The Wireless Obstacle Detection Assistant System for Teleoperation

Anantachai Suwannakom, Buntoon Wiengmoon, and Thanaban Tathawee

***Abstract*— We present the obstacle assistant detection for tele-operation of the robot via wireless communication. Which can solve the problems of the robot such as obstacle detection and collision avoidance. We report three implementations, first is distance estimation of an ultrasonic sensor by Kalman's filtering. The second is a laser range finder, and the third, visualization of a camera. These systems can assist the human during tele-operation. The results indicate this architecture is suitable for improving the tele-operation of a robot.**

***Index Terms*—obstacle detection, ultrasonic, laser range finder, intelligent robot, teleoperation**

I. Introduction

Currently, the wireless communication technology is maturing. Which provide high performance and dependable of intelligent robots. The efficiency of wireless communication has improved the capability of robot perception. The human can use this advantage to make a decision from a camera installed on a robot. Moreover, this can decrease the limitation of control range. However, the communication can be lost or weak, which can lead to lose of control. Thus, various sensors such as laser range a finders, ultrasonic sensor, cameras and Lidar have been applied to vehicles to detect and avoid collide with obstacles [1, 2, 3].

The perception of the robot can be divided into two types. The first is detection and sent to be human for making decision. Another type is detection, and decisions making produced by itself. Although the human decisions are more effective than the robot but the problem of losing data can affect the human decision capability. Thus, the robot making these decisions can decrease this limitation and provide better performance of perception as well as improving tele-operation.

Sensing system include the camera, ultrasonic, laser range finder and infrared sensors. Those sensors have different advantages and limitations. The camera has high performance and effective of perception because it can be applied with a recognition algorithm such as face and human detection, lane detection as well as pedestrian detection [4], but this requires a few seconds for processing which depends on the processing unit. Thus, simply sensors such as ultrasonic and laser range finders, which require less processing time than the camera are applied for increasing performance.

Ultrasonic sensors are practical for many applications because low-cost and easy to implementation [5, 6]. Although, the performance of ultrasound is very effective in liquid, it is less effective air. Thus an effective ultrasonic sensor provides operation range up to only 10 meters. Sensor improvement trend will be a hybrid sensor. Each sensor can support and decrease each other limitations side by side [7, 8]. For instant, the laser range finder can decrease the limitation of an ultrasonic sensor. In other hands this sensor can increase the dynamic range of the laser range finder when using only one module because it is expensive. Therefore, the combination of camera, ultrasonic sensor and laser range finder will improve performance of tele-operations by solve high-level and low-level problems.

Due to the above problem of perception and tele-operation, we propose to study the potential of hybrid sensor network by using a camera, laser range finder and ultrasonic sensor for obstacle detection and collision avoidance as well as improve teleoperation. Which can improve performance of the intelligent robot and flexible in various applications.

II. System Architecture

Developed system consists of station, remote station and working station. The communication that is applied in this project is based on the wireless 5 GHz Ethernet and remote desktop application. Each station has central operation based on a computer, which has high performance in process and communication. The hybrid sensor network on the remote station has a separate microcontroller which is called peripheral operation. The peripheral operations are connected to central operation by USB interface and tiny wireless module. The diagram of connection shown on Fig. 1. However, the detail of each system on remote station will explain below.

A. Implementation of visualization and remote control system

A webcam camera is used for testing visualization of the robot, which is connected to a computer directly through a USB interface. The software for the camera was developed based on visual studio C# and EMGU library. Moreover, the image-processing methods were applied of each frame by converting RGB color space to Gray scale for improving remote control performance.

Manuscript received January 8, 2016.

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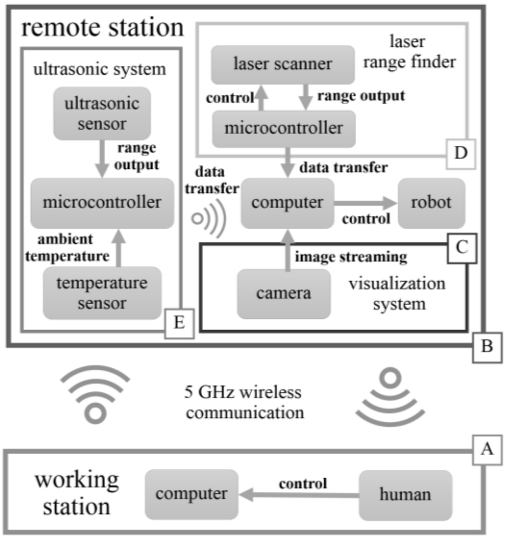

Fig. 1 Hardware diagram of tele-operation system. Working station and remote station show on A and B box respectively. At remote station consist of three peripheral operation. Visualization system (C) and Laser's range finder (D) connect to central operation (computer) through USB interface. Otherwise, ultrasonic system connected to computer by tiny wireless module (E).

The controls of the robot are based on the window camera input (Fig. 2) shown on a remote desk application. The human can use this window to visual and make a decision in remote areas.

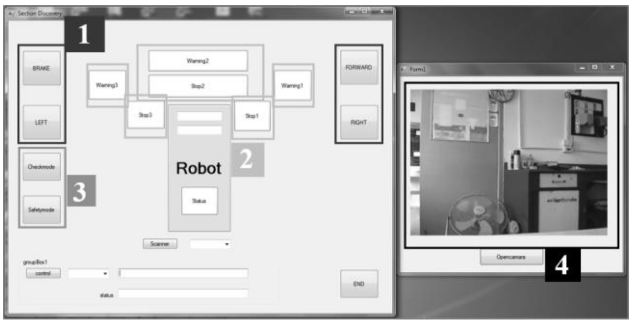

Fig. 2 the GUI of control on teleoperation. No. 1 box represent the control. No.2 box show the detection of the laser range finder. No. 3 box is choose mode buttons and the last no. 4 box show the visualization.

B. Implementation of laser range finder

The first laser range finder is set to detect three zones, each zone divided into warning and safety zones (detection mode). The waring zone and safety zone are from the robot at 0-1 meter and 1-3 meter respectively (Fig. 3).

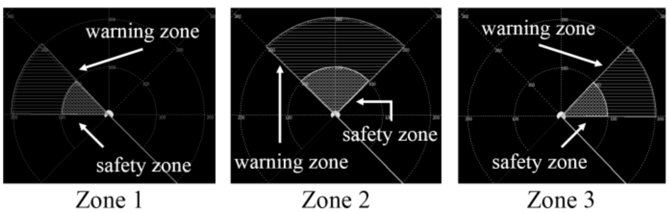

Fig. 3 Laser range finder zone setting.

When the laser range finder detects the object, it will send an electric signal to an Arduino microcontroller board. Because of, this the detection mode can choose only one zone at a time. Thus, we developed the circuit to choose each zone automatically, which changes from 1-2-3-2-1 zone number. This change will repeat until receive stop command from the user. In addition, the collision avoidance will be affected by zone change delay. So, we developed the laser detection system other modes which are called safety mode. Safety mode has one zone (Zone 2) that was shown in Fig. 3. It can decrease a changing zone delay. The safety mode has a role when found the object in safety zone, microcontroller will sent the command for braking on the brake system. Thus, safety mode can improve the effective remote operation compared to the detection mode.

C. Implementation and validation of ultrasonic system based on Kalman's Filtering

Ultrasonic sensors (HC-SR04) were set on 360 degree detection. Eight sensors were set on circle pattern. Circuit diagrams of the ultrasonic system represent on Fig. 4.

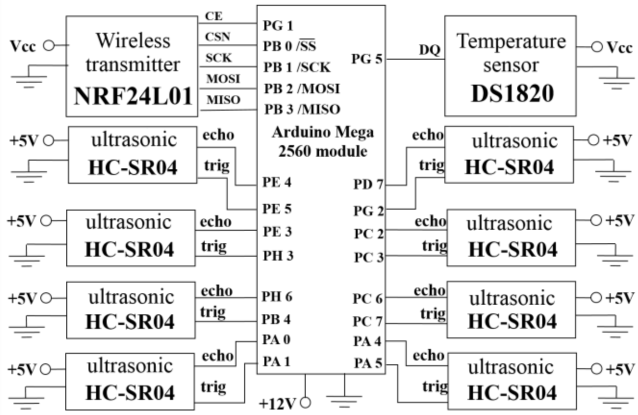

Fig. 4. Ultrasonic system diagram

Each sensor connected to microcontroller on specify port that shown in Fig. 4. In addition, the temperature sensor (DS1820) was installed to measure the ambient temperature. The measured temperature was used for eliminating the error of temperature compensation effect on the velocity of sound waves by the implicit equation (1).

$$S = t * (0.01655 + 0.00003T) \qquad (1)$$

Where S is the distance between ultrasonic module and detected object (cm), t is time interval (millisecond) and T is measurement temperature (Celsius).

The equation 1 is measured for a static system, but on the robot system it is a dynamic system. Normally, which system obtains noise signal and effects the error measurement. Therefore, data from the whole ultrasonic sensors on the robot are filtered based on Kalman's filtering. The ultrasonic sensor can simulate the equation (2)

$$z_k = x_k + v_k \qquad (2)$$

Denote z_k is the estimated distance, x_k is distance value from the sensor, v_k is a noise signal of ultrasonic sensor, $v_k \sim N(0,R_1)$. R_1 is variance noise of v_k. Then the estimation was

ISBN: 978-988-14047-6-3
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

found according to equation (3) to (5) by recursive loop. First steps compute Kalman's gain by equation (3).

$$K_k = P_k^- H_k^T [H_k P_k^- H_k^T + R_k]^{-1} \quad (3)$$

Second step update state estimation by equation (4).

$$x_k^+ = x_k^- + K_k [z_k - z_k^-] \quad (4)$$

Final step computes a variance error following equation (5).

$$P_k^+ = [I - K_k H_k] P_k^- \quad (5)$$

Moreover, the wireless module was connected to microcontroller to send data from the ultrasonic sensors through the central system.

Before testing the system, calibration methods proceeded for this system. The calibration point measured the object far from a sensor based on Kalman's filtering. Each point, 10 cm and the last point at 400 cm. After calibration, the performance was tested of a system by detect an object at 50, 100, 150, 200, 250, 300 cm. from sensor. The object moved circularly around the base of the station by 10 degrees, which is shown in Fig. 5.

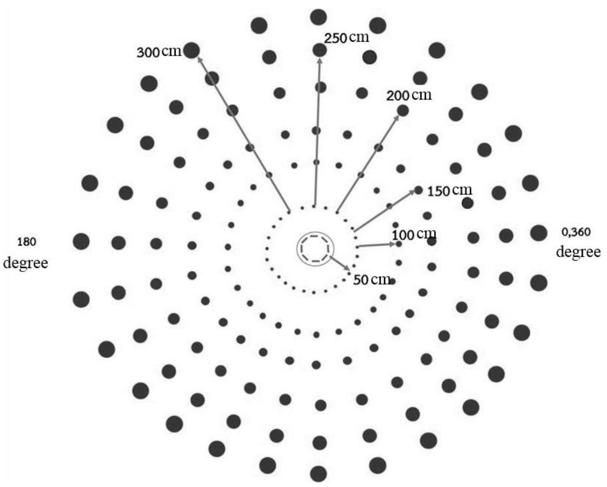

Fig. 5. Illustration of object detection position (dot).

III. EXPERIMENTAL RESULT

Visualization and remote control system

Before the image-processing procedure, we found at distances lower than 100 meters (line of sight) the control as well. On the other hand, distances longer than 100 meters performance was decreased, which show on a delay on visualization from a camera and sending command. However, the performance will increase after change the output picture streaming color space from RGB to Grayscale. In addition, the display output of remote desktop is set to 15 bit and lowest resolution. The remote control can operate up to 400 meters (line of sight). Although, the poor quality of visualization decreases the decision making ability of a human, the hybrid sensor network will improve performance as shown in Fig 6.

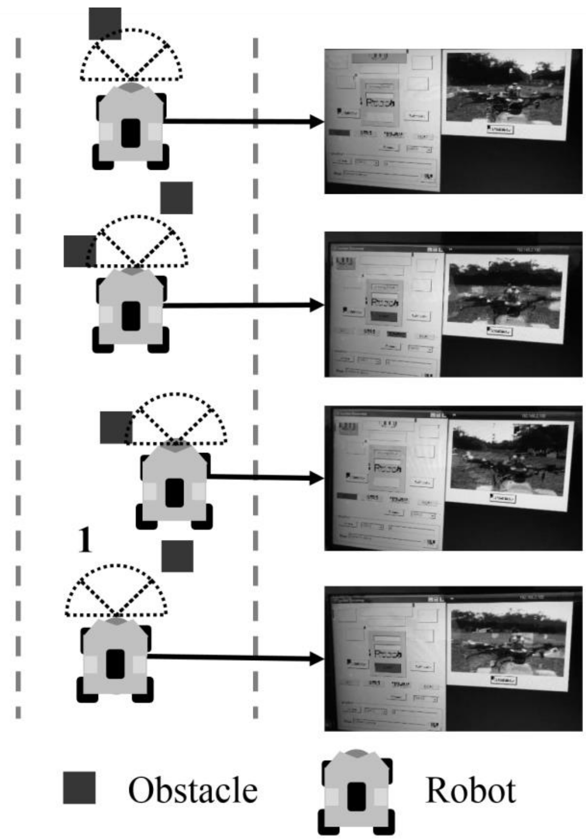

Fig. 6 the example of tele-operation control is shown on the right hand. The left represented the testing field. The rectangular is the obstacle. The semicircle no. 1 represented the detection area.

Laser range finder system

On detection mode, each zone was selected by a signal from the microcontroller. The durations of detection time of each zone are 300 ms, which were shown in Fig. 7.

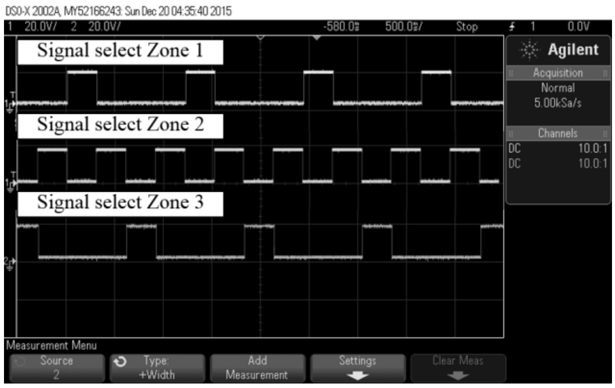

Fig. 7 signals from microcontroller. The top, middle and bottom represent the select zone 1, 2 and 3 respectively.

When the laser range finder detects the object, the output signal will be sent to computer through microcontroller and show on display GUI for making decision by human (Fig. 8). Moreover, on safety mode, the system can operate satisfactory.

ISBN: 978-988-14047-6-3
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

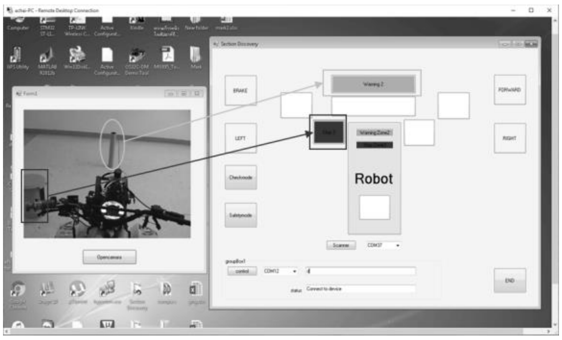

Fig. 8 GUI of tele-operation detection mode. The objects on the front of the robot were detected in the waring zone which represented in the front of robot. Left object is shown on the safety zone.

Ultrasonic system

The ultrasonic system monitoring was running on C# application which is shown in Fig. 9.

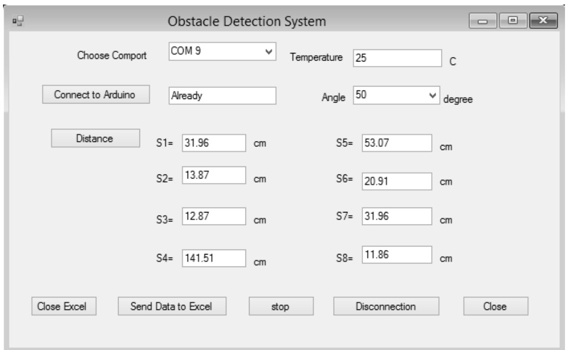

Fig. 9 the GUI of ultrasonic monitoring.

The distance estimation from ultrasonic sensors combined with Kalman's filtering method; we found the error of sensor lowest at 0% and highest 17% at 10 cm and rapidly decrease close to 0 at 40 cm. (Fig. 9).

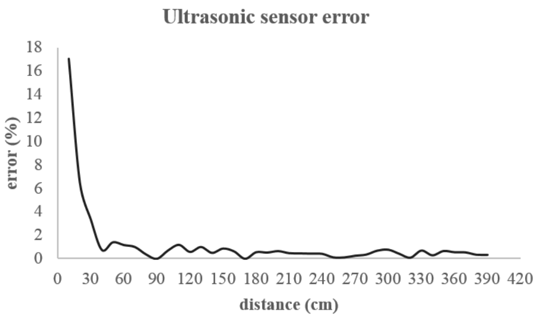

Fig. 9 percentage error of ultrasonic sensor.

Moreover, the result of 360 degree object detection has a similar trend by the lowest error is 0.012% and highest error is 5.467%, which are shown in Table 1. Even so, when consider the overlap of angle ultrasonic beam (Fig. 10). At the distance 50 centimeters, the object was detected by only one ultrasonic sensor except for 190-200 degree of the system. Otherwise, the distance more than 100 cm, the area detections of each sensor are overlapped. However, the design of sensor layout to more space between sensors can decrease the overlap but more space is affected by the blind area.

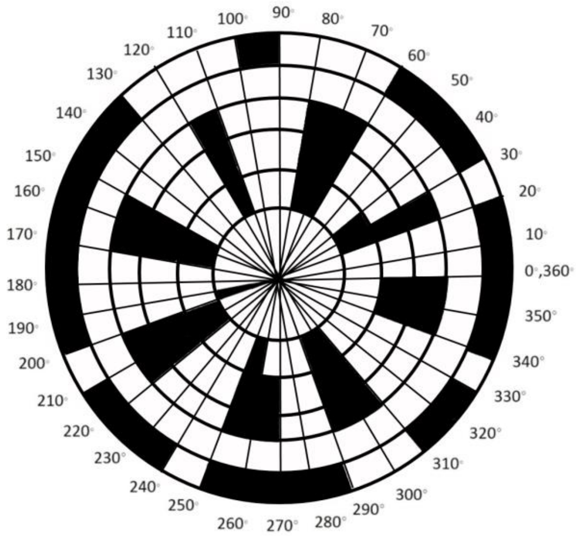

Fig. 10 the capable of each ultrasonic sensor to detect the object which plot from data on table I, the black color represent the detection overlap by multi-ultrasonic sensor.

TABLE I
PERCENTAGE ERROR OF ULTRASONIC SENSOR EACH DISTANCE AND ANGLES

Angle (degree)	Error (%)					
	50 cm	100 cm	150 cm	200 cm	250 cm	300 cm
0,360	0.100	0.973	0.527	0.100	0.516	0.881
10	0.773	0.033	0.078	0.233	0.249	0.770
20	2.120	1.643	0.078	0.737	0.020	0.658
30	0.100	1.643	0.749	0.067	0.249	0.769
40	1.233	1.037	0.524	0.437	0.517	0.770
50	1.233	0.703	0.749	0.437	0.651	0.770
60	2.120	0.033	0.300	0.233	0.153	0.770
70	4.793	1.307	1.038	0.400	0.555	0.770
80	0.100	0.033	0.973	0.100	0.249	0.433
90	0.567	0.033	0.144	0.605	0.516	0.434
100	0.100	0.637	0.749	0.437	0.249	0.770
110	5.467	1.307	0.369	0.568	0.383	0.770
120	0.100	0.973	0.300	0.102	0.287	0.770
130	1.233	0.367	0.524	0.268	0.383	0.881
140	0.100	0.367	0.524	0.067	0.384	0.770
150	2.120	0.637	0.591	0.233	0.153	0.770
160	2.120	1.307	0.591	0.737	0.287	0.770
170	0.100	0.367	0.144	0.268	0.249	0.770
180	1.233	0.033	0.748	0.605	0.651	0.323
190	1.447	0.367	0.078	0.100	0.383	0.546
200	4.120	0.303	0.591	1.072	0.153	0.770
210	1.447	0.973	0.524	0.100	0.384	0.770
220	1.233	0.367	0.524	0.102	0.383	0.012
230	0.567	0.033	0.300	0.268	0.248	0.770
240	2.120	0.637	0.144	0.233	0.020	0.881
250	2.120	2.647	1.038	1.072	0.420	0.770
260	0.100	1.643	0.078	0.100	0.152	0.770
270	0.567	0.303	0.524	0.268	0.517	0.124
280	0.100	0.703	0.078	0.067	0.248	0.433
290	2.787	0.640	0.367	0.737	0.420	0.433
300	0.100	1.310	0.144	0.568	0.020	0.770
310	0.100	0.367	0.591	0.067	0.824	0.770
320	0.100	0.700	0.300	0.067	0.115	0.546
330	1.447	0.703	0.078	0.402	0.824	0.770
340	4.120	1.643	0.367	0.900	0.020	0.657
350	0.773	0.637	0.367	0.568	0.019	0.657

IV. CONCLUSION

The result indicated that the developed hybrid sensor network has the potential for improving tele-operation as well. Include with high-level perception of the camera. Although, single camera is difficult to make a distance decision but the laser range finder can decrease limitation. Moreover, ultrasonic sensor will repeat checking around the robot for obstacle detection and collision avoidance.

ISBN: 978-988-14047-6-3
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

ACKNOWLEDGMENT

This research project financially is supported by the Naresuan University research fund.

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