EVALUATING COLLABORATIVE ROBOT SAFETY FOR HUMAN-ROBOT INTERACTION IN A SIMULATED DOMESTIC ENVIRONMENT

TAMANNA -E- KAONAIN

SUPERVISOR: DR. MOHD AZIZI BIN ABDUL RAHMAN

CO-SUPERVISOR: DR. MOHD HATTA BIN MOHAMMED ARIFF

ADVANCED VEHICLE SYSTEM RESEARCH GROUP

MALAYSIA-JAPAN INTERNATIONAL INSTITUTE OF TECHNOLOGY

UNIVERSITI TEKNOLOGI MALAYSIA

ABSTRACT

The use of collaborative robots or cobots plays an important role in human-robot interaction in many sectors is driving researchers to focus more on human–robot interaction (HRI). Human-robot interaction carries several challenges, the most important being the risk of injury to the human. Increasing complexity of human-robot interactions coupled with decreasing proximity between robots and humans only causes the risk of injury to rise. In industrial robotic systems, robots are mostly caged and isolated from humans in a safety guard environment. However, as time has passed the use of domestic robots has emerged, leading to a large need in research on robot safety in domestic environments. In this report, simulations of human safety during human-robot interactions in a domestic environment without a safety fence is presented. Human-Robot Collaboration is still in an initial stage, with previous research being done mainly in industrial workplaces. Thus, safety assessments in domestic environments are critical in the field of cobots, with simulations being the first stage of research. In this report, a Gazebo software in which designed to replicate complex environments that a robot may face - is used, written in Python language. The robot model is designed and developed to simulate for human robot interaction. In the robot trajectory, the safety interaction can be simulated. In one example, the robot's speed can be reduced before a collision with a human about to happen, and it minimized the risk of the collision or totally reduce the damage of the risk. After successful simulation, this can be applied to the real robot in a real domestic environment.

CHAPTER 1

INTRODUCTION

1.1 Background

Robots have been successfully employed in industrial settings to improve productivity and perform dangerous or monotonous tasks. Recently, research has focused on the potential for using robots to aid humans outside the strictly “industrial” environment, in medical, office or home settings. One important motivation for using service or personal robots is the aging population in the developed world [1, 2]. Robots that can interact with humans in a safe and friendly manner would allow more seniors to maintain their independence and could alleviate some of the non-medical workload from health-care professionals. To this end, robots are being designed to perform homecare/daily living tasks1 [3], such as dish clearing [4], co-operative load carrying [5, 6] and feeding [7,8], and to provide social interaction [2, 9]. Robots are also increasingly marketed for entertainment purposes [10], and for home maintenance activities [11]. As robots move from isolated work cells to more unstructured and interactive environments, they will need to become better at acquiring and interpreting information about their environment [12]. One of the critical issues hampering the entry of robots into unstructured environments populated by humans is safety [13], and more broadly, dependability [14]. As defined by Lee, dependability incorporates both physical safety and operating robustness [14]. Some robots, which are intended primarily for social interaction [9, 10, 15], avoid safety issues by virtue of their small size and mass and limited manipulability. However, when the tasks of the interaction also include manipulation tasks, such as picking up and carrying items, assisting with dressing, opening and closing doors, etc, larger, more powerful robots will be employed. Such robots (e.g., articulated robots) must be able to interact with humans in a safe and friendly manner while performing their tasks. Figure 1.1 A fault to a safety critical system of a robot can pose fatal or serious injuries to humans and may also result to the loss of capital investments in the machines [16].

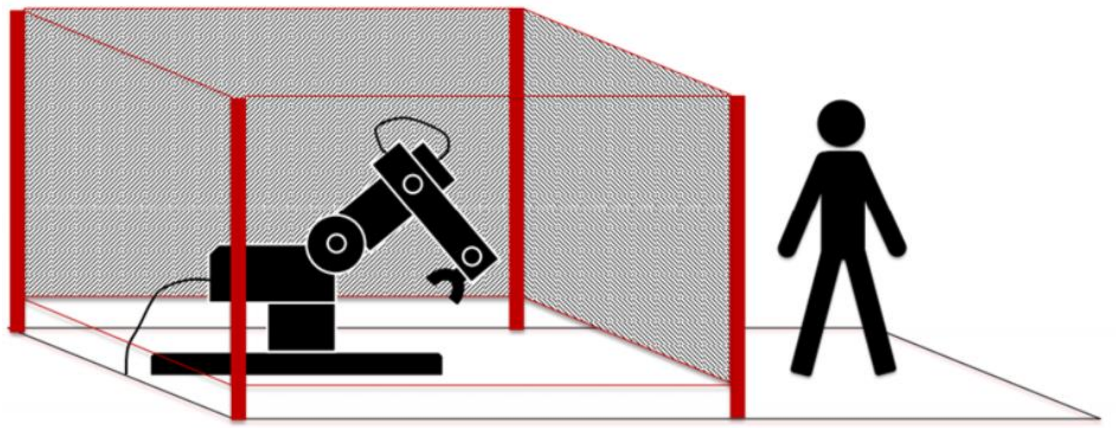

Figure 1.1 Conventional industrial robot with safeguarding devices preventing operator's access to workspace (Courtesy of Robotics Industries Association) [25].

1.2 Problem statement

The primary industrial robot safety standard in North America is the ANSI/RIA 15.06 Standard for Industrial Robots and Robot Systems - Safety Requirements [17]. This standard is written specifically for industrial robots and is not applicable to autonomous or service robots. Therefore, the safety of human-robot interaction is affected by isolating the robot from the human [13, 17, 18]. In effect there is no interaction. As robotic applications transition from isolated, structured, industrial environments to interactive, unstructured, human workspaces, this approach is no longer tenable [13]. However, in unstructured environments such as domestic area, mechanical design alone is not adequate to ensure safe and human friendly interaction. Additional safety measures, utilizing system control and planning, are necessary. In order to ensure a safe interaction, the robot must be able to assess the level of danger in its current environment, and act to minimize that danger. Safety can further be enhanced if the robot is able to anticipate potential hazards in advance, and plan to avoid those hazards. This research study focuses on collaborative robots or cobots safety that has been mainly limited to workplace environments. However, cobots still need to undergo safety assessments before implementation in a real environment. This can be achieved by using sensors and reducing robot's motion speed in its trajectory during human robot interaction.

1.3 Research Objectives

The Objectives of the research study are as follow:

1. To design and develop an arm robot in the simulated non-industrial workspace.
2. To investigate and evaluate the interactions between cobots and humans in domestic environments.
3. To validate the algorithm of proposed arm robot with the recent benchmark problem.

1.4 Research Scope

The scopes of the research are given as follows,

1. Figuring out a measurement for the degree of risks in a human-robot collaboration for use in planning and control in domestic environment only.
2. The developed methodology is for safe planning during human-robot interaction applicable to arm robot or manipulator only, ensuring about the safe and valid paths through the domestic place.
3. Formulation of a real-time reactive robot controller for safety in which the controller reduces the accident during human and robot interaction.

1.5 Research significance

The significations of the research are highlighted as:

1. A human monitoring system for estimating the position and orientation of the human participant, and for estimating the human affective state during human-robot interaction. The human monitoring information is then incorporated into the planning and control system.

2. Implementation and testing of an exemplar human-robot interaction system.

1.6 Research outline:

Figure 1.1 shows a flowchart of framework of the research study. In 1st section, a total study of the background of research, and set the problem statement and objectives were discussed. Below in section 2, the literature review of this research study discussed. The system design of the model and Analysis of Proposed model discussed in section 3 and development of the model also discussed there. The initial results will be analysis in section 4. The proposal will be concluded in section 5. Figure 1.1 shows a flowchart of framework for the whole of the research.

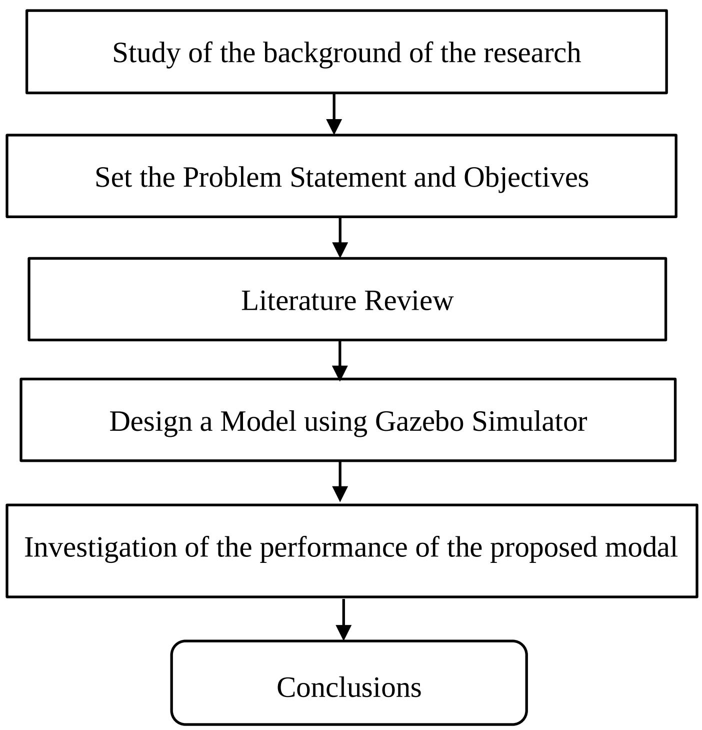

Figure 1.2 Flowchart of the framework of the research study

CHAPTER 2

LITERATURE REVIEW

2.1 Background

Industrial safety standards focus on ensuring safety by isolating the robot away from humans, and are, therefore, not directly applicable to human-robot interaction applications. However, industrial experience has shown that eliminating hazards though mechanical re-design is often the most effective safety strategy [17]. This approach has also been applied to interactive robots. For example, Yamada et al. [19] developed a whole-body robot viscoelastic covering. The impact force attenuation of the covering is selected based on the human pain tolerance limit. In [20], in addition to a viscoelastic covering, spherical joints are used, and mechanical limits are installed on all joints to prevent pinching. Bicchi et al. [21, 22] advocated the use of compliant joints (McKibben actuators) to design an intrinsically safe system that is user back drivable. Zinn et al. [23, 24] proposed using distributed parallel actuation to lower the effective inertia of the robot. While these and other mechanical re-design approaches have made contributions to reducing the impact force during a collision, they do not prevent the collision from occurring. To ensure safe and human friendly interaction in unstructured environments, additional safety measures, utilizing system control and planning, are necessary as discussed in the following sub-sections.

2.2 Human Robot Interaction

Richard in 2018 [25] reviewed about safety and automation of collaborative robot system in work environment and concluded about this fact at the end of the paper that the safety related issues for automation and robotics need to be optimize the performance to avoid the limits of safety. Uwe at el. (2018) [26] pointed out some importance of the digital factory tools for the planning of human-robot collaboration (HRC). Weitschat and Aschemann [27] developed a novel method for improving the robot performance that still complies with the international safety standards for collaborative robots. The approach based on a projection of a human arm motion into the robot's path to estimate a possible collision with the robot and also optimization approach by minimizing the time needed by the robot to reach the goal position under human-in-the-loop constraints. Zhu, Yan, and Xing [28] introduced several methods to solve the problem where robot trapped at a local minimum before reaching its goal and evaluated the artificial potential field approach with simulated annealing (SA) as one of the powerful techniques for escaping local minimum, simulated annealing has been applied to local and global path planning.

Anas AlMajali at el. [29] identified estimated and prioritized the risks associated with attacks targeting the availability of the robotic system and performed an impact oriented semi-quantitative risk assessment of the loss of availability on the well-known PeopleBot™ mobile robot platform. After that they experimented with several well-known attacks that can target and affect the availability of the robot to examine the cyber-physical impacts of the attacks on the robotic system, we setup a ten-goal test area and constructed a 2D map. Slim Daoud at el. [30] has presented an efficient method to optimize the performances of the robotic system. By defining the suitable combination of scheduling rules, our method allows each robot to perform the assigned pick and place operations in real time in order to maximize the throughout rate and developed different resolution methods which define the scheduling rule for each robot in order to seize the products from the first side of the system and to place them on the second side with a strong industrial constraint regarding the functioning of a real industrial robotic system. N. Yakymets at el. [31] focused on the safety aspect and propose a methodology and associated framework for safety assessment of RSs in the early phases of development. The methodology relies upon model-driven engineering approach and describes a preliminary safety assessment of safety-critical RSs using fault tree (FT) analysis (FTA). The framework supports a domain specific language for RSs called RobotML and includes facilities (i) to automatically generate or manually construct FTs and perform both qualitative and quantitative FTA, (ii) to make semantic connections with formal verification and FTA tools, (iii) to represent FTA results in the RobotML modeling environment.

Süleyman Demir and Akif Durdu [32] reviewed the aim of the human-robot relationship research to define the models of people's expectations of robot interaction in order to guide robot design and algorithmic development that allows for a more natural and effective interaction between humans and robots. With these models, robots can be used to serve, train, support, entertain, inform, direct, clean, secure certain areas or promote a product or brand in all areas (hospitals, cafes, airports, educational institutions, nursing homes, home environment, entertainment centers, shopping centers, fairs etc.) where people are present. Thorsten Gecks and Dominik Henrich [33] presented an industrial robot system whose workspace is supervised by several stationary cameras to ensure safe human-robot cooperation. All robot transfer motions are checked for collision by detecting obstacles using a difference image method. Whenever a collision is detected, the robot motion path is changed accordingly.

Svante Augustsson, Linn Gustavsson Christiernin, Gunnar Bolmsjö [34] pointed out how to implement flexible safety zones. In the case study an industrial robot cell emulates the environment at a wall construction site, with a robot performing nailing routines. Tests performed with humans entering the safety zones of a Safety Eye system. The zone violation detected, and new warning zones initiated. The robot retracts but continues its work tasks with reduced speed and within a safe distance of the human operator. Ali Ahmad Malik, Arne Bilberg [35] explores various types and levels of interactions between humans and robots in a manufacturing domain. A synthesizing architecture of human–robot collaboration is suggested based on three dimensions of team composition, level of engagement and safety. The architecture describes the collaboration using a 3-dimensional reference scale. Sven Stumm, Johannes Braumann, Sigrid Brell-Cokcan [36] combined visual CAD based programming with skill-based programming through demonstration. This constitutes the basis of the outline’s strategy and employed human feedback through hand gestures for incremental parameter modification and also proposed this approach in order to potentially lower times to production for new products and allow efficient use of robotics in low lot-sizes especially in the context of assembly for construction.

2.3 Summary

This chapter is discussed about the literature of the human robot interaction whatever work done previously. It is described here about the methodology, used and the limitation of the previous related research. This chapter is also elaborated that in very early stage of the research work with robotics, the industrial robot was used without any interaction with human for their research study. Later, they worked on interaction between human and industrial robot with the safety barrier. As the industrial robot has many limitations, they start working with collaborative robot which is very useful for different purposes but still isolated with the human in order to make safe interaction between cobot and human in different environment such as dynamic, factory.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Path planning for safety is an important component of an overall safety strategy for human-robot interaction; however, it has received less attention than control and impact strategies. Including safety criteria at the planning stage can place the robot in a better position to respond to unanticipated safety events. Planning is used to improve the control outcome, like using smooth trajectory design to improve tracking [37, 38], Herein, a similar approach to [39, 40] is considered. However, in order to address safety in unstructured environments, the whole arm configuration of the manipulator, rather than only the end-effector state, is considered in the planning stage. Within this context, potential danger criteria are formulated and evaluated, using a motion planning framework like [41,42]. Each proposed criterion explicitly considers the manipulator inertia and center of mass location with respect to the user to evaluate danger. A two-stage planning approach is proposed to address issues of potentially conflicting planning criteria. The proposed approach is evaluated in simulation to compare the criteria and to demonstrate their efficacy in an example handoff task.

3.2 System overview

Figure 3.1 shows the flow chart of the system overview. Human robot interaction can be two kind of such as cobot and industrial robot, while cobot can be mobile robot or arm robot. This research study focuses on the arm robot in domestic environments. The system will be realized using Gazebo, a simulator for robotic research. The safety model will be designed and developed using Python language and the trajectory planning for the collision with humans will be investigated. At the end, the safety of human to robot interaction will be assessed and validated the model with standard benchmark problem.

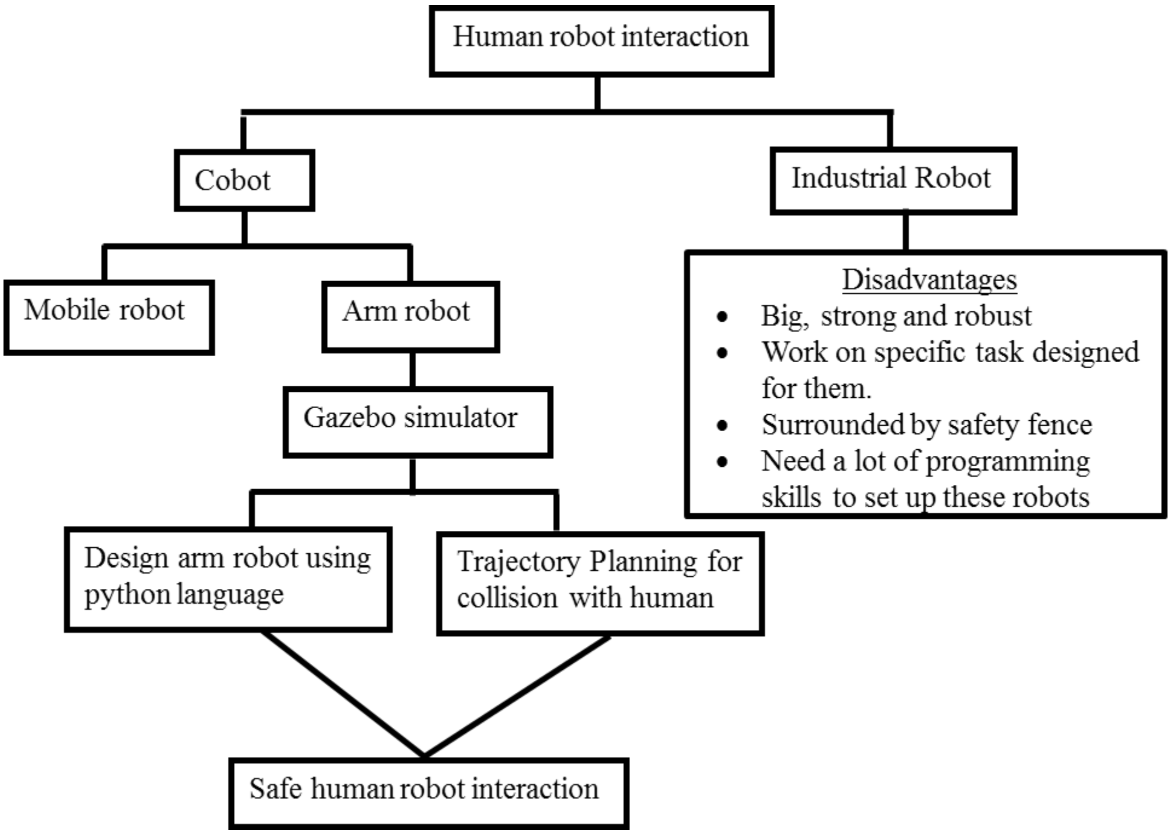

Figure 3.1 Flow chart of the system overview

3.3 System design

Figure 3.2 illustrates the steps or the process of this research work. To locate a safest configuration the arm robot needs to pass successfully to the end stage. If the arm robot cannot find any obstacle then its moved forward but if it find any obstacle then it can be able to analysis what kind of obstacle is it, if it is non-human then its moved backward but if it is human then the robot reduce its speed and check the risk factor of their interaction, if there is no risk then its moved forward but it any risk is there it can be minimized the danger for that interaction moved forward and check the safety of the interaction. If the interaction is not safe, then the robot reduces its speed and stop after a while but if the interaction is safe then it moved forward. At the end, this algorithm checks the goal of the research, if the algorithm is not achieving the goal the its return an error but if it's achieving the goal then the algorithm is run successfully.

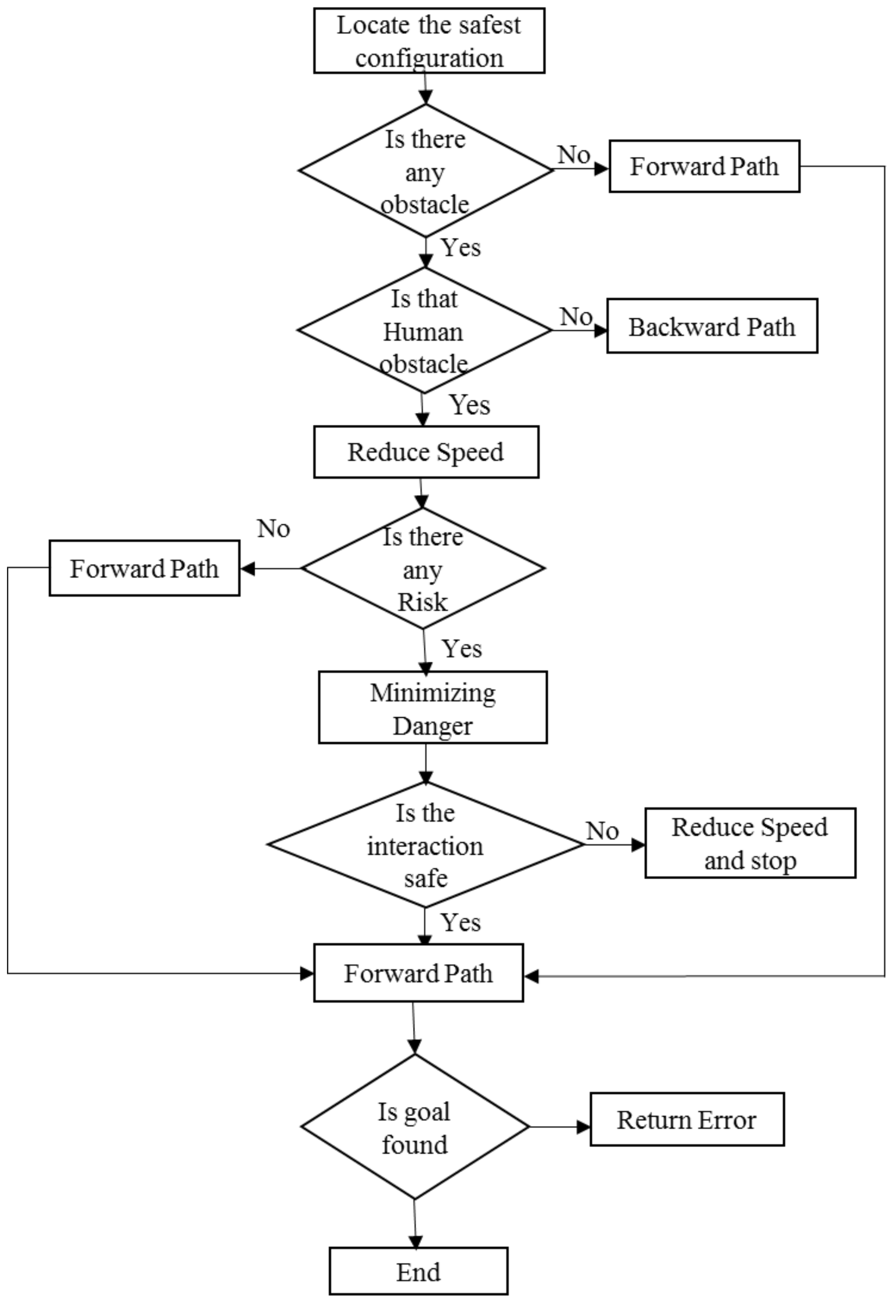

Figure 3.2 Flowchart of the process of the proposed research

In order to realize the methodology proposed for this research work, a test simulation system is designed based on the experiment setup, simulation recorded for motion sensor without object. Figure 3.3 shows a domestic environment and figure 3.4 the arm robot motion simulation on its trajectory in a domestic environment with figure 3.4 human and Robot interaction in a domestic environment respectively.

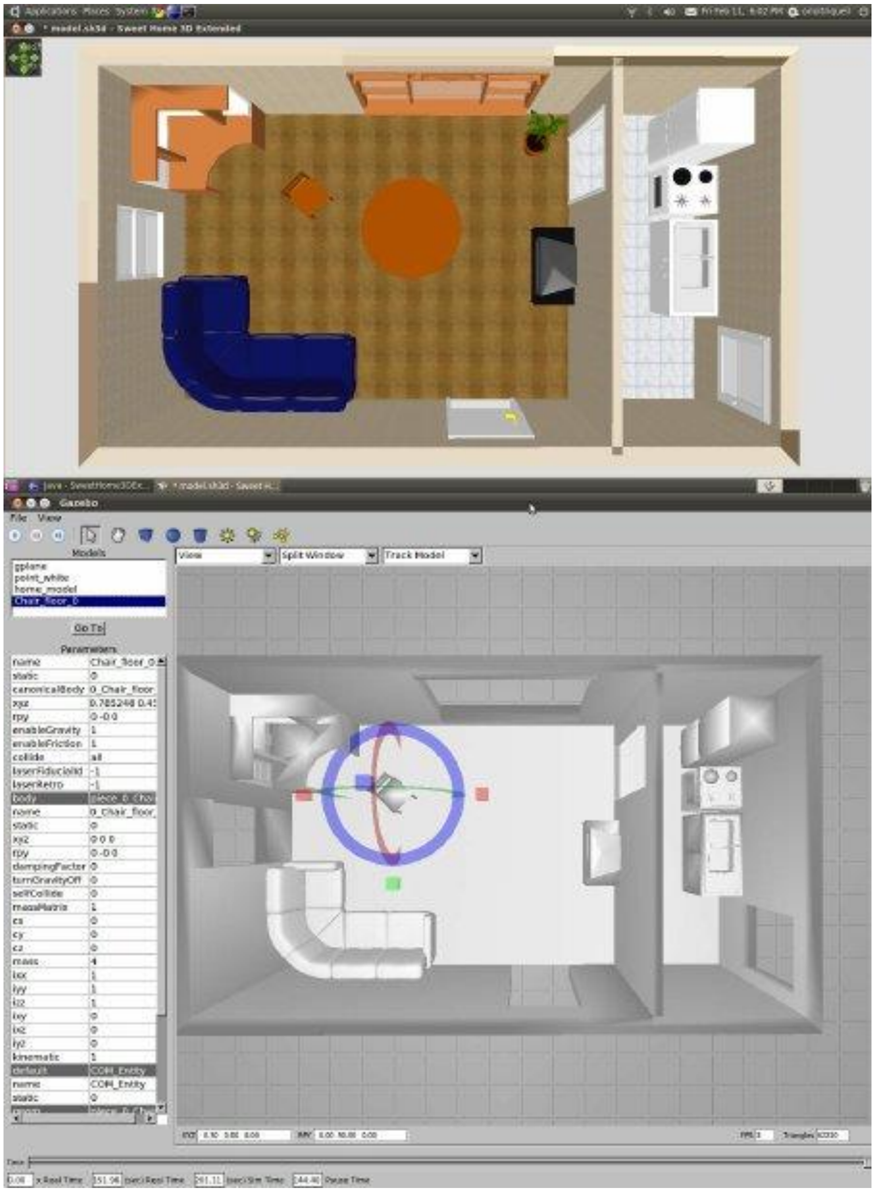

Figure 3.3 A Domestic environment

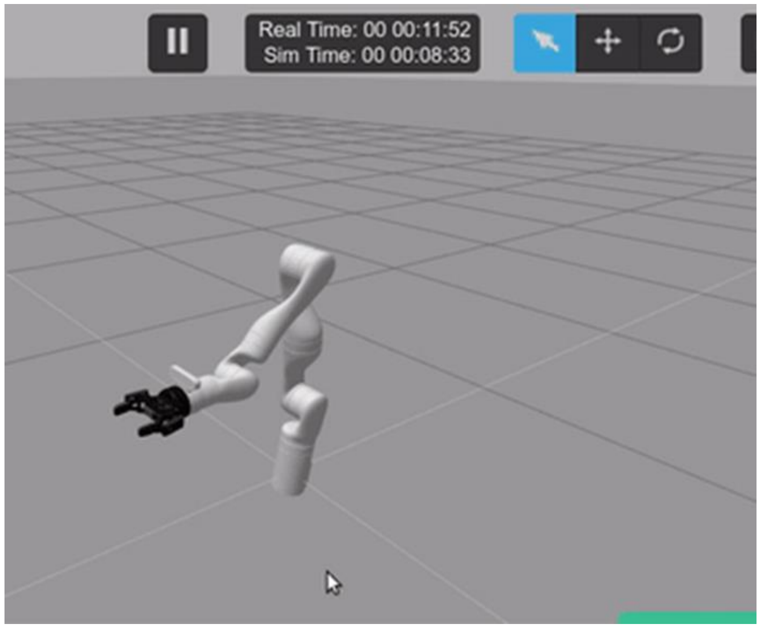

Figure 3.4 An arm robot in a domestic environment

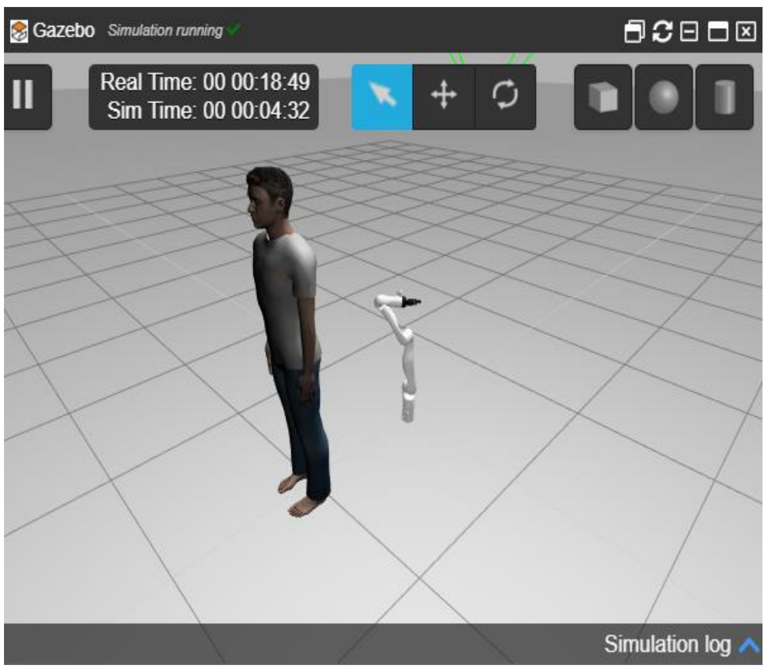

Figure 3.5 Human and Robot interaction in a domestic environment

A simulation domestic environment is developed and illustrated in Figure 3.4. In this environment, a human is placed and it can moved in 360° diction and forward and backward steps also, on the other hand an arm robot is placed there which can move in 360° and in 3 direction x, y and z axis and also move forward and backward steps.

3.4 Gantt Chart

Figure 3.6 shows the Gantt chart of the whole research study. According the Gantt chart the problem statement and the objective of the research already set through the literature review. Literature review will be done in this whole project. Currently this research is in the third stage of design and developing the safety model and gets some preliminary result. After that this model will be modified and validated through deeper investigation. At the last stage a thesis will be written and submitted for evaluation.

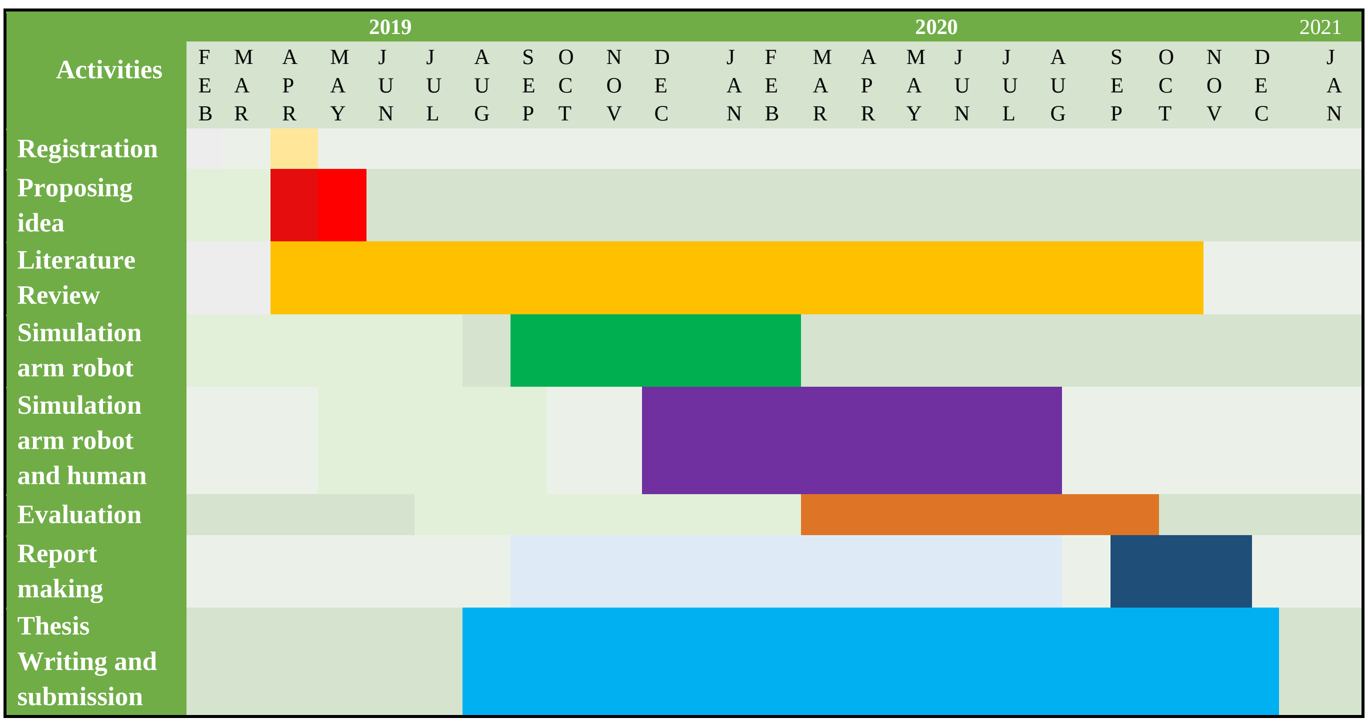

Figure 3.6 Gantt Chart of the research

3.5 Summary

This chapter provides a fundamental view of the research framework and system design of the proposed human and robot interaction. The flow chart and the algorithm of the proposed system are also discussed. The arm robot simulation environment is illustrated here and the human and robot interaction in a domestic environment is also developed and analysis here. At the end of the chapter, a brief future plan of this research study is provided using Gantt chart.

CHAPTER 4

PRELIMINARY RESULTS

4.1 Simulating Robotics Hardware

A popular simulation framework for robots is GAZEBO Player/Stage in ROS. This framework is capable of simulating multiple robots in complex outdoor environments. For every robot, a broad variety of sensors and actuators can be modelled. These sensor models generate realistic feedback. The environment is modelled as a three-dimensional world consisting of static objects, which, however, can be moved by the robots. This capability is predicated on a simulation of rigid-body physics which is additionally included within the framework, permitting physically plausible interaction between objects.

4.2 Simulating Human Characters

Simulation environments for the event of robots are widespread but in most cases the simulation of humanoid interaction partners is missing. For the event of such a simulation two main aspects need to be realized: On one hand the human model has got to be animated and on the opposite the model has got to be controlled to get realistic behaviour. The animation of the humanoid models is often limited to non-natural characters. These simulations are wont to visualize the robot itself and not an interaction partner. For the animation of interaction partners motion capture systems are often wont to store motion primitives which may be applied to a broad range of human characters. An additional challenge to the generation of motions is variable human models which either varies in size or joint hierarchy. To control human characters there exist different approaches. Environment knowledge of the agent is used to determine the human character's behaviour. At the moment the proposed framework does not provide a mechanism to realize autonomous behaviour of the simulated human character. However, such functionality can be imagined as a useful extension and can be realized as future work.

4.3 Simulation Framework

Figure 4.1 illustrated the simulation framework of this research. From the figure depending upon the environment the arm robot stated, rewarded and agent take the necessary action.

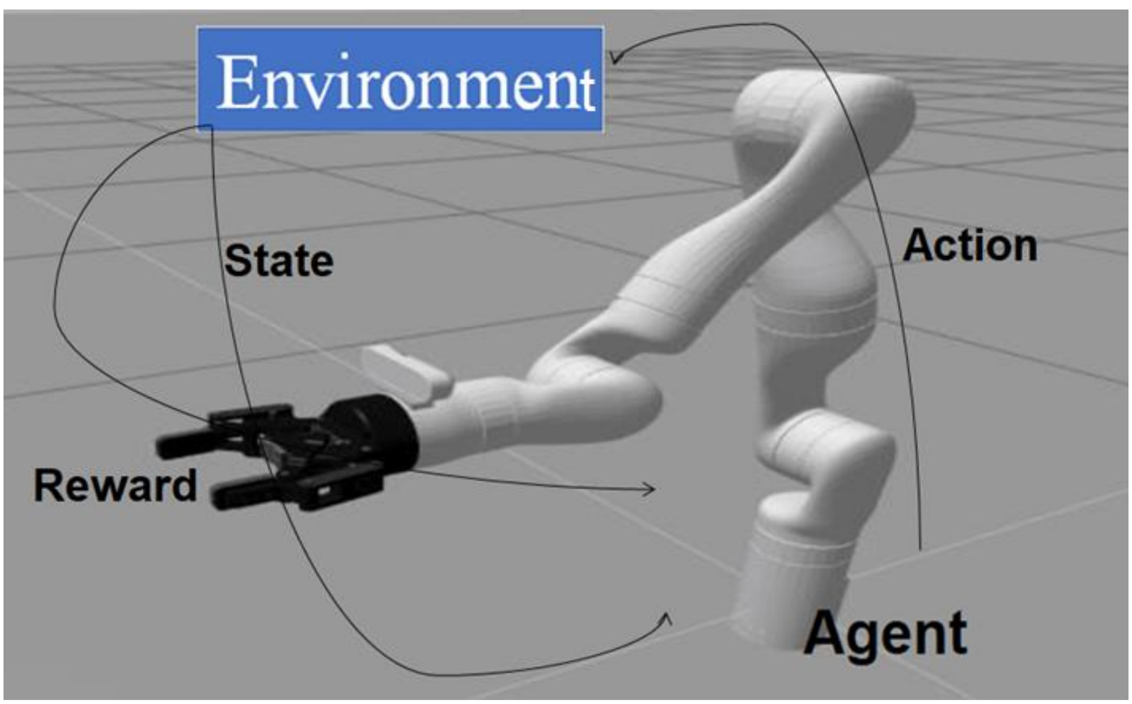

Figure 4.1 Simulation Framework

4.4 Simulation result

In order to implement the proposed model, a test simulation is done online based ROS platform with Gazebo framework website which is already presented in chapter three.

4.5 Expected Results

- The safety of human-robot interactions can be simulated
- The motion speed can be reduced.
- The number of collisions does not exceed 2 out of every 10 trials.
- Simulations can be implemented in a real domestic environment

4.6 Summary

This chapter is summarized the basic characteristic of an arm robots and simulating robotics hardware. Then focus on human characteristics and simulating their characters. Simulation framework also discussed here with some preliminary results of the simulation. At the end the expected results also analyzed.

CHAPTER 5

CONCLUSIONS

Visualization can be the first step towards gathering research results, before any implementation in the real world. Now, it can be eventually focused on the generation, propagation and use of sensor values and corresponding actuator events, without taking care of an actual environment implementation. In order to achieve the objective of this research study, a novel process will be developed for ensuring safety during human-robot interaction in domestic environment, based on an explicit quantification of the level of danger in the interaction using gazebo simulator in ROS platform. Specifically, a method for assessing the level of danger at both the planning and control stages will be developed. Path/trajectory planning and control algorithms will be proposed for minimizing the estimated danger during the interaction. Further, to accomplish the desired task of moving to the goal with a probability of collision with the human, an evaluation trajectory fitness will be applied. The trajectory results in an endpoint with this potential position for the robot along with the known positions of the goal, can be accurately modeled the relationship between the robot’s distance to the goal and the time spent moving to the goal. At the end, the novel method will be investigated into physical system components that have been integrated and validated on a robot platform during real-time human-robot interaction and tested.

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