Sensor Coordination for Behavior of Search Robot Using Simultaneous Localization and Mapping (SLAM)

Indra Adji Sulistijono[1], Endah Suryawati N.[1], Eko Henfri B.[1], Ali Husein A.[2], and Ananda Verdi S.[2]

Abstract— **We developed a robot for searching victims for survivors of natural disasters. Almost all robots need to navigate a state in the environment to help people around them, therefore the robot should have performance a mapping system. Thus improve the performance of robots in knowing the obstacles, the position and the direction toward the robot with the task of each sensor is to detect obstacles or objects that exist in the use of ultrasonic sensors to avoid bumping into obstacles, to detect the position and determine the distance of the robot using a rotary sensor encoder and to determine the direction toward, direction and elevation angle of the robot using IMU sensor. Whole of the sensor is set by the microcontroller STM32F407VGT6 that sent data from each sensor to a PC using XBee Pro. Therefore, robot create a mapping with OpenGL on the PC. Mapping system plays an important role for fast and accurate to the destination. We conclude, in the robot SLAM method depends on the precision of the data in the sensor US2 (Right), US4 (Left) and the rotary encoder. The test results of the output data at the right ultrasonic sensor produces error US2 16.9%, 14.6% US4 left ultrasonic and rotary encoder sensor error to 19.45%.**

Keywords—**Search Robot, Disaster Robot, Simultaneus Localization and Mapping (SLAM), Sensor Coordination.**

I. Introduction

The long duration to search victims make an innovation in natural disaster victims searching robot that is: iSRo (intelligent Search Robot) is a robot that searching for natural disaster victims. By focusing not only in mechanic but also the intelligent control on iSRo mechanism design can be able to explore all kind of places. Such as the buildings ruin the narrow tunnel, ascents or at framed environment. In order to cover the weakness of iSRo G 2.1, that there is no intelligent control so it would be made intelligent control with SLAM (Simultaneous Localization and Mapping) hope that iSRo G 2.2 will be able to explore all kind of places that would be mapping and will knowing the places map that through by it fast and accurately.

Because the place that will be through will be mapping so that iSRo G 2.2 is so helpful to SAR team to give a fast response to knowing the location that unreachable by SAR team. Here are the figure 1(a) from iSRo 1 robot, iSRo G 2.1 and G 2.2 robot and each of it shown on Figure 1(b) and 1(c).

The purpose from this research is to create mapping system to knowing the map location that use by SAR team independently with a figure as an output using the wireless technology for PC by reporting the recent condition of robot movements. the problems of this research is how to make ARM Cortex m4 software use Keil u vision 4, hardware communication and software using XBee Pro, making the simulation 3d program by OpenGL, gaining the sensor data the send to simulation software that already made, inputting the measurement's sensor data that use into mapping simulation and do the mapping

accurately and fast based in measurement's sensor data area from the robot use SLAM. the limitations problems of this research is the area that through by the robot is dry field, hard and strong that also the obstacles is according to the dimension and the size of sensor range.

II. Methods

A. SLAM Method

The used method in this research is SLAM (Simultaneous Localization and Mapping) the origins words mean together, meanwhile Simultaneous well born English means work together localization and mapping, then Localization means know of location robot and the last is Mapping means make map. And several meaning from those words, we can translate the Simultaneous Localization and Mapping that the ways of robot to mapped its territory and also to used measurement data continuously. So in this SLAM, the robot done the two tasks in one algorithm that is mapped the area and also to decided its position in one area that discovered altogether could be able its position in this area. In the first algorithm to decide the position used the

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dead reckoning method if the mapping use the ultrasonic and compass (IMU) sensor coordination.

The consideration of mobile robot through the environment took the relative observation from several landmarks known used sensor that placed on the robot like shown on figure 2 in K time, quantity decided.

- x_k : The vector pictured the location and the vehicle orientation
- u_k : The control vector activated in k-1 to move of the vehicle
- m_i : The vector shown the right landmark's location
- z_{ik} : The observation took from the south east area in k time. When there are observations in one time or when occasional landmark irrelevant with the discussion, observation would be written just as z_k

The electronic system has a important role in a robot. Because all of the robot movement or the robot task controlled with the electronic system that had been made for the robot. Between the robot and PC has the different electronic system but still keep in touch through serial PC. In the blue is the robot mapping system of iSRo G 2.2 has the work system that the robot has the wheel as its movement completed with dc motor with the rotary encoder. For the input mapping of ultrasonic sensor, compass sensor and rotary encoder sensor send to STM32F407VGT6 then programmed according to its need. Then the mapping result shown on PC, to connected it needed XBee Pro help. For the work system of robot from iSRo G 2.2 that the movement robot on track then when there is obstacle the robot will do the mapping and sending the serial data to PC. Inside the robot is also completed with control with STM32F407VGT6 to make easy SLAM process. While the way of system work could be illustrated on Figure 3.

On blue line is the mapping system of robot iSRo G 2.2 has the work system that the robot has a wheel as the movement completed with motor dc with rotary encoder sensor. For the input mapping the ultrasonic, compass and rotary encoder sensor sent to microcontroller then programmed consider to needs. On the blue half line shown the mapping result shown on PC that already settled and to connected it need help usb XBee Pro.

B. *The Sensor Placement on The Mechanic*

The sensor placement on robot iSRo G 2.2 could affected the system because on the same sensor with the same algorithm that result the different output. So it needs do the mapping that fit with robot mechanical characteristic, the sensor placement is available on Figure 4.

C. *Odometry*

Odometry is he technic to count the mobile robot position with the each of rotary measurements of right and left wheel. Odometry needs the rotary encoder to count the wheel rotary accurately. The simple way of the position calculation is on the differential drive system with a pair of drive wheel and the idle wheel. One of this mobile robot that commonly used especially to operate inside the room is the mobile robot with differential drive system. Technically, this kind of robot basically has 2 main wheel that each of it moved by driver (commonly is permanent magnetic DC motor with reductor gear to empower the motor torque, beside that this robot is completed with one or two calstor wheel that placed in the back of the robot to stabilize. If the two robot wheel rotated with the same speed so the robot will move in the straight direction, while if the one of the wheel moved slower than another so the robot will make a curve to the slower wheel position [4]. There is so many process for this odometry, one of this is the differential drive mobile robot. This methode use the difference of the right and left wheel rotation to gain the x and y position. The equation that use in this methode is [5].

$$X_{k+1} = X_k - \frac{L_r+L_i}{2}\sin(\emptyset_k + \frac{L_r+L_i}{2D} \quad (1)$$

$$Y_{k+1} = Y_k + \frac{L_r+L_i}{2}\cos(\emptyset_k + \frac{L_r+L_i}{2D} \quad (2)$$

$$\emptyset_{k+1} = \emptyset_k + \frac{L_r+L_i}{2D} \quad (3)$$

Where,

- X : X coordinate position
- Y : Y coordinate position
- k : Time
- L_r : Right wheel distance to end point
- L_i : Left wheel distance to end point
- D : The distance between the right and left wheel
- $\emptyset$: The angle degree

D. *Dead Reckoning Method*

The closement with the dead reckoning system. The equation of this method is the estimation process of the in time position based on the speed measurement in conditional time range and the previous position. Because of the calculation habit that integratif so the mapping that use this methode has minus point by adding error cumulatively for each calculation so the bigger distance of the robot has passed the smaller accuration that would got. But the plus point of this point is the simplicity for the designing because of just need the inersial error to calculate the distance and the speed. To implementthe dead reckoning principle on the mobile robot mapping differential driver so need to know the kinematics of the differential mobile robot driver. To practical applications *dead reckoning*, can be approximated by the following equation:

$$S = \frac{S_r + S_l}{L} \quad (4)$$

$$\emptyset = \frac{S_r - S_l}{L} + \emptyset_o \quad (5)$$

$$X = S\cos(\emptyset) + X_o \quad (6)$$

III. EXPERIMENTAL RESULTS

A. *Ultrasonic Sensor Testing*

This testing use microcontroller timer to gain the obstacles object values with the robot, in Figure 5. seen that the US output that show the distance between object and the obstacle.

B. Rotary Encoder Sensor Testing

In this rotary encoder testing will be tested in order to know accuracy and response that could be covered by rotary encoder sensor. The equipment required are STM32F407VGT6, rotary encoder right and rotary encoder left, power supply and HTerm.

In this testing, the microcontroller send data rotary encoder sensor to a computer through serial communications. To know results of output rotary encoder sensor using terminal from Hterm.

Where:
π = 22/7 = 3,14
r = finger of circle
the circumference of a circle of the disc rotary encoder:
Circumference of a circle = 2* π *2,2 = 13,8 cm
Distance = (circumference of a circle / amount of hole)* amount of pulse raised by rotary encoder sensor.

The result percentage error of distance measurement between theory and practice large average 19,45%. Many case that causes error of distance measurement, one of them is slip of wheel. While rotary encoder still considers slip as the pulse. Fact the wheel is not moved cause slip.

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To gain the X and Y position using the dead reckoning odometri method:
distance = (the periphery of a circle rotary plat/the holes in rotary plat) * rotary pulse
where :
omron datasheet = 200 P/R (200 Pulse/round)
while the practice value gained the dead reckoning pattern :
Position of X = S * cosØ
Position of Y = S * sinØ
where:
S = Distance range (cm).
Ø = The direction to the robot.

Algorithm that used for mapping and localization is using the dead reckoning method. Where all of the process whether mapping or localization is based on calculation of dead reckoning method. the input of this system is the output of 3 sensors (4 ultrasonic sensors, 2 rotary encoder and a compass) that will be send as the data package "F<space>sensor data1<space>sensor data2<space>sensor data3<space>so on", on Figure 7 shown the output results of the serial data.

The shipping by this configuration is in order to program able to recognising the data that have to be receiveated each of data and have to be not. After the data package received, the next is visual studio 2010 that made to separate each of received data package. In serial OpenGL program where the output result is from its serial program. Besides resulted a figure, this system is shown the recent position in X, Z coordinates, rotary and the robot's angle simultaneously.

D. SLAM Testing on PC

The mapping results in Figure 10 when the robot is freeze with the right cube and left is changing for green cube shown the green figure in OpenGL. While for the blue cube shown the red color in OpenGL. To get the accurate figure in OpenGL pixel, the ultrasonic data is divided by 600 for each 1 pixel. in 300 mm distance the received data is 133:600 = 0,221 will resulted the pixel translation about 0.221 in OpenGL from the right cube to left so there is arise the differences of obstacle mapping from right to left.

The result mapping on Figure 11 when the robot is freeze with the counter rotary encoder 1 right cube to changing left cube to the green cube shown the green figure in OpenGL. Meanwhile the blue cube showed the red color with OpenGL. To gain the accurate figure in data OpenGL pixel ultrasonic divided by 600 for each 1 pixel. To add the result data from 1 pixel to another pixel is the old mapping add by the new pixel coordinate to add the green rectangle figure and red so that gain the straight mapping with the obstacle differences from right to left.

From several result above that already done shown that the localization and mapping system with the SLAM method in the robot is depend on the accuracy of the data of US2 sensor (right), US4 (left) and rotary encoder due to the used sensor are the higher error more than 10% so that caused the error figure in OpenGL. The result of the data output resulted the right ultrasonic US2 16,9%, left ultrasonic US4 14,6% and error for rotary encoder sensor 19,45% needs of any recalibration to the rotary encoder, right ultrasonic and left to got the suitable pixel with the real measurement robot.

IV. CONCLUSION

After do the testing and analyzing concluded that some of the conclusions about the work system from the made system is below:

1. SLAM method in the robot depends on the accuracy of the data US2 sensor (right), US4 (left) and rotary encoder. The result of output data produced the right ultrasonic error US2 16,9%, left ultrasonic US4 14,6% and error for rotary encoder 19,45%. For calibration in OpenGL following the sensor data US2 (right), US4 (left) and rotary encoder that accepted in OpenGL serial.
2. To gaining the distance sensor data from ultrasonic sensor has to given an hard object and a mistaken that

never happened if the object obstacles distance not really close with range 30 mm and very far with 4 m range.

3. XBee Pro will be in a worked well with not too far distance and there is no obstacles in maximal 40m range with the 0 cm altitude and the distance maximal 200 m with the altitude 80 m.
4. Ultrasonic sensor is succeed to make a mapping on OpenGL and made a wall for the OpenGL display

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REFERENCE

[1] H Durrant-Whyte and Bailey Tim, "Simultaneous Localisation and Mapping (SLAM) Part 1 The Essential \ Algorithms.," *Robotic & Auto Magazine*, vol. 13, no. 2, pp. 1070-9932, June 2006.

[2] Rezha Fajar Kurniawan, "Desain dan Realisasi Sistem Mapping pada Kawasan Jelajah Robot Pengambil Sampah untuk Aplikasi Proyek Visual Servoing Robot (VSR-1) Application," Politeknik Elektronika Negeri Surabaya, Surabaya, Final Project 2008.

[3] Achmad Lutfi Rosyadi, "Pemetaan dan Lokalisasi Secara Simultan Robot iSRo menggunakan Multi-Sensor," Politeknik Elektronika Negeri Surabaya, Surabaya, Final Project 2006.

[4] Anderson David. (2006, August) IMU Odometry. Article. [Online]. http://www.geology.smu.edu/dpa-www/robo/Encoder/imu_odo/

[5] Erni D Wahyuni, "Rancang Bangun Program Visualisasi Pergerakan Differential Drive Mobile Robot," Politeknik Elektronika Negeri Surabaya, Surabaya, Final Project 2010.

(a) (b) (c)

Figure 1. There are the figure of the iSRo robot from iSRo 1, iSRo G 2.1 and iSRo G 2.2: (a) iSRo 1 robot (b) iSRo G 2.1 robot (c) iSRo G 2.2 robot.

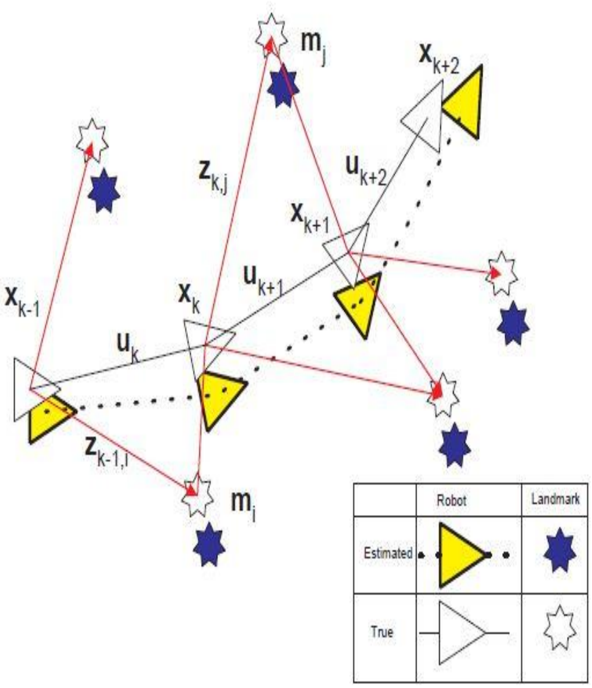

Figure 2. Position and obstacles adjustment on robot by SLAM.

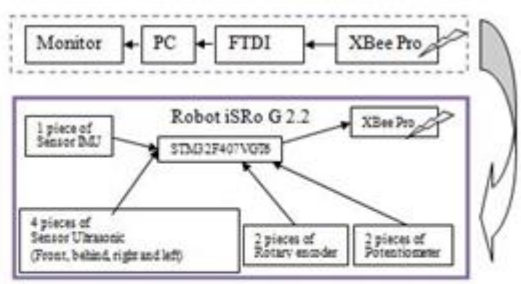

Figure 3. System mechanism.

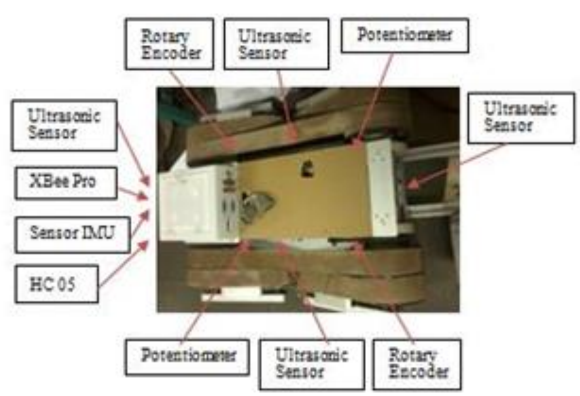

Figure 4. Sensor placement in robot iSRo G 2.2.

(a) (b)

(c) (d)

Figure 5. There are the figure of placement ultrasonic sensor in robot iSRo G 2.2 **:** (a) Behind of US (US1), (b) Front of US (US3), (c) Left of US (US4), (d) Right of US (US2).

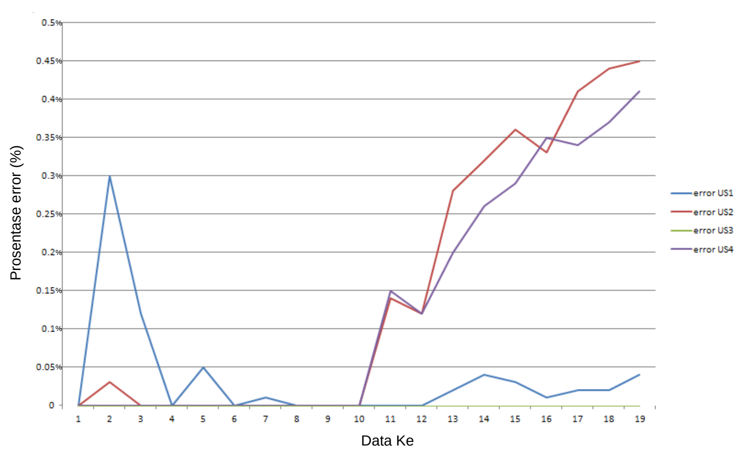

Figure 6. US1, US2, US3 and US4 error ch.

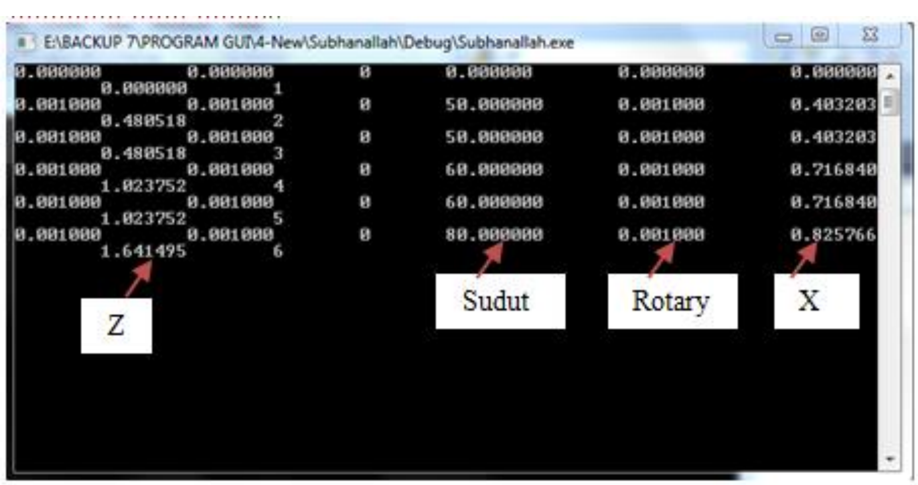

Figure 7. Dead reckoning method testing.

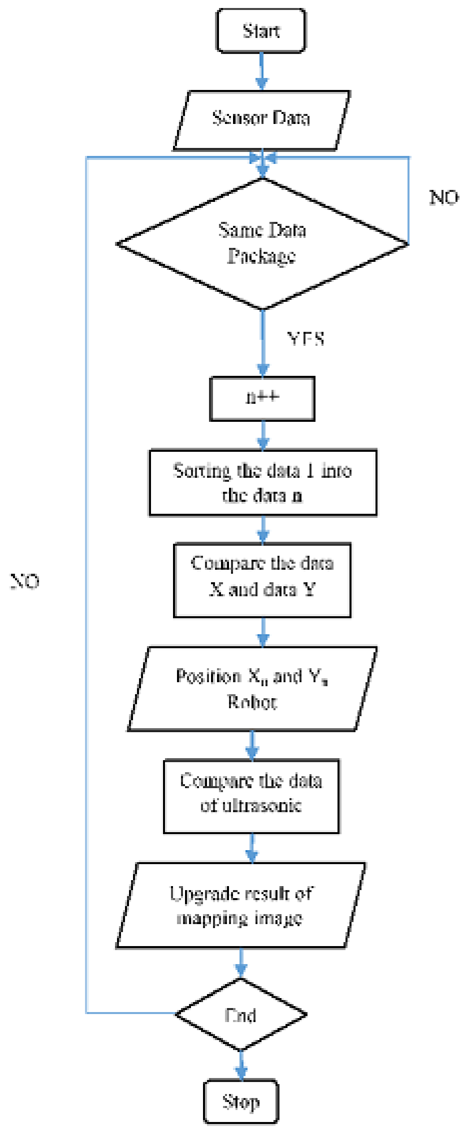

Figure 8. Algorithm of SLAM method.

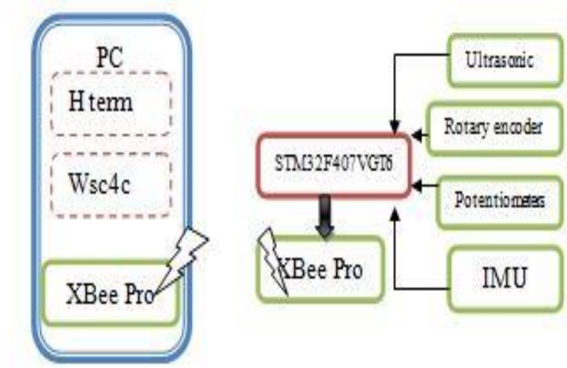

Figure 9. Block diagram of SLAM method testing.

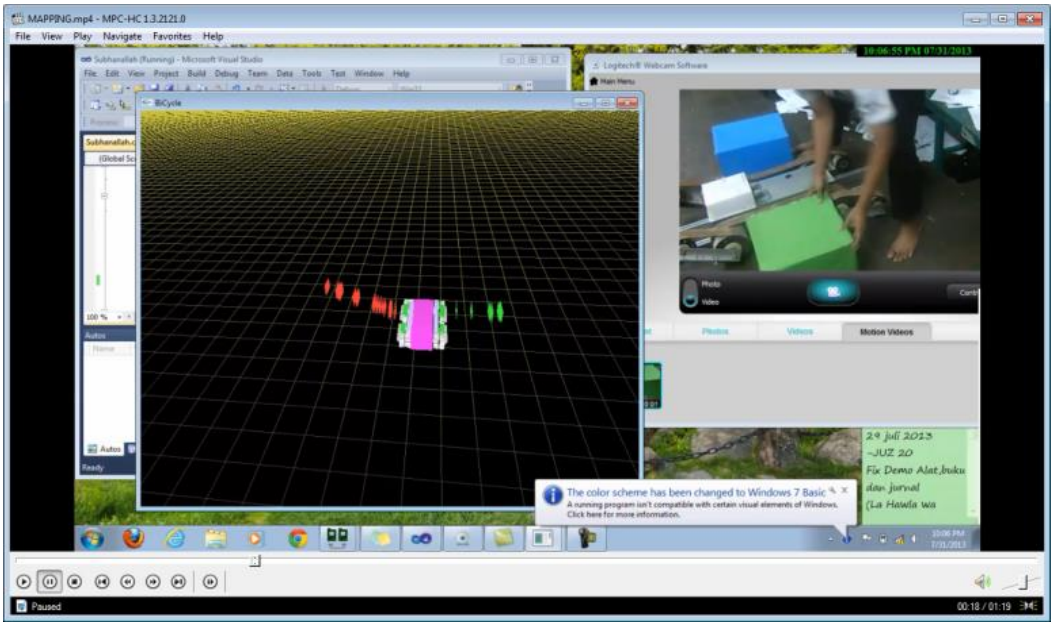

Figure 10. The ultrasonic result display on OpenGL when the robot is freeze.

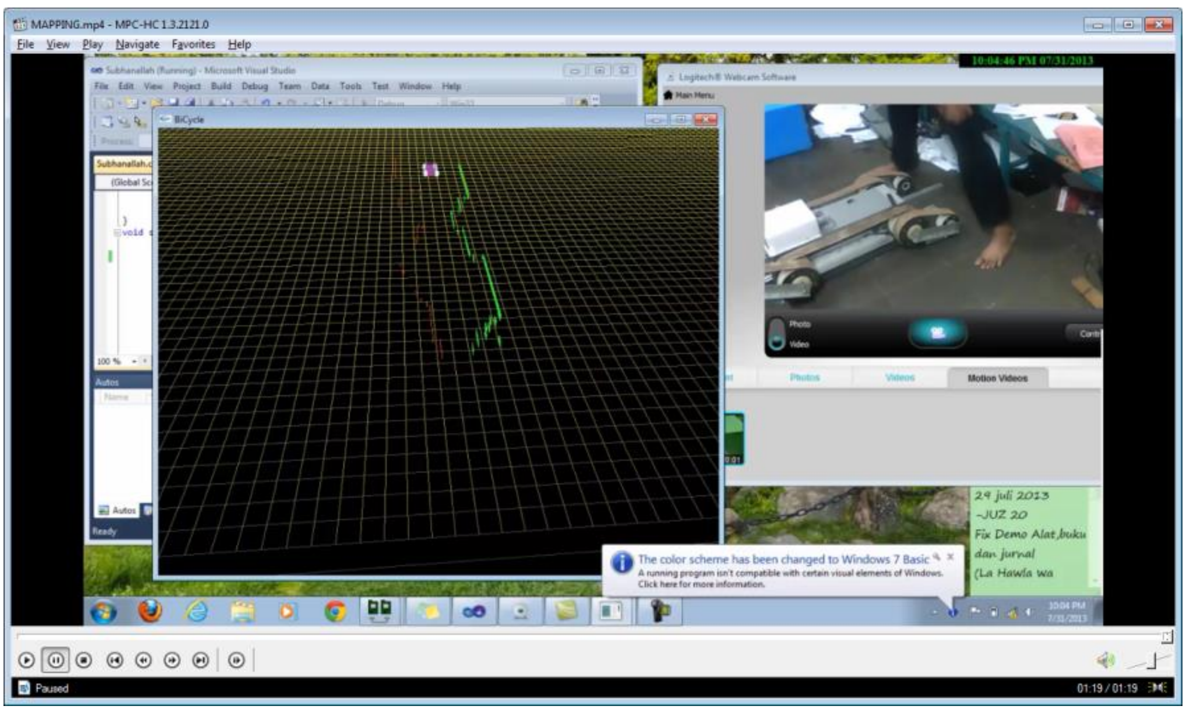

Figure 11. The ultrasonic result display on OpenGL when the robot is freeze with rotary encoder counter 1

TABLE 1.
ERROR VALUE OF THE ULTRASONIC SENSORS TO THE MEASUREMENT

Data	Distance (mm)	US1 (mm)	US2 (mm)	US3 (mm)	US4 (mm)	Error US1 (%)	Error US2 (%)	Error US3 (%)	Error US4 (%)
1	30	39	29	30	30	0,30	0,03	0	0
2	40	47	40	40	40	0,12	0	0	0
3	50	51	50	48	50	0	0	0	0
4	60	57	60	55	60	0,05	0	0	0
5	70	70	70	70	70	0	0	0	0
6	80	79	80	78	80	0,01	0	0	0
7	90	91	90	109	90	0	0	0	0
8	100	101	100	112	101	0	0	0	0
9	110	110	110	112	110	0	0	0	0
10	120	120	103	112	102	0	0,12	0	0,15
11	130	130	101	113	114	0	0,12	0	0,12
12	140	137	101	130	110	0,02	0,28	0	0,20
13	150	143	101	136	111	0,04	0,32	0	0,26
14	160	155	102	155	114	0,03	0,36	0	0,29
15	170	168	103	155	109	0,01	0,33	0	0,35
16	180	175	105	165	118	0,02	0,41	0	0,34
17	190	185	106	173	118	0,02	0,44	0	0,37
18	200	192	109	183	118	0,04	0,045	0	0,41

TABLE 2.
ERROR VALUE OF THE ROTARY ENCODER SENSORS TO THE MEASUREMENT

Amount of Pulse	Distance of traveled (theory)	Distance of traveled (practice)	Error (%)
5	3	2	33,1
10	6	5	16,7
15	9	8	11,1
20	12	10	16,7