Ultra-wide band positioning for automatic guided vehicles

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Abstract. In this paper we propose ultra-wide band radio solution for indoor AGV positioning. Advantages over known solutions are described. Characteristics of the used ultra-wide band component base are given. Considered solution consists from anchors and tags. System operates with RTDoA method. Extended Kalman Filter algorithm is used to estimate the coordinates of the tag. Modified Extended Kalman Filter algorithm is obtained. It allows to eliminate erroneous measurements from solution. Result of the experiment are shown.

1. Introduction

Technologies of artificial intelligence are advancing very fast. Tasks that automatic guided vehicles (AGV) are performing are complex and sophisticated. Knowing itself coordinates (position) is very important for these aims and demand for accuracy is endless. In the same time there are a lot of solutions and technologies that used for AGV positioning, but they are different, have their own advantages and disadvantages [1]. All of approaches differ in accuracy and cost.

The most known solution is using marked magnet lines or wires on the floor (figure 1). Robot follows these lines and always moves along known constant paths [2]. It’s a cheap and reliable solution that works well but restricts freedom of movements of the robot. It’s not suitable for smart AVG that performing complex tasks and cannot be used in case of complicated goals.

There is a lidar-based solution. It is based on optical technology (figure 2). That solutions provide sub-millimeter accuracy but they are expensive are not suitable for wide scale usage [3]. Also their performance depends on the illumination of the room. In addition, lidars tend to aging and wear.

Also solutions based on Inertial Measurements Units (IMU) exist [4]. They use measurements of gyroscopes and accelerometers. Pedometers and odometers are also used (Pedestrian dead reckoning). Inertial technology provides high rate and low noisy measurements, but have increasing systematic error. They need frequent calibration and are usually used in combination with other technologies.

Ultrasonic solution (figure 3) may be accurate low-cost solution, but has low rate and big latency and is not suitable for fast moving objects [5].

Solutions based on narrowband radio like Wi-Fi, BlueTooth and RFID have 5-7 meters accuracy that is not enough for AGV positioning (figure 4) [6]. At the same time narrow band radio technologies provide very low latency and high rate and large operational ranges comparing to ultrasonic solutions. Also they can perform in conditions when there a lot of obstacles in the room (for example walls, furniture, people). Solutions based on radio technologies need infrastructure of anchors to perform. AGV need to be equipped by tags.
It seems that radio-based technologies are the most suitable for that purposes except their accuracy. The main reason of such poor accuracy of radio systems is multipath. One of the ways to reduce multipath influence is increasing of signal band or it’s similar – to decrease the radio impulse duration. Narrowband signals have long radio impulse duration. There may be a situation when delay between direct and reflected signals is less than impulse duration. In the results these signals may interfere on the receiver antenna. It’s difficult to make out these signals and it causes errors of coordinate’s calculation. On the other hand ultra-wide band signals have short radio impulse duration and in the same situation they are not interfere. That’s why ultra-wide band (UWB) signals are more suitable for using in aims of AGV indoor positioning. They provide centimeter-level accuracy and become a cheap alternative for lidar-based solutions [7].

2. System overview
Ultra-wide band is a standard technology that operates at carrier frequencies from 3 to 9 GHz and has 500 MHz signal band.

In our work we use radio transceivers complement to that standard. They are Loligo LPS2 mini units based on Decawave DWM1000 UWB module (figure 5). They have very small form factor and can be easily placed at the moving object (e.g. AGV). These units provide RTDoA method of positioning with rate up to 24 times per second.

The navigation system based on these units consists of anchors and tags. Anchors are situated around the perimeter of a working zone (figure 6). There are anchors of two types: master and slave. Master is a main anchor that determines the pace of the entire system. Illustration of the system performance is illustrated on figure 7. Tags may be installed on mobile objects like robots or humans. Tags measure difference of distances from anchors to estimate itself position.
3. Models and algorithms

Differences of ranges are measurements in proposed system. It can be written as:

\[ \mathbf{y}_k = (y_{1,k} y_{2,k} \ldots y_{N,k})^T = \mathbf{\Delta R}_k + \mathbf{n}_k, \]

where \( \mathbf{n}_k \) – is vector of white Gaussian noises, \( k \) – discrete time step. Differences of ranges calculated as:

\[ \mathbf{\Delta R}_{i,k} = \sqrt{(x_k - x_i)^2 + (y_k - y_i)^2} - \sqrt{(x_m - x_i)^2 + (y_m - y_i)^2}, \]

where \( (x_k, y_k)^T \) are coordinates of vehicle on \( k \) step, \( (x_i, y_i)^T \) – coordinates of \( i \)-th slave anchor, \( (x_m, y_m)^T \) – coordinates of master-anchor.

Model of measurements (1) may be written as:

\[ \mathbf{y}_k = \mathbf{S}_k (\mathbf{c} \mathbf{x}_k) + \mathbf{n}_k, \]

where \( \mathbf{S} \) is non-linear matrix function.

To estimate the coordinates of the tag we need to know their dynamic models. To describe dynamic model of the object we need to define the state vector. It includes two dimension coordinates, velocities and accelerations:

\[ \mathbf{x} = (x \ V_x \ a_x \ y \ V_y \ a_y)^T. \]
Then we obtain the dynamic model:

$$x_k = F_{k-1}x_{k-1} + G_{k-1} \xi_{k-1}. \quad (5)$$

It’s a classic linear dynamic model with known matrices $F$ and $G$. $\xi_{k-1}$ is a white Gaussian noise vector:

$$F = \begin{bmatrix}
1 & T & 0 & 0 & 0 & 0 \\
0 & 1 & T & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & T & 0 \\
0 & 0 & 0 & 0 & 1 & T \\
0 & 0 & 0 & 0 & 0 & 1
\end{bmatrix},
G = \begin{bmatrix}
0 & 0 \\
T & 0 \\
0 & 0 \\
0 & 0 \\
0 & 0 & 0 & 0 & T \end{bmatrix}. \quad (6)$$

All information needed to estimate the tag position is described. The Extended Kalman Filter algorithm is used (7-12). It’s a well known solution described in a lot of sources [8].

$$\tilde{x}_k = F_{k-1}\hat{x}_{k-1}, \quad (7)$$

$$\tilde{D}_{x,k} = F_{k-1}D_{x,k}F_{k-1}^T + G_{k-1}D_{x}\xi_{k-1}^T, \quad (8)$$

$$\tilde{y}_k = S_k(c\tilde{x}_k),$$

$$K_k = \tilde{D}_{x,k}H(\tilde{x}_k)^{-1}(H(\tilde{x}_k)\tilde{D}_{x,k}H(\tilde{x}_k)^{-1} + D_n)^{-1}, \quad (10)$$

$$D_{x,k} = \tilde{D}_{x,k} - K_kH(\tilde{x}_k)\tilde{D}_{x,k}, \quad (11)$$

$$\hat{x}_k = \tilde{x}_k + K_k(y_k - \tilde{y}_k). \quad (12)$$

In (10) there is a design matrix $H$ that can be calculated as

$$H(\tilde{x}_k) = \frac{dS_k(c\tilde{x}_k)}{dx} = \begin{bmatrix}
H_{1,1} & 0 & 0 & H_{1,4} & 0 & 0 \\
H_{2,1} & 0 & 0 & H_{2,4} & 0 & 0 \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
H_{N,1} & 0 & 0 & H_{N,4} & 0 & 0
\end{bmatrix}. \quad (13)$$

where

$$H_{i,1}(x,y) = \frac{x-x_i}{\sqrt{(x-x_i)^2 + (y-y_i)^2}} - \frac{x-x_M}{\sqrt{(x-x_M)^2 + (y-y_M)^2}}, \quad (14)$$

$$H_{i,4}(x,y) = \frac{y-y_i}{\sqrt{(x-x_i)^2 + (y-y_i)^2}} - \frac{y-y_M}{\sqrt{(x-x_M)^2 + (y-y_M)^2}}. \quad (15)$$

We obtained the algorithm that allows us to estimate the position of an object for described model of measurements (1). But in real conditions there are a lot of interferences that cause distortion of measurements except noises $n$. They exist because of obstacles in the room and non static electromagnetic field. There a lot of moving objects in working zone of the system (people, another vehicles) that can make "bad" measurements for navigated vehicle.
In this case we need to modify proposed algorithm with procedure of elimination of abnormal errors from position solution. It is known that the minimum amount of anchors to calculate the object position in 2D is 3. But if we have redundancy of anchors (more than the minimum amount) it allows us to exclude anchors with erroneous measurements.

Information about measurement errors is contained in the residuals of the measurements:

\[ \rho_k = y_k - \tilde{y}_k \]  

(16)

If distribution of residuals is known, it's possible to define thresholds \( h \). If one of the residuals exceeds the threshold \( \rho_i > h_i \), it means that corresponding measurement contains error. That erroneous measurement can be eliminated by zeroing. Modified algorithm shown at figure 8.

4. Experiment

To estimate the efficiency of proposed algorithms experiment has been held. Navigation system was deployed in the building (figure 9). Size of working zone was 5x4 meters. Navigation system contains 8 anchors and 1 user. User was a wheeled robot equipped by UWB tag (figure 10).

Experiment consisted of two parts. In the first part robot was in static in the point with known coordinates. In the second part robot was driving in a circle. Obtained measurements were processed using two algorithms: Extended Kalman Filter (EKF) and Modified Extended Kalman Filter (MEKF). Results are shown on figures 11-14.
Obviously, estimations obtained by EKF algorithm have some abnormal errors (figures 11,13) compared to estimations obtained by MEKF algorithm (figures 12,14). The results show that MEKF have higher accuracy than simple EKF and allows avoiding abnormal estimations of position. Accuracy of MEKF positioning is less than 5 centimeters. It is a good result comparing to known solutions described in section 1.

5. Conclusion
In this paper we proposed ultra-wide band radio solution for indoor AGV positioning. Advantages of that solution are high accuracy and high rate of measurements. Also such systems are cheaper than precision optical systems. Modified Extended Kalman Filter algorithm is obtained. It’s allows to exclude errors of measurements from positioning solution caused by multipath and obstacles. It’s a big problem for indoor radio systems. The directions of current and future research are the following: using IMU measurements to increase accuracy. Integration of radio and IMU measurements can improve current results.

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