Novel Trajectory Control System on Mobile Robot Using Visual Feedback

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***Abstract*—IEDs (Improvised Explosive Device) are one of the main causes of injuries during war. IEDs are also the most commonly used weapon by malefactors for it is cheap and easy to be crafted. This weapon may vary in color, shape, and size. They can be triggered remotely by radio signal, pressure, or even timer. The complexity of their system has made them to be carefully treated. One of the most promising solutions to counter these explosives is using EOD (Explosive Ordnance Disposal) robots. These robots may pack so many features to counter measure the varying types of IEDs. The more feature the robot has, the more difficult how it would be controlled. Some researchers have tried to add intelligent or autonomous features to aid the operator. In this study is proposed an autonomous feature to the robot. Compared to conventional methods in which the operator has to control both the manipulator and mobile robot manually this method helps reducing the complexity of operator's job. The robot will approach autonomously to the target while maintaining its trajectory. The trajectory control is using proportional control method with visual feedback. The robot is panning its body with the camera attached to maintain its trajectory. This is important because in such live threatening condition it will be difficult to concentrate on so many jobs. The data shows that with this control system the robot respond to the input in only 12 seconds, and during the experiment, its highest error is 6.5^{o} of panning degrees. The accuracy of the system is relative to the distance of the robot and the target. The maximum distance is up to 330 cm.**

Keywords*—*mobile robot; trajectory tracking; visual feedback; ordnance disposal.

I. INTRODUCTION

The most commonly used weapon by malefactors is IEDs (Improvised Explosive Device). IEDs are cheap and easy to be made. Data that were represented by British Military Field Hospital Shaibah showed that from 100 war casualties, 53% of them were injured or killed by IED (1).

IED is varying in shape and size from as small as pipe bomb to something big and complicated as car bomb. These bombs use different mechanism and making them hard to be defused. Some of them are not even defused at all, but rather transported to a safer place or containment system so they can be handled with proper treatment.

Bomb suit is one of popular equipment that is used to disarm IED. There are several down sides on this suit. Apart from its weight (approximately 37 kg), this suit restricts air flow to the wearer. The weight and increasing wearer's body temperature are considerably dangerous enough to alter the wearer's judgment in a live threatening situation (2). The accident in 7th of January 2015 when a bomb disposal officer died as he tried to defuse bomb in Cairo is proving that wearing bomb suit does not guarantee invincibility.

Another method to disarm or transport IED is using EOD (Explosive Ordnance Disposal) robots. These robots are considered safer because it can be controlled remotely. The down side of using these robots is they require time to master how to control them. Radio controller is often used to control the robot. Researcher has been developing methods to make controlling these robots easier. Many of them have incorporated the robot with autonomous feature to ease solve these problems.

Some researchers used camera mounted on the end-effector of mobile robots. The operator than choose the target by clicking a target on a touch screen. The robot will follow the target trajectory as a straight line. The robot also avoids obstacles on the way. This system is verified effective trough simulation (3).

Another research was including fixed cameras on the room. These fixed cameras are networked and placed on the ceiling. The robot was tagged with mark. Cameras were used to recognize the robot by its mark and a target. The cameras acted as visual feedback to control the robot's trajectory towards the target (4).

Our goal is to suggest another method of trajectory control to aid the operator with autonomous feature. The trajectory control uses camera as feedback. Compared to the first research that has been mentioned above, this system uses a practical approach to prove its effectiveness rather than a simulation. The camera is placed on the body of a mobile robot so the robot can maintain its trajectory by panning its body towards the target. The second research above is considered incompatible to our system for the lack of its practical functions in the real field.

This autonomous system is specified to pick object on the ground. The trajectory control will help the robot approaching the target until a certain range. This range is obtained using ultrasound range finder sensor. The sensor will also avoid the robot from collision.

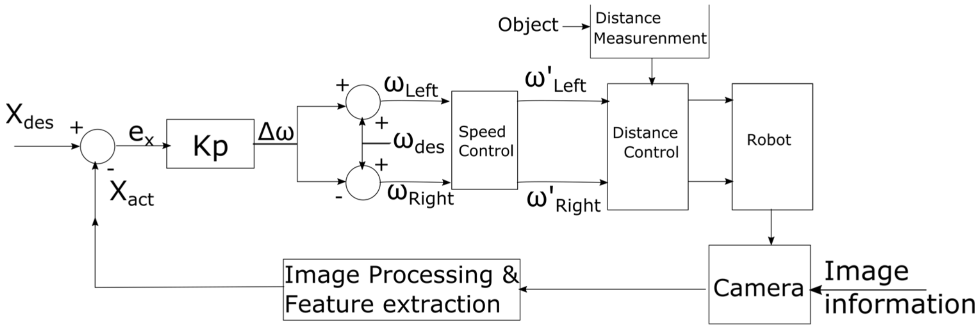


Figure 3. Trajectory control diagram

II. Proposed Control Method

A. Speed Control

The system uses two motors to accelerate and steer the platform. This method is also known as differential steering. In order to turn the robot right, the speed of the right wheel must be slower than the left wheel and vise versa.

Maintaining the speed is important, since the same PWM signal does not deliver the same motor speed. This phenomenon is caused by the power delivered from the battery is depending on its power stored. The whole speed controlling is done in Arduino Uno microcontroller and the speed sensor that is used is rotary encoder. To increase or decrease the speed of the robot, the system sends a Pulse Width Modulation (PWM) signals to the motors. Basically the processor responds to desired speed by using rotary encoder sensor as an input and motors driven by PWM signals as output.

Rotary encoder sensor represents angular velocity by generating a pulse. From the pulse, we can be obtained the period and the frequency. This angular velocity from each motor is measured to obtain more stable output angular velocity. This step is important because sometimes the same value of PWM signal does not produce the same angular velocity output. The control method used in this system is proportional controller. The diagram can be seen in Figure 1. Input angular velocity is denoted as ω_{input} and output angular velocity is denoted as ω_{output} and Kp is proportional constant.

B. Trajectory Control

The robot maintains its trajectory by panning its platform toward the chosen target. Robot uses camera as visual sensor. The camera is placed on the middle front of the robot so it can guide the robot to face a target. The position of the target based on the visual information can be calculated. This position is then used to decide the robots next move.

The image processing and feature extracting process is done by Raspberry pi. Target is tracked using Lucas-Kanade sparse tracking method. The tracking point is chosen by the operator. The position of the object, relative to the screen is calculated in pixels. This tracking position is a feature that is used as trajectory control feedback. The illustration of the calculation is shown in Figure 2.

In the Figure 2 it is shown how the tracking point coordinates are represented. The set point (x_{des}) of the system is along the middle of x axis. The main purpose of this is to keep the robot facing the target's direction. This can be achieved if the camera is placed in the middle and facing the same direction with the robot. The position of the tracking point (x_{act}) relative to the set point is considered error. The error value (e_x) either can be positive or negative depending on the position of the tracking point. The origin of the picture coordinate is in the upper left corner of the image. If the tracking point is on the right it will be positive and the other way around. Since the error value is calculated only using x axis, the tracking point position according to y axis can be neglected. The diagram of the process is shown on the Figure 3.

III. Data and Analysis

The experimentation is done in a room with a level surface. The room is illuminated with a constant light intensity and with background color contrast to objects color. The distance between the robot and the target is remaining constant (300cm) in each experiment. This condition is set to minimize the interference of unknown variables. The object that is used to be target is also the same in each experiment. The illustration of robot's position is shown on Figure 4 and the target is shown in Figure 5. During the data gathering the object that is used is fixed in color, shape, and size. The size of the target is 13cm in length, 8cm in height, and 5cm in width.

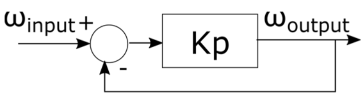


Figure 1. Speed control diagram

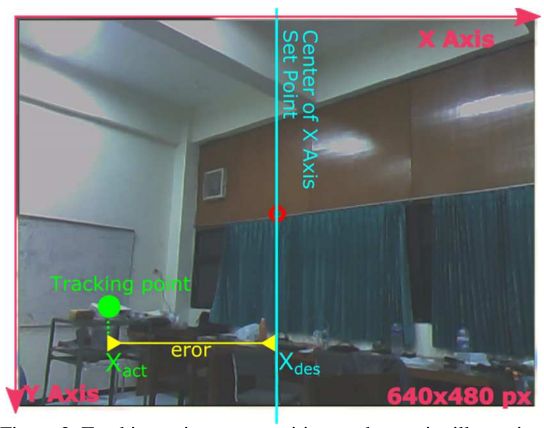


Figure 2. Tracking point, error position, and set point illustration

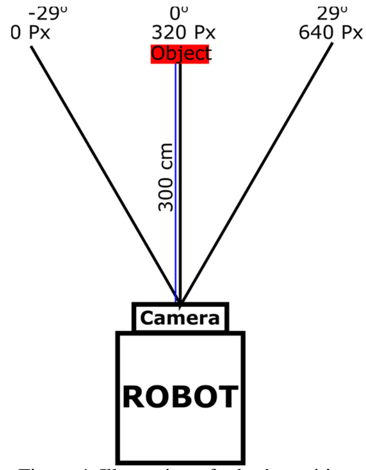


Figure 4. Illustration of robot's position


Figure 5. Target model.

A. *Panning speed experiment*

The goal of this experiment is to get the information of the speed of the robot responding to the set point. The experiment is done by placing the object in a certain pixel position relative to the image. The position according to y axis is ignored since the system only use the x axis. The data results are shown on Figure 6a. The y axis of the graph in Figure 6a shows the magnitude of the error value. The x axis shows the time in seconds. During data gathering, the object is placed in various positions resulting in various amount of error value in the beginning of each experiment. To simplify the data presentation, only four of the data is displayed in Figure 6a.

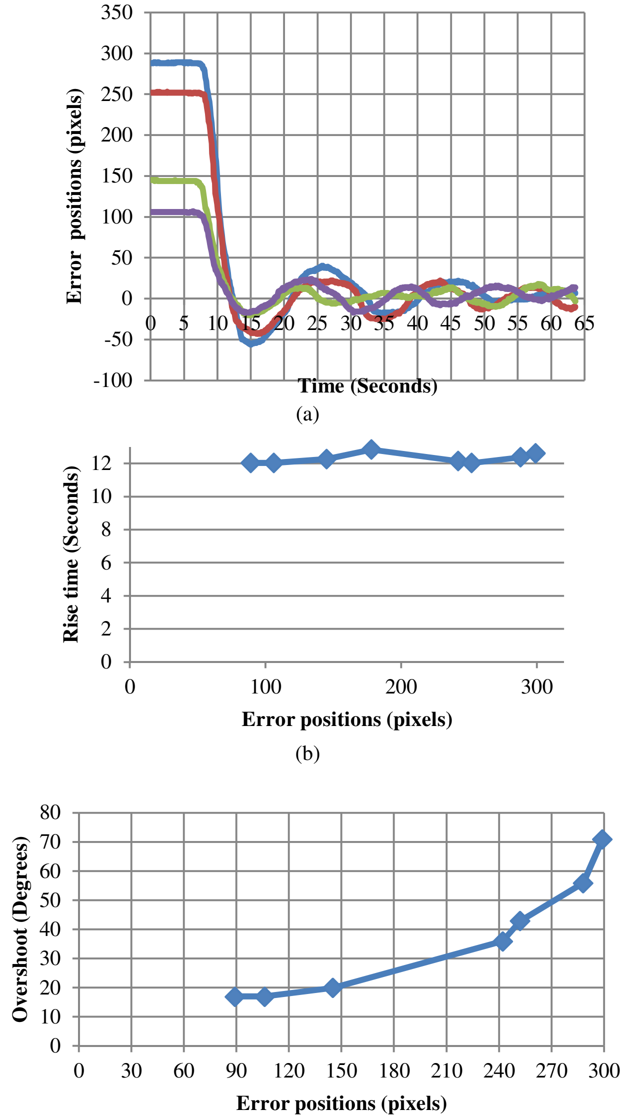
Each experiment is resulting two kinds of data, one of them is the rise time and the other is overshoot. Rise time is the time that is needed by the robot to correct the error position. Overshoot is the biggest error while tracking and it's usually the first error on the control system. In Figure 6b is shown various amounts of rise time in second (y axis) according to error input (x axis). In Figure 6c is shown various amounts of overshoot in degrees (y axis) according to error input (x axis), the data in degrees is linear to data in pixel.

From rise time graph (Figure 6b) can be concluded that the rise time is around 12 seconds. Every error in put is not giving a significant change to the rise time. That is because the system uses proportional control system. From the overshoot graph (Figure 6c) can be concluded that with the bigger error input the bigger the overshoot is. The data show the overshoot is between 17 to 71 pixels. It is ranging from 1.5 to 6.4 in degrees and ranging from 2.6% to 11% of error value compared to the input.

B. *Successfulness rate*

The robot will approach the target and when the range finder sensor detects the target it will pick it. The robot is said successful if it can approach the target and pick it autonomously. The strongest variable that is related to successfully rate is the distance from the robot to the target. This experiment is done to test how far the robot can keep its accuracy to control the trajectory and approach the target. Data are shown in Table 1. In the Table 1 is presented the data of various distance input. This distance is a distance between the robot and the target. Data from each distance is collected seven times. The robot considered success (showed by number 1) if the robot can approach then pick the object.

Data show that using the purposed system, the robot will optimally maintain its trajectory up to 330 cm in distance between the robot and target. The distance beyond it decreases the ability of the robot to maintain its trajectory.



(a)

(b)

(c)

Figure 6. Data results

Robot to Target Distance (cm)	Test number (1=succeed, 0=failed)							Successfulness rate
	1	2	3	4	5	6	7	
120	1	1	1	1	1	1	1	100
150	1	1	1	1	1	1	1	100
180	1	1	1	1	1	1	1	100
210	1	1	1	1	1	1	1	100
240	1	1	1	1	1	1	1	100
270	1	1	1	1	1	1	1	100
300	1	1	1	1	1	1	1	100
330	1	1	1	1	1	1	1	100
360	1	1	1	1	0	1	1	85,7
390	1	0	1	1	0	0	0	42,8
420	0	0	1	0	0	0	0	14,2
450	0	0	0	0	0	0	0	0

Table 1. Successfulness rate

IV. CONCLUSSION

The purpose of this study is to introduce a novel method that can aid EOD robot operator with an autonomous feature. To achieve this we design a robot with the ability to approach its target and maintaining its trajectory. The system is test with real application approach rather than a simulation. The data show that the system is remaining optimal if the target and robot have a distance below 330cm. Time that is needed by the system to respond the input is 12 seconds. The system's biggest error when it's panning to hold the trajectory is 6.4^{o}.

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