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Colour Tracking Technique by using Pixy CMUcam5 for Wheelchair Luggage Follower

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***Abstract*—Wheelchair user will face various challenges during travelling from one destination to another. Their hands will be required to maneuver the wheelchair around. It is difficult for a wheelchair user to identify the appropriate location to place their luggage within the wheelchair itself. Therefore, luggage carrying following cart is an initiative that could lighten the burden for wheelchair users. The method used is via colour tracking system using Pixy CMUcam5 sensor, Arduino MEGA microcontroller, ultrasonic sensors, servo motor, motor driver and transaxle motor. Pixy CMUcam5 sensor is used to perform colour tracking on target of interest. Arduino MEGA is the main microcontroller that controls all the input and output data based on the program. Servo motor is used to steer the direction of the front wheel while ultrasonic sensors are used to perform obstacles avoidance task. The movement control of transaxle motor is performed through motor driver. Colour tracking technique is based on surface area of the target of interest and brightness from the background. The field of view (FOV) of Pixy CMUcam5 sensor is 73.98° when the distance between the sensor and the target is at 1.50m. In addition, the ultrasonic sensors and servo motor are also discussed to identify the performance and its sensitivity respectively. The maximum error on the ultrasonic sensors is 2.00%. The percentage error for the servo motor without a load is 1.58% while with a load is 15.74%. Lastly, an effective target tracking system is successfully designed for this project.**

***Index Terms*—Following task, Autonomous mobile robot, Visual based sensor, Colour tracking, Pixy CMUcam5, Cart follower, Wheelchair.**

I. INTRODUCTION

Nowadays, the society has given privilege to those disable people in many ways. For example, special toilets, lift and many more have introduced to help them in our daily life. Therefore, infrastructures and innovations are created to fit the demand in helping those people with difficulties to lessen their burden. Disabled people, especially wheelchair users, faced problems in handling challenges during travelling.

Wheelchair user will face various challenges during travelling from a destination to destination. Their hand will be required to maneuver the wheelchair around. It did not help when wheelchair user chose where to place their luggage. Normal wheelchair does not have a space design to carry stuff on them. This will further burden them with the addition luggage when the luggage is carried along on the wheelchair. The weight of the luggage can roughen up the movement for the wheelchair user if the luggage is heavy. Besides, the extra load of luggage will further increase the weight of the wheelchair and may cause extra strain on the arm of the user that may lead to serious injury.

The objective is to design and develop a wheelchair following cart for wheelchair user using visual-based tracking technique to carry their luggage. First, colour tracking technique must be fulfilled based on visual-based sensor to identify the object in which the cart will follow. Second, a cart which uses transaxle motor as a drive and navigation system is developed for it to move. Finally, there must be an allowable distance between wheelchair and cart to prevent collision.

This research covers the study of how an embedded system can apply in the application on wheelchair system. It consists of hardware and software since the whole application of this luggage following cart will depend on these two factors. The hardware consists of a camera for vision, a motor for the movement of the cart, servo motor for the steering of direction and sensors. On the other hand, software part will depend on microcontroller used.

II. TYPE OF FOLLOWING TASKS

A. Object Following

Object following requires image processing type of sensor to fulfill the task. Pixy CMUcam5 sensor is used as the vision-based sensor to detect a specific pattern on the target object, which in this case is the two colour patterns located at the back of a wheelchair. Two colour patterns are chosen instead of one in order to increase the efficiency for pattern identification. The controller used is Altera DE0 Nano FPGA which uses programming software such as Quartus II, Qsys and Nios II eclipse [1].

B. Leader Following

The study involves several non-holonomic robots to achieve the leader following formation without any communication among each other. The leader following method is achieved by using image sensor which is camera. The camera used is pan-controlled camera which can find the specific pattern of the leader robot easily by rotating the angle along the x-axis of the camera faced [2]. Another project that implement the same leader following technique was introduced by Mariottini [3]. A panoramic camera was equipped on a unicycle robot so that other robots were in the range of the observed angle from the unicycle robot. Panoramic camera provides a 360º field of view which is ideal for surveillance application mostly required wide area coverage in a single view.

C. Human Following

"ApriAttenda^{TM}", the name of the human following robot, was created by Yoshida and his team. This human following robot uses image processing to identify the individual's cloth colour and texture. The target of interest must be within the range in the middle of the frame as it is normally the location for the human clothing. Furthermore, it also uses ultrasonic sensor to avoid obstacles. When the robot loses visual contact with the target, it will able to search and reconnect with the target. The highlight of this human following robot is it has high robustness and was capable to undergo the human following task smoothly [4].

D. Vision-based sensor

Visual Servo Control was introduced by Chaumette and Hutchinson [5] to compare the efficiency between image-based and position-based servo control technique. However, it is purely depends on the undergoing task. Stability is the main factor that can differentiate good technique.

Another research shows a low cost project using CMUcam2, second generation of CMUcam, to measure the performance and additional functionality compared to CMUcam, first generation of CMUcam system [6].

A PISALA project, which uses artificial vision embedded method to detect floor line with CMUCAM3, is introduced by Girbes [7]. The main point of this project is to find Automated Guided Vehicle (AGV) a solution for line following using vision-based method.

The latest model of CMUcam is CMUcam5. [8] came out with overtaking asistant system (OAS) that help the driver to make decision on overtaking using a CMUcam5 camera with color optical sensor meanwhile [9] used CMUcam5 for capturing image trajectory for air hockey system. Another reseacher build a distance estimation based on colour block model with CMUcam5. By this they can get an information on X and Y coordinate and block tracked [10].

III. Methodology

A. Luggage carrying following cart

1) Design of the cart

The cart consists of two parts which are front half section and bottom half section. The front half section of the cart will contain all the electronic components while the bottom half section of the cart will consist of mainly of battery and space for luggage. Figure 1 shows the dimension for the cart base in three views by using Solidworks program.

2) Specification of the cart

The cart width is around 340mm and the length is 550mm and 255mm is the height. It weighs about 10kg and can lift until 50kg of luggage weight. The maximum speed is 5 km/h. The power source of the cart is 24V lead acid battery. The battery will supply the power to all the systems inside the cart. Figure 2 presents the overall concept diagram of the luggage carrying cart.

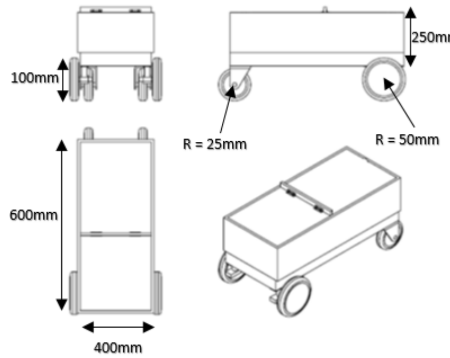


Fig. 1 Dimension of the cart base in three views by using solidworks program

a) Object Identification

Pixy CMUcam5 sensor is used as the camera for object identification. The sensor will then be connected to Arduino MEGA microcontroller as the microcontroller will dictate the next move for CMUcam5. Furthermore, two colour patterns are used as the target of interest and will be placed behind the wheelchair. The colour pattern will be placed at the position 30cm above ground so that it is mostly at the same level with Pixy sensor.

b) Cart Movement

The task for the cart movement can be achieved through the transaxle motor. Pixy camera has an ability to detect the target object while providing information for example width, height and even the angle faced from the object towards the camera sensor. The cart can be programmed such that when the size of the target object is shrinking, which indicates the target object has moved away from sensor, the transaxle motor will be triggered to move forward in a constant speed. On the other hand, when the size of the target object is expending, which indicates the target object has moved toward the sensor, the transaxle motor will move backward [11].

c) Cart Turning Direction

The cart turning direction can be help through the usage of servo motor. The design for the steering mechanism will be done base on the positioning of the servo motor. Furthermore, the servo motor will be positioned in the middle of the parallel linkage rode that connect with two front caster wheels. Servo motor can also operate based on the Pixy sensor programming to increase the efficiency.

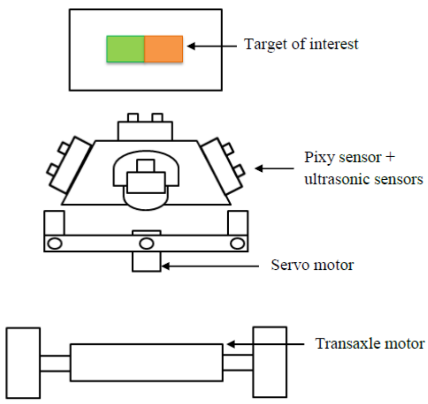


Fig. 2 Concept design diagram for the luggage carrying cart

d) Obstacle Avoidance

Obstacle avoidance task is considered as an important aspect in this project. Ultrasonic sensor is used as it is the best option available in the market nowadays due to its robustness and low cost. In this project, three ultrasonic sensors will be used. One of the ultrasonic sensors will be mounted at the middle front section of the cart while the other two ultrasonic sensors will also be placed at the front section but in right and left of the side.

When the ultrasonic sensors sense obstacle within the programmed distance, the cart will either stop or turn to the opposite direction based on which sensors it triggers. After entering a new path, the cart will continue follow the wheelchair back to its original path as soon as there is no any obstacle detection. Moreover, since there is an extra sensor which senses the obstacle in front of the cart, it can maintain a safe distance between the cart and the wheelchair, thus acts as an extra cushion of safety.

B. System sections

The block diagram for the overall process is illustrated in Figure 3. The microcontroller used is Arduino MEGA which acts as the main component to control the overall system. The driving force of the luggage cart comes from Brushed Electric Scooter Geared DC Transaxle Motor. This transaxle motor requires DC 24V with maximum supplied current of 3.0A to boost up. The maximum output power rate is 270W and the maximum speed that can be achieved by this motor is 4700rpm. The power supply for the transaxle motor is from a 24V battery via motor driver MD30B. This motor driver controlled the motor movement. For the electromagnetic brake pin, another 24V battery is required to connect to its positive terminal and negative terminal.

Pixy CMUcam5 camera is used as the main vision based sensor to perform the colour tracking technique. This sensor is chosen due to its ability to solve problems occurred when image sensors are used [12]. It used colour-based filtering algorithm method to identify objects due to its robustness, faster speed and higher efficiency that it possesses.

The servo that was used is RC Servo motor with metal gear. This servo motor has 17kg.cm holding torque at 6V voltage supplies. However, the torque can be improved to 20.45kg.cm if the voltage supplied is increase till 7.2V with the maximum speed of rotation remain the same at 6V voltage supplies (0.14sec / 60°). The maximum load that the servo motor can lift is 10.225kg.

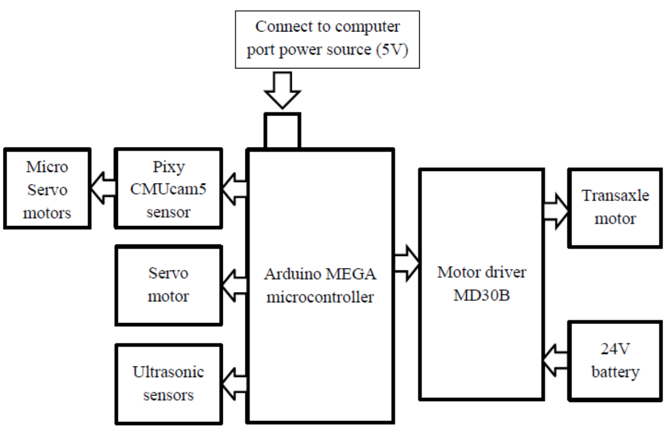


Fig. 3 Block diagram for the overall process

Other sensors used are Ultrasonic sensor, HC-sr04. It can be used for remote measurement of physical quality via ultrasonic waves. This module has an ability to detect a distance from 2cm to 400cm in a correct matter. This sensor mainly used to detect the distance between the luggage cart and the wheelchair to prevent collision and for obstacles avoidance purpose.

C. Pixy CMUcam5 sensor field of view with Pan-tilt mechanism device

The combination of pan-tilt device with Pixy camera will improve the efficiency of tracking process. With the help of pan-tilt mechanism, the sensor can easily follow the target of interest even when the cart is not facing the target of interest. The Pixy sensor can still able to detect the target of interest without rotating the cart as the target of interest is within the maximum field of view for Pixy sensor completed with pan-tilt mechanism. Figure 4 shows the Pixy CMUcam5 sensor field of view (FOV) from top view while Figure 5 shows the Pixy CMUcam5 FOV with pan-tilt mechanism device.

The FOV for the Pixy sensor can be determined by using derivation from the Pythagoras theorem as shown in Equation 1.

a = Distance between camera and tracked object

b = Wall Length

$$c = \frac{b}{2}$$

$$\phi = \frac{FOV^o}{2}$$

$$\tan\phi = \frac{c}{a}$$

$$\phi = \tan^{-1}\frac{c}{a}$$

$$FOV^o = 2\phi = \theta$$

$$FOV^o = 2\tan^{-1}\frac{c}{a} \tag{1}$$

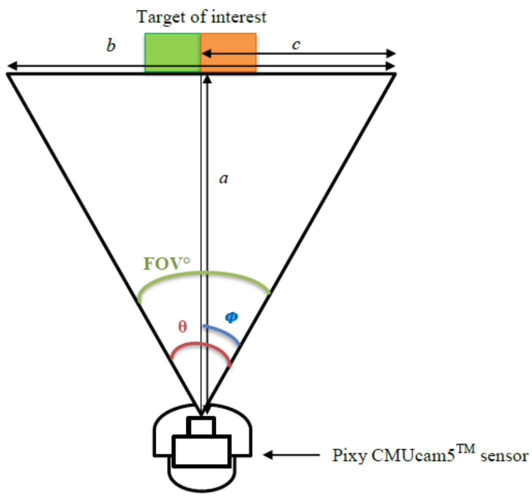


Fig. 4 Pixy CMUcam5 sensor FOV from top view

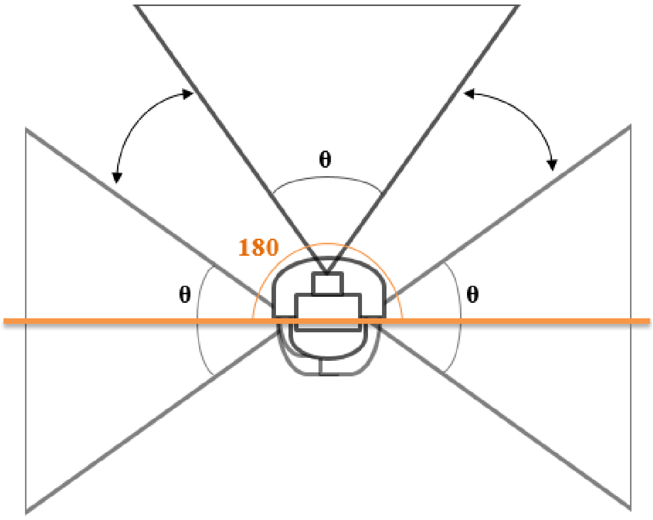


Fig. 5 Pixy CMUcam5 FOV with pan-tilt mechanism device

D. Target Area comparison

Pixy CMUcam5 sensor is used as the vision sensor to identify the targeted colour pattern. There is a distance where the sensor could not identify the target due to the distance limit which is around 1.50m. However, this factor does not affect the criteria in the project as the distance between the target of interest and the Pixy CMUcam5 sensor will not exceed 1.50m.

In this project, the colour of the target interest chosen is the combination of green and orange colour. The purpose of using more than one colour is to enhance tracking result for the object recognition. The combination of colour helps to prevent Pixy CMUcam5 sensor from sensing more than one targeted object from the background.

Figure 6 and 7 show the target of interest with different dimension. The calculation for the ratio that was used to establish the Table 2 in Results and Discussions is shown in Equation 2.

$$Ratio = \frac{Area}{Maximum\ distance} \quad (2)$$

E. Brightness of environment

Another experiment was done to detect and identify how the different background condition can have the effect on Pixy sensor. The specification used in the experiment is different background condition, which are during daylight and night time.

F. Obstacle detection with Ultrasonic Sensor

Three ultrasonic sensors, HC-sr04 had been used and placed at the front section of the luggage carrying cart alongside with other sensing hardware. The orientation for the ultrasonic sensors placing is crucial for the maximum field of view coverage efficiency. In theory, each ultrasonic sensor will have field of view (FOV) angle of about 60° but varies with the maximum distance the sensor is capable to sense the object. This factor is determined from the material made and size of the target. The sensor will inform the reading at the Arduino serial monitor. Figure 8 shows the ideal position for 3 ultrasonic sensors to achieve maximum efficiency.

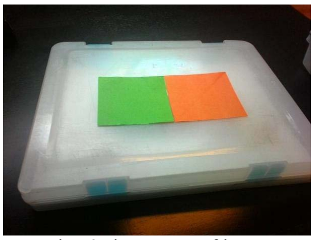


Fig. 6 First target of interest

Fig. 7 Second target of interest

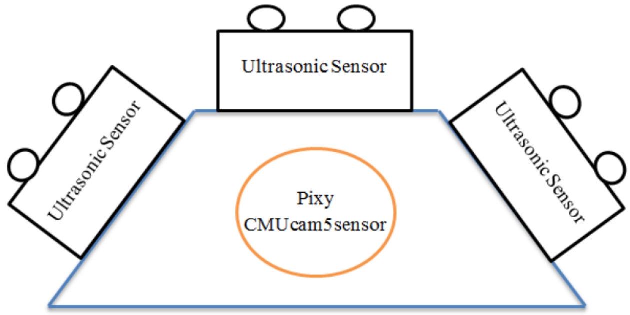


Fig. 8 Positioning for the 3 ultrasonic sensors

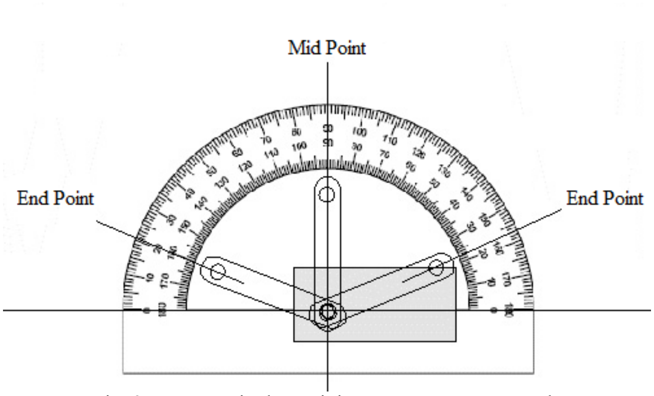


Fig. 9 Protractor in determining servo movement angle

G. Rotation of servo motor according the tracked colour

Servo motor HD-1051MG is tested using the protractor to identify its sensitivity. The servo motor is used to steer the direction of the wheelchair following cart according the tracked colour. The angle of the servo motor is set to determine the sensitivity and precision rate. The tracked colour will be placed at each of target interest angle in a range of 1.50 meter from the servo motor. Figure 9 shows the illustration in determining servo movement angle.

IV. Results and Discussions

A. The cart design

The luggage carrying cart has been successfully fabricated by using iron material as the backbone. Figure 10 shows the final developed luggage carrying cart model that fully equipped with all the components.

B. Pixy CMUcam5 sensor field of view with Pan-tilt mechanism device

The result obtained from TABLE I shows that the further the distance from the target, the wider the field of view. The maximum distance between the target of interest and Pixy camera where the camera can still identify the target is 1.50 meter.

Fig. 10 Fabricated cart

TABLE 1. FOV OF THE PIXY CMUCAM5 SENSOR

Distance from the wall, a (cm)	Horizontal distance, b (cm)	Horizontal distance used, d (cm)	FOV (°)	FOV (°) with Pan-tilt
100	146	73	72.26	216.78
110	162	81	72.73	218.19
120	178	89	73.13	219.39
130	194	97	73.46	220.38
140	210	105	73.74	221.22
150	226	113	73.98	221.94

C. Area comparison

One experiment has been carried out to compare how the size of the target of interest varies with the maximum distance detected by the Pixy camera. TABLE II presents the data collected based on two different sizes of targets. From the result collected, the larger the surface area of the target of interest, the further the distance Pixy sensor able to detect. Therefore, the efficiency of the Pixy sensor is proportional to the surface area of the target. Since the required maximum distance for detection is 1.50m, the area for the target of interest will be determined through the calculation based on information from TABLE I. The ratio for Target A, which is 65.38, is chosen for calculation due to its smaller value compared to Target B, which is 75.56. The value of the ratio is directly proportional to the surface area required on the target.

D. Brightness of environment

The background brightness will also affect the performance and sensitivity on Pixy sensor. The differences between image captured during daylight and night time are quite straight to the point. The factors that differentiate between these two conditions are the noise generated from the background of the image and the stability of the target lock by Pixy sensor. Since this luggage carrying cart for wheelchair will mostly be implemented indoor, which the sensor will come across with both these conditions, the image quality and result will mostly be the same as in TABLE III.

There are some complications when dealing with image that has bright background which normally occur during daytime. When the background is too bright, this situation will cause the target of interest to be rather difficult to identify thus causing the instability on the target lock. However, the Pixy sensor's brightness can be adjusted until the target lock is stable.

TABLE 2. PERFORMANCE SHOWN BETWEEN TWO TARGETS WITH DIFFERENT SIZE

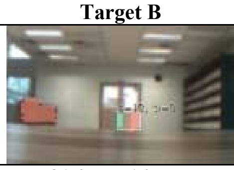
Factors	Target A	Target B
Image		
Size	17.0cm x8.5cm	21.0cm x14.5cm
Area	144.5cm^2	304.5cm^2
Maximum distance	2.21m	4.03m
Horizontal distance	3.38m	5.98m
Ratio	65.38	75.56

TABLE 3. COMPARISON OF THE EFFECT BETWEEN BRIGHT AND DARK SURROUNDING

Condition	Bright	Dark
Image captured		
Differences	The background noise is more drastic	The background noise is less drastic
	Target lock is less stable	Target lock is stable

TABLE 4. SENSITIVITY PERFORMANCE OF THE THREE ULTRASONIC SENSORS

Distance (cm)	Actual Distance			Actual Average Distance (cm)	Average Error (%)
	Sensor A	*Sensor B*	*Sensor C*		
0	0	0	0	0	0.00
5	5	5	5	5.00	0.00
10	11	11	10	10.67	6.70
15	15	15	15	15.00	0.00
20	20	21	20	20.33	1.65
25	25	25	25	25.00	0.00
30	30	31	30	30.33	1.10
35	35	35	35	35.00	0.00
40	40	41	40	40.33	0.83
45	45	45	44	44.67	0.73
50	52	51	50	51.00	2.00

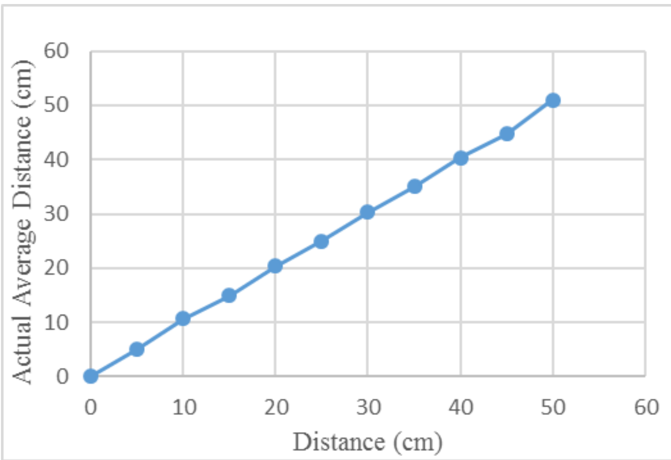


Fig. 11 Graph of Average Actual Distance (cm) vs Distance (cm)

TABLE 5. SENSITIVITY OF A SERVO MOTOR WITH AND WITHOUT LOAD

Angle (°)	Without Load		With Load	
	Actual Angle	*Percentage Error (%)*	*Actual Angle*	*Percentage Error (%)*
0	3	1.67	40	22.22
30	33	1.67	55	13.89
60	62	1.11	75	8.33
90	90	0.00	90	0.00
120	116	2.22	105	8.33
150	147	1.67	120	16.67
180	178	1.11	135	25.00
	Average error (%)	1.58	**Average error (%)**	15.74

E. Obstacle avoidance

An ultrasonic wave will send out by the transmitter and then received by the receiver. By using Arduino programming configuration, the data collected can be converted into distance in the unit cm. TABLE IV presents the result on the sensitivity performance for the three ultrasonic sensors. A graph of Average Actual Distance (cm) versus Distance (cm) has been plotted in Figure 11.

F. Rotation of a servo motor

Table V shows the comparison sensitivity of a servo motor with and without load for seven different angles taken from the range of 0° to 180°. The percentage error for the servo motor without a load is 1.58% while with a load is 15.74%. The increment of error happened when a load is exerting on it. This is due to the movement limitation that both castor wheels at the front of the cart that being attached to the servo motor. It is impossible for the castor wheels to move flat 0° and 180° since it will make the cart unable to move.

V. CONCLUSIONS

The luggage carrying cart able to follow the wheelchair from behind without the help of human control. The objective was achieved. Several hardware accompanied with its software are implemented in the development of the luggage carrying cart.

The hardware used are divided into 2 sections which are sensor components and respondent components. Sensor components are used for object and target recognition and obstacle avoidance purposes. The sensors used are Pixy CMUcam5 sensor and ultrasonic sensors HC-SR04 while the respondent components include servo motor and transaxle motor. Data and reading obtained from the sensor components will dictate the functionality for respondent components.

Pixy CMUcam5 sensor has the field of view (FOV) of 73.98° at the distance of 1.50m. This shows that the greater the distance between the target of interest and the sensor, the higher the field of view (FOV). Furthermore, ultrasonic sensors have a maximum error of 2.00% due to its inconsistency. In addition, servo motor also has the sensitivity error of 15.74% when a load was applied on it.

Some improvements can be made on the luggage carrying cart mainly on the hardware part. Extra ultrasonic sensors can be located at the back part of the following cart. The obstacle at the back can be avoided and ensure the luggage carrying cart is not being damaged.

Furthermore, the efficiency of the colour signatures detected by the Pixy camera can be improved by setting more than two different colours coding to be tagged together through the usage of colour code (CC) function. Internet of Things (IoT) related projects have bloom in recent years. Therefore, IoT technology can be implemented in this project, where wireless connection can be established for indication purposes. This kind of improvement make easier for the wheelchair user to control the cart via wireless connection.

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