta t) \times v_p}{2} \tag{3}$$

where, d_{ij} is the distance between the two nodes, t_{RT} is time delay of the round-trip transmission, Δt is the time delay between receiving and sending the signal at the receiving node and v_p is the transmission speed.

Although RTOF decreases the requirement of the clock synchronization of TOA, it does not solve the issue completely. The calculation of RTOF needs to know the exact delay time of the receiving node which requires very good synchronization or fast processing speed. Liu *et al.* (2007) calculate that the processing time as short as 1 msec, with 25 ppm accuracy crystal clock, can generate positioning deviation up to several meters (Fig. 4).

Angle of Arrival (AOA): In AOA, the location of the unknown node can be found by measuring the angle of arrival of the signal. The angle is measured by the directional antennas or sometimes

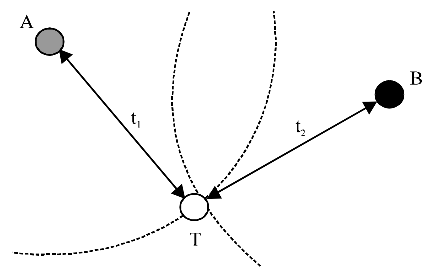

Fig. 4: RTOF where, t_1 and t_2 are the measured roundtrip times, from the target, T, to reference points A and B, respectively and back

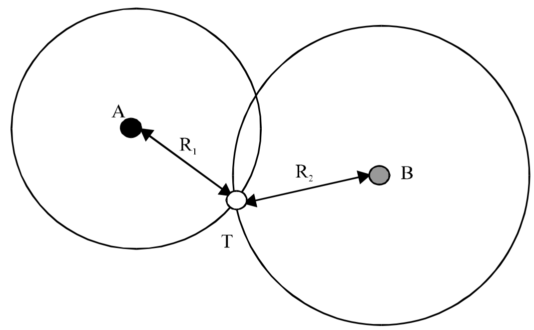

Fig. 5: Sensors A and B measure the RSS, R_1 and R_2, respectively, to the target, T

by the array of antennas. When the antennas receive the signal, the difference of time between different antennas is also known, together with the angle. With these measurements, the geometry of the sensor nodes and the target node can be constructed. The measurements from two known sensor nodes are enough to determine the location of the target in 2-D and measurements from three known sensor nodes are enough to determine the location of the target in 3-D. Another advantage of AOA over the other measurements is that it does not require the synchronization of the clocks of the sensor nodes. However, the main disadvantage of it is the cost of implementation. To measure the signal parameters for AOA, it requires the installation of the complex, large and costly hardware. Another disadvantage is the distance between the nodes. The distance between the sensor node and the target nodes is inversely proportional to the accuracy of the angle measurements. This means that the further away the target from the measuring nodes, the less the positioning precision would be. In addition, the positioning using this method of signal measurement is not very suitable for moving targets.

Received Signal Strength (RSS): RSS is the measure of voltage by Received Signal Strength Indicator (RSSI) circuit of the node. To measure RSS, the sensor nodes usually do not require any additional hardware. So, the implementation of RSS measurement is in a way simpler than the measurements of the other mentioned signal parameters (Rozyyev *et al*., 2010). After measuring the RSS, the theoretical models are usually used to convert the RSS into a distance estimate. Figure 5 shows how RSSI values are used to locate the target.

Position computation: As has been mentioned in the previous section, the localization of the target is divided into two steps. The first step, signal measurement was described also in the previous section. After the measurements are complete, the computation of the target's location can be continued with the second step. In the second step the acquired measurements are put into respective equations to calculate the location of the target node. There are many equations and methods derived nowadays on how to compute the location of the node with known coordinates of the neighboring nodes and known signal measurements but all of them are derived from the basic geometric formulas of triangulation and trilateration.

Triangulation: Triangulation is often used with AOA signal parameter. Triangulation does not require knowing the distance between the target node and the neighboring nodes to calculate the distance. It measures the angles between the intersection lines of the target and the reference nodes. The distance can be calculated with those angles. Triangulation only requires two reference points to calculate the location of the target, as shown in Fig. 6.

In Fig. 6, A and B are the minimum required reference points with known coordinates, θ_1 and θ_2 are the angles measured with AOA method and T is the target node with unknown coordinates.

Trilateration: Trilateration is another one of the widely used methods to obtain the location of the target node. It uses three reference points to calculate the location of the target in 2-D., as shown in Fig. 7, the reference nodes must be non-collinear to be able to position the between them.

If the coordinates of the reference points are known, the location of the target node can be found as shown in Fig. 7. (x_1, y_1), (x_2, y_2) and (x_3, y_3) are the coordinates of reference points A, B and

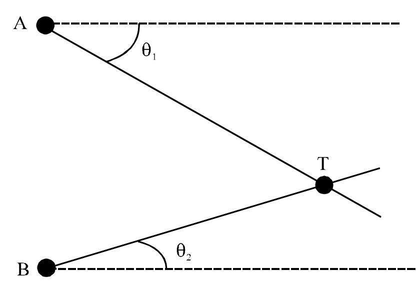

Fig. 6: Triangulation of the objects location based on AOA

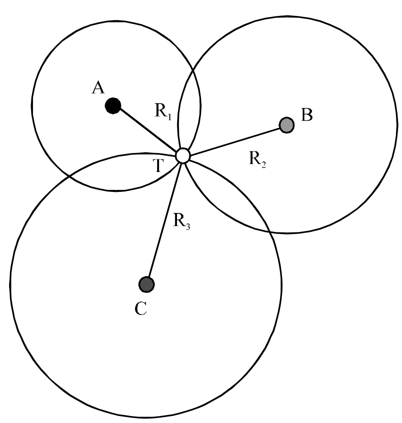

Fig. 7: Positioning of the target using trilateration

C, respectively. R_1, R_2 and R_3 are the distances between the target node T and reference points A, B and C, respectively. R_1, R_2 and R_3 are also the radiuses of the three circles with origins A, B and C, respectively. With these known the coordinates of T, (x_T, y_T) can be calculated with the following equations:

$$\begin{cases}(x_1 - x_T)^2\,(y_1 - y_T)^2 = R_1^2\\(x_2 - x_T)^2\,(y_2 - y_T)^2 = R_2^2\\(x_3 - x_T)^2\,(y_3 - y_T)^2 = R_3^2\end{cases} \quad (4)$$

Fuzzy logic: Fuzzy logic, first introduced by Zadeh (Akpolat, 2005) in 1965, is the multi-valued logic that accepts the estimated values and returns estimation in result. It doesn't only consider the exact crisp values for its input. It accepts a range of values (Zadeh, 1965). Teuber *et al.* (2006) used Fuzzy logic, to estimate the location of the target. Chen *et al.* (2010) proved that it gives more accuracy than commonly used triangulation method. However, the main advantage of using Fuzzy logic is not only the accuracy. To minimize the errors and consider the measurements as in real world scenarios, mathematical methods of positioning use statistical methods and/or filters after calculating the values. Using Fuzzy logic allows developers of the application to skip this step. The use of statistical methods and filters will not be needed. This saves time by skipping long calculations.

Neural networks: Neural networks are also used as a localization method. Although, it is not as popular as other mentioned methods, it gives good results. For the training purpose of the neural networks, the RSS measurements and the position of the corresponding targets are measured in offline stage. The weights are obtained after the training. These weights are used to calculate the location of the hidden layers in the neural network. The weights are multiplied by the inputs. This process repeats for the hidden layer, to get to the output function. Bouzenada *et al.* (2007) explained the target location in the video images is tracked. Similarly, Neural networks can be used to track target locations using signal properties. Shareef *et al.* (2008) compared four families of Neural Networks for localization. The authors also prove that in some cases the neural networks give better results, in terms of accuracy than the other methods.

METHODOLOGY

This section defines the methodology used to develop the child tracking system using fuzzy logic in Wireless Sensor Network (WSN).

System model: All Fuzzy Logic based applications have one component in common, the Fuzzy Inference System (FIS). FIS is the heart of the fuzzy logic applications which does the logic part. Referring back to Fig. 1, we can change it to define the steps of positioning using fuzzy logic which is illustrated in Fig. 8.

Measurement of RSSI: RSSI value will be measured in the first step. The measured value is then to be converted to the distance using the Friis equation:

$$\text{RSSI [dBm]} = -(10*n*\log(d) + A) \quad (5)$$

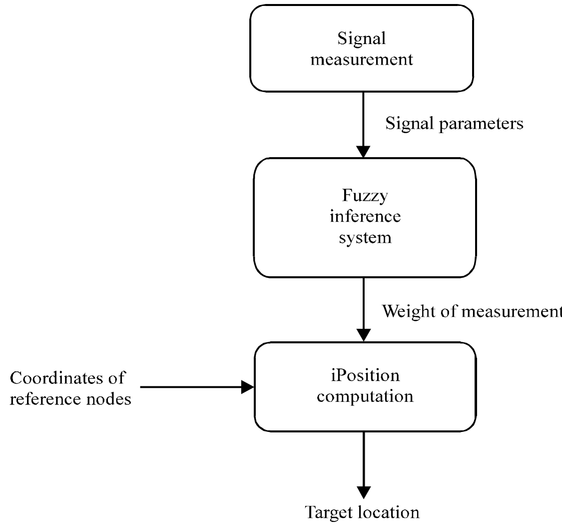

Fig. 8: Steps of localization using fuzzy logic

where, RSSI is the received signal strength, d is the distance between the nodes, n is the damping coefficient of the signal and A is the absolute value of the signal strength with 1m distance between the transmitter and the receiver.

$$d = 10^{\left(\frac{-RSSI\,[dBm]-A}{10*n}\right)} \tag{6}$$

Putting the values of A and n into Eq. 6 we get:

$$d = 10^{\left(\frac{-RSSI\,[dBm]-49}{10*2.25}\right)} \tag{7}$$

Fuzzy inference system: Fuzzy logic toolbox of Matlab was used to design the Fuzzy Inference System (FIS). FIS consists of two main parts: Membership functions and Rules.

Membership functions: The membership functions, define the relationship of the input and output to the system. The membership functions for Child tracking were adopted from Chen *et al.* (2010). In their study the authors use Mamdani-type Inference, in this study Sugeno-type Inference is used. Instead of Mamdani singletons, Sugeno constants are used for the output function. Figure 9 shows the membership functions of the input.

The output membership function is Sugeno constant. There are five output constants with values: 0, 0.25, 0.5, 0.75 and 1.

Fuzzy rules: There are five rules in FIS. They are as follows:

- If (distance is Very Near) Then (weight is VeryLarge)
- If (distance is Near) Then (weight is Large)
- If (distance is Medium) Then (weight is Medium)
- If (distance is Far) Then (weight is Small)
- If (distance is Very Far) Then (weight is VerySmall)

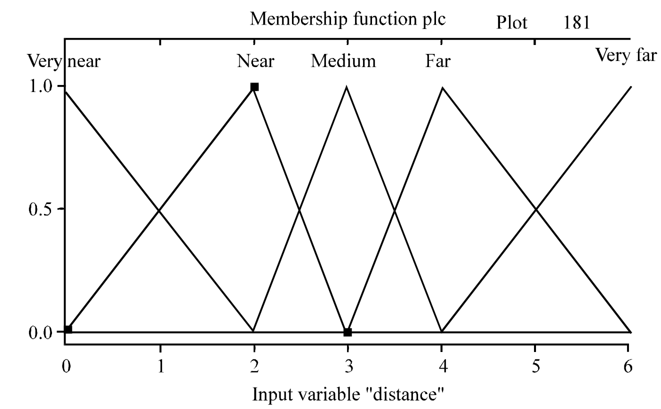

Fig. 9: Input membership function. Input-distance from the sensor node to the target node

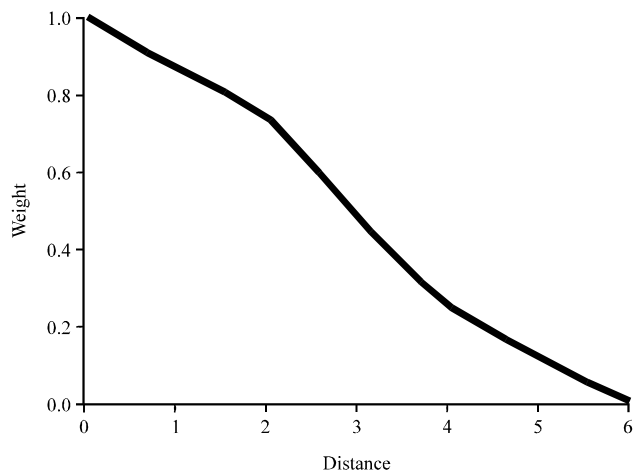

Fig. 10: The relationship between distance (input) and weight (output)

Respectively to the rules, the relationship between the input, distance and output, weight, is shown in Fig. 10. The further away the target is from the node, the smaller the weight will be.

Calculating the coordinates: The RSSI values used for the calculations are dummy values which were calculated using the Eq. 5. With input distance, the weight will be obtained from the FIS. For example, when the input distance is 2.5, the weight is 0.625. This weight will then be used to calculate the coordinates of the target by using the following equations:

$$x_T = \frac{\sum_{i=1}^{N} w_i * x_i}{\sum_{i=1}^{N} w_i} \quad (8)$$

$$y_T = \frac{\sum_{i=1}^{N} w_i * y_i}{\sum_{i=1}^{N} w_i} \quad (9)$$

RESULTS AND DISCUSSION

To theoretically check the positioning using fuzzy logic, four sensor nodes were assumed to be placed in the corners of the square with the area of 6 m^2. Five target nodes are assumed to be placed in the square. The coordinates of the reference nodes are known.

The assumed RSSI values by each node are presented in Table 1. Table 2 shows the calculated distance between the reference nodes and the target node. Table 3 displays the calculated coordinates of the target nodes.

The distribution of the assumed positions of target nodes and the calculated positions is shown in Fig. 10. As can be seen from the Fig. 11, the coordinates calculated using fuzzy logic are quite accurate. The further simulations will help to calculate the error rate and the deviation of the nodes from the actual positions.

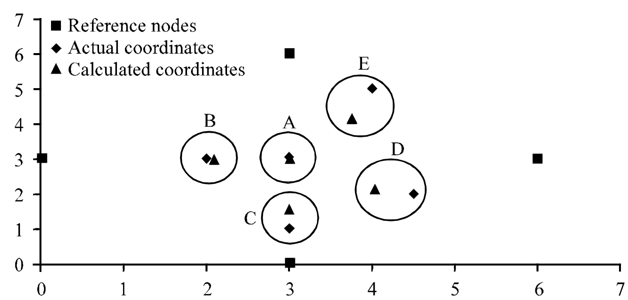

Fig. 11: The location of target nodes

Table 1: RSSI values measured by the reference nodes

	RSSI measured between the nodes				
Reference nodes	Node A	Node B	Node C	Node D	Node E
N1	-59	-55	-62	-64	-64
N2	-59	-61	-65	-64	-50
N3	-59	-63	-62	-54	-58
N4	-59	-61	-49	-57	-64

Table 2: Distances between the reference nodes and target nodes

	Calculated distance between the nodes				
Reference nodes	Node A	Node B	Node C	Node D	Node E
N1	2.78	1.85	3.78	4.64	4.64
N2	2.78	3.41	5.14	4.64	1.11
N3	2.78	4.19	3.78	1.67	2.51
N4	2.78	3.41	1	2.27	4.64

Table 3: Calculated coordinates of the target nodes

Node	X	Y
A	3.00	3.00
B	2.09	3.00
C	3.00	1.56
D	4.03	2.15
E	3.75	4.13

CONCLUSION AND FUTURE WORKS

Since the introduction of the Sensor Networks, their development has been rapid. The applications that use these networks developed day-by-day. Moreover, these applications, such as health monitoring, have really benefitted people. Localization is one type of applications of sensor networks.

This study has described two steps of localization which are the signal measurement and the position computation. The signal measurement is the process when the sensors, sometimes equipped with special hardware, measure some parameters of the signal which help to estimate the distance to the target. After estimating the distance to the target, the estimated distance from some reference sensors can be used in position calculation, the second step of the localization. Triangulation and Trilateration are the two famous methods used to calculate the position of the target. Nevertheless, the other methods such as Fuzzy Logic and Neural Networks are proven to work just as good, if not better, for some applications.

This study proposed to use fuzzy logic for the positioning for the child tracking application. Using some approximated input, this study showed that fuzzy logic could detect the location of the target.

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