A UWB-Based Low-Cost and Precise Localization Method for Mobile Robots

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Abstract. The need for automating cargo management in a manufacture environment is urgent. Recent advance in big data and artificial intelligence areas has made it possible. As we known, most cargoes are transported using autonomously guided vehicles or manpower. Many autonomously guided vehicles follow paths that are predefined and usually marked by labels that can be easily found by vehicles. The use of predefined path for vehicle navigation greatly limits the deployment of autonomously guided vehicles. A few vehicles use high accuracy Light Laser Detection and Ranging for sensing and guidance. In this paper, a low-cost and precise method for mobile robots has been developed. Considering the high nonlinearity of UWB ranging data, a least square method is used to find optimal locations and a gradient decent approach is applied for fast convergence to the optimal results. The proposed method is also able to diagnose the ultra-wide band data and will throw away any data corrupted by noise. Therefore, the robustness is obtained.

1. Introduction

Mobile robots can be used for carrying cargos and this type of mobile robots is called automated guided vehicle (AGV). According to whether AGVs guidance is based on predefined paths or not, AGVs are divided to two types, AGVs based on predefined paths and AGVs not. AGVs based on predefined paths will require to pave roads with artificial marks or labels to be detected by special sensors on the vehicles. These vehicles can only move on those paths, which largely constrains their applications [1], [2], [3]. This type of AGVs usually works in structured manufacture environments. They are lack of flexibility and cannot deal with unexpected changes.

AGVs without relying on predefined roads use some internal sensing equipments either to detect environment nearby or to directly achieve positions and locate themselves. The other AGVs normally use sensing technologies such as satellite positioning systems, ranging sensors and vision cameras, and so on. Localization is the centre of the navigation system of an AGV. In the past decades, Light Detection and Ranging (LiDAR) has been heavily applied in the localization of AGVs due to the great precision and reliability. Compared to AGVs with predefined paths, this type of AGVs has much better flexibility. In [4], a system using laser ranger finder has been developed for autonomous navigation. In [5], a unmanned flying vehicle using a 3D ranging sensors has been presented. But, LiDAR is not fit for many low-cost applications due to its bad cost efficiency. And the laser signals are subject to specular reflection, thus can not work in environments with glass. In [6], a camera-based system for robot localization and obstacle avoidance has been presented. The system is able to run real time with a frame rate of 30Hz, however, it consumes lots of computational resource to process the large amount of images, thus not suitable for cost sensitive applications either. Outdoor applications using satellite positioning systems can refer to [7], [8]. However, they don’t work indoor because of...
the signal attenuation. Developing a cost effective indoor positioning system is urgent. Recently, the UWB chip, Decawave DW1000 achieves a big success because of the low-cost (roughly $5 per chip) and accuracy. Recently, some UWB-based systems have been developed. In [9], a UWB-based low-cost system is presented, where the system uses triangulation to localize and the sensor noise is not really treated. Some researcher [10] developed an UWB error model and used it to increase the positioning. In our method, a new UWB based method is presented. UWB sensors are normally called anchors if they are fixed in some places, while other UWB sensor are normally called labels if they are movable and need to localize themselves. In our method, a satellite like system where there are three anchors and one label is developed. The UWB sensor noise are also considered for robustness. The following are the details of the method.

2. The Proposed Method
In our system, the test bed is a differential-drive mobile robot with a UWB label attached. In the test environment, three anchors are installed in the right positions. As shown in Fig. 1, the UWB label is located in the middle of the UWB anchors. The first position of the test bed is defined as the origin (0,0). The label receives ranging signals from three anchors real time. In order to get better positioning, the anchors are recommended to be installed in a relatively high position, for example, a height about 2 meters. And anchors are preferred to be deployed a couple of tens of meters away from each other. Such a UWB sensing system can cover a field as much as a couple of hundreds of square meters.

![Figure 1. UWB reference frame](image)

In the figure, \( T1, T2, \) and \( T3 \) denote three UWB anchors. The UWB label is equipped on the test bed. The distance \( d_{ij} \) is between anchor \( i \) and \( j \); the distance \( d_i \) is between the anchor \( i \) and the label. A triangle like deployment is preferred for a bigger sensing coverage.

Without loss of generality, assume there are \( n \) UWB anchors \((T1, T2, \ldots, Tn)\). And their coordinates are \((a1, b1), (a2, b2), \ldots, (an, bn)\). At any moment, distances of UWB anchors from the robot located in \((a, b)\) are denoted as \(d1, d2, \ldots, dn\). Then,

\[
\sqrt{(a-a_1)^2+(b-b_1)^2} + \sigma = d_1 \\
\sqrt{(a-a_2)^2+(b-b_2)^2} + \sigma = d_2 \\
\ldots \\
\sqrt{(a-a_n)^2+(b-b_n)^2} + \sigma = d_n
\]  

(1)
There, \( \sigma \) is the positioning error. At the given moment \( k \), the test bed location is \((a_k, b_k)\). Based on Taylor series, the above equations can be linearized as the Equations (2).

\[
H = \begin{bmatrix}
\frac{a(k) - a_1}{\sqrt{(a-a_1)^2 + (b-b_1)^2}} & \frac{b(k) - b_1}{\sqrt{(a-a_1)^2 + (b-b_1)^2}} \\
\frac{a(k) - a_2}{\sqrt{(a-a_2)^2 + (b-b_2)^2}} & \frac{b(k) - b_2}{\sqrt{(a-a_2)^2 + (b-b_2)^2}} \\
\vdots \\
\frac{a(k) - a_n}{\sqrt{(a-a_n)^2 + (b-b_n)^2}} & \frac{b(k) - b_n}{\sqrt{(a-a_n)^2 + (b-b_n)^2}}
\end{bmatrix}
\]

\[
Q = \begin{bmatrix}
d_1 - \sqrt{(a(k) - a_1)^2 + (b(k) - b_1)^2} \\
d_2 - \sqrt{(a(k) - a_2)^2 + (b(k) - b_2)^2} \\
\vdots \\
d_n - \sqrt{(a(k) - a_n)^2 + (b(k) - b_n)^2}
\end{bmatrix}
\]

Using above symbols, the Equations (2) can be rewritten as shown in the Equation (3).

\[
Q = H \cdot \Delta a(k)
\]

Using the least square approach, we can obtain the iteration variable at instant \( k \) as,

\[
\Delta a(k) = (H^T \cdot H)^{-1} \cdot H^T \cdot Q
\]

In order to find the optimal result, the iteration law is computed as,

\[
\begin{bmatrix}
a(k+1) \\
b(k+1) \\
\sigma
\end{bmatrix} = \begin{bmatrix}
a(k) \\
b(k) \\
0
\end{bmatrix} + \lambda \cdot \Delta a(k)
\]

There, \( \lambda \) is the learning ratio. In a few iterations, the optimal result is likely to be computed.
Usually, UWB range data is corrupted by noises. So a mechanism that can analyze the sensor data is needed. Assume,

$$\zeta = [\Delta a(k)]^T \cdot \Delta a(k)$$

In this way, the factor \(\zeta\) can be used to exam whether the range data is good or not. Any bad sensor data will be thrown away. Hence the robustness could be obtained.

3. The Experimental Results

As shown in Fig. 2, the test bed is a differential-drive mobile robot and it has a UWB sensor installed. Besides, three are three more UWB anchors installed in the testing environment, which forms the overall UWB sensing network. The robot position is estimated during the experiment. In order to know the accuracy of the robot position, a Real-Time Kinematic (RTK) satellite positioning system that is a positioning accuracy of up to 2 cm is also equipped on the test bed. In Fig. 2, the front white disk is the UWB sensor and the rear white disk is RTK receiver.

In the reference frame system as Fig. 1, the coordinates of anchors are unique. The robot as shown in Fig. 2 is differentially driven with a minimum turning radius of zero. In the experiments, the robot was programmed to run in a zigzag-like way as shown in Fig. 3. Inside the area, it travelled in straight lines as much as possible. The robot positions of the localization algorithm are presented in Fig. 4 and Fig. 5.

![Figure 2. A test bed](image)

![Figure 3. A zig-zag like motion](image)

![Figure 4. Localization results](image)

![Figure 5. Positioning error of the UWB System](image)

4. Conclusions

A UWB-based low cost localization approach is developed. A least square method is used to find optimal results and a gradient decent algorithm is applied for fast convergence to the optimal results. The proposed system itself can diagnose the UWB data and will throw away any data corrupted by noise. Therefore, the robustness is obtained. The test results show the algorithm is able to localize the robot with an accuracy about 20 cm. Besides, the geometry of UWB sensors can also affect the
localization precision. The robot is likely to achieve much higher accuracy when it is located in the central region of other UWB anchors, which is a known in a satellite positioning system.

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