

# USING VIRTUAL REALITY SIMULATION FOR SAFE HUMAN-ROBOT INTERACTION

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## 1. INTRODUCTION

It is becoming more common in manufacturing environments for a human to work alongside a robot. Using Virtual Reality for Safe Human Robot Interaction explored various ways a robot can successfully interact with a human who enters its range of motion without causing harm to the human. Virtual reality simulation with EON Reality software was used to test the different scenarios with a virtual robot and a virtual human. Virtual reality was used to do these studies because experimentation with a robot can be dangerous and expensive. In addition, industrial standards such as the National Institute for Occupational Health and Safety (NIOSH) requires that no person can be in the operating area of any robot, and that the robot must have barriers around them of gates that have electrical locks that shut off the robot if opened (NIOSH, 1984).

### *1.1 Objectives*

The purpose of this project was to improve safety conditions for those who work alongside robots. To do this a computer simulation of a virtual robot, modeled after a real robot and a virtual human hand was developed to show various ways interaction can take place. For example, a robot may be programmed to work in an industrial environment doing a repetitive task, such as picking up an object off of a conveyer belt and moving it to another location. If a human hand enters its range of motion the robot will be able to detect the hand, find a new route for movement that does not disrupt the hand, and continue working. This simulation can be used in programming the real robot.

## 2. BACKGROUND

Virtual reality, human robot interaction, and sensors make up the three main components of this project. The robot's behavior logic was first tested in a virtual reality environment. After completion, the real robot will be equipped with sensors so it can perceive the real human. Finally, the real robot will be programmed so it can fully interact with the human based on the behavior logic tested in virtual reality.

## *2.1 Virtual Reality*

Virtual reality simulation is an artificial environment created with computer hardware and software that is presented to the user in such a way that it appears and feels real. To enter a virtual reality environment, a user wears special sensors such as data gloves and head mounted displays that receive input from the computer. In addition to receiving input, the sensors monitor the user's actions by tracking which way they move and adjusting the environment accordingly.

By using virtual reality simulation with a virtual robot, one can experience a field of three-dimensional design that is still relatively new and be able to test any outcomes that may be encountered without having to actually program the real robot. Using virtual reality will save time and money, and will allow work in a controlled, safe environment.

## *2.2 Human-Robot Interaction*

Human-robot interaction, also known as HRI, is a new field of study but is growing rapidly in interest among researchers. The use of robots in everyday locations, like the office or home, and in technical environments, like space stations or underwater, is quickly becoming a reality due to the improved capabilities of the robots (Rogers and Murphy, 2003). There are slightly different definitions of what a robot is. The Robot Institute of America defines a robot as “a reprogrammable, multifunctional manipulator designed to remove materials, parts, tools, or specified devices through various programmed motions for the performance of a variety of tasks,” while the Webster dictionary defines a robot as “an automatic device that performs functions normally ascribed to humans or a machine in the form of a human” (Thrun, 2004).

The majority of robots used today are in the manufacturing industry for assembly and transportation. These robots have minimal sensing and computing capabilities and are programmed to do repeatable tasks. However, robots that are currently under development will be able to work directly with people assisting them in the home or workplace. These robots will have the ability to respond and accommodate to changes in their environment, which will distinguish them from other physical devices, like household appliances. (Thrun, 2004)

## *2.3 Sensors*

A sensor is a device that responds to a stimulus, such as heat, light, or pressure and generates a signal that can be measured or interpreted (St. Jude, 2006). The type of sensor that a particular robot uses is crucial to fully implementing that robot's functioning capability. Various types of sensing devices exist, including touch, stereo vision, infrared or ultrasound, laser, and lader.

Touch sensors work when a robot hits an obstacle. The force of the impact pushes in the robot's bumper sensor. The robot's programming then tells it to either move left, right, or back up in response. In this way, the robot changes direction whenever it comes in contact with an obstacle. Stereo vision is the sensor process of using two cameras that give the robot depth perception, while image-recognition software gives it the ability to locate and categorize objects. Simpler robots can use infrared or ultrasound sensors to see objects. These robots will send out a sound signal or beam of infrared light that will reflect and be able to detect surrounding objects. The

robot can then determine the distance from the objects based on how long it takes the signal to bounce back (Harris, n.d.).

Laser sensors are used to get the exact coordinates of the object. A transmitter projects a beam of light to the targeted object where the reflection is then focused via an optical lens to a receiver. When the object changes position, the spot of light on the receiver also changes. These changes are then detected and analyzed (Copitate, n.d.). Lader sensors are sensors that contain a group of laser beams. These sensors can scan an area with high speed and accuracy to provide more data points of an object for a sharper, clearer shape of the object.

Proximity sensors are used in virtual reality to measure the exact three dimensional distances from one object to another. In addition, these sensors are also able to measure the magnitude of an approaching object.

### 3. METHODOLOGY

To accomplish this project, a virtual environment was established, the behavior logic for the virtual robot's movement and assembly of gripping the pipe was determined, and virtual sensors were attached and programmed.

#### 3.1 Virtual Environment

CAD files of the robot were needed to import into the simulation. The real robot was made up of eight different components, and a CAD model of each of these components needed to be created (see Figure 1). The CAD files were then converted to the proper format necessary and imported into the simulation.

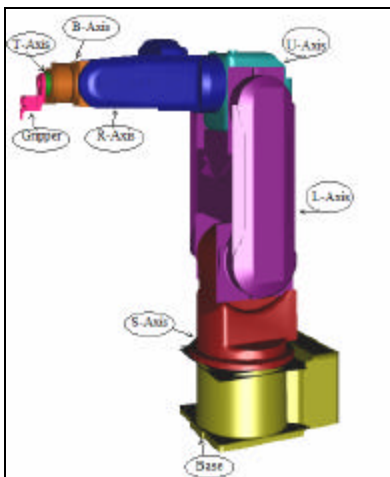


Figure 1: Components of the robot

The virtual environment was then established to create a more realistic setting for the user while in the simulation. This was done by adding a room to provide orientation and distances for the user in the simulation. Without this room the user would not be able to become oriented since

the default simulation background is black. Conveyor belts were then added to provide a place for the pipe to move to before and after the robot picked it up and transported it. A small table was also added for the robot to sit on. A cylindrical pipe was created to provide the robot something to pick up and transport. Finally, a hand was added to represent the human in the simulation. The user could control and direct the hand by either wearing data gloves or a keyboard. These objects were then positioned in the desired locations and scaled appropriately.

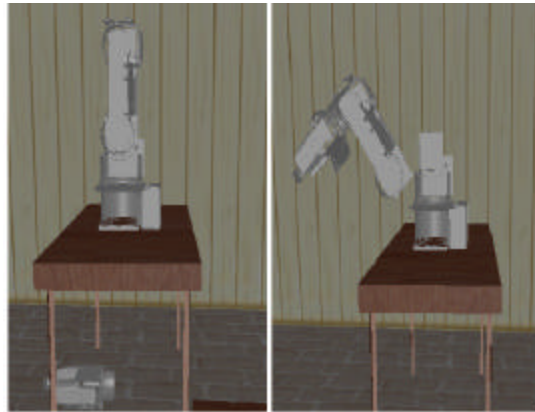


Figure 2: Movements without degrees of freedom

### *3.2 Robot Movement Behavior Logic*

Once the simulation was arranged, the behavior logic to determine the movement of the robot was established. In order to do this, degrees of freedom behaviors were added to each of the different joints of the robot. This was necessary so all the parts would be able to move relative to one another. For example, if the L-axis (see Figure 1) was rotated, all the other axes connected with it should also rotate instead of becoming detached from the robot (see Figure 2). After the initial movement and rotation positions were defined, programming and choosing sequences for the robot to move through began. These movements were modeled after the limitations of the real robot and as many paths as possible were created to demonstrate all of the robot's movement capabilities.

The behavior logic also had to be determined for the assembly of the pipe to the gripper to signify the gripper picking up the pipe (see Figure 3). The locations on the gripper and pipe where the connection was to take place had to be established and the amount of strength of the connection also had to be programmed. This strength provides a relative force and weight to the connection, which assures the connection won't fail during movement. The tolerance for how close the objects need to be before connection occurs was also determined. Finally, the trickier part of the connection determined which part connects to which -- whether the pipe connects to the gripper during the connected phase or vice versa. This hierarchy determines which of the objects does the moving and which object is referenced.

### 3.3 Sensors

Sensor nodes were then applied to the virtual robot and programmed to tell the robot how to interact with the virtual hand. Sound was added that would play when a collision took place to easily identify the collision. Different colored ellipsoids were attached to represent the sensors for each component of the robot; with each color corresponding to the color of the component they were attached to (see Figure 3). These ellipsoids represent proximity sensors in the simulation. The sensors work by detecting the hand's presence when it enters the sensor's radial surrounding. When the hand's presence is detected by the sensor, a signal is sent that stops the movement of the robot, which moves back to its default position.

Finally the sensor definitions were integrated with the movement logics, setting specific paths in the program for the robot to follow. If collision took place, the robot would move back to its original position and the simulation would end (see Figure 3).

Figure 3 is a series of pictures that show how the sensors work and how the robot reacts to collision with the hand. Figure 3a shows the robot in its default position with the hand working outside of the sensor area. Figure 3b shows the robot going through its optimal movement path to pick up the pipe. The hand is still working outside of the area of the sensors. In Figure 3c the hand has now collided with the sensors, which pauses the robot's movement. In Figure 3d the robot abandons its programming to pick up the pipe from this movement path and begins to return to its default position. In Figure 3e the robot has now returned to its default position and begins to try another movement path to pick up the pipe. Figure 3f shows the robot going through the right side path movement to try to pick up the pipe with the hand still in its working area.

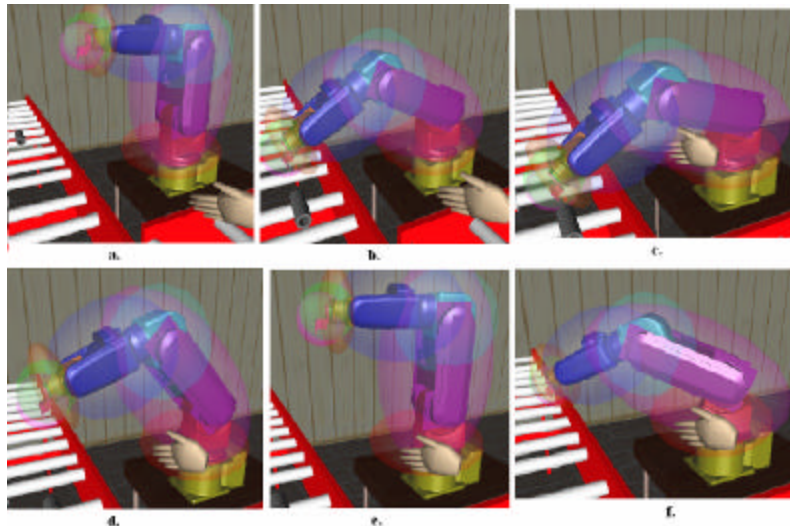


Figure 3: How the sensors work on the robot

## 4. VR SIMULATION

The data produced consisted of several VR simulations. These simulations documented the progress through the project and can be used as a guideline for creating more simulations for various types of robots. They include how to fix graphics problems and creating behavior logic. Various very simple simulations were also created as a way to better understand and test the sensors, movement, and assembly before trying to implement them in the complex simulation. The final simulation shows the behavior logic that was developed with the integration of the robot being able to sense its environment in order to avoid colliding with the human hand.

For the final graphics of the robot simulation, additional objects were imported to make the simulation look more realistic. These included a room for the robot to sit in, a table for the robot to sit on, a conveyor roller system for the robot to take objects from and put on, and a pipe part for the robot to pick up and transport (see Figure 3). Also in the simulation is the hand that represents an actual human hand (controlled in real time from human movement using magnetic position sensors attached to a human body) and ellipses around the components of the robot that represent visually the volume that the sensors cover.

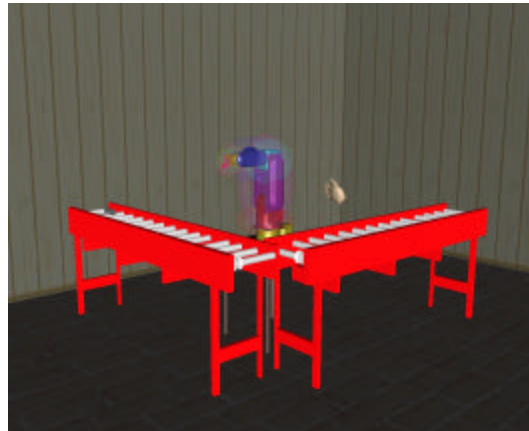


Figure 4: Final Virtual Environment

### 4.1 Simulation Events

The first simulation shows the robot in its virtual environment with just a few movement positions. This simulation is then expanded to show a wider variety of possible movements. Also available are simulations of the robot before fixing graphics issues. These graphics issues included “holes” and gaps in the robot, making parts appear transparent and not properly importing the CAD files, which resulted in a slower run time. These simulations would be helpful in comparing what not to do with future simulations and by looking at the comparison, show how to fix problems. Several simple “test” simulations that demonstrate how the sensor and degree of freedom nodes work were created. The final simulation demonstrates human robot interaction in the virtual environment. The virtual robot is able to detect the distance to the hand, which determines the collision, and can adjust to a new position accordingly.

#### 4.2 VR Simulation Behavior Logic

The behavior logic that needed to be established included: the paths the robot would take, how the robot would react when its sensors detected a collision with an object, and how the gripper would assemble with the pipe (see Figure 3 and Figure 5). To determine the paths, different locations of where the hand could come from were created, then a path option was designed that would make the robot still be able to work if that happened. The optimal movement path is for the robot to just bend straight down and pick up the object. If the hand is in the way to perform the optimal path, e.g., the hand is right in front of the robot, a movement path that has the robot come in from the right side to pick up the object or from the left side was designed, depending on whether the location of the hand is in front to the left or right of the robot. In case all three of those paths are blocked, a path that has the robot bend backwards a bit and then bend underneath in order to pick up the object, in case the hand was up higher. The last movement path, in case all the others are also blocked, accounts for the hand being lower so the robot bends up and over to try to grab the part from behind.

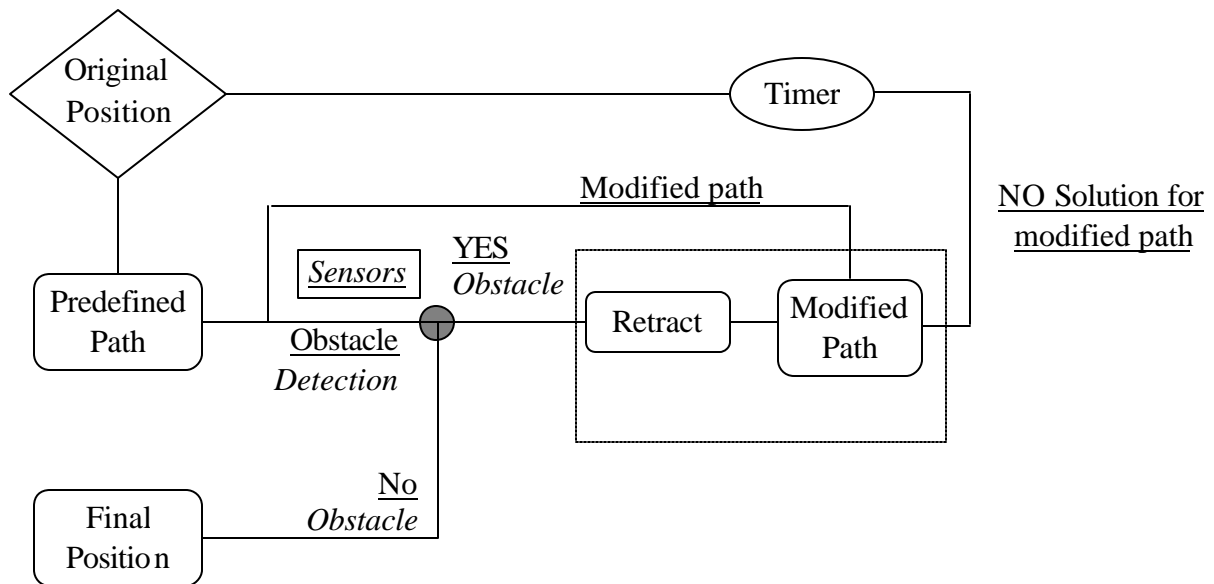


Figure 5. Behavior logic of robot motion and sensor detection

For these alternate movement paths for the project we only focused on if the hand gets in the way during pickup; it was assumed that the hand didn't get in the way during drop off. No matter which of the movement paths the robot used to pick up the object, the robot uses the same drop off movement path.

To determine the intelligence of the robot when it senses a collision with the hand, a decision had to be made on what the robot needed to do. It was first decided to have the robot stop and back away from the hand whenever it sensed a collision, so as to not harm the human. The robot then tries a different path option; if it still collides, it backs off again and tries another. It continues

going through all its movement path options until it has found a path that will allow it to continue working or determines that every path option is a failure. If every path results in a collision, then the robot backs off and returns to its start position and waits a few minutes to give the human a chance to get out of its way. It then goes through all its path options again trying to find a way to work.

## 5. CONCLUSIONS

The completion of this project has produced a virtual reality simulation. This simulation consists of a virtual robot modeled after a real robot and a virtual human hand. Artificial Intelligence has been programmed for the virtual robot so it can detect, react to, and continue working in the presence of the hand.

Virtual reality simulation, human-robot interaction, and sensor technology were the three main aspects involved with the project. Virtual reality was chosen to create a simulation because it was faster, cheaper, and safer than actually programming the real robot. Human-robot interaction explored various types of robots and ways they can be programmed to interact with humans. Finally, sensor technology is the means by which the robot can detect and classify its surroundings.

With the use of virtual reality, a virtual environment was created. This consisted of a room, robot, pipe, tables, and a hand that can be controlled in real time. Behavior logic was developed and programmed giving the robot primary and alternative pathways to pick up and move an object. Ellipsoidal sensors were then placed encircling all components of the robot. These sensors continuously measured the distance to the hand. Using the combination of the sensors and the behavior logic, whenever collision with the hand occurred, the robot's programming told it to abandon its initial pathway and retreat to a neutral position leaving the hand undisturbed.

This project was one of the important steps towards the final goal of having a robot that can work safely with a human in industry. The final simulated program will continue to be refined to enhance the behavior logic so the robot has more movement capabilities and pathways to choose from when the hand approaches. This research will be used to program the real robot so it can be implemented in industry.

## 6. RECOMMENDATIONS FOR FUTURE STUDY

Following the investigations described in this report, we recommend several areas for further study: improve Artificial Intelligence and behavior logic, attach sensors to the real robot modeled after the virtual ones, and program the real robot. Improving Artificial Intelligence can further be developed by adding more path options when the hand collides with the sensors. Attaching the sensors to the real robot and programming the real robot will both be ways to test the accuracy of the simulation.



Based on our developed simulation, further investigations have been done to detect and recognize objects within the vicinity of the robot. These studies utilized various sensing devices to explore the unknown area surrounding the robot. Each sensor, mounted on the robot, activates in succession to increase the quality of the measurement. The first sensor, a proximity sensor, activates and measures any moving object that enters its sensing area and sends the data back to an Intelligent Optimized Control System (IOCS). The second sensor, a video camera, is then activated by the proximity sensor that records only the moving human or object and is used by IOCS to calculate the silhouette. Lastly, a laser or lader sensor is activated and scans just the silhouette of the moving human or object to determine data points for its volume. This will reduce the amount of required 3D data scan and calculation to data only relevant to the situation. These points are then analyzed by IOCS along with previous data to provide a definite position and orientation for the object. The robot is then able to predict the point of collision and is able to adjust its movement accordingly. This will allow a real collaboration between robot and human as the robot is completely aware of the situation and intentions of the human or object. This investigation is still under development and will eventually be applied to the real robot.

## 7. ACKNOWLEDGMENTS

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