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AGV Positioning Based on Multi-sensor Data Fusion

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Abstract: In recent years, with the rapid development of robot technology and explosive growth of robot demand, AGV robot has gradually infiltrated into many aspects of human production and life, and has become a global hot research direction. However, due to the changeable and compact working environment, AGV robot still has many technical problems to be solved. The localization of AGV robot is the premise and key for AGV robot to move freely. To address the problem of accumulated error in wheel Odometry positioning and data drift in ultra-wideband (UWB) positioning when positioning AGV robots in an unknown environment, this paper establishes the coordinate system of AGV robots based on an independently built AGV robot motion control system, and combines the advantages and disadvantages of wheel Odometry and UWB positioning sensors, and uses the TEKF algorithm to fuse the positioning data of the two sensors The TEKF algorithm is used to fuse the positioning data of the two sensors in order to improve the positioning accuracy of the AGV robot. The experimental results show that the integrated positioning system of wheel Odometry and UWB can effectively restrain the cumulative error and data drift, and the positioning accuracy of multi-sensor fusion positioning is greatly improved compared with that of a single sensor, providing accurate and reliable positioning data for the motion control of AGV robot.

Keywords: AGV, Odometry, UWB, Fusion, TEKF

1. Introduction

AGV is a type of industrial robot, it is integrated with microcomputer, mechanical structure and multiple sensors. It can perform autonomous, manually controlled, and navigated obstacle avoidance movements and data exchanges over computer network. They are practically used in Intelligent Logistics, transportation, distribution and reception service. Accurate Estimation of the position and posture of AGV by making use of positioning sensors is a critical technology in researches for realizing AGV's autonomous movement. Theoretically, the precise positioning of AGV has been able to be realized under simulation environment recently. But in practice AGV positioning is affected by mechanical dimensional error, frictional loads and accuracy of sensors so is liable to non-trivial error [1]. Many researches on positioning technology have been dedicated by scholars, challenges and problems still exist.

In practical applications of the positioning technology, the sensors' merits vary due to the influence of environmental factors, the illuminating, time and temperature for instance. It is possible to make use the advantages of different sensors to estimate the position and posture of the robot. Multi-sensor fusion technology [2], in many scholars' favors, becomes critical to increase the capability of interference resistance and the accuracy of AGV positioning. Jian Chen et al proposed a REKF with a state transfer equation derived from the model of PDR trajectory estimation error model, the matching difference between DPR and magnetic field and that between DPR and WiFi are used as observation equation, to form a multi-sensor fusion positioning method, the result demonstrated the reduction of positioning error, and the increase of robustness [3]. Wenbao Pan et all made a fusion of GNSS, RTK and LIDAR data that relies on the stability of GNSS and RTK data to realize the switching the positioning methods optimally and the stable, reliable positioning of the autonomous rail vehicles running in any track condition can be obtained [4]. Xiaoxu Liang et al combined SLAM with a mobile measuring system which fused a LIDAR, an inertial measure unit and other sensors to realize the 3D real scene map [5].

As discussed above, the UWB provide accurate global positioning data but NLOS error [6] exists and the wheel type

Odometry behaves better in short time period but in long term error non-trivial error will be built up due to the accumulation [7]. Making use of their respective advantages by sensor fusion to obtain orientation angle of the AGV with two UWB, the combination of UWB and the Odometry can provide reliable positioning and posture of the AGV. In this paper the trajectory of the AGV obtained with single sensor and that obtained with sensor fusion are compared so as to validate the applicability of the sensor fusion method.

2. AGV Robot System Architecture

2.1. Hardware System Design

The AGV was equipped with 4 Mecanum wheels [8-9] to provide capability of omni-directional movement. In control system, NVIDIA Jetson Nano is used as upper computer which communication with the UWB labels through USB bus, an MSO multi-shaft controller acts as lower computer to control motors through CANopen bus. Figure 1 shows the block diagram of the control system. The upper computer of the AGV receives the positioning information, and sends control commands to the lower computer through serial communication port. The lower computer of the AGV calculates the rotating speed of motor according to the commands received to drive the servo motors. It also calculates the odometry data according to the feedback from encoders and sends the data to upper compute.

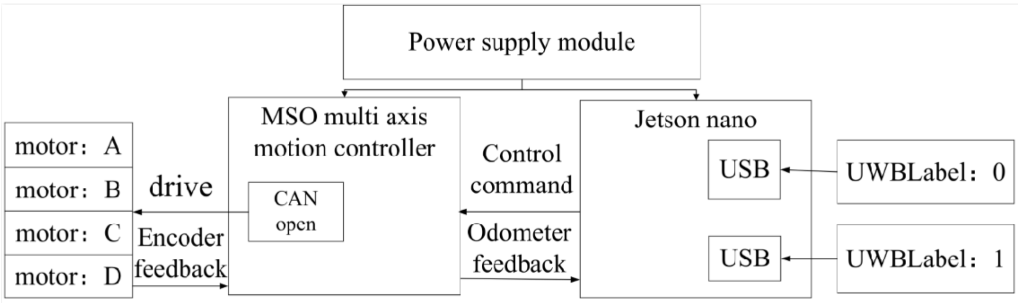

Figure 1. *AGV hardware system.*

The upper computer runs ROS robot operating system [10, 11] on the operating system Ubuntu 18.4 as the brain of the AGV in order to facilitate the code re-usability and ease the software development difficulties. The lower computer is the multi-shaft controller independently developed by Jiangsu OCEAN&MACRO INTELLIGENT TECHNOLOGY [12]. The CPU of the multi-shaft controller is STM32F407 capable of communicating through 232, 485 and CAN. There are 4G wireless module on board for remote communication etc. The upper computer of Jetson Nano and the lower computer of multi-shaft controller are shown in Figure 2 and Figure 3 respectively.

Figure 2. *Upper computer of Jetson Nano.*

Figure 3. *Lower computer of multi-shaft controller.*

2.2. Positioning System and Coordinate System

Multi-sensor fusion positioning system is composed of UWB, AGV, and a PC computer. The UWB positioning system has 4 base station A0, A1, A2, A3, two positioning Labels T0, T1 and a control console. The AGV robot is installed with encoders and UWB positioning Label T0 and T1, A notebook computer is used both as the positioning system server and the AGV monitor station.

Usually there are more than one 3D coordinate system defined onto a robot, every coordinate system is of 6 degrees of freedom, it is necessary to execute coordinate transform when position and posture of the robot changed to obtain their expression in different coordinate frame by translation and rotation. For the AGV moving on a flat plane, the transform only is only applying to two translation axis x, y and one rotation axis yaw: the movement orientation angle. The transform is applied by using formula (1):

$$\begin{bmatrix} x_2 \\ y_2 \end{bmatrix} = \begin{bmatrix} x_1 \\ y_1 \end{bmatrix} + \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x_1 \\ y_1 \end{bmatrix} \tag{1}$$

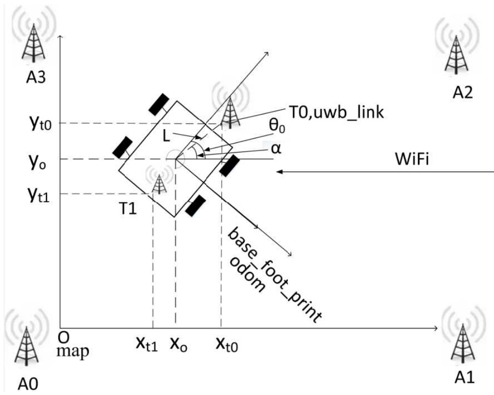

Figure 4. Coordinate system of the AGV.

As it is shown in Figure 4, UWB is assigned with the global frame named "map", Odometry has a sub-frame of the map named "odom", a sub-frame of the odom is attached at the geometrical center of the AGV named "base_footprint", T0 Label is attached with sub-frame of the base_footprint named "uwb_link". Regarding to the problem of initializing the coordinates of the odom in the map fame, it is to be solved by transform to obtain the coordinates of the odom in the map using the data obtained from T0 and T1 in initial time. The coordinates of T0 in the map can be represented as (x_{T0},y_{T0},θ_{T0}), and that of T1 as (x_{T1},y_{T1},θ_{T1}), the initial coordinates of the odom in the map (xo,yo,θo) can be obtained by formula (2):

$$\begin{bmatrix} x_o \\ y_o \\ \theta_o \end{bmatrix} = \begin{bmatrix} x_{T0} - L*\cos(\theta_0 - \alpha) \\ y_{T0} - L*\sin(\theta_0 - \alpha) \\ \arctan(\frac{y_{T0} - y_{T1}}{x_{T0} - x_{T1}}) \end{bmatrix} \tag{2}$$

3. The Method of Multi-sensor Fusion

3.1. The Odometry Estimation

The translation velocities of the AGV platform in its x, y axes and yaw angular velocity can be obtained by calculate the linear velocities of the 4 independent servo motors with the forward kinematic model (3):

$$\begin{cases} V_X = \frac{V_{W1} + V_{W2}}{2} \\ V_y = \frac{V_{w3} - V_{W1}}{2} \\ W_{yaw} = \frac{V_{W4} - V_{W1}}{2*(a+b)} \end{cases} \tag{3}$$

In (3), Vx, Vy and Wyaw are the translation velocities of the AGV platform in its x, y axes and yaw angular velocity, $V_{wi(i=1......4)}$ are respectively the linear velocity of the 4 Mecanum wheels, a and b the distance from the platform center to the wheel's center along the y and x axes directions. Given Δt is the control period of the AGV robot, the odometry estimation model is described by (4):

$$\begin{cases} X_{k+1} = X_k + V_x * \Delta t * \cos(\theta_{k+1}) \\ Y_{k+1} = Y_k + V_y * \Delta t * \sin(\theta_{k+1}) \\ \theta_{k+1} = \theta_k + W_{yaw} * \Delta t \end{cases} \tag{4}$$

3.2. UWB Observation Model

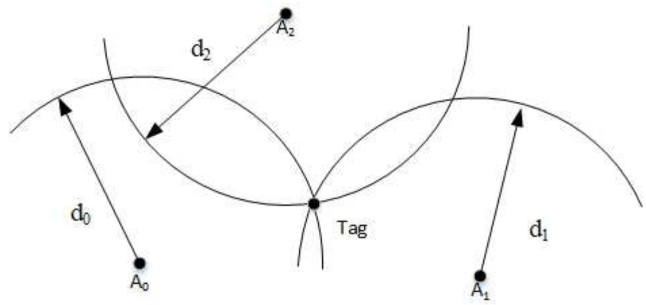

Figure 5. UWB positioning model.

In this paper, the algorithm Time of Arrival (TOA) is used for the UWB [13, 14] positioning. The base stations signal to the positioning label tag first, and records the current time t1, the label tag signals back and record the time t2, the time difference t2-t1 is calculated then the distance can be obtained by making use of light speed c. Using the distances obtained from three base stations as the radii of three circles with their centers located at the respective base station positions, the intersection of the three circles is the label tag's position. The algorithm model is shown in Figure 5.

Suppose positioning label Tag 0 has coordinates (x_{T0},y_{T0}), and that of Tag 1(x_{T1},y_{T1}), base stations Ai's coordinates are $(X_i,Y_i)_{(i=1......3)}$, The AGV robot position and orientation angle θ can be calculated with (5).

$$\begin{cases} \sqrt{(x_{T0} - X_0)^2 + (y_{T0} - Y_0)^2} = c*(t_2 - t_1)/2 \\ \sqrt{(x_{T0} - X_1)^2 + (y_{T0} - Y_1)^2} = c*(t_2 - t_1)/2 \\ \sqrt{(x_{T0} - X_2)^2 + (y_{T0} - Y_2)^2} = c*(t_2 - t_1)/2 \\ \theta = \arctan(\frac{y_{T0} - y_{T1}}{x_{T0} - x_{T1}}) \end{cases} \tag{5}$$

3.3. Fusion Algorithm Framework

The algorithm framework applies the TEKF algorithm to fuse the information from wheel type Odometry and UWB positioning system. TEKF consists of two steps: estimation and update steps. In estimation step the odometry information is processed, UWB information shall be the observation in update step. The framework is illustrated in Figure 6.

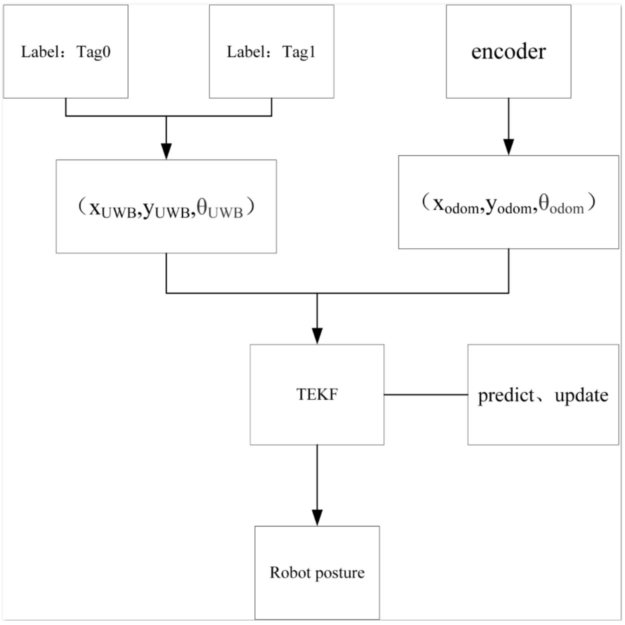

Figure 6. *Framework of the fusion algorithm.*

3.3.1. State Prediction

AGV robot dynamic state equation is described in equation (6):

$$x_{k+1} = f(x_k, u_k) + w_k \qquad (6)$$

In (6), f is the kinematic modeling function of the robot, x_k is the position and posture $[x,y,\theta]^T$ of the robot at time k, x_{k+1} is that of the robot at time k+1, u_k is the control inputs $[V_x,V_y,W_{yaw}]^T$ of the robot at time k. w_k is the Gaussian noise of the process.

Step 1: estimates the AGV position and posture with odometry information according to the estimation model equation (7):

$$\hat{x}_{k+1}^{-} = x_k^{\wedge} + \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} V_x \\ V_y \\ W_{yaw} \end{bmatrix} * \Delta t \qquad (7)$$

In (7), $\hat{x}_{k+1}^{-}$ is the estimated value of the AGV robot's position at time k+1. $x_k^{\wedge}$ is the optimal estimated value of the robot's position at time k.

Step 2: The formula of the covariant matrix for the a priori estimated value of the position and posture of the robot is shown in (8):

$$P_{k+1} = TFP_kF^T + Q_{odom} \qquad (8)$$

The angle of yaw, θ's variation of the AVG in time is nonlinear, it is necessary to linearize it. In (8), F is the Jacobian matrix:

$$F = \begin{bmatrix} 1 & 0 & [-V_X * \sin(\theta_k) - V_y * \cos(\theta_k)] * \Delta t \\ 0 & 1 & [V_X * \cos(\theta_k) - V_y * \sin(\theta_k)] * \Delta t \\ 0 & 0 & 1 \end{bmatrix}$$

The covariant matrix of odometry noise is:

$$Q_{odom} = \begin{bmatrix} 0.01 & 0 & 0 \\ 0 & 0.02 & 0 \\ 0 & 0 & 0.17 \end{bmatrix}$$

In (8), the factor T is:

$$T = \begin{bmatrix} T_x & 0 & 0 \\ 0 & T_y & 0 \\ 0 & 0 & T_{yaw} \end{bmatrix}$$

Definition:

$$T_i = \begin{cases} 1, \left|x_{odom,x,y,yaw} - x_{UWB,x,y,yaw}\right| \le e_{var} \\ 1.5, \left|x_{odom,x,y,yaw} - x_{UWB,x,y,yaw}\right| \le e_{var} \end{cases}$$

In the formular e_{var} is the error threshold for the Odometry and UWB system, $x_{(odom,x,y,yaw)}$ and $x_{(UWB,x,y,yaw)}$ are the realtime states of the Odometry and UWB system.

3.3.2. Status Updates

At the moment k + 1, the UWB provides the positional information as $[x_{k+1,UWB}, y_{k+1,UWB}, \theta_{k+1,UWB}]$ and the observation model at this point is equation (9):

$$z_{k+1} = \begin{bmatrix} x_{k+1,UWB} \\ x_{k+1,UWB} \\ x_{k+1,UWB} \end{bmatrix} + v_{k+1} \qquad (9)$$

Where z_{k+1} is the observed volume of the system at time k + 1, and v_{k+1} is the observed noise at the moment k +1.

Step 3: Calculate Kalman gain K equation (10):

$$K = P_{k+1} * H^T * (H * P_{k+1} * H^T + R_{k+1})^{-1} \qquad (10)$$

where H is the Jacobi matrix of the observed model, which is a 3*3-unit array. R_{k+1} is the covariance matrix of the observed noise.

$$R_{k+1} = \begin{bmatrix} 0.05 & 0 & 0 \\ 0 & 0.05 & 0 \\ 0 & 0 & 0.052 \end{bmatrix}$$

Step 4: The robot a posteriori state estimate is equation (11):

$$\hat{x}_{k+1}^{'} = \hat{x}_k + K * (z_{k+1} - H * \hat{x}_k) \qquad (11)$$

Step 5: Obtain the optimal covariance matrix after the forecast update in preparation for the next forecast update Equation (12):

$$P_{k+1}^{'} = (I - K * H) * P_K \qquad (12)$$

where I is a 3*3 unit array.

4. Experiment

AGV movements can be divided as translation and rotation at the spot, hence the experiments are designed so that the movements are composited into a circular movement in order to validate the positioning effectiveness. The software that controls the robot are based on QT [15-16], to realize the robot's circular trajectory and to facilitate the measurement of the actual trajectory. The experimental environment is shown in the Figure 7.

The robot control software is executed with command in format of (LM,x,y,v) and (CM, R,yaw,v). Where LM realize a translation movement and CM a circular movement. R is the radius of the circular trajectory, yaw the rotation angle, v the velocity of translation or rotation movement. QT GUI of the software is shown in Figure 8. it saves every positioning data from sensors and that of the fusion algorithm to produce the chart in Figure 9.

In the experiments the AGV robots moves along straight line 8 meter long in advance then goes enters the circular path of 8 meters in diameter. The positioning was much effective in straight line movement and the mean error calculated is 1.47cm, but in circular movement, due to the non-trivial influence of the angle yaw, the mean error of odometry positioning is approximately 44.07cm, and 7.67 cm of the fusion algorithm. It is proved that the eventual positioning accuracy of the AGV product is 8 cm.

The comparison between the positioning errors of the single sensor data and the data of the fused algorithm with respect to the theoretical trajectory is shown in Figure 4. The root-mean-square errors are summarized in the following Table 1.

Figure 7. *Experimental environment.*

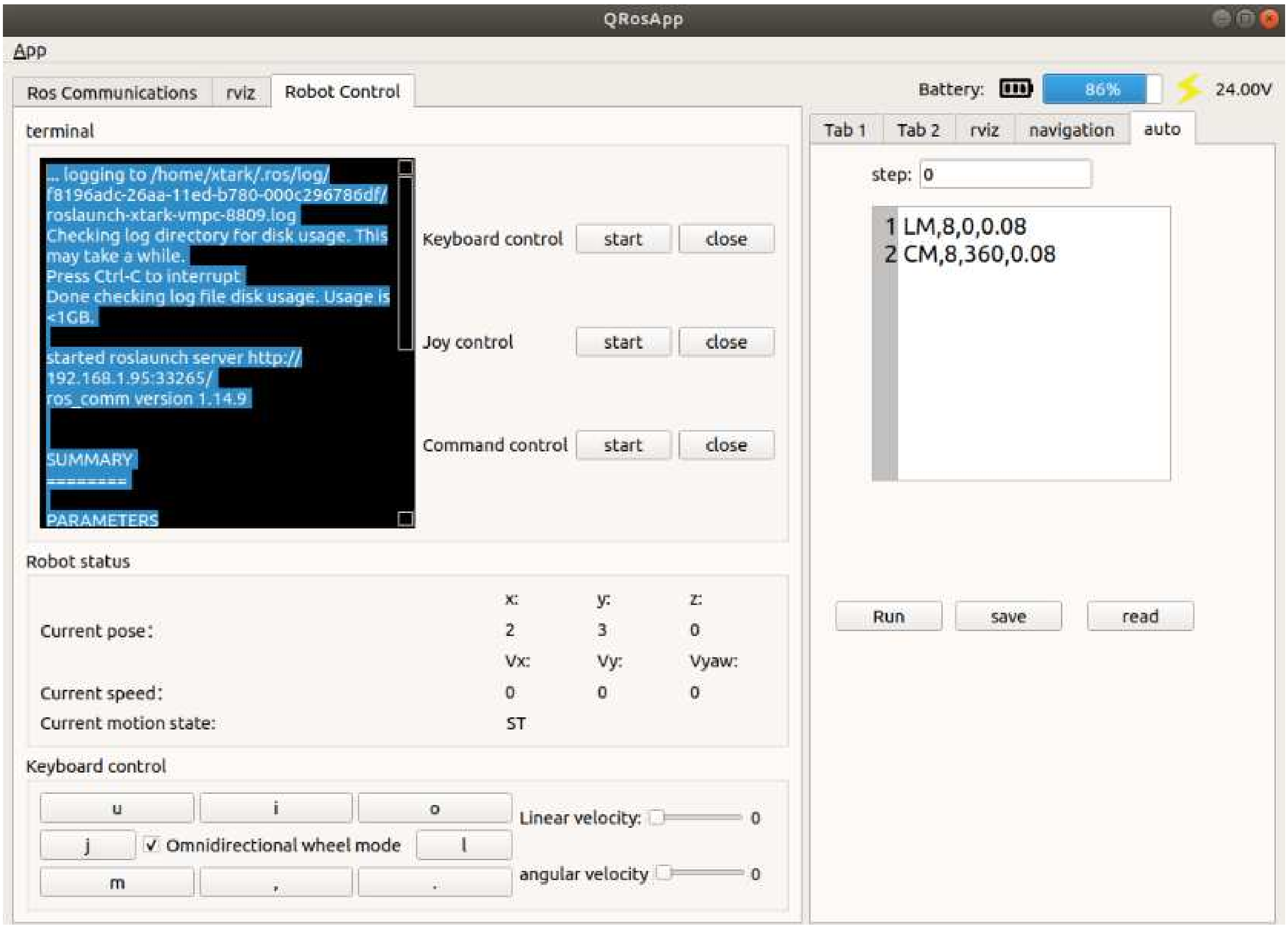

Figure 8. *QT control software.*

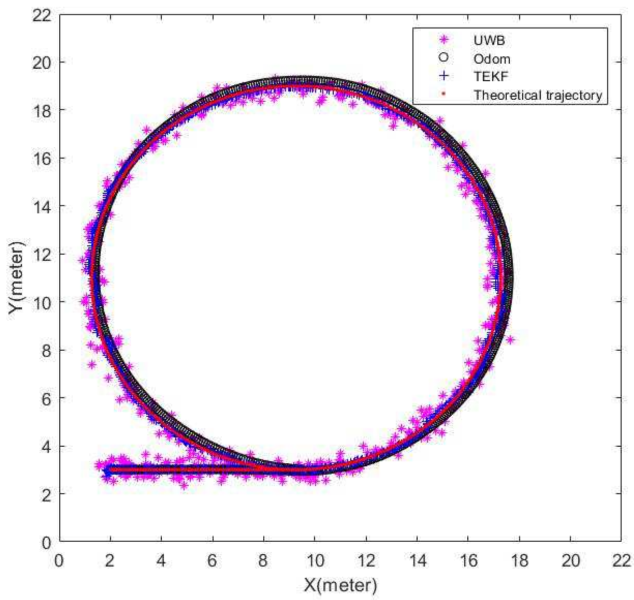

Figure 9. *AGV trajectory diagram.*

Table 1. *Table information.*

Comparison of errors	Root-mean-square errors (cm)
Odometry	44.07
UWB	31.45
TEKF	7.67

5. Conclusion

This paper proposed a multi-sensor fusion method for positioning of the AGV robot. The odometry coordinates obtained by calculating the encoder data, the UWB global coordinates and the angle of yaw calculated with 2 UWB labels are fused with TEKF. The method is tested by experiments on an independently built robot system. The result of the experiments shows that translation movement shall have better positioning result duo to the absence of the change in angle of yaw. When the rotation of the robot platform involved, odometry positioning demonstrates significant error. After the fusion through TEKF, the positioning accuracy has a remarkable improvement. Hence the effectiveness of the multi-sensor fusion method is verified as a satisfactory to its targeted product requirement.

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