Pre-Contact Sensor Based Collision Avoidance Manipulator

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***Abstract*—In industrial environments where humans and robot manipulators co-exist, it is always a risk that humans get injured while operating alongside robot manipulators in its workspace. In fact, this kind of accidents do occur and in some cases, results in fatalities. Reasons include the negligence of the safety procedures from the human worker or any form of carelessness when the human operator is inside the manipulator's workspace. Industrial robots are rigid, performance-based machines, but can be equipped with sensors and algorithms to accommodate human presence in the work envelop. The objective of this paper is to propose a pre-contact sensor-based collision avoidance manipulator that adjusts its motion when a human presence is detected by using proximity sensors placed at different locations of the manipulator. The system is then analyzed in terms of sensor positioning and direction of the approaching human. Results indicate that by using ultrasonic sensors and new reference trajectory, the robot is able to detect the approaching motion of the human and decide on the alternative path, if necessary.**

***Index Terms*—Collision Avoidance; Proximity Sensors; Robot Manipulator; Trajectory.**

I. INTRODUCTION

The use of automation robots in industrial sector become more common in order replace human workers in performing risky, tedious, difficult and monotonous tasks. Sometimes, human workers also need to work in close cooperation with robots. In the resulting situations, human-robot interaction (HRI) becomes more frequent and unavoidable while at the same time creates the possibilities for an accident.

In Malaysia, the number of occupational accident took place in the manufacturing sector had recorded the highest number of victims in both non-permanent disability and permanent disability categories in the year 2015. However, based on the occupational accident statistics [1] by Department of Occupational Safety and Health (DOSH), Malaysia, other sector which contributed to the largest economic growth, such as construction, agriculture, forestry, logging and fishing also gave a higher number of accidents which caused death, non-permanent disability and permanent disability. Exhaustion, distraction and negligence of procedures, lack of experience or following the wrong instructions for the initial robot start-up are considered as human mistakes and also one of the factors of industrial accidents. Human mistakes are more controllable if compare with engineering error (Programming bugs, faulty electronics, defective algorithm of controller) and environmental factors (poor sensing due to haze or lighting condition, high temperature).

In reality, it is a complex task to build a robot which has a balance between performance and safety. Machines that have to deliver performance in terms of welding, cutting and molding are not attainable to have a perfect safety strategy in all contingencies. Physical safety barrier or safety gate to keep the robot is one of the commonly used safety strategy installed outside of the robot workspace. The purpose of having this safety barrier is to define a restricted area for robot against access by humans when the robot is in operation.

Other than teleoperation robot, some robot also requires collaboration between workers to complete the task given. Therefore, it's not a practical way to shut down the robot for collision avoidance. This problem can be solved by equipping the robot with force-torque sensor combined with the appropriate control method. The robot will react based on that real time moment when sensor attains the specific information required, such as force and direction, and then robot will be controlled by limiting the maximum allowable velocity of the robot's movement.

With the limit speed mode of the robot, it is still not adequate to ensure the safety of approaching worker because it will create an unexpected high axis speeds when motion of robot manipulator passes near the worker. In this situation, if the singularities are not avoidable by the robot manipulator, it needs to stop operation and display warning or generate precaution signals prior to letting the robot pass through.

In this research, the main idea is to design or develop a sensor based manipulator's collision avoidance strategy that will detect approaching motion of human and produce a new reference trajectory for the manipulator to avoid collision with human. In Section 2, related literatures are reviewed, in Section 3, the methodology for the system is described and Section 4 presents the results of the simulation work using V Rep software.

II. RELATED WORK

There are three different categories of the sensor system which is reviewed; projection-based sensor system, vision-based and proximity-based sensor system.

A. Projection Based Sensor System

This type sensory safety system is operated using a projector to emitted light rays so that it can establish safety spaces for the movement of the robot. In the research paper by Christian (2011) [1], the proposed safety–space produced by projector can dynamically change its position, form and size, based on current position or movement of a robot. The safety space configuration can be defined by the user or programmatically which, depending on a robot's position and trajectory. Then from the obtained results, the projection image and expected-state mask used to detect interruptions are determined.

B. Vision Based Sensor System (MS Windows Kinect 3D Optical System)

Kinect is a device which combines features of "RGB camera, depth sensor and multi-array microphone running proprietary software" that can interpret specific gestures, performs completely hands-free control of electronic devices and track the movement of objects or individuals in three dimensions. The research paper by Filip and colleagues (2015) [4] had applied the Window Kinect 3D optical camera system on a mobile robotic system (MRS) where the 3D optical system is used to recognize objects, then provide a collision-free manipulation for the robotic arm of MRS based on the said objects.

C. Proximity Based Sensor Systems

The proximity-based Sensor systems that will be discussed are capacitive, infrared and ultrasonic proximity sensors

C1. Capacity Proximity Sensor

This type of sensor can detect both conductive and non-conductive obstacles by disturbing the electric field through a shielding effect. When there are obstacles within the electric field, the sensor capacitance will change. The Whole Arm Proximity (WHAP) sensor concept has been introduced in Novak and Feddema (1992) [6] which uses two plates on a single substrate to generate and measure changes in an electric field

C2. Infrared Proximity Sensor

A modified method by Vladimir and Edward (1993) [9] which applied the "whole-sensitive arm" concept for a hybrid robot teleoperation system. The sensitive skin consists of hundreds of active infrared proximity sensors will provide the sensory information about the obstacles in the arm environment, then this data is processed by motion planning algorithms to avoid collisions for the entire arm body.

C3. Ultrasonic Proximity Sensor

Besides using ultrasonic sensors in distance measuring, it's also applied commonly in proximity detection, object localisation and mobile robot guidance. An obstacle avoidance method for robotic manipulators using ultrasonic sensors is used by Llata (1998) [10]. The whole sensor introduced in [10] is made up of 16 emitter and receiver sensors that spatially distribute round the grip. The whole sensors are added to the end effector of the robot without affect the dynamic behavior of the robot.

III. METHODOLOGY

A. System Design

This part is more focused on the system design in terms of software simulation of the sensor based collision avoidance manipulator concept by using V-Rep (virtual robot experimentation platform). By using this software, users can control each of the object or model contain in the library via any embedded script, a remote API client, a ROS node or a custom solution. Due to the versatile and ideal features for multi-robot applications, V-REP is normally used by industrial and manufacturing sectors for remote monitoring, factory automation simulations and safety double checking.

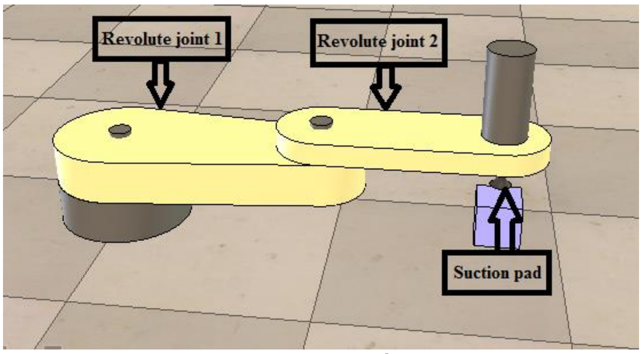
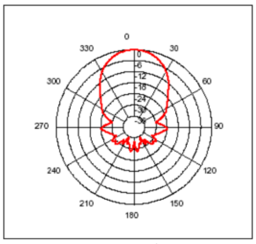


Figure 1: MTB robot

A Machine Type B (MTB) robot which is a simple two links planar manipulator is chosen to be included in the system. This MTB robot is one of the models under the non-mobile robots category. This MTB robot can be controlled by a specific robot language called plugin. In other words, a plugin also means that a shared library that is automatically loaded by V-Rep's main client application at program start up. With this plugin, users are able to directly control the motion by inserting the commands into the MTB robot properties dialog. Inside the properties dialog, several commands with function description are given. The commands are allow the users to changes the revolute, prismatic joint velocity, joint positions in degrees, sets or clears the output buffer and can applied the simple programming function like time delay and label.



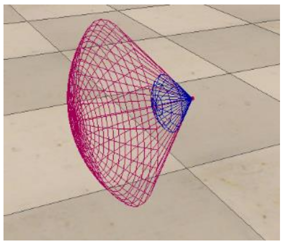


Figure 2: (Left) Conical beam pattern; (Right) Cone type proximity sensor

Furthermore, users can also programmatically trigger the robot or changes the behavior by reading or writing the robot's outputs and inputs certain commands inside the "script". The custom user interface that originally attached with the MTB robots model allows the user to clearly observe the change of the robot's input and output port bits. After exploring the control of MTB robot, sensors are added on the manipulator to senses the obstacles.

Ultrasonic range detection sensor HC-SR04 is being targeted to perform obstacles detection task together with the manipulator in a real world due to its user friendly features and requiring a short trigger pulse. The beam pattern of the SRF04 is conical with the width of the beam being a function of the surface area of the transducers and is fixed. The beam pattern of the transducers used on the

SRF04 is shown in Figure 2. In order to imitate the operation of a real-world process into the simulation, a cone type proximity sensor is applied in the system to illustrate the beam pattern of SRF04.

The manipulator is a 2 degree of freedom system in the same plane and the way to describe its motion is to obtain the two independent coordinates. According to forward kinematics, relationship of Cartesian position of the end-effector tip with each of the joint angles is shown in Equation (1) and (2). α_1 and α_2 are lengths of the first (near to the base) and second link and θ_1 and θ_2 are joint angles of link 1 and 2.

$$x = \alpha_1 \cos\theta_1 + \alpha_2 \cos(\theta_1 + \theta_2) \tag{1}$$

$$y = \alpha_1 \sin\theta_1 + \alpha_2 \sin(\theta_1 + \theta_2) \tag{2}$$

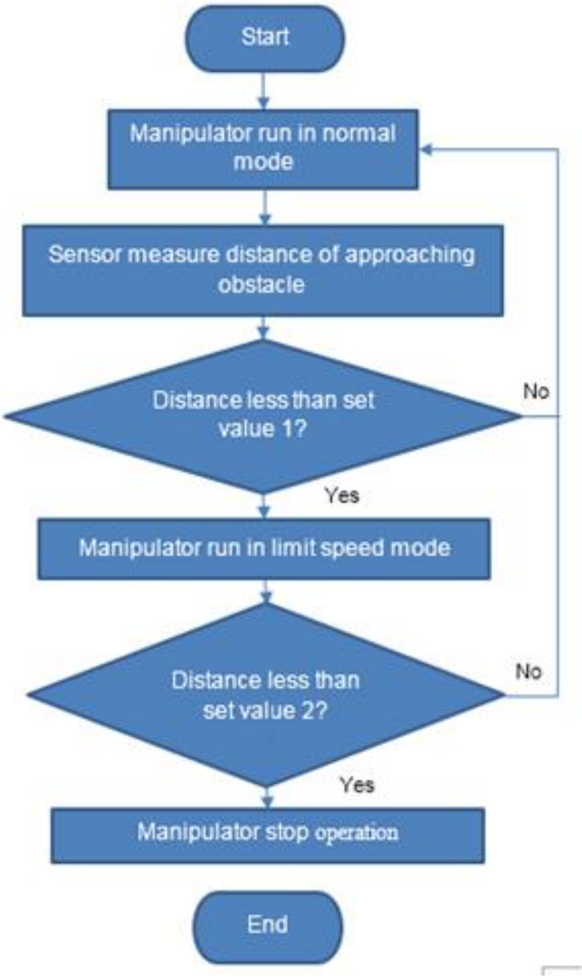


Figure 4: System flow chart of the collision avoidance strategy

IV. RESULTS AND DISCUSSION

A simple system is designed using V-Rep software simulation which involves the process of interfacing between the sensor and motion of manipulator. Through useful features of V-Rep simulator, the performance of designing system can be clearly observed and the data related to the motion of manipulator are recorded then shown in the graph form. Analysis and discussion are made based on the collected result.

A. *System Configuration*

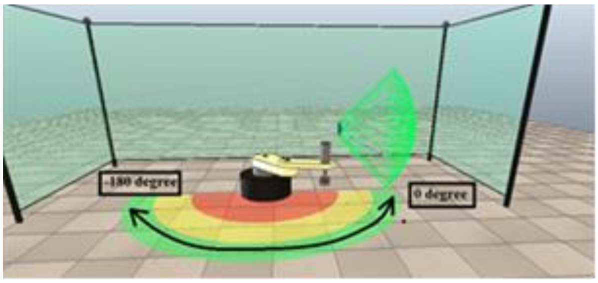


Figure 5: System configuration

The green region is defined based on the set value 1 while yellow region is defined based on set value 2. The red configuration and the area enclose by each regions are clearly shown in Figure 5. The cone type proximity sensor is placed near the end effector. The rotation angle of both revolute joints is limited between 0 until -180 degree. The primary task of the manipulator is to perform a repeated motion where the revolute joint need to rotate back and forth from 0 degree to -180 degree, so that it will form a semi-circle shape trajectory.

B. *Manipulator runs in normal mode*

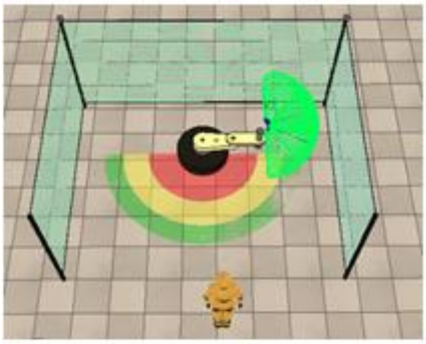


Figure 6: Illustration of the reach of the robot and the direction of the approaching human

In this mode, the human is out of the reach of the robot. It is expected that the robot will move with the default speed set for the joints. As seen in Figures 7 and 8, both result of angular velocity and position for revolute joint 2 is almost same with the results obtained from revolute joint 1, which also shows a periodic graph. This is because the repeated motion of manipulator is shown in both joints. The trajectory of manipulator is plotted based on the coordinates of the end effector which shown in Figure 9.

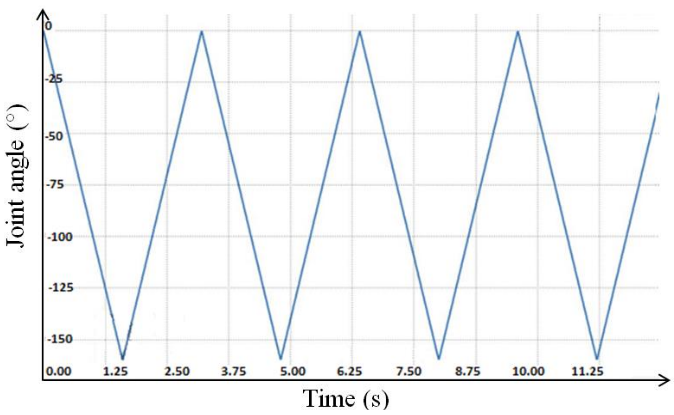


Figure 7: Joint angle 1 of the manipulator in normal mode (no obstacle)

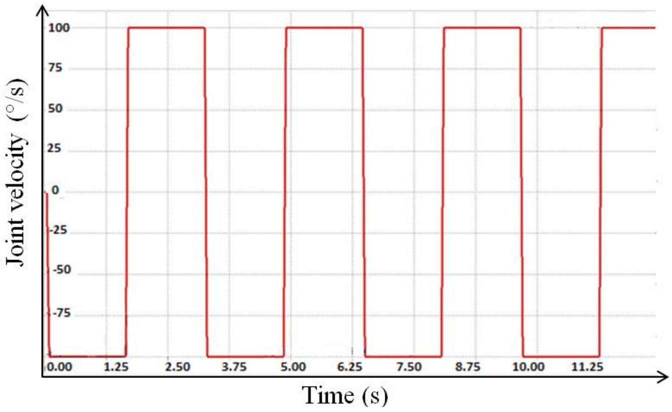


Figure 8: Joint 1 angular velocity in normal mode

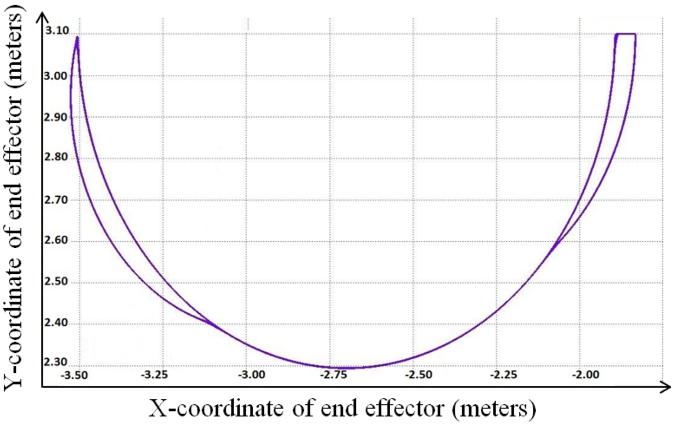


Figure 9: Cartesian position of end-effector

C. *Manipulator in "limit speed" mode (Green Zone)*

The limit speed mode is illustrated as in Figure 10. At this moment, the obstacle enters the green zone of the robot. The joint angle is depicted in Figure 11. By comparing the revolute joint 1 position versus time graph with Figure 7, there are slight changes on the graph after obstacles was detected by the sensor. In this situation, when revolute joint 1 approximately turns -18.40 degree in clockwise direction from its origin, the obstacle is detected by the sensor and triggered the limit speed mode but the manipulator still need to carry out the repeated motion. Due to the changes of joint velocity from 100 to 45 degree/second, this causes the position of revolute joint to change when in limit speed mode in the presence of obstacle.

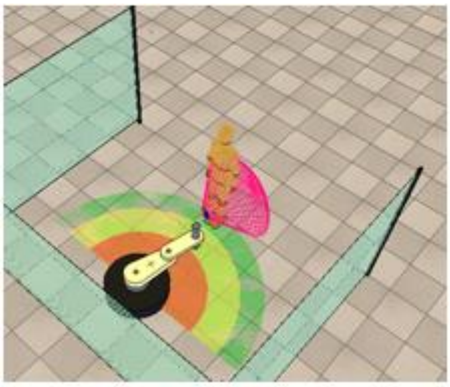


Figure 10: Illustration of 'limit speed' mode

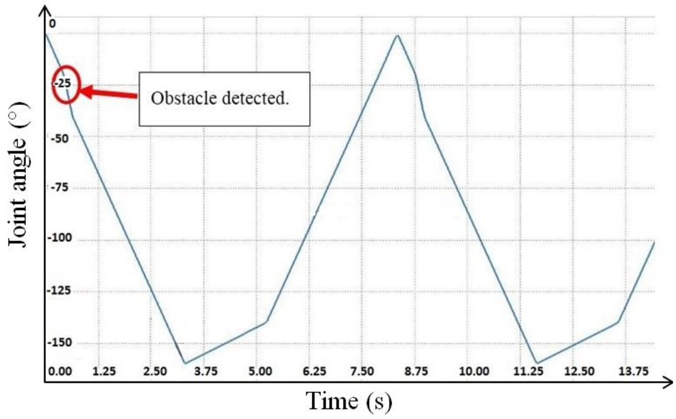


Figure 11: Joint angle 1 in "limit speed" mode

The change in revolute joint 1 velocity is shown in Figure 12. Figure 12 is also periodic, because the manipulator is still running in repeated motion but with a limited speed.

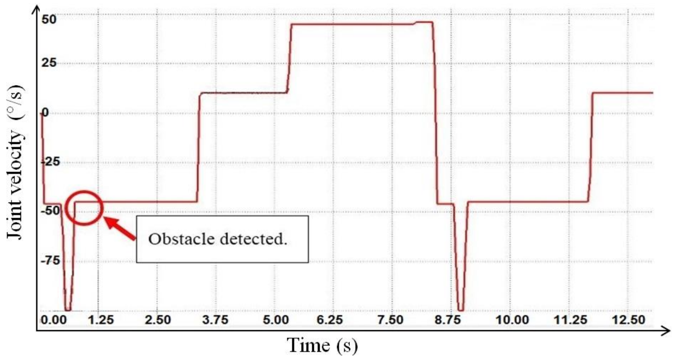


Figure 12: Joint 1 angular velocity in 'limit speed' mode

Figure 13 shows the distance of obstacle detected by referring the position of sensor placed near the end effector.

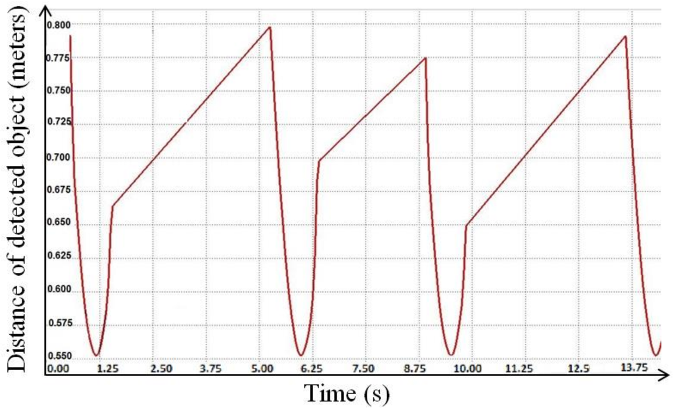


Figure 13: Distance of obstacle detected in 'limit speed' mode

D. Manipulator stop operation (Yellow Zone)

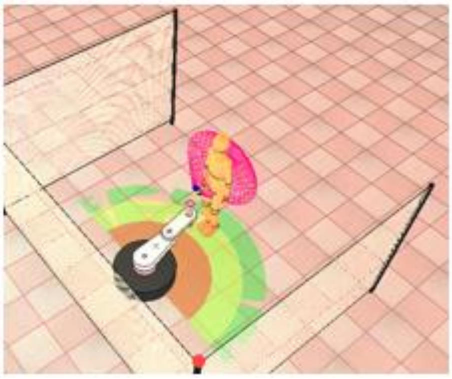


Figure 14: Illustration of 'stop' mode

The Yellow Zone in Figure 14 illustrated the zone where the robot has to stop. This is due to the object entering the working region of the robot that will hit the object for certain. Figure 15 shows the joint angle response when the obstacle is detected. Based on the graph in Figure 15, after the manipulator start to run a few milliseconds, the joint position decrease frequently until the position where the obstacle being detects. The reason is mainly due to the limit speed mode for revolute joint was triggered first before the manipulator stops operating. The change in the revolute joint angular velocity before 1.25 seconds shown in Figure 16 proves the statement above. After 1.25 seconds, the results for both graphs maintain at zero. The graph shows that distance between the obstacle and sensor is 0.2472 meter and the angle will maintain the same value if the obstacle remain in the same position.

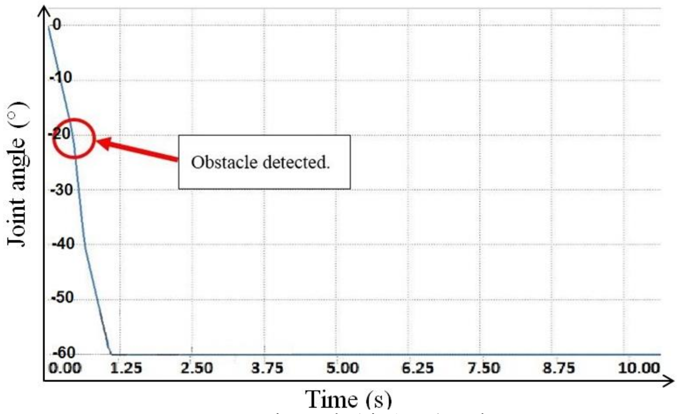


Figure 15: Joint angle 1 in 'stop' mode

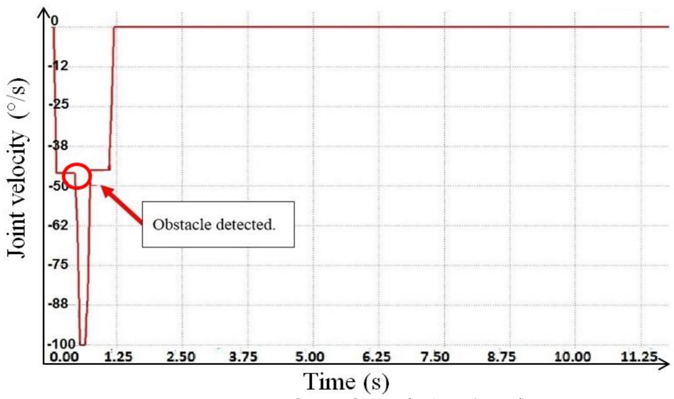


Figure 16: Joint angle 1 velocity in 'stop' mode

V. Conclusion

A simple designed system that covered the interfaces process between the sensor and manipulator with collision avoidance function is being presented. During the simulation, a cone type proximity sensor is used to detect obstacle, by the same time measure the distance of the obstacle within the detection area of the sensor. The manipulator will decide whether to operate in limit speed mode or just stop the operation by referring to each of distance set value defined in the system. If no obstacle appears, the manipulator will run in repeated motion with a normal speed. Position and angular velocity produced from each joint was presented to show the reaction of the robot.

Further improvement or modification shall be done on the collision avoidance strategy, so that the manipulator can follow a new reference trajectory to avoid from collision.

Acknowledgment

Authors would like to acknowledge UTeM research grant PJP/2014/FKE(11D)/S01339. Authors would also like to acknowledge the Robotics and Industrial Automation group from the Centre of Excellence in Robotics and Industrial Automation and the Faculty of Engineering.

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