Jurnal Teknologi

Full paper

Model Sensor Device for 3D Object Reconstruction

Siti Asmah Daud[a], Nasrul Humaimi Mahmood[b*], Leow Pei Ling[b], Fauzan Khairi Che Harun[a]

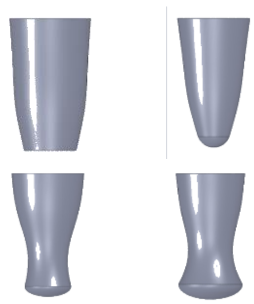
[a]*Faculty of Bioscience and Medical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia*
[b]*Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia*

*Corresponding author: nasrul@fke.utm.my

Article history

Received : 25 March 2015
Received in revised form :
11 April 2015
Accepted : 13 April 2015

Graphical abstract



Abstract

In this paper, the use of infrared sensor installed in the model sensor device is presented. Infrared sensor measured distance of the model surface and the data are used to reconstruct the 3D image. The implementation of five sensors helps in reducing time for data collection, and blind spots can be minimized. The scanning device consists of IR sensor array is placed in a black box with the object in the middle. The scanning process required the object to turn 360° in clockwise in x-y plane, and the resolution for z-axis is 2 mm in order to obtain data for the image reconstruction. Four different lower limb prosthetic models with different shapes were used as the object in the scanning experiments. The device scan object diameter every 2 mm in thickness, 100 mm in height, and total time require to collect data for each layer is 60 seconds. The reconstructed object accuracy is above 90 % based on the comparison between a solid and printed model dimension. The accuracy for each model, and all results and graphs are shown in the paper.

Keywords: Infrared; 3D image; accuracy

Abstrak

Dalam penulisan ini, penggunaan sensor inframerah dipasang dalam model peranti sensor dibentangkan. Sensor inframerah diukur jarak dari permukaan model dan data yang digunakan untuk membina semula imej 3D. Penggunaan lima sensor membantu dalam mengurangkan masa untuk pengumpulan data, dan tempat-tempat yang menjadi titik hitam dapat dikurangkan. Peranti mengimbas terdiri daripada sensor IR diletakkan di dalam kotak hitam dengan objek berada di tengah-tengah. Proses pengimbasan mengkehendaki objek untuk berpusing 360° mengikut arah jam di dalam satah xy dan resolusi untuk z-paksi adalah 2 mm untuk mendapatkan data bagi pembinaan semula imej. Empat model anggota prostetik badan yang berbeza telah digunakan sebagai objek dalam eksperimen imbasan. Peranti diameter objek mengimbas setiap 2 mm tebal, 100 mm tinggi, dan jumlah masa yang diperlukan untuk mengumpul data bagi setiap lapisan ialah 60 saat. Ketepatan objek dibina semula adalah melebihi 90% berdasarkan perbandingan di antara pepejal dan dimensi model yang dicetak. Ketepatan bagi setiap model, dan semua keputusan dan graf ditunjukkan dalam kertas ini.

Kata kunci: Inframerah; gambar 3D; ketepatan

1.0 INTRODUCTION

Infrared sensors (IR) have been widely deployed in robotic system to avoid collision [1], to measure distance [2], for surface-trace detection [3] and to calculate 3D depth and the surface angle of an object [4]. The IR offers low cost, faster response, easy installation and smaller size. Additionally, this sensor comes with multiple range detection characteristics. For example, short range sensors measure distances from a few centimeters (cm) to 30 cm, and a long range sensor has an effective range up to a few meters (m) [5]. Researchers have used IR sensor for many applications.

Benet *et al.* [6] demonstrated the use of ultrasound rotary sensor (US) placed on top and eight sets of infrared sensor installed around the perimeter of a mobile robot prototype known as YAIR. The robot was based on the direct measurement of the magnitude of the IR light. Maximum effective range for YAIR was approximately 1 m. The mobile robot had been designed to accurately build maps within real time constraints, given the fast response time of the IR. The precision of this robot was 0.5 mm.

In [1], a total of five IR sensors were used in the mobile robot. It was used to avoid collision with the wall and 'dead lock' in danger situation. Effective measuring distance for the robot was less than 15 cm and the accuracy was 90%.

Meanwhile, [7] developed a robot fitted with six IR and eight US sensors. IR sensors were used to measure distance less than 60 cm and when it was more than 60 cm, US sensor would take over the reading. The resolution of the sensor was 500 mm and it was used to model the environment for mobile robots path planning.

Other than that [8] used five US and four IR sensors to design a mobile robot. The US sensors were installed evenly in an arc of 50 mm radius with a spacing of 30 degrees from adjacent sensors. Meanwhile, an IR sensor was installed in the mid-point. The reason for installing both US and IR sensors side by side was to reduce blind spot, and mutual interference was effectively eliminated between the sensors. This robot was designed to avoid obstacle and adapt with the environment. The effective measurement distance was 50 mm. Back propagation (BP) neural network was applied to fuse information from the sensors to increase the accuracy of obstacle identification.

In [9], 12 IR sensors are used to be installed around their mobile robot. The idea to use 12 sensors was to shorten scanning time for 360 degrees area compared to using only one sensor and to reduce blind spots. The stepper motor was set to rotate with a step size of 1.8 degrees and the effective range was set to a distance of 62.4 cm. Park used Gaussian distribution to consider the uncertainty of the sensor information. This mobile robot was capable of accurately building maps of environments with obstacles.

Based on the principles of distance measurement using IR sensors that have been widely tested in mobile robot applications, this project uses the IR sensor in a sensor rig for 3D image reconstruction. In this experiment, five IR sensors of GP2D120XJ00F (Sharp Corporation, Osaka, Japan) [10] are installed in a sensor rig. Unlike previous research, this sensor rig will rotate the object model placed at the center of the plate for 360 degree, and data received is used to reconstruct 3D image of the object surface. The novelty in this experiment is applying reverse engineering to the model sensor device. This sensor rig can be used in medical field to reconstruct 3D image of a prosthetic lower limb model. In the experiment, a model similar to the prosthetic lower limb shape was used and results show that the device is able to reconstruct the object image. In addition, it can also be used to reconstruct any shape of object for 3D printing purpose. The accuracy and percentage error of the image is reported in this paper.

■2.0 SYSTEM DESIGN

2.1 Control Board Design

The model sensor device is installed with five IR 2D120X sensors, stepper motor, motor driver SD02B [11], sensor rig, Arduino Uno board, model plane, and control board. Figure 1 shows the schematic diagram for the design of control board for the device.

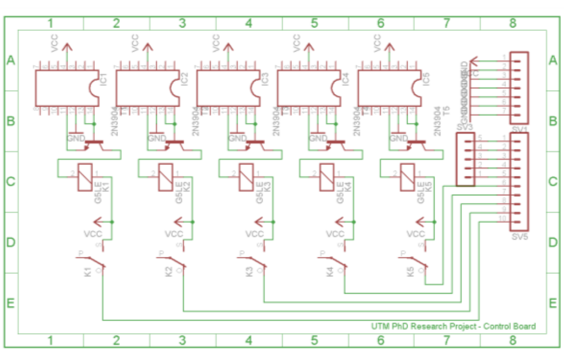


Figure 1 Control board schematic diagram design

As shown in Figure 1, the device control board consists of transistor (2N3904), IC comparator (LM234), and power source connection points (V_{CC} and GND). It is responsible for controlling the power supply connection to the sensors and transferring IR data to the Arduino board. The IR will turn ON one at a time in order to avoid redundant signal reflectance received by the sensor from the object surface.

Meanwhile, the Arduino Uno is a microcontroller which is used to control all the functions of the model sensor device. When power source is connected to the Arduino board, a welcome note is displayed written as “3D Image Reconstruction for Lower Limb Prosthetic Design”. The algorithm in the microcontroller will instruct only one IC comparator to turn ON the IR sensors one at a time. The sensor will collect distance data between the IR and object surfaces and transport them to the CoolTerm for storage. CoolTerm is an open-license software that can be connected with Arduino in order to receive data form the microcontroller. Data received can be saved in .txt file. By connecting the serial port from CoolTerm and Arduino, all data from the analog pin can be displayed in the serial monitor.

After the first sensor has completed its job, the second IR will be ON. When all five sensors complete data harvesting, a stepper motor will turn 2 degrees for the next collecting data cycle. The steps will be repeated until the motor completely rotates 360 degrees. Data transported to the CoolTerm is then saved in a .txt file for post-processing.

2.2 Model Sensor Device

The effective distance measurement for 2D120X sensor is between 4 cm to 30 cm, so, in the setup device, the minimum distance between the IR and object surface is fixed to 5 cm. All the sensors are installed at the sensor rig leg (spider leg) and the object model is placed at the center beneath the device. Figure 2 shows the model sensor device in this experiment.

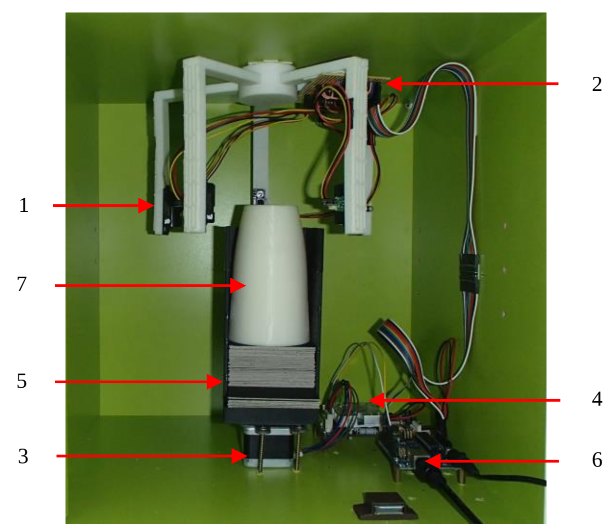


Figure 2 Model sensor device

The device is setup in a closed box due to the sensitivity of the IR sensor with a light source. During the experiment, the box is closed and the surrounding area inside the box is dark. The function of each component installed in the model sensor device is explained in the Table 1.

Table 1 Model sensor device component and its function

No.	Component	Function
1	Sensor array model	Collect data regarding distance measurement from the IR sensor to the object surface and transfer data into the Arduino.
2	Control board	Control all the functions in the device including sensor array model, stepper motor, and motor driver.
3	Stepper motor	Rotate the motor plane of an object every 2° until 360° for one complete cycle.
4	Motor driver	As a driver to the stepper motor. The entire algorithm for stepper motor rotation is uploaded into the driver.
5	Model plane	Place where the entire model in the project is located while sensor array collect data.
6	Arduino Uno	Microcontroller of the device to control all the function in the model sensor device regarding on the data collection.
7	Object Model	Model used in the experiment for data collection (Model 1, Model 2, Model 3, and Model 4).

The output measurement of 2D120X is in digital, so it does not require any conversion from an analog to digital converter (ADC), and the distance in the centimeter (cm) can also be calculated. This board has an analog-to-digital conversion function within the voltage range of 5 V. The calculation for conversion is:

$$V = \frac{1}{(R + 0.42)} \quad (1)$$

where V is a voltage and R is the range (in this device R is the IR sensor value). This equation will produce a straight-line graph. The value 0.42 is a constant for GP2D120 sensor based on the calibration point in the Sharp datasheet.

$$y = m.x + b \quad (2)$$

Converting the equation into a straight line graph, y is equal to the linear range or distance. Substituting the linear function from Equation 1 and 2 for y and substituting V for x yields:

$$\frac{1}{(R + 0.42)} = m.V + b \quad (3)$$

The equation is rearranged to give range as a function of voltage:

$$R = \frac{1}{(m.V + b)} - 0.42 \quad (4)$$

$$R = \frac{m'}{(V + b')} - 0.42 \quad (5)$$

where $m' = \frac{1}{m}$ and $b' = \frac{b}{m}$

After plugging in the calibration data for GP2D120 and adjusting the constant, the following formula may be derived for the sensor as follows:

$$R = \frac{2914}{(V + 5)} - 1 \quad (6)$$

From the equation above, 2914 is the constant value for IR sensor GP2D120 after rearranging equation. R is the distance from the sensor and V is the voltage reading from the sensor. Equation 6 is used in this device to calculate measured distance from sensor values in centimeters [10].

2.3 Device Flow Chart

After sensor device complete collecting data, post-processing will take over the next step for 3D image reconstruction. The overall function of the device is illustrated in the Matlab flowchart in Figure 3, which shows the post-processing technique developed in Matlab software.

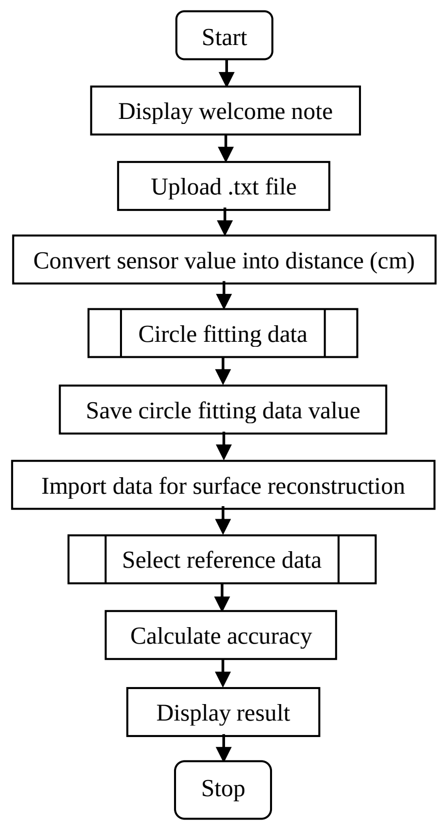


Figure 3 Data post-processing technique flow chart

In the data post-processing technique, Matlab software has been used to reconstruct 3D image of an object surfaces. Text file (.txt) was uploaded into the software and a few algorithms are applied to the data. When Matlab algorithm is run, it will welcome the user to the reconstruction program. All data in the .txt is then converted into distance in cm using the algorithm in Equation 6. After that, a circle-fitting algorithm is applied to find the best circle in each data layer and to filter noise formed during the data collection process. Noise might occur when there is a light source in the surroundings or when the reflectance signal suddenly fluctuates during the process. New data for circle fitting were saved for image reconstruction. Data for 3D image were uploaded into the program. Circle fitting data is used to reconstruct 3D image of an object surfaces and an accuracy of an image is calculated. A reference object needs to be selected to compare the similarity of the image. Results from the calculations are displayed in the Command Windows.

Each model is placed at the center of the sensor rig, which is then placed at the bottom of the device. Data taken for one layer is 180 data, and in the experiment it required 50 layer which produced a total of 9000 data (180 data × 50 layer) for one model. The height for every layer is 2 mm, since there are 50 layers collected, so the 100 mm height of the model is covered in the experiment. In the post-processing technique, noise has been filtered using the Circle Fitting method, and the data used to reconstruct 3D image is a new data.

The limitation of height is due to the length of the spider leg. The size of the object cannot exceed 80 mm long and must be smaller than 10 mm in diameter. The top and bottom surface of the object will be assumed as a flat surface. This is due to the position of the sensor installed in the device.

In the experiment, prosthetic lower limb models have been used for data collection. Since the shape of the model is circular, a circle-fitting algorithm is used to filter noise. The prosthetic model is not an arbitrary shape, so the fitting algorithm can be applied to the data. Meanwhile, an arbitrary shape can be reconstructed without applying circle-fitting algorithm. A spline fitting algorithm can be applied to these shapes for noise elimination.

3.0 RESULTS AND DISCUSSION

Four models have been used in the experiment for reconstructing 3D image of an object. Each model is classified based on their shape. Model 1, 2, 3, and 4 has different diameter at different height. Sensor value is directly proportional with distance measurement, the higher the sensor value the closer the distance. Figure 4 shows the image which has been successfully reconstructed using data collected by the IR sensors.

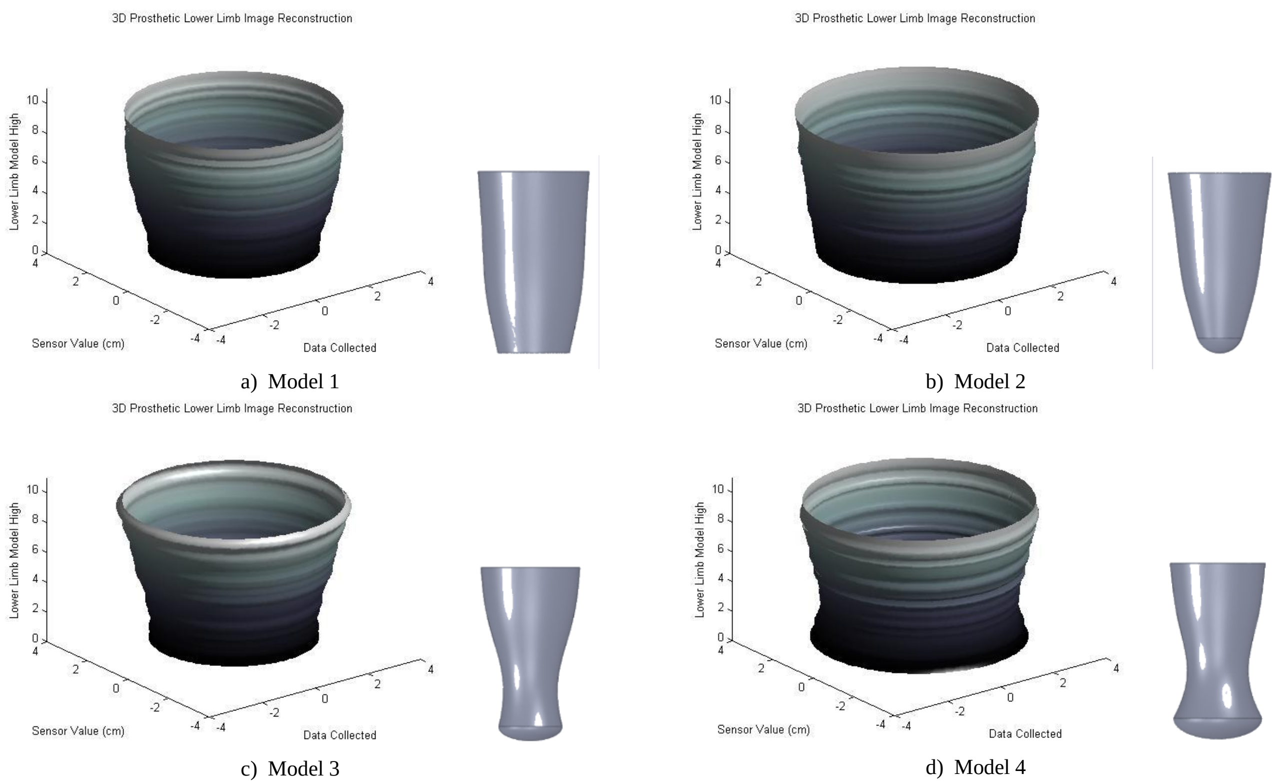


Figure 4 The graph shows an image reconstruction from different shape of an object

The results have shown that the device is capable to measure distance of a model with different diameters. The graph from Matlab shows the 3D image reconstruction of a model and the small figure shows the reference model. The image is not as smooth as the reference. Even though the device is placed in a closed box, noise can still occur during transfer of data from the IR to Arduino microcontroller. Percentage error and accuracy for all the model are shown in Figure 5.

A total of five measurements are considered to calculate the percentage error and accuracy of the models. The calculations have been made based on the reference data for each model and the reconstructed images. The algorithm have been set if the accuracy is less than 70%, it is considered as 'Unacceptable Image'. This is due to the references from other researchers, as the lowest accuracy of an image was obtained at 71% [4]. The image is considered an 'Acceptable Image' when the accuracy ranges between 71% to 100%.

Figure 5 Accuracy and the percentage error graph

From the graph, the accuracy of Model 1 is 97.839% and the percentage error is 2.161%. Meanwhile, Model 2 is 95.34% in terms of accuracy, with a percentage error of 4.66%. The accuracy for Model 3 is 96.22 % and the percentage error is 3.78%. Finally, Model 4 hasthe accuracy of 95.78% and the percentage error is 4.22%. It shows that for all four models the accuracy is above 90% and considered an 'Acceptable Image' for this device.

There are three factors that reflect the accuracy of an image reconstructed. One of the factors is the surface reflectivity of the object. The reflectance signal of the IR sensor is very dependent on the object surface, smooth surface give higher signal reflectance compared to rough surface. Other than that, the second factor is the surrounding area of the model sensor device.

The sensor rig has been placed in a closed box, preventing errors from occurring during the experiment by avoiding any light source in the surroundings. The third factor is the turning of stepper motor, as a smaller motor decreases the probabilty of missing a small spot. These three factors help in increasing the accuracy of the 3D image reconstruction.

The limitation of this device, it is unable to collect data for a shape bigger than 80 mm in diameter and 120 mm in height. This is due to the size of the sensor array itself. A bigger size of the sensor array is needed for a bigger model object. Since the IR is very sensitive to a light source, a close box or a dark surrounding area is required during the application of the sensor.

In the experiment, each model will take 50 layers of data and each layer requires one minute for the IR to collect data. A total time of 50 minutes is required to harvest data of each model with a dimension of 70 mm in diameter and 112 mm in height.

■4.0 CONCLUSION

In this paper, a model sensor device to reconstruct 3D image of an object surface has been presented. The use of an IR sensor in collecting data between sensor and the object surface helps reduce the cost of the device. The IR sensor is chosen because the IR sensor is small in size, requires easy installation, gives fast response, is capable to measure distance accurately, and not expensive [6].

A few aspects must be considered when dealing with the IR sensor, which are the effective measurement distance, reflectance from surface, noise filtering, and the blind spot. The effective measurement distances ensure that the object to be detected is within the IR sensor's range and capability. In order to achieve high signal reflectance, a smooth surface of an object gives a better reflectance signal. Alternatively, a 100 µF capacitor can be installed at the IR sensor V_{CC} and GND points to filter the incoming data before transmission to the microcontroller. Lastly, the blind spot of the sensor can be reduced by turning the stepper motor with as small a rotation as possible.

The model sensor device developed in the experiment is capable to reconstruct 3D image for different prosthetic lower limb shape of an object. It shows that the use of the IR sensors installed in the sensor rig is able to measure object distance, and that the accuracy for the image is above 90%, which is an 'Acceptable Image' result for the device. The accuracy proved that the device could be used to reconstruct 3D image of a prosthetic lower limb model, which is in a circular shape. Total time require for the device to captured data for one prosthetic model is 50 minutes. The scanning time is quiet long and it can be reduce by installing more IR sensor at the device. But in this experiment, the quantity of IR used is fixed to five sensors due to the design of the spider leg shape.

Acknowledgement

The authors are indebted to Universiti Teknologi Malaysia (UTM) and the EScience Grant for supporting and funding this study (EScience Vote R.J130000.7923.4S027). The author also would like to express gratitude to Biomedical Electronic Laboratory Group members for their ideas and comments to the study.

References

[1] S. Nurmaini. 2011. Intelligent Low Cost Mobile Robot and Environmental Classification. *International Journal of Computer Applications*. 35(12): 1–7.

[2] I. Matijevics. 2007. Infrared Sensors Microcontroller Interface System for Mobile Robots. 5th International Symposium on Intelligent Systems and Informatics. 177–181.

[3] G. Akihiro and Y. Omura. 2008. Surface-Trace Feasibility for IR-Based Position-Sensing Devices. The Second International Conference on Sensor Technologies and Applications. 372–377.

[4] U. Dugan, R. Dongseok and K. Myungjoon. 2011. Multiple Intensity Differentiation for 3-D Surface Reconstruction With Mono-Vision Infrared Proximity Array Sensor. *IEEE Sensors Journal*. 11(12): 3352–3358.

[5] A. Tar and G. Cserey. 2011. Object Outline and Surface-Trace Detection Using Infrared Proximity Array. *IEEE Sensors Journal*. 11(10): 2486–2493.

[6] G. Benet, F. Blanes, J. E. Simo and P. Perez. 2002. Using Infrared Sensors for Distance Measurement in Mobile Robots. *Robotics and Autonomous Systems,1006 (2002)*. 1–12.

[7] Y. Qing, J. Hou and L. Wang. 2011. Measuring System for Mobile Robot Based on Multiple Sensors. 2011 International Conference on Electronic & Mechanic Engineering and Information Technology. 980–983.

[8] F. Changhong, W. Shunxiang, L. Zhifeng, F. Xu and M. Fanling. 2009. Research and Design of The Differential Autonomous Mobile Robot Based on Multi-Sensor Information Fusion Technology, 2009 International Conference on Information Engineering and Computer Science. 1–4.

[9] H. Park, S. Baek and S. Lee. 2005. IR Sensor Array for a Mobile Robot. Proceeding of IEEE/ASME International Conference Advance Technology Mechatronics. 928–933.

[10] SHARP GP2D120XJ00F Analog Output Type Distance Measuring Sensor. Datasheet.

[11] Cytron Technologies SD02B 2A Stepper Motor Driver. Datasheet.