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PID Application: RTLS

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1. Introduction

Locating systems are categorized as macro or micro locating systems, depending on service coverage. Macro locating systems offer wide coverage of over ten kilometers. These systems are allowed large error margins of over ten meters. They are for use in a global positioning system (GPS) [1] and in mobile locating systems between a mobile station (MS) and a base station (BS) [2]. A micro locating system, by contrast, operates in a small coverage area of less than ten meter, such as indoor environments where it is hard to use a GPS system.
A micro locating system requires a high accuracy of within one meter. Moreover, it requires real-time calculation for more accurate estimation when the target node changes position. Such a real-time locating system (RTLS) is frequently required in robotics applications. However, the conventional direct calculation (DC) method requires a heavy computation load, such as floating point calculation. This not only imposes a high computational load on an embedded system, but also decreases the accuracy [3].
This chapter introduces a PID application in real-time locating system. A ToA algorithm is used to obtain the target node coordinates, but a conventional DC method, which incurs heavy calculation time, is not suitable for embedded systems. This paper proposes the use of a P-control in the PID control algorithm to resolve real-time locating system issues. Performance measures of the accumulated operator number and position error are evaluated. It is shown that the PID method has less calculation and more robust performance than the DC method.

2. Conventional location system

To calculate the target node coordinates, the triangulation method requires more than three fixed reference nodes for which the coordinates are already known. In this method, each reference node calculates the distance between the reference and target nodes to count the propagation time by using time of arrival (ToA) algorithm. The target node estimates two-dimensional coordinates (X_T, Y_T) using this information
The triangulation method is shown in Figure 1 [4]. This method consists of three known reference nodes $((X_1, Y_1), (X_2, Y_2)$, and $(X_3, Y_3))$ and an unknown target node (X_T, Y_T). Each reference node measures its distance (D_{R1}, D_{R2}, and D_{R3}) from the target node. The DC method uses the relation between the coordinates and the distance. Each distance is expressed by the coordinates of the reference and target nodes, as shown in equation 1.

$$\begin{aligned} D_{R_i} &= \sqrt{(X_T - X_i)^2 + (Y_T - Y_i)^2} \\ &= \sqrt{X_T^2 + Y_T^2 - 2(X_i X_T + Y_i Y_T) + X_i^2 + Y_i^2} \end{aligned} \tag{1}$$

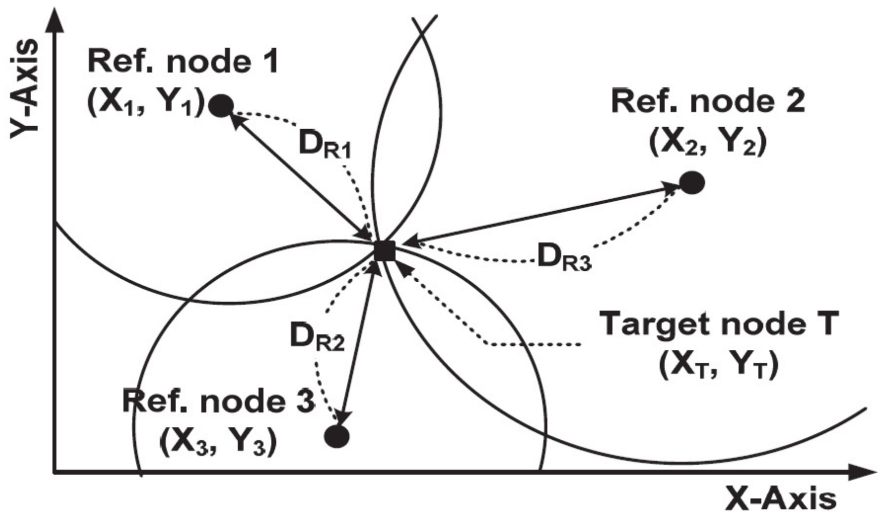

Fig. 1. The triangulation method using the DC method when the number of reference nodes is three

These equations are simplified by squaring and repositioning, as shown in Equation (2).

$$\begin{aligned} X_T^2 + Y_T^2 - 2(X_1X_T + Y_1Y_T) &= D_{R_1}^2 - X_1^2 - Y_1^2 \\ X_T^2 + Y_T^2 - 2(X_2X_T + Y_2Y_T) &= D_{R_2}^2 - X_2^2 - Y_2^2 \\ X_T^2 + Y_T^2 - 2(X_3X_T + Y_3Y_T) &= D_{R_3}^2 - X_3^2 - Y_3^2 \end{aligned} \tag{2}$$

Using these equations, it is complex to calculate X_T and Y_T, so it is assumed that reference node 3 is located at $[0, 0]$. then total coordination are change as $\widehat{X}_T$, $\widehat{Y}_T$, $\widehat{X}_i$, and $\widehat{Y}_i$, which is shifted values as shown in

$$\begin{aligned} \widehat{X}_T \triangleq X_T - X_3,\ \widehat{X}_1 \triangleq X_1 - X_3,\ \widehat{X}_2 \triangleq X_2 - X_3 \\ \widehat{Y}_T \triangleq Y_T - Y_3,\ \ \widehat{Y}_1 \triangleq Y_1 - Y_3,\ \ \widehat{Y}_2 \triangleq Y_2 - Y_3 \end{aligned} \tag{3}$$

Then, the third equation ($X_T^2 + Y_T^2 - 2(X_3X_T + Y_3Y_T) = D_{R_3}^2 - X_3^2 - Y_3^2$) is simplified with $X_T^2 + Y_T^2 = D_{R_3}^2$, as shown in Equation (4).

$$\begin{aligned} \widehat{X}_1\widehat{X}_T + \widehat{Y}_1\widehat{Y}_T &= \frac{D_{R_3}^2 - D_{R_1}^2 + \widehat{X}_1^2 + \widehat{Y}_1^2}{2} \\ \widehat{X}_2\widehat{X}_T + \widehat{Y}_2\widehat{Y}_T &= \frac{D_{R_3}^2 - D_{R_2}^2 + \widehat{X}_2^2 + \widehat{Y}_2^2}{2} \end{aligned} \tag{4}$$

To make the easy calculation, the complex constant value of equation 4 notate simple A and B symbols. those are descried in following equations.

$$A \triangleq \frac{D_{R_3}^2 - D_{R_1}^2 + \widehat{X}_1^2 + \widehat{Y}_1^2}{2}, \quad B \triangleq \frac{D_{R_3}^2 - D_{R_2}^2 + \widehat{X}_2^2 + \widehat{Y}_2^2}{2} \tag{5}$$

Using those notations, the equation 4 will be changed as.

$$\hat{X}_1\hat{X}_T + \hat{Y}_1\hat{Y}_T = A, \quad \hat{X}_2\hat{X}_T + \hat{Y}_2\hat{Y}_T = B \tag{6}$$

Next, the coordinates of the target node are obtained by using elimination of the $\hat{X}_T$, and $\hat{Y}_T$ in both equation.

$$\hat{X}_T = \frac{A\hat{Y}_2 - B\hat{Y}_1}{\hat{X}_1\hat{Y}_2 + \hat{X}_2\hat{Y}_1}, \quad \hat{Y}_T = \frac{A\hat{X}_2 - B\hat{X}_1}{\hat{X}_1\hat{Y}_2 + \hat{X}_2\hat{Y}_1} \tag{7}$$

Then, the real target node coordinates are compensated to the coordinate values of reference 3, which values are shifted as assumed. Finally, the coordinates are obtained, as shown in equation 8.

$$X_T = \frac{A\hat{Y}_2 - B\hat{Y}_1}{\hat{X}_1\hat{Y}_2 + \hat{X}_2\hat{Y}_1} + X_3, \quad Y_T = \frac{A\hat{X}_2 - B\hat{X}_1}{\hat{X}_1\hat{Y}_2 + \hat{X}_2\hat{Y}_1} + Y_3 \tag{8}$$

The DC method is complex and uses many multiple and floating point operations; therefore, it is not suitable to embedded systems. Furthermore, the processing delay caused by use of the DC method results in position errors when the target node is moved, and the method always requires a substantial amount of calculation time whether the target node position changes or not. These features cause a performance reduction when using applications such as a real-time robotics locating system

3. PID algorithm application: RTLS

3.1 ToA algorithm using PID algorithm

The conventional method has the problem of heavy computation load for an embedded system. Therefore, a new coordinate calculation method is necessary for use with RTLSs. In this chaper, the PID calculation method is proposed to meet this need. The PID algorithm is a generic control loop feedback mechanism widely used in control systems. It attempts to correct the error between a measured process variable and a desired set point by calculating and then performing an appropriate action that can adjust the process accordingly. This algorithm involves three separate parameters: the proportional, integral and derivative values. The proportional value determines the reaction to the current error, the integral determines the reaction based on the sum of recent errors and the derivative determines the reaction to the rate at which the error has been changing. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve or the power supply of a heating element, as shown in equation 9 [5] [6].

$$u = K_P e + K_I \int e d\tau + K_D \frac{de}{d\tau} \tag{9}$$

Where K_P, K_I and K_D are tuning parameters and e is the error value. The PID algorithm was applied to the proposed coordinate calculation method. Figure 2 provides a more detailed explanation of the coordinate calculation method.

First, the pseudo target node is placed at an arbitrary position. Subsequently, the distance between the pseudo target node and each reference node is calculated, thereby giving the

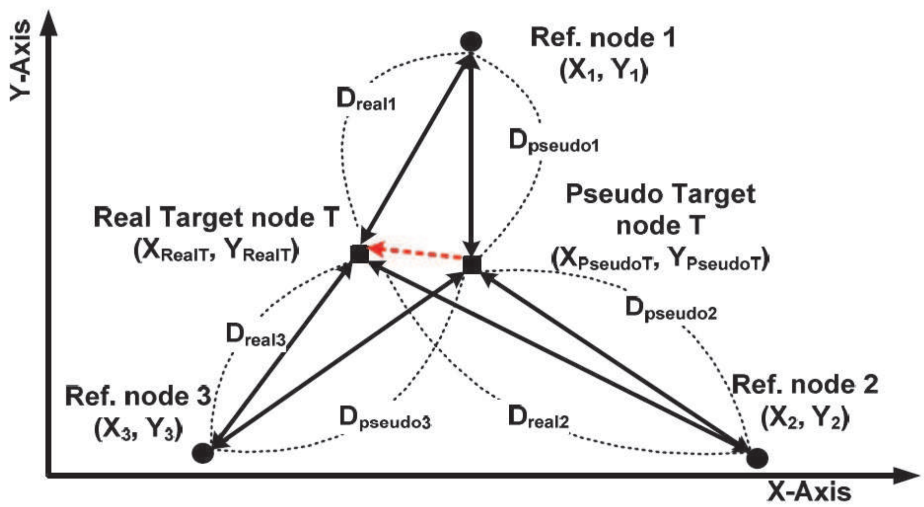

Fig. 2. Triangulation method using the PID calculation algorithm

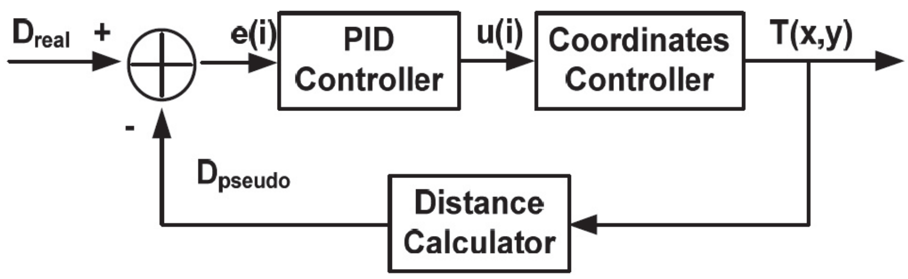

Fig. 3. A PID calculation block to obtain the target node coordinates

pseudo distance ($D_{pseudo1}$, $D_{pseudo2}$, and $D_{pseudo3}$). Using the PID algorithm, the pseudo target node converges to a real target node to control for distance error between the two positions. To utilize the PID algorithm in the coordinate calculation, the PID controller block consists of three blocks to calculate the coordinates, as shown in Figure 3.
First, the PID calculator obtains e by subtracting D_{pseudo}, from D_{real}, as shown in equation 10.

$$e(i) = D_{pseudo}(i) - D_{real}(i), \quad i = \{1, 2, \ldots, N\} \tag{10}$$

where i is the index of the reference nodes. Next, the PID controller block checks the error between the actual distances and the pseudo distances, and the PID controller calculates u using the input e value from each of the reference nodes.

$$u(i) = K_P e(i) + K_I \int e(i)dt + K_D \frac{de}{dt} \tag{11}$$

The coordinate controller adjusts the pseudo target node coordinates to be closer to the real target node. These processes are explained by Figure 4 and in the following equations.
The u values change the coordinate value to compensate for the position of the pseudo target node. It is assumed that the u values have the same vector as the D_{pseudo} value. The

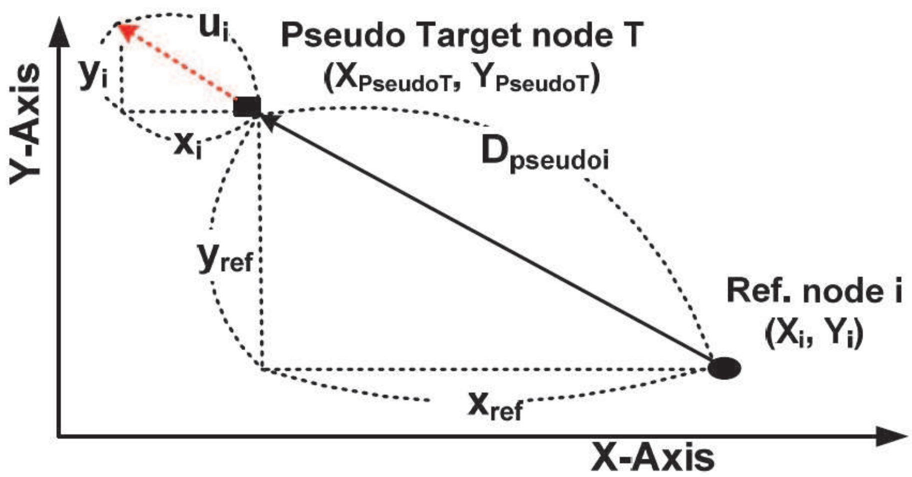

Fig. 4. A coordinate calculation algorithm to obtain the u value from the pseudo target node coordinates

compensation coordinates values ($x_{com}(i)$, $y_{com}(i)$) then have a proportional expression, as shown in equation 12.

$$
\begin{aligned}
x_{com}(i) : x_{ref}(i) &= u(i) : D_{pseudo}(i) \\
y_{com}(i) : y_{ref}(i) &= u(i) : D_{pseudo}(i)
\end{aligned}
\tag{12}
$$

Here $x_{ref}(i)$ and $y_{ref}(i)$ are calculated as $X_i - X_{pseudoT}$ and $Y_i - Y_{pseudoT}$. The expressions are changed as in the following equation.

$$
\begin{aligned}
x_{com}(i) &= \frac{u(i)}{D_{pseudo}(i)} \times x_{ref}(i) \\
y_{com}(i) &= \frac{u(i)}{D_{pseudo}(i)} \times y_{ref}(i)
\end{aligned}
\tag{13}
$$

The new coordinates of the pseudo target node are obtained by using the last pseudo target node coordinates($X_{pseudoT}$, $Y_{pseudoT}$), ($x_{com}(i)$ and $y_{com}(i)$).

$$
\begin{aligned}
X^{(n+1)}_{pseudoT} &= X^{(n)}_{pseudoT} - \sum_{i=1}^{N_{ref}} x_{com}(i) \\
Y^{(n+1)}_{pseudoT} &= Y^{(n)}_{pseudoT} - \sum_{i=1}^{N_{ref}} y_{com}(i)
\end{aligned}
\tag{14}
$$

where N_{ref} is the number of references.
Lastly, D_{pseudo}, which is the feedback value for the next calculation, is obtained using a distance calculator. This is shown in Equation (11). The pseudo target coordinates converge to the real target node after the iteration process.

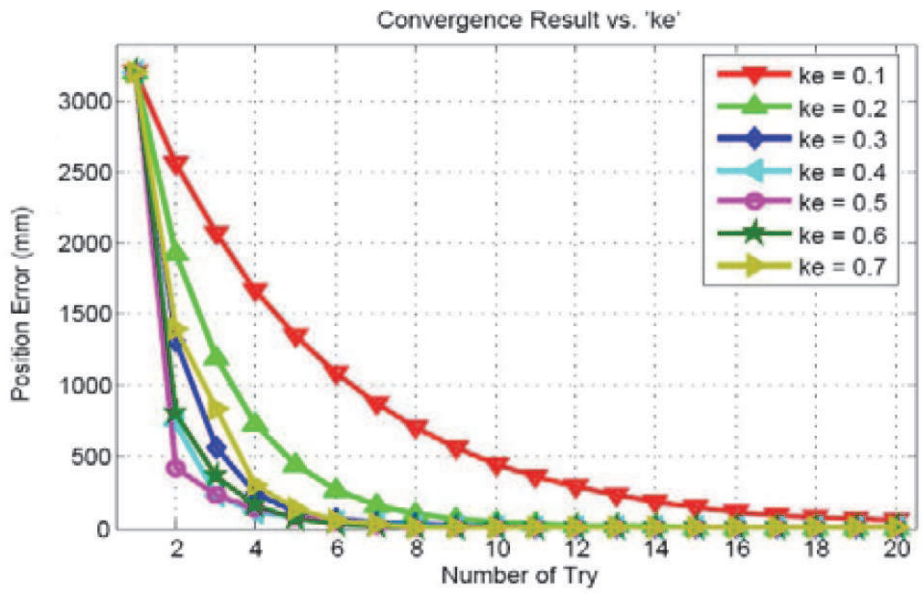

Fig. 5. The position error transition of the pseudo node using the PID method for each value of Kp

$$D^{(n+1)}_{pseudoT}(i) = \sqrt{(X^{(n+1)}_{pseudoT} - X_i)^2 + (Y^{(n+1)}_{pseudoT} - Y_i)^2} \tag{15}$$

The PID calculation method offers the advantage of continuous calculation because, in contrast to the DC method, its calculation time is reduced by using information from past positions. If the target node coordinates are calculated, the processing to calculate the next position is further reduced. Furthermore, the PID calculation method does not require a complex floating point operation. The PID calculation method is useful in embedded systems which use compact micro-processors and specific applications, such as real-time or continuous locating systems. Furthermore, this algorithm reduces the calculation process when the number of reference nodes is increased.

3.2 Simulation and result

In this section, the performances of the DC method and the proposed PID calculation algorithm are compared. The simulation environment is three reference nodes and one target node. The reference nodes are located at [100, 100], [100, 5000] and [5000, 100] (mm), respectively, and the target node is located at [3000, 3000] initially. The ranging result is set to have an error of 0.01   0.1%. The PID algorithm's parameter is set to P-control ($K_P = k_E$, $K_I = 0, K_D = 0$).
First, the PID calculation process will be explained. Figure 5 shows the position error of the pseudo target node versus the number of try times for each k_P parameter (k_E). The pseudo target node converges to the target node, where the pseudo target node is located at the coordinates of [2000, 2000] arbitrarily. As a result, the pseudo target node converges to the target node after eight iterations with a high accuracy of less than ten centimeters, except when k_P is 0.1. The parameter of k_P (k_E) has an optimal tuning value when set to 0.5.
Second, the calculation time of the DC method and that of the PID method are compared by counting the number of adders and multipliers when the target node has mobility. The mobility of a target node is generated by a normal distribution random model, and the

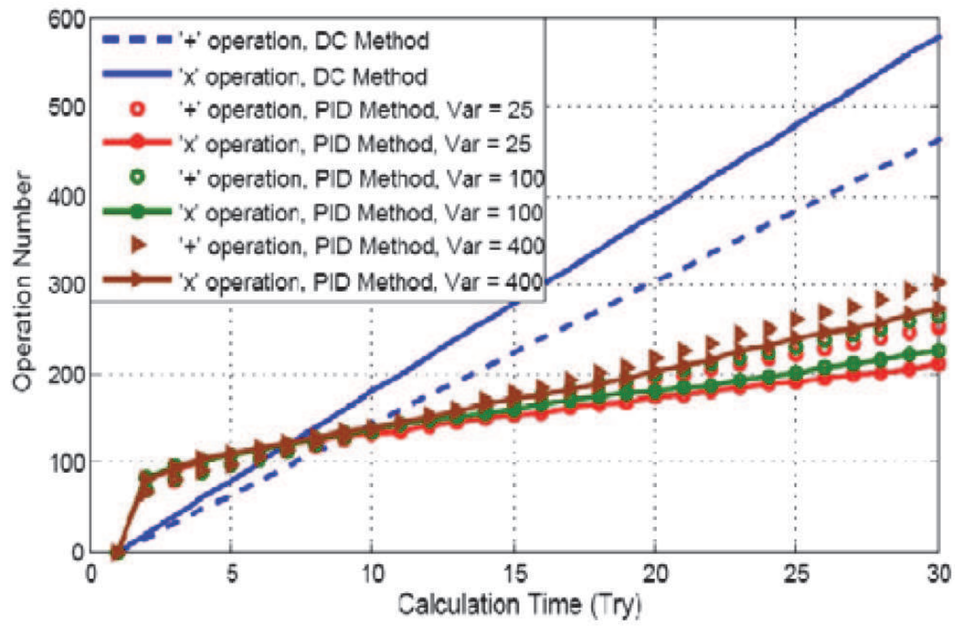

Fig. 6. Accumulated operation number result of the DC method and the PID calculation method when target node has mobility

ranging error is set to 0.01%. The DC method requires 16 adders and 20 multipliers for every calculation time. In contrast, the PID method requires 15 adders and 21 multipliers for each iteration time and 3 adders when the target position does not change. The results show the accumulated calculation time for each method. The calculation time of the conventional method increase linearly. This indicates that the DC method is not related to the mobility of the target node. In contrast, the PID method requires many operators compared to the DC method at the transition region to obtain the target node position. After convergence, the accumulated number of operators for the PID method shows fewer calculation operators compared to the calculation time of the DC method.
Third, the performance of the conventional DC method is compared with that of the proposed PID calculation method in Figure 6. The simulation parameters are the same as in the previous iteration, and the ranging errors are set from 0.01% to 0.1%. As shown in the result, when the ranging errors are small, performance enhancements are small. However, the PID method performs better than the conventional method in cases of a high ranging error because the DC method must use truncated data to operate in a small micro-processor system. In addition, the PID calculation method has better performance when using four reference nodes, but it does not require a complex calculation process.

4. Conclusion

This chapter describes an application of PID algorithm which is a coordinate calculation method in locating systems. The conventional DC method occur a delay of calculation time and gives inaccurate results when used in embedded systems or location system of the moving target. Therefore, a novel method using a PID control algorithm is proposed here. we used a P-control algorithm in this simulation. Therefore we show that this system will require less calculation and shows robust performance when using RTLS applications such as embedded locating systems, home networking systems and robotics positioning systems. If more complex PID control algorithms, such as PI, PD, and PID-control, are used, location

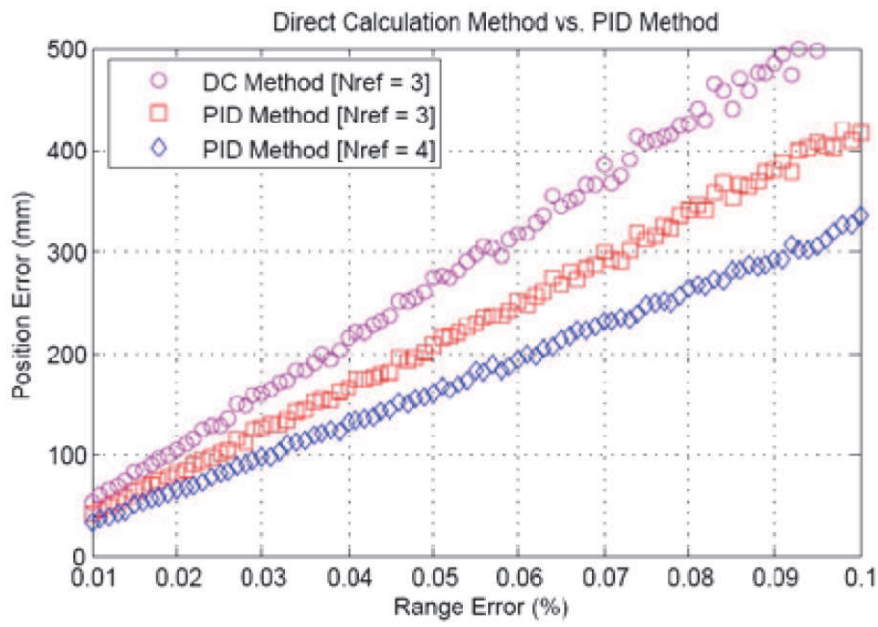

Fig. 7. Position error of the DC method and the PID calculation method when the ranging result has error

accuracy will be enhanced more. furthermore this concept can be also used other location algorithm such as the TDoA method.

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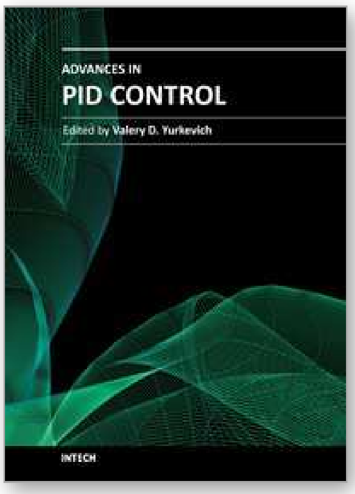

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Since the foundation and up to the current state-of-the-art in control engineering, the problems of PID control steadily attract great attention of numerous researchers and remain inexhaustible source of new ideas for process of control system design and industrial applications. PID control effectiveness is usually caused by the nature of dynamical processes, conditioned that the majority of the industrial dynamical processes are well described by simple dynamic model of the first or second order. The efficacy of PID controllers vastly falls in case of complicated dynamics, nonlinearities, and varying parameters of the plant. This gives a pulse to further researches in the field of PID control. Consequently, the problems of advanced PID control system design methodologies, rules of adaptive PID control, self-tuning procedures, and particularly robustness and transient performance for nonlinear systems, still remain as the areas of the lively interests for many scientists and researchers at the present time. The recent research results presented in this book provide new ideas for improved performance of PID control applications.

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