Control Position of Mobile Robot Based on Odometry Method and PID Controller

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Abstract. A mobile robot had been made based on kinematics drive differential concept. This robot used odometry method in order to reach a position and determine its current position. Proportional Integral Derivative (PID) control has been applied for improving response of robot while it reach a detemined position. Two rotary encoder sensors were attached at right and left side of robot motors for measuring distance. While motor rotating, rotary encoder sensors counted a number of pulses conversed into left and right wheel mileage. Both of them were used to get robot position at certain time (x, y, and heading angle). Robot passed some tracks and reached two positions in each track as destination positions. These positions are the position which had final heading 30° and 90° on first track, 45° and 90° on second track, 60° and 90° on third track. PID control was examined by put mobile robot in first position 0,0,0°. Some PID parameters have been applied to examine the performance and response of robot. The increment of derivative parameter reduced the steady state error and increased the stability of system.

1. Introduction
The increment of robot usage in many life aspects stimulates people to increase either its construction technology or its control system. Some robot constructions had been discovered, one of them was mobile robot. The mobile robot is mostly used in industry sector for the logistics purpose which the robot is ordered to reach a certain position for doing something in a room (indoor). A main process of the logistics purpose is position determination which is called as localization, while a main system for mobile robot localization is called as navigation system.

Research concerning the mobile robot navigation system which is integrated with GPS (Global Positioning System) had been done by Hamid et al. GPS can recognize the mobile robot real time position, so robot can reach the desired position. In spite of that, GPS has less accuracy for indoor usage as what observed [1].

The indoor mobile robot in commercial rooms is a new segment in autonomous robot scope which will grow fastest at arrival years [2]. The commercial rooms include public serving room such as school, hospital, bank, office, and so on. The appropriate method used for the indoor mobile robot navigation system is odometry method because this method relatively precise on a short distance [3].

Albab et al and Haq et al got research concerning a mobile robot navigation system using the odometry method without any control or open loop. The mobile robot was examined in some tracks.
which had one final position. This examination showed that the mobile robot has no ability to reach the desired positions and produced error more than 100% for each track. In the same research [4, 5], researchers added PID control into mobile robot algorithm as position corrector so that mobile robot can reach the desired position. By varying PID constants (Kp, Ki, and Kd), the researcher got some good results from close loop examination. The mobile robot is able to reach the desired positions either within or without oscillation.

As indoor mobile robot utilization, the odometry method must be matched with the robot environment. As we know, a public serving room is a dynamic and unstructured room. Some changes can happen over the time. It is not avoidable that mobile robot track with only one desired position is not sufficient. If there any obstacle stands on a straight mobile robot track, the mobile robot needs odometry method to reach two or more desired positions.

2. Method
DC motor used as mobile robot actuators had been completed with two rotary encoder sensors. Rotary encoder turning caused by motor turning produces a number of pulses which can be used by microcontroller to determine the mobile robot position at a current time. This position determination process is called as odometry method. Figure 1 shows mobile robot odometry geometry.

![Figure 1. The Detail of Odometry Geometry](image)

Mobile robot is illustrated put on initial position x, y, and had passed amount of distance with angle difference $\theta - \frac{\pi}{2}$ to P point. The mobile robot reaches a certain distance with forming an angle $\varphi$ to P point before reaching last position $x'$, $y'$. The mobile robot is assumed to reach very short distance so $\varphi$ is very small angle. Allow that assumption, the left and right wheel mileage ($w_r$ and $w_l$) which also are arc length to $\varphi$ can be determined by:

$$w_r = \varphi \times r_r$$

$$w_l = \varphi \times r_l$$

$r_r$ and $r_l$ are the distance between the wheels and P point. The mobile robot mileage:

$$d = \frac{(w_r + w_l)}{2}$$

If the distance between both of wheels is $l$, so

$$r_r + l = r_l$$
By eliminating eq. (2) to eq. (3), It will get:

\[ \varphi \times r_r - \varphi \times r_l = w_r - w_l \]  
\[ \varphi \left( r_r - r_l \right) = w_r - w_l \] (5)  
(6)

\( w_r \) and \( w_l \) becomes two arcs which have an identical angle, that is \( \varphi \) so it will get:

\[ \varphi l = w_r - w_l \] (7)

\[ \varphi = \frac{w_r - w_l}{l} \] (8)

Heading in radian:

\[ \theta' = \theta_0 + \varphi \] (9)

Heading in degree:

\[ \theta' = \left( \theta_0 + \varphi \right) \frac{180}{\pi} \] (10)

\( w_r \) and \( w_l \) can be determined through equation 11 and equation 12

\[ w_r = e_r \times c \] (11)

\[ w_l = e_l \times c \] (12)

\( e_l \) and \( e_r \) are a number of pulses produced by the left and right wheel at a current time. \( c \) is wheel circumference divided with encoder resolution. Encoder resolution is the number of pulses in one wheel turning. By illustrating the mobile robot movement in cartesian, \( x' \) and \( y' \) coordinate can be obtained by:

\[ x' = d \times \sin \theta' \] (13)

\[ y' = d \times \cos \theta' \] (14)

The design of mobile robot consists of mechanical and electrical design showed by figure 3. Mechanical design allows kinematics drive differential concept which is mobile robot has two wheels put in one axle at the back of robot and controlled by DC motor. Calibrated rotary encoder had been attached in the shaft of DC motor. It will enable the sensor turning along with the motor turning so effective mechanical design can be found. Mobile robot also uses rollerball wheel as front actuator which doesn’t have contribution to be drived. The microcontroller used is ATmega 1284P. To get response system when added PID controller, the mobile robot had been examined on flat field with some tracks shown in Figure 2.

Mobile robot has a same initial position in each track, that is \( x_1, y_1, \theta_1 \). By using first PID parameters, the mobile robot moves 200 cm and reaches first desired position \( x_2, y_2, \theta_2 \). Then, the mobile robot moves 400 cm and reaches second desired position \( x_3, y_3, \theta_3 \) using second PID parameters.
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Figure 2. Mobile Robot Examination Tracks

The analysis of PID controller examination result was done by determining some transient responses system consisting rise time, maximum (percent) overshoot, settling time, and steady state error. Based on [6], rise time is the time required for the response to rise from 10% to 90% of its final value. Maximum (percent) overshoot is the maximum peak value of the response stated as percentage. Settling time is the time required for the response curve to reach and stay within a range about the final value of size specified by absolute percentage of the final value (usually 2% or 5%). On the other hand, settling time is time required for the system to reach steady state. Error gotten at steady state is called as steady state error (SSE). SSE is also stated in percentage.

The graph gotten shows average heading at every time gotten from five repeatings. PID parameters vary was done by increasing Kd based on the first response of system. In the first examination, PID parameter given to system without Kd (Kd = 0) and it was gotten bad result which there is no system steady state. Then, to repair this response, Kd was increased.

3. Results and Discussion

Figure 3 shows the response system within and without increased Kd. All graphs of examination are underdamped system. It can be known by their transient response which is oscillatory. The damping ratio of the system ζ allows 0<ζ<1. The more near ζ to unity, the fewer oscillation will be found. So, ζ effects on the settling time and stability of the system. Based on the graphs, It can be inferred that every system without increased Kd has little amount of ζ. It causes a better stability for system within increased Kd.

Error signal exhibits a damped sinusoidal oscillation. There is almost no error at steady state. Based on the graphs, the system can reach steady state when Kd is increased. It means that increasing Kd also reduce error signal particularly on steady state error.

Rise time affects the first slope of the graphs. For each desired heading, the first slope between either response system within or without increased Kd are same. It is because of the same Kp given to both of them.
Figure 3. The Results of Adding PID Controller at first desired heading (a) 30°, (b) 45°, and (c) 60°

All tables below show the detail value of transient response parameters for each track. For desire heading 30° and 90°, the maximum overshoot (Mp) has been decreased 57.6% and 12.2% respectively. SSE has been decreased 44% and 97.9% respectively. Settling time also has been decreased 30.4% and 4.87% respectively (see table 1 and 2).

Table 1. Transient Response of The System with $K_p = 3.5$, $K_i = 0$, $K_d = 0$ for Heading 30° and $K_p = 2.5$, $K_i = 0.1$, $K_d = 0$ for Heading 90°

| Transient Response  | Desired Heading 30° | Desired Heading 90° |
|---------------------|----------------------|----------------------|
| Mp (%)              | 110.3                | 22.1                 |
| Rise Time (ms)      | 8                    | 128.7                |
| SSE (%)             | 44.5                 | 100                  |
| Settling Time (ms)  | 115                  | 205                  |

Table 2. Transient Response of The System with $K_p = 3.5$, $K_i = 0.2$, $K_d = 0$ for Heading 30° and $K_p = 2.5$, $K_i = 0.1$, $K_d = 2.5$ for Heading 90°

| Transient Response  | Desired Heading 30° | Desired Heading 90° |
|---------------------|----------------------|----------------------|
| Mp (%)              | 52.7                 | 9.9                  |
| Rise Time (ms)      | 8.5                  | 159.1                |
| SSE (%)             | 0.5                  | 2.1                  |
| Settling Time (ms)  | 80                   | 195                  |
At the second desired heading (60° and 90°) without increased Kd, the system cannot reach steady state. It causes there doesn’t find SSE and settling time. When Kd has been increased, the system can reach steady state with small SSE. It means that the increment of Kd can improve stability of the system. The increment of Kd also decreases Mp. There is decrement of Mp 50.2% and 15.7% for desired heading 60° and 90° respectively (see table 3 and 4).

Table 3. Transient Response of The System with Kp = 2 Ki = 0.3 Kd = 0 for Heading 60° and Kp = 2 Ki = 0.3 Kd = 0 for Heading 90°

| Transient Response | Desired Heading 60° | Desired Heading 90° |
|--------------------|---------------------|---------------------|
| Mp (%)             | 93.5                | 22.2                |
| Rise Time (ms)     | 10                  | 121                 |
| SSE (%)            | -                   | -                   |
| Settling Time (ms) | -                   | -                   |

Table 4. Transient Response of The System with Kp = 2 Ki = 0.3 Kd = 3 for Heading 60° and Kp = 2 Ki = 0.3 Kd = 3 for Heading 90°

| Transient Response | Desired Heading 60° | Desired Heading 90° |
|--------------------|---------------------|---------------------|
| Mp (%)             | 43.3                | 6.5                 |
| Rise Time (ms)     | 7                   | 135.1               |
| SSE (%)            | 1.4                 | 1.6                 |
| Settling Time (ms) | 90                  | 190                 |

For the desired heading 45°, system cannot reach steady state when Kd = 0. Mp decreases 37.6% by Kd increment. The rise time needed by system to reach heading 90° is larger when Kd is increased. It causes the settling time also becomes larger. This anomaly is caused by a spike (a large but brief response in the measured value) which would cause a large action by derivative mode [7]. That large action happens on system with long dead time like system response to reach desired heading 45° (see table 5 and 6).

Table 5. Transient Response of The System with Kp = 4.6 Ki = 0.1 Kd = 0 for Heading 45° and Kp = 4.7 Ki = 0.06 Kd = 0 for Heading 90°

| Transient Response | Desired Heading 45° | Desired Heading 90° |
|--------------------|---------------------|---------------------|
| Mp (%)             | 62.4                | 1.47                |
| Rise Time (ms)     | 14.1                | 113.6               |
| SSE (%)            | -                   | 1                   |
| Settling Time (ms) | -                   | 175                 |

Table 6. Transient Response of The System with Kp = 4.6 Ki = 0.1 Kd = 4.5 for Heading 45° and Kp = 4.7 Ki = 0.06 Kd = 8.7 for Heading 90°

| Transient Response | Desired Heading 45° | Desired Heading 90° |
|--------------------|---------------------|---------------------|
| Mp (%)             | 24.8                | 7.4                 |
| Rise Time (ms)     | 10                  | 133.5               |
| SSE (%)            | 3.6                 | 2.1                 |
| Settling Time (ms) | 65                  | 200                 |

Based on the results of examinations, it can be inferred that increment of Kd can reduce overshoot, settling time, and SSE so stability of the system improve. This analysis is same as what were stated by [8]. The PID controller gained superiority (lesser damping oscillations, minimal settling time with less Mp value) [9]. Astrom [10] also said that the damping effect on the system increases with increasing derivative time (Td) which means increasing Kd.
Error position gotten for desired heading 45° reach the largest value 3.04% when Kd = 0, then the smallest value is 1.34% when Kd is increased. For desired heading 60°, the largest error value is 2.97% at Kd = 0 and the smallest error position value is 0.40% when Kd is increased. For desired heading 30°, the largest error value is 2.53% at Kd = 0 and the smallest error position value is 0.97% when Kd is increased.

The same examination had done by [11]. The researcher asked mobile robot to pass some paths with some desired positions. It showed that the usage of PID controller (Kd ≠ 0) makes mobile robot able to do path planning with the largest error 33.33%.

4. Conclusion
Mobile robot can reach the desired positions with close loop. The system without derivative controller (Kd = 0) has oscillatory response until the end of time. Kd increment causes system able to reach steady state so system has reduced settling time. It is showed by the result of examination that settling time has been reduced minimum 4.88% and maximum 100%. When the system reaches steady state, stability of system increases and steady state error reduced.

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