

# A novel field search and rescue system based on SIM card location

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**Abstract.** Nowadays, the rapid development of outdoor sports and adventure leads to the increase of the frequency of missing accidents. On the other hand, it becomes much more convenient and efficient for the criminals to escape with the help of new technologies. So we have developed a long-distance raids targeted field search and rescue system which utilizes RSSI ranging and Kalman filtering algorithm to realize remote positioning and dynamic supervision management only by a mobile phone with a SIM card, without any additional terminal equipment.

## 1 Introduction

Recently, with the acceleration of urbanization process, more and more people would like to get closer to the nature which leads to the astonishing development of outdoor and adventure sports and the increase in the number that people get lost due to lack of field survival knowledge. What's worse, it becomes much more convenient and efficient for the criminals to escape with the help of advanced technologies. It increases the searching difficulty and manpower input with accidents happening in the relatively wide environment and the complex geomorphological field. Therefore, it is urgent to develop an outdoor rapid position search and rescue system to find the target person quickly and accurately so as to minimize the accident loss. This paper describes the application of search and rescue system based on mobile phone positioning which consists of a central control car, a mobile base station, and a mobile phone with a SIM card. The RSSI ranging and Kalman filtering algorithm are utilized to achieve real-time tracking of target [6], location information dynamic supervision and management.

## 2 System description

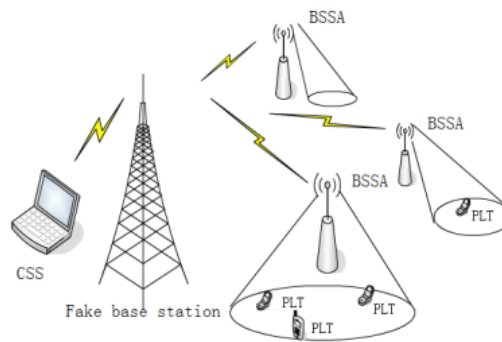
### 2.1 System Structure

The system consists of a central control station (CCS), 4 base stations with Smart antenna (the BSSA), a repeater, and a plurality of hand held mobile positioning terminal (portable location terminal, PLT) [2], as shown in Figure 1.

The main functions of CCS: providing each group of repeater station with the unified clock, sending the feature information related with mobile phone through the fake base station to the signal processing module of control center, processing the information, and utilizing the localization algorithm to calculate the estimated location of the mobile phone and PLT position which are displayed in the whole search and rescue location map. What is more, CCS has a very important function which is to command the PLT to conduct secondary positioning search and rescue work. BSSA is used for transmitting the broadcast message, and inducing the searched mobile phones and



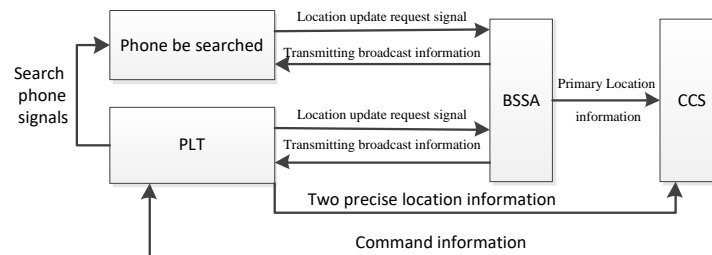
PLT replied signal. The BSSA makes the first positioning. PLT is a mobile positioning terminal with the function of mobile phone. BISA can position the location information of phones, at the same time, it can also be positioned. Since the PLT is on the ground, the location information is more accurate. PLT can show the whole search and rescue location map, and the map is displayed and updated in real time. When it reaches the location of the label range of the first-positioning mobile phone, PLT begins to search mobile phone signal from close range, and a precise positioning is achieved [2][4][7].



**Figure 1.** system structure

## 2.2 System Working Principle

The working principle of the system is shown in figure 2. Firstly, four BSSA cars shall be distributed in the target area. Then BSSA emission broadcasts news according to the emission signal registration principle of mobile phone. If the location parameters in broadcasting message are different from the location of current cell, the mobile phones think that they have come across the edge of the location area, and will start the location updating procedures to request for accessing to the new cell which is composed of 4 BSSA cars. According to the signal emitted by the phone, BSSA uses the RSSI algorithm to position it [4]. Due to non-line of sight (NLOS) propagation, multipath effect and many other adverse factors, the positioning accuracy can deteriorate with different degree. Hence, after the positioning, the position of mobile phone cannot be accurately determined, but in a small range, as shown in Figure 1. BSSA is also ready to send PLT's location information to CCS.



**Figure 2.**system working principle

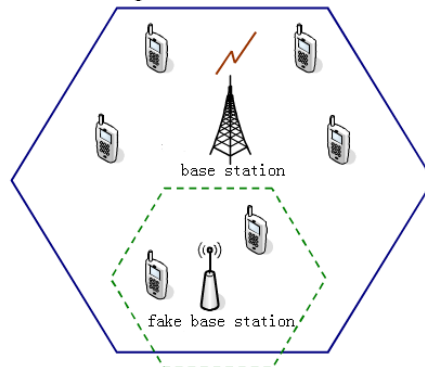
The four BSSA cars transmit the phone and PLT position information to CCS. With the gathered four groups of data, CCS will show position information of the mobile phone and PLT on the whole search and rescue location map. Then, CCS commands every search and rescue team consisting of 4 PLTs through wireless walkie-talkie to approach to the phone which is searched [4][7]. When each PLT arrives at the position in the mobile phone marking range, it begins to search for phone signals in close distance. The RSSI positioning accuracy in short distance search is higher. The Kalman filter is also used to fuse the primary positioning result and the RSSI positioning result, so that more accurate positioning of the mobile phone is achieved. Finally, the position of the person equipped with the mobile phone is quickly determined through the communication between PLT and CCS.

## 3 The key technologies of system

### 3.1 Phone Signal Detection

In order to detect whether the rescue raids field phone exists in real time, the system should be designed according to the working characteristics of mobile phone. The mobile phone is a radio transmitter and receiver device, and its existence can be judged through detecting the electromagnetic signals emitted by the phone. At present, the second generation of mobile communication systems are extensively applied including GSM and CDMA and mobile transmitting signals of them have the following three conditions: switching machine, calling (including SMS and data service), and registering. Obviously, the registration which means position updating is used in this system and it includes three cases: regular update, across the location update, and boot update. The across the location update is to register when a mobile phone transfers from a location area to another location. The criterion for judging a mobile phone entering a new location is that whether it receives a stronger broadcast channel and the message of decoding system shows different location identifier.

Therefore, as shown in the diagram, we can induce the phone to start the position update by crossing the district location. This is to say, an equipment that is similar to the mobile base station (fake base station) can be designed and the base station is used to transmit the broadcast information. If the broadcast channel signal is stronger and the location area parameters is different from the current cell, phones around the area could think it had crossed the edge of the location area and start the location update procedure to request access to the virtual community [5][7]. According to the signal emitted by the phones, the existence of the phone can be determined. In the designed system, the RSSI Kalman filtering algorithm can also be more accurate in judging the number of mobile phones in detection range and access the location of the phones.



**Figure 3.** Induced registration

### 3.2 Location Algorithm

Nowadays, with the existing domestic and foreign mobile phone technologies, the positioning accuracy of 150m, 100m, or 50m is difficult to meet the requirements of search and rescue and field cellular networks may often be destroyed. Therefore, the existing positioning techniques cannot realize accurate positioning in field search and rescue raids based on mobile phone signals. In the indoor and outdoor positioning system, the positioning is achieved based on the electromagnetic wave transmission signal which contains a variety of information. However, wireless signal transmission is influenced by external environment, especially on a moving body of NLOS location where great influence is produced because of signal reflection or diffraction. Therefore, a proper signal propagation attenuation model should be established to improve the position accuracy [1].

In this paper, the RSSI and Kalman filter algorithm is used. The RSSI value of the node is collected by each reference node and mathematical model between the RSSI value and distance is established according to the specific relationship between the RSSI value and the distance:

$$RSSI = -(10n \lg d + A) \quad (1)$$

In the formula,  $n$  is the signal propagation constant,  $d$  is the distance away from the emitter, and  $A$  is the value of RSSI at 1m distance.

Assuming a reference node spatial location is  $(x_i, y_i, z_i)$ , spatial location of the location node is  $(x_u, y_u, z_u)$ , the distance between reference node and spatial node is  $d_i$ , following equation is obtained:

$$\begin{cases} d_1 = \sqrt{(x_1 - x_u)^2 + (y_1 - y_u)^2 + (z_1 - z_u)^2} \\ d_2 = \sqrt{(x_2 - x_u)^2 + (y_2 - y_u)^2 + (z_2 - z_u)^2} \\ \vdots \\ d_n = \sqrt{(x_n - x_u)^2 + (y_n - y_u)^2 + (z_n - z_u)^2} \end{cases} \quad (2)$$

To solve the above equation, at least four reference nodes are needed and equation(2) should be linearized. Linearize the formula(2) at a position  $(\hat{x}_u, \hat{y}_u, \hat{z}_u)$  and wrote it in matrix form, which is derived that:

$$\begin{bmatrix} \Delta d_1 \\ \Delta d_2 \\ \vdots \\ \Delta d_n \end{bmatrix} = \begin{bmatrix} a_{x1} & a_{y1} & a_{z1} \\ a_{x2} & a_{y2} & a_{z2} \\ \vdots & \vdots & \vdots \\ a_{xn} & a_{yn} & a_{zn} \end{bmatrix} \begin{bmatrix} \Delta x_u \\ \Delta y_u \\ \Delta z_u \end{bmatrix} \quad (3)$$

In the formula,  $\hat{r}_i = \sqrt{(\hat{x}_i - \hat{x}_u)^2 + (\hat{y}_i - \hat{y}_u)^2 + (\hat{z}_i - \hat{z}_u)^2}$ ,  $a_{xi} = (\hat{x}_i - \hat{x}_u) / \hat{r}_i$ ,  $a_{yi} = (\hat{y}_i - \hat{y}_u) / \hat{r}_i$ , and  $a_{zi} = (\hat{z}_i - \hat{z}_u) / \hat{r}_i$ . Denote  $\Delta d = [\Delta d_1 \ \Delta d_2 \ \dots \ \Delta d_n]^T$ ,

$\Delta x = [\Delta x_u \ \Delta y_u \ \Delta z_u]^T$ ,  $H = \begin{bmatrix} a_{x1} & a_{y1} & a_{z1} \\ a_{x2} & a_{y2} & a_{z2} \\ \vdots & \vdots & \vdots \\ a_{xn} & a_{yn} & a_{zn} \end{bmatrix}$ , the formula (3) can be written in the following form:

$$\Delta d = H \Delta x, \text{ where } \Delta x = H^{-1} \Delta d. \quad (4)$$

With more than four reference nodes, equation (4) is an inconsistent equation. Another solution is:

$$\Delta x = [H^T H]^{-1} H^T \Delta d \quad (5)$$

The least square method can be used to solve the above equation iteratively. This method starts from the transmission distance error between position nodes and probably values, The calculation results are gradually obtained which meet the requirements of measurement, This value is taken as the final positioning value. The advantage of this method is that, while performing calculations with computer, all kinds of valuable information is sufficiently used and the error introduced in the calculation process is reduced.

### 3.3 The Establishment of The Kalman Filtering Model

The focus of RSSI localization is the distance measurement. However, the RSSI measurement is vulnerable to the effects of interference noise, which makes these methods cannot meet the positioning accuracy requirements. The Kalman filter is the optimal filtering algorithm for Gaussian process. Through combination of the Kalman filter and the location method, the influence of noise posed on system can be reduced and the positioning accuracy can be greatly improved.

The state equations of displacement and speed based on the location information of the system are established and discretized. The state equation of positioning system is:

$$X(k+1) = AX(k) + W(k) \quad (6)$$

$$S(k) = CX(k) + V(k) \quad (7)$$

In these formulas, the state vector  $X(k)$  is localization information for optimization,  $X(k) = [x_k \ y_k \ z_k \ V_k^x \ V_k^y \ V_k^z]^T$ ,  $x_k, y_k, z_k$ , and  $V_k^x, V_k^y, V_k^z$  are the displacement and speed estimation in three directions at  $k$  moment, respectively;  $A$  is the system matrix; Observation vector  $S(k)$  is the observation of mobile phone localization information and  $S(k) = [s_k^x \ s_k^y \ s_k^z]^T$  where  $s_k^x, s_k^y, s_k^z$  are displacement observations in three directions at  $k$  moment, respectively;  $C$  is the output matrix;  $W(k)$  and  $V(k)$  are the state noise and observation noise, respectively, which meet the formulas  $E[W(k)] = E[V(k)] = 0$ ,  $E[W(k)W(k)^T] = Q$ , and  $E[V(k)V(k)^T] = R$ , namely  $W(k)$  and  $V(k)$  are independent zero-mean white noise sequence. The statistical characteristics of the initial state vector  $X(0)$  are:

$$E[X(0)] = \mu_0, \text{Var}[X(0)] = E[(X(0) - \mu_0)(X(0) - \mu_0)^T] = P_0.$$

The procedures of Kalman filter are:

(1) The prediction process of Kalman filter

$$X(k|k-1) = A\hat{X}(k-1|k-1) \quad (8)$$

$$P(k|k-1) = AP(k-1|k-1)A^T + Q \quad (9)$$

(2) The calibration process of Kalman filter:

$$K(k) = P(k|k-1)C^T [CP(k|k-1)C^T + R]^{-1} \quad (10)$$

$$\hat{X}(k|k) = X(k-1|k-1) + K_k(S(k) - C\hat{X}(k|k-1)) \quad (11)$$

$$P(k|k) = [I - K(k)C]P(k|k-1) \quad (12)$$

The position of the user's 3d model is as follows:

$$\begin{bmatrix} x_k \\ y_k \\ z_k \\ V_k^x \\ V_k^y \\ V_k^z \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0.1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0.1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0.1 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_{k-1} \\ y_{k-1} \\ z_{k-1} \\ V_{k-1}^x \\ V_{k-1}^y \\ V_{k-1}^z \end{bmatrix} + \begin{bmatrix} w_k^x \\ w_k^y \\ w_k^z \\ w_{k-1}^{V_x} \\ w_{k-1}^{V_y} \\ w_{k-1}^{V_z} \end{bmatrix} \quad (13)$$

$$\begin{bmatrix} s_k^x \\ s_k^y \\ s_k^z \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_k \\ y_k \\ z_k \\ V_k^x \\ V_k^y \\ V_k^z \end{bmatrix} + \begin{bmatrix} v_k^x \\ v_k^y \\ v_k^z \end{bmatrix} \quad (14)$$

The selection of initial value

$$P(0|0) = \begin{bmatrix} 20 & 0 & 0 & 0 & 0 & 0 \\ 0 & 20 & 0 & 0 & 0 & 0 \\ 0 & 0 & 20 & 0 & 0 & 0 \\ 0 & 0 & 0 & 20 & 0 & 0 \\ 0 & 0 & 0 & 0 & 20 & 0 \\ 0 & 0 & 0 & 0 & 0 & 20 \end{bmatrix}$$

$X(0) = 0$ ,

#### 4 Positioning technology simulation

The simulation experiment for locating and tracking algorithm is performed to verify the effectiveness of the algorithm. The moving trajectory model is unchanged in the simulation example. The tracking performances in the situation of uniform linear motion, angular motion, and sinusoidal movement are mainly tested[3]. The simulation results are shown in the Figure 4 to Figure 7.

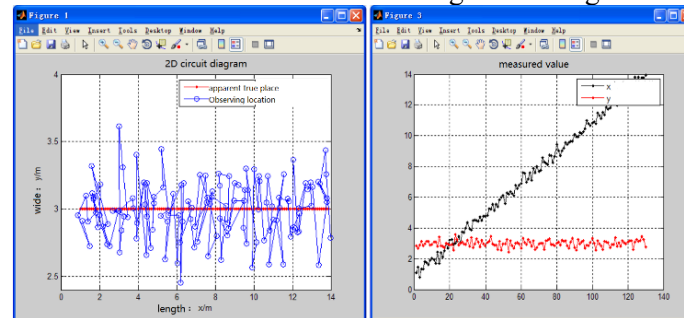


Figure 4. uniform linear motion and uniform linear x,y

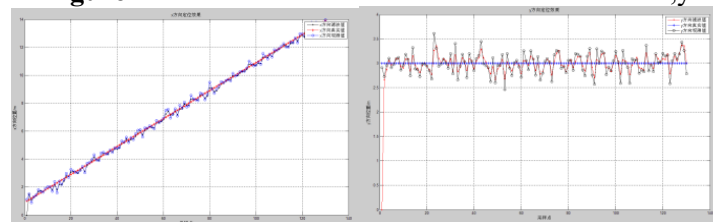


Figure 5. information of uniform linear motion x/ y

Uniformly accelerated motion:

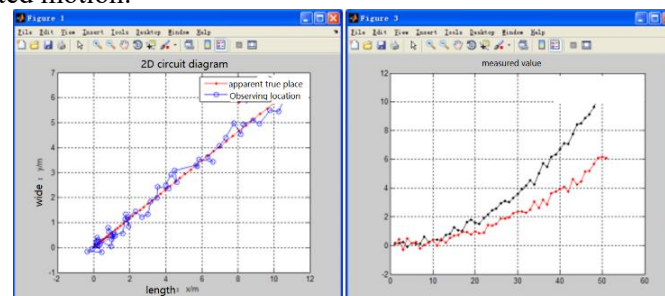


Figure 6.information of uniform accelerated motion/x,y

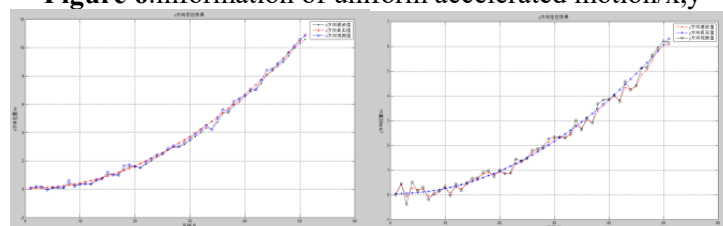


Figure 7.Uniformly accelerated motion-x/y position filter

It can be seen from these figures that the Kalman filter based locating method can locate the mobile nodes accurately in the simulation example and it can also estimate the change of target motion state. Therefore, it is proved that the Kalman filtering algorithm is effective in estimating the location.

#### 5 Conclusion

This paper proposes an outdoor search and rescue system on the basis of SIM card location based on the active detection of the mobile phone signal and RSSI locating technology. The system can locate the rescued personnel quickly and accurately in the complex wild environment without additional equipments but a mobile phone. Through the combination of RSSI positioning method and kalman filter algorithm, positioning accuracy and positioning speed of the algorithm in the node mobile and

non-line-of-sight environments are improved which are verified by using a computer simulation example.

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