

**INTEGRATING NEW SENSOR AND REMOTE CONTROL
MODULES INTO ROBOSIM**

by

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A REPORT

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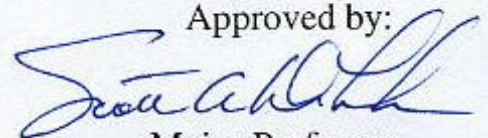
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ABSTRACT

RoboSim is a simulator developed for simulating the interaction, cooperation, and communication among various robots existing in a complex virtual environment. It is a distributed system in which the Environment acts as a controller and authorizes the movement of the robots based on other objects present in it. RoboSim is mainly used for simulating various heterogeneous real-world applications involving robots, which can be later ported to a real robot. Therefore, it provides a cost-effective and efficient manner of testing the feasibility of large applications.

In this project, I added additional components to the existing simulator. Specifically, this report discusses the implementation of a set of sensor modules and a remote control module, which help in enhancing the capabilities of the robots. The sensor modules were used for providing the robot with information about the environment within which it is operating. The set of sensor modules implemented were a Sonar Range Finder, Laser Range Finder and Heat Sensor. These sensors provide near-accurate information relative to the current position of the robot within the environment. The Remote Control module simulates the controlling of the robot from a remote system using a joystick. The user controls the movements of the robot using the joystick and can view the robot's characteristics and its sensor information on a GUI panel.

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Chapter 1 Introduction

1.1 Problem

Simulation is the method of implementing an imitation of a complete real-world process. It is an indispensable problem-solving methodology for various real-world problems. A system that is simulated not only imitates the results of the process, but also the internal working of the system. Application of simulations can be seen in a variety of areas like Financial Market analysis, Assembly Line Balancing, Traffic Control, Search and Rescue operations using intelligent robots.

RoboSim aims at developing a simulator for testing heterogeneous cooperative robotic applications that can be later used for practical implementation of real-world robots. The simulator creates a virtual environment for the robots to interact and communicate with other robots and thereby cooperatively achieve goals that are required by the user. These robots are simulated by application code running on them, which will later be used for programming real-world robots like the Scout, and Pioneer models.

The existing system that was developed by the previous team was capable of simulating the environment for a set of robots and allowing movement along the horizontal XY plane. Some of the drawbacks of the system were as follows. When the number of robots increased the simulator considerably slowed down. Hence the Environment module had to be remodeled for faster communication. In the existing environment only a limited set of sensors/ effectors were implemented. The robots in the environment have to be provided with additional sensors for better performance. The Scout interface was the only interface that was implemented for simulating robots. Additional robot interfaces like the Pioneer had to be implemented. With these aspects in mind, we started our work on the simulator.

1.2 System Overview

RoboSim is made up of the following components, namely: Environment, ControlPanelClient, GeometryClient, CommunicationSystem, Viewer, HardwareSimulator, RemoteControlRobot and RemoteControl. The Environment and ControlPanelClient function as the controller modules for the entire system. Each module mentioned above communicates with any of the other modules through sockets.

The GeometryClient is responsible for maintaining a 3D geometric representation of the environment. It is used by the Environment to determine if the moves requested by the robots

are valid, i.e. no objects overlap with each other. Apart from the 2D Sonar Range Finder simulated in the environment package, the `GeometryClient` simulates 3D Sonar Range Finder. The sensor values are calculated by sending a collection of rays through the environment and finding the collision distance of these rays with the objects.

The `ControlPanelClient` acts as a user interface to control the RoboSim system. It can be used to load a new environment file, start or stop the simulation. It communicates with the `Environment` as shown in the component diagram in Figure 1.

The `CommunicationSystem` is responsible for handling message passing between the Robots in the environment. Because the RoboSim is distributed and the robots having to perform cooperative activities, there is a lot of messaging that has to be handled. This is implemented using the `CommunicationSystem`.

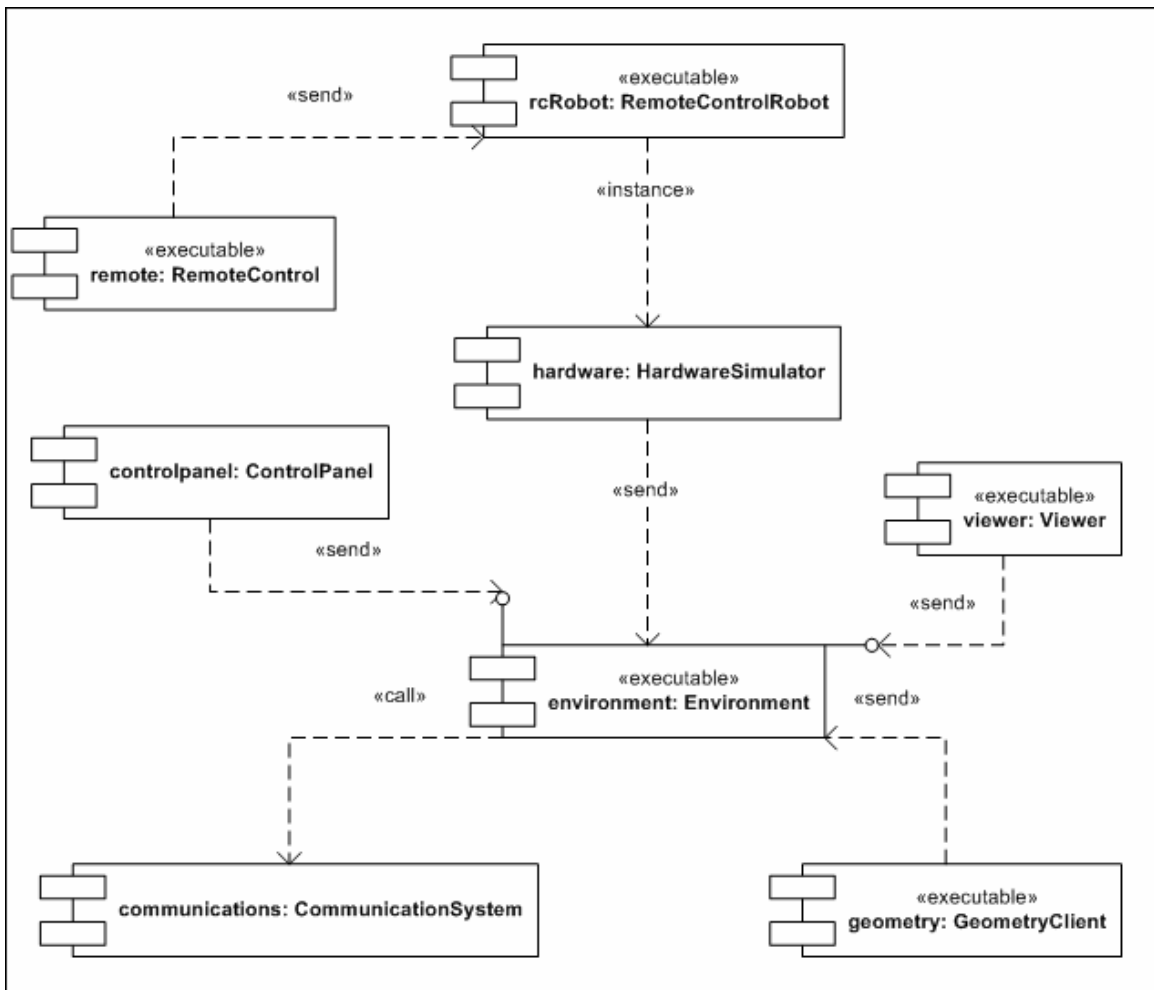


Figure 1. RoboSim Components

The `Viewer` is responsible for displaying either 2D or 3D view of the environment. There is no limitation on the number of viewers that may be connected to the environment. Moreover, any `Viewer` can connect with the `Environment` even after the simulator has started. 3D Viewers are capable of having multiple views of the environment from various viewpoints either relative to the Robots position or from any other point inside the environment.

The `RemoteControlRobot` contains the control code for the robot to function autonomously as well as code that interfaces with the `RemoteControl`. It sends commands to the `HardwareSimulator` by translating the commands that it receives from the robot autonomous control code or that from the `RemoteControl`. The `RemoteControlRobot` is derived from the `ArRobot` class present in the `edu.ksu.cis.cooprobot.simulator.robot.pioneer.aria` package. This class contains the API which the `RemoteControlRobot` uses to send requests to the `HardwareSimulator`.

The `HardwareSimulator` acts as the interface between the `RemoteControlRobot` and the `Environment`. It is responsible for sending the action commands and the sensor requests from the `RemoteControlRobot` to the `Environment`.

The `RemoteControl` acts as an interface between the user and the `RemoteControlRobot` simulating a real world remote control. It receives input from the user by two methods: one, by listening to the input from a joystick and other, through a GUI that has buttons for controlling the movement of the robot and for obtaining the sensor readings of the robot. When the `RemoteControl` is started, it is given an XML file, `RobotConfigFile`¹, as input. The file contains information about the robots that can be controlled using this `RemoteControl`. The `RemoteControl` connects to the robots specified in the file and controls only the primary robot specified. The other robots function based on the autonomous control code. When the user wants to switch to a different robot, the `RemoteControl` switches to the next active robot in the list of robots.

The `Environment` is responsible for maintaining the state of all the components of the system including the robots. All the other modules interact through the environment. The `Environment` has a total of three servers running within it in parallel, for interfacing with the various modules in the simulator. The servers are as follows: the `ViewerServer` interfaces with the viewers, the

¹ `RobotConfigFile` contains the information of the robots and the hostname of the system in which they are running. Verify section Appendix A for more details.

RobotServer interfaces with the HardwareSimulator of each robot, and the GeometryServer interfaces with the GeometryClient. An XML file (EnvironmentConfigFile²) containing details of the objects in the environment is given as input to the Environment when it is started. It loads the information from the file and performs the following sequence of operations to initialize the system. It starts the ViewerServer, the RobotServer, and the ControlPanelClient in that order. It then starts the GeometryServer if required, and waits for all the robots specified in the input file to get connected. On completion of these operations, the Environment initializes the connected viewers and enters the main control code. RoboSim is a time step based system, wherein the time step is maintained by the Environment. The following steps are done by the Environment at each time step. It initializes any new viewers that are connected and processes the messages received from the HardwareSimulator. Finally, it updates the time step and sends the new time step information back to the robots.

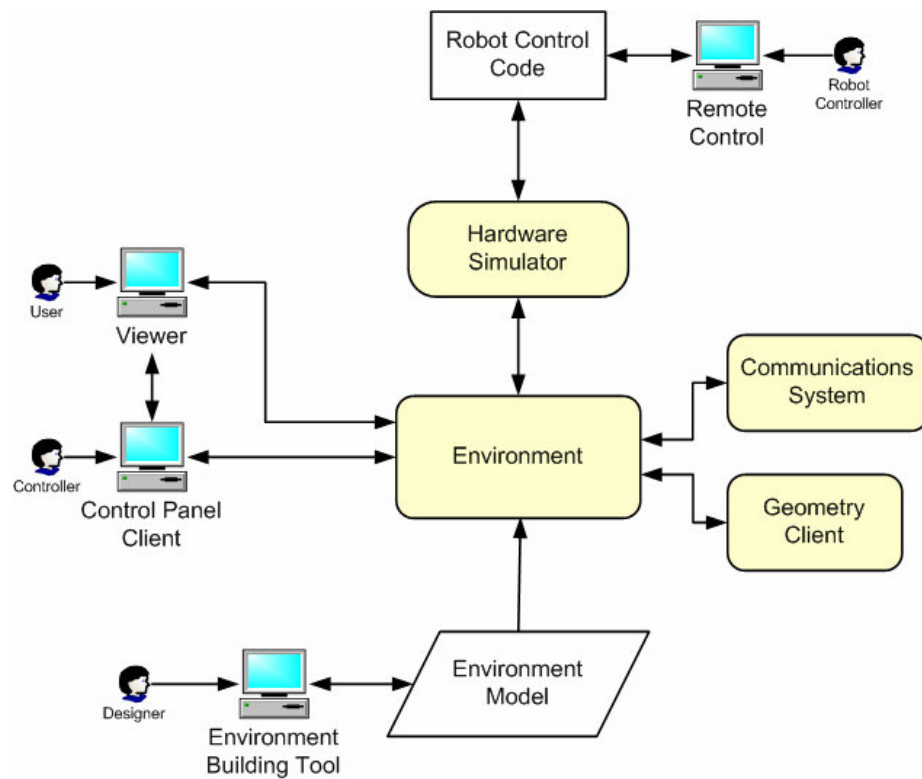


Figure 2. System Overview

² Check section Appendix A for more details

The diagram shown in Figure 2 shows the high-level overview of the whole system. The Remote Control is used by the user to send commands or requests to the Robot Control Code. The Robot Control Code is the control code written on the robot for either communicating with the Remote Control or functioning autonomously within the environment. This control code converts the commands into calls to the Robot Hardware Simulator. The Hardware Simulator sends the requests to the Environment. The Environment module processes these requests

1.3 Scope and Objectives

The RoboSim system simulates the real world scenario of a group of robots aimed at achieving a goal. The current system has a limited set of sensors that have been implemented. For a full-scale simulation, the number of different types of sensors that are simulated should be increased. Moreover, the user should have the ability of controlling the robots from a remote system. Hence, this project aims at satisfying two primary goals. First is the simulation of three new sensors namely, SONAR Range Finder, LASER Range Finder and the HEAT Sensor. These sensors assist the robots in acquiring better knowledge concerning the environment and the objects present in it. The second goal is the creation of a `RemoteControl` capability that can be used to control robots from a remote location or system.

1.4 Document Overview

The document so far gives a basic overview of the entire system. In Chapter 2, a discussion about similar research is done. In Chapters 3 and 4, the document moves on to discuss the methodologies and implementation of the `Sensor` modules and the `RemoteControl` module respectively. The discussion then shifts to the testing of the developed modules in Chapter 5 where the Maze application developed for testing the system is discussed in detail.

The final chapter presents a conclusion to the report and specifies the future enhancements and changes that could be brought into the simulator with respect to the `Sensor` and `Remote Control` modules. The appendix explains the steps for starting the application and operating it.

Chapter 2 Literature Review

2.1 Introduction

In recent years, Robotic Simulators have been a particular area of interest for a number of researchers and developers. There have been many projects that are similar to the RoboSim simulator. This chapter is aimed at discussing certain projects that fall in the same category of RoboSim. This chapter provides a foundation for knowledge about similar research in the area of Robotic Simulators.

2.2 Rossum – RP1 Simulator

Rossum [4] is a robotic simulator project that is currently under development by a group of three programmers at sourceforge.net. The Rossum's project aims are building a client-server based robotic simulator, which can be used for testing code that will be running on the original robot. The first version of the project is named the RP1 simulator. It allows the users to create robot models by specifying the physical layout, wheel actuators, optical (or IR) sensors, range sensors, and bumper sensors. Internally, it represents the world as a 2D environment, and models the interactions and movements in a 2D manner. Though it has not been currently implemented, the ultimate aim of the geometric model will be a 3D representation. The simulator is written with Java as the programming language. It provides the user with a server. The server provides a world in which the simulated robot can move about and interact with its environment. Though the robot is simulated by the server, it does not implement any navigational logic. It is the work of the client program, which connects to the server, to provide the robot with navigational logic. The client program is written by the user/developer who wants to test the code they will be running on the actual robot. The environment provides information to the client such as bumper sensor readings, IR sensor readings, etc. Based on these readings and any other information, that client has, it issues commands, like 'move forward', to the simulator. One of the major advantages of this system is that the client connecting to the server can be written in any language suitable to the developer/user. Though the server is implemented in Java, it can communicate with a client written in C, C++, Forth, Lisp, Prolog, even Basic. However, a major constraint in the current release is that it can support only one client in a full-fledged manner, at any instant of time.

2.3 RoboCup – Soccer Simulator

RoboCup [6] is a robotic simulator whose main goal is to simulate a soccer match played by robots. The ultimate goal of the project is to develop a team of fully autonomous humanoid robots that can win against the human world soccer champion team.

The main module of the system is the Soccerserver. The Soccerserver enables autonomous agents consisting of programs written in various languages to play a match of soccer against each other. A match is carried out in a client-server style. Soccerserver, provides a virtual field and simulates all movements of a ball and players. Each client controls the movements of one player. Communication between the server and each client is done via UDP/IP sockets. Therefore, users can use any kind of programming systems to interface with the server.

The Soccerserver consists of two programs, Soccerserver and Soccermonitor. Soccerserver is a server program that simulates movements of a ball and players, communicates with clients, and controls the games according to rules. Soccermonitor is a program that displays the virtual field from the Soccerserver on the monitor using the X windows system. A number of Soccermonitor programs can connect with one Soccerserver, so it can display field-windows on multiple windows.

A client connects with the soccer server using a UDP socket. Using the socket, the client sends commands to control a player of the client and receives information from sensors of the player. In other words, a client program is the brain of the player. The client receives visual and auditory sensor information from the server, and sends control-commands to the server.

2.4 MobileSim

MobileSim [8] is a simulator developed by ActivMedia Robotics Corporation, manufacturers of the Pioneer class of robots. MobileSim simulates mobile robots and their environments, for debugging and experimentation with Aria based control programs and other software. It converts an ActivMedia map³ to a Stage environment, and places a simulated robot model in that environment. It then provides a simulated Pioneer control connection accessible via TCP port 8101⁴. Most Aria based programs will automatically connect to that TCP port if available. MobileSim is based on the Stage library, created by the Player/Stage project [9].

³ A .map file created by Mapper3 or Mapper3-Basic

⁴ Similar to real Pioneer's serial port connection

The Player/Stage project [9] consists of two modules namely the Player and the Stage. Player is a networked robot/sensor device interface and Stage provides a 2D simulated world. Player provides a clean and simple interface to the robot's sensors and actuators over the IP network. The client program talks to Player over a TCP socket and reads data from sensors, writes commands to actuators, and configures devices on the fly. Player supports a variety of robot hardware. The original Player platform is the ActivMedia Pioneer 2 family, but several other robots and many common sensors are supported.

Stage is responsible for providing a population of robots, sensors and objects within a 2-dimensional environment. The development of Stage is based on multiagent systems. Since the Stage provides a population of virtual devices to the Player, users can write robot controllers and sensor algorithms as client programs to the Player server. Various sensors and actuators are provided, including sonar, scanning laser rangefinders, vision (color blob detection), odometer, and a differential steer robot base.

Chapter 3 Sensor Module Simulation

3.1 Introduction

One of the primary goals of this project was aimed at simulating the various sensors present on the robots. These sensors are responsible for providing essential information about the environment, which could be used by the robots to determine the state of the environment. By determining the state relative to their current position in the environment, they issue the next best possible move towards achieving their goal. Each robot is provided with set of sensors, which varies based on the model of the robot. The Nomad Scout, and the ActivMedia Pioneer are the two robots which have been implemented in the simulator. The Nomad Scout robot can have a SONAR range finder and/or a HEAT sensor. The ActivMedia Pioneer has the option of having a SONAR range finder, LASER range finder, and/or HEAT sensor. This chapter discusses the simulation of a SONAR range finder, LASER range finder and HEAT sensor for the robots.

3.2 Sensor Modules – An Overview

The main classes in the Sensor module are the `RobotSensor`, `RobotSensorLaser`, `RobotSensorSonar` and `RobotSensorHeat`. They are implemented as part of `edu.ksu.cis.cooprobot.simulator.environment` package. Any new sensor class that is implemented is derived from the `RobotSensor` class. This class comprises all the common characteristics that are necessary for each sensor type. The `RobotSensor` has an abstract method `generateSensorResponse()` that should be implemented in each sensor class that is derived from it. This abstract method is used for obtaining the corresponding sensor response whenever the robot requests it.

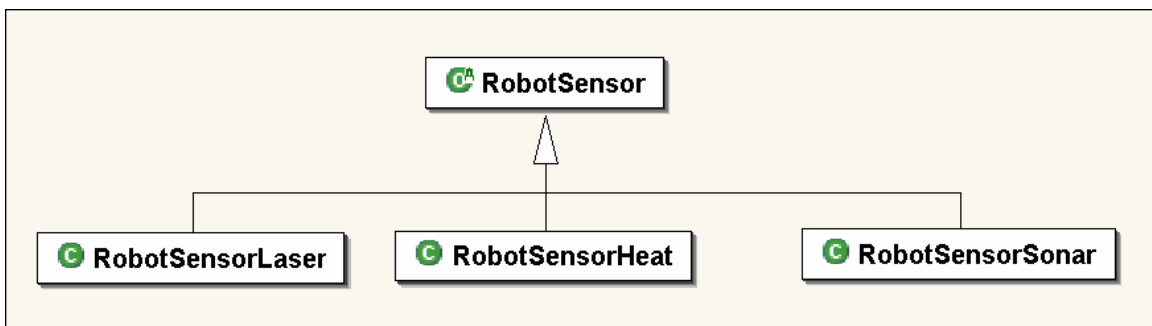


Figure 3. Sensor Modules - High Level Class Diagram

Figure 3 shows a high-level view of the sensors that have been implemented in this project. It shows that the `RobotSensorLaser`, `RobotSensorHeat`, and `RobotSensorSonar` classes that

simulate the LASER, HEAT, and SONAR sensors respectively are derived from the `RobotSensor` class. Each robot is associated with an instance of the corresponding class for each sensor it carries. This instance is stored in the `Environment`. Since the position and characteristics of all the objects are maintained and updated by the `Environment`, these classes are implemented as a part of the `edu.ksu.cis.cooprobot.simulator.environment` package and are invoked when the robots request for any of the sensor readings.

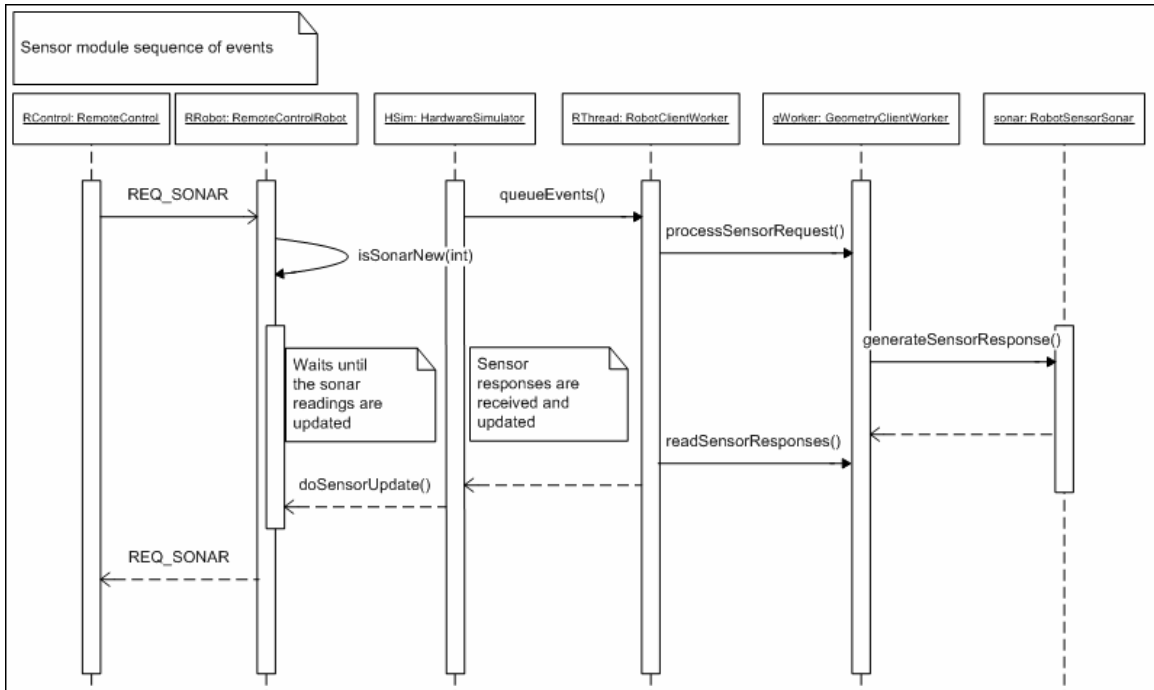


Figure 4. Sensor Module - Sequence Diagram

Figure 4 shows the sequence of events happening when a remote control object requests a sonar sensor reading. The sequence of events happening will be similar in the case of the other sensors too. These events are triggered when the `RemoteControl` or other application code requests for the sensor readings. The `RemoteControl` sends a `REQ_SONAR` message to the `RemoteControlRobot`. The `RemoteControlRobot` maintains a buffer of sensor readings and hence, checks if the sensor readings are relative to the current time step, waits infinitely until the sensor message buffer is updated by the `HardwareSimulator`. The `HardwareSimulator` executes as a separate thread and periodically updates the sensor readings by sending requests to the `RobotClientWorker`. On receiving the request from the `HardwareSimulator`, the `RobotClientWorker` sends the set of sensor requests to the `GeometryClientWorker`. The `GeometryClientWorker` obtains references of the robots from the `Environment`. These references contain instances of the corresponding class for each sensor the robot contains. It calls

the `generateSensorResponse()` method of the corresponding sensor class and puts the response into the queue of messages to be sent back to the `RemoteControlRobot`. The `RobotClientWorker` obtains this queue of messages and sends it to the `HardwareSimulator`. On receiving the sensor response, the `doSensorUpdate()` method of the `RemoteControlRobot` is invoked. This method updates the sensor readings buffer and the Boolean flags to indicate that the information has been updated. The `RemoteControlRobot` waiting for the sensor reading, on return of a true from the `isSensorNew()` method, comes out of the wait state and sends the requested sensor information to the `RemoteControl` or to the application code. A similar sequence of events happens when a sensor request is obtained for the Laser and Heat sensor readings.

3.3 Methodology

3.3.1 LASER Range Finder

The laser range finder is responsible for determining the distance and coordinate information of an object that is in the line of sight of the direction in which the sensor is pointing and within its maximum range. This is done by shooting a pulse in the direction in which it is pointing. Based on the reflection of the laser from the face of an object, the distance of it and its coordinate information is calculated. The Laser range finder is capable of rotating through an angle of 90 degrees on either side from the direction in which the robot is facing.

3.3.2 SONAR Range Finder

Each type of robot has a specific setup for the SONAR range finder. The SONAR that has been simulated is done using the specifications of the Pioneer 3 model. The Pioneer 3 model may have a total of either 8 or 16 array of sonar sensors. They are placed as one or two sets, based on the number of sensors, thus forming the front and rear array of sonar sensors. If there are 8 sensors, then only the front array is present, else if there are 16, then both the rear and front arrays are present. These sonar sensors individually cover 20 degrees each and in turn scan a total angle of 360 degrees around the robot. Every time a reading is requested from the SONAR sensors, a sonar pulse is sent from each of the SONAR, one at a time. Each sonar sensor in the array returns the distance of the closest object in its sector and its x, y, and z coordinates relative to the robot. Hence, 8 or 16 readings are sent back to the robot.

3.3.3 HEAT Sensor

The Scout and the Pioneer class of robots do not have an actual heat sensor available. This sensor was mainly simulated in order to help in certain specific application like a search and rescue, wherein the victims are identified based on the heat that is emitted from them. A detailed description of the heat sensor is given in section 3.4.3.

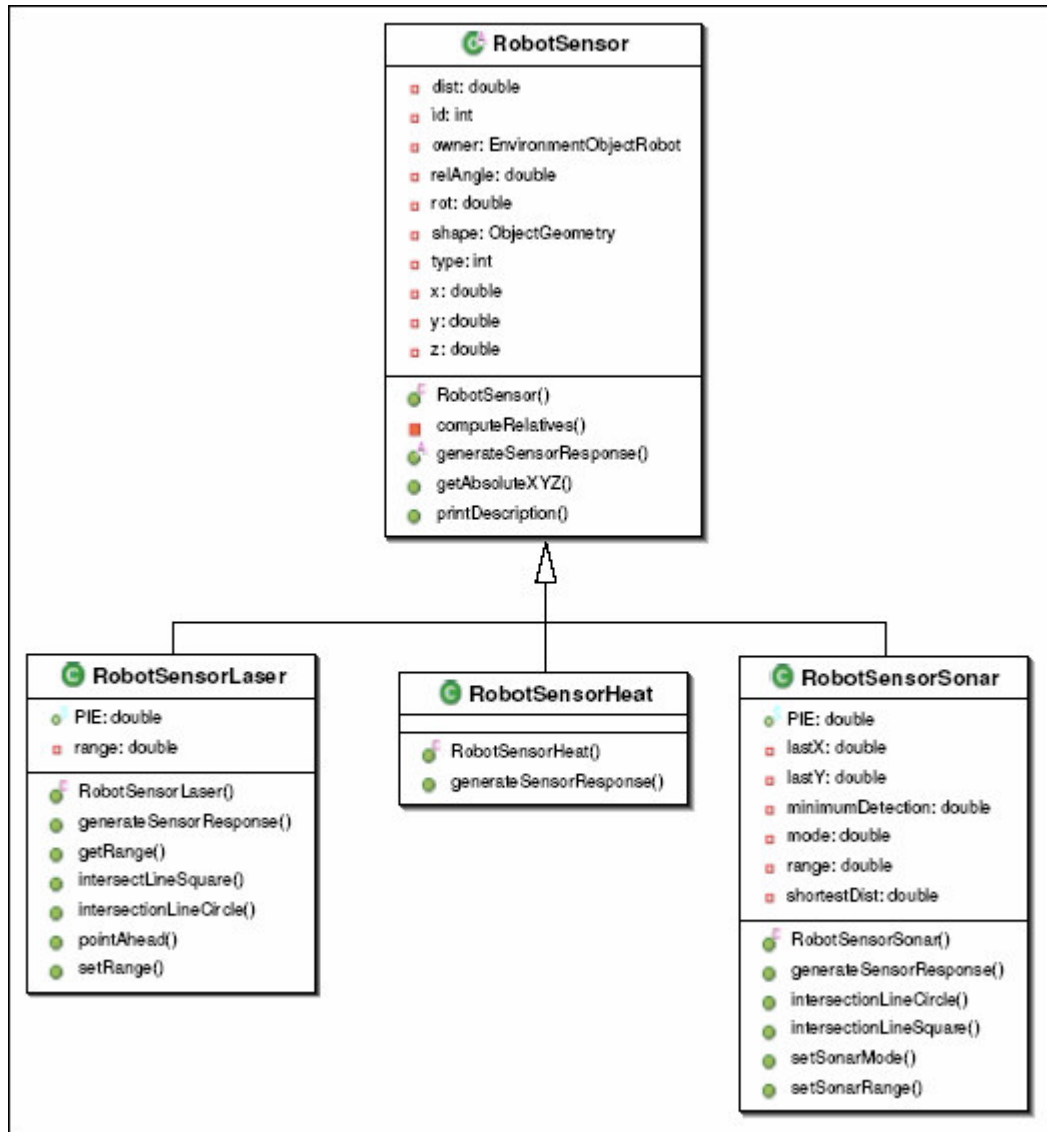


Figure 5. Sensor Modules - Detailed Class Diagram

3.4 Implementation

3.4.1 LASER Range Finder

The `RobotSensorLaser` class simulates the Laser Range Finder. The attributes of the class are shown in Figure 5. An instance of this class is created for each robot that has the laser sensor. The parameters required for initializing the sensor are the `direction`⁵, `range`⁶, `id` (id of the sensor), and `xyz` coordinates relative to the position of the robot are provided in the `EnvironmentConfigFile` file supplied to the environment. The response of the laser is calculated in the `generateSensorResponse()` method of the `RobotSensorLaser` class. The `GeometryClientWorker` passes the updated information of the environment objects packed in an `EnvironmentMap` object as a parameter to the `generateSensorResponse()` method. There are two types of objects present in the environment, namely, cubes and cylinders. The Laser sensor performs a 2D geometry based calculation. It uses the shapes made by the objects against the horizontal XY plane. Hence the cubes and cylinders are considered as circles and rectangles respectively.

Initially it calculates the absolute position of the sensor based on the position of the robot and the `xyz` relative positions. In the second iteration, the method checks if the height of the object is greater than the position of the sensor, to check if it is hit by the laser. In the next iteration, it determines the point and distance of intersection of a horizontal line, drawn from the origin of the laser in its pointing direction, with the object. The methods `intersectLineCircle()` and `intersectLineSquare()` are used for calculating the intersection points with circles and rectangles respectively. This process is repeated for all the objects and the closest objects intersection point and distance is sent back to the environment. In case there are no objects within the range of the Laser, it returns the maximum `range` of the laser. The return values are packed in to a `RobotSensorResponse` class object.

3.4.2 SONAR Range Finder

The `RobotSensorSonar` class is responsible for simulating the Sonar Range Finder. The attributes and methods of this class can be seen in Figure 5. The sensor object is created and it

⁵ Indicates the direction in which the laser is facing relative to the robot. It is stored in the attribute `rot` of the `RobotSensor` class.

⁶ Indicates the range within which the sensor can detect objects. It is stored in the attribute `range` of the `RobotSensorLaser` class.

parameters are loaded in a similar way as the Laser Range Finder. The parameters required for initializing the sonar sensor are the `range`⁷, `id` (id of the sensor), and `mode`. The mode parameter indicates if the robot has 8 (mode =1) or 16 (mode = 2) sensor array. The response of the SONAR is determined in the `generateSensorResponse()` method of the `RobotSensorSonar` class. Initially, the absolute position of the sonar sensors around the robot is determined. Using this position as the origin, two lines showing the boundary of the sonar's area of coverage is drawn. Each environment object is verified against these two lines, if they lie in between them and within the `range`. The sonar makes use of the `intersectLineCircle()` and `intersectLineSquare()` for this purpose. This process is repeated for all the sonar sensors in the array. The method finally returns the distance and point of intersection of the closest object in each sonar sector. This information is packed in an object of the `RobotSensorResponse` class.

3.4.3 HEAT Sensor

The `RobotSensorHeat` class is responsible for simulating the HEAT sensor. A detailed view of the class can be seen in Figure 5. The parameters for initializing the Heat sensor are the `range` and `id` (id of the sensor). The `range` specifies the distance within which it is capable of sensing heat. When a request for readings from the Heat sensor is requested for a robot, the control is passed to the `generateSensorResponse()` method of the `RobotSensorHeat` class. Here, it finds each environment object within the range of the sensor, checks if the object is generating heat, if so a value, inversely proportional to the distance of the object from the sensor and directly proportional to the temperature of the object, is added to the reading of the sensor. This is packed in an instance of the `RobotSensorResponse` class and sent to the robot.

⁷ Indicates the range within which the sensor can detect objects. It is stored in the attribute `range` of the `RobotSensorSonar` class.

Chapter 4 Remote Control Simulation

4.1 Introduction

Apart from the simulation of the sensors, the other primary goal of this project was to create a remote control that could be used for controlling the activities of the robot from a remote machine. An additional feature that was to be integrated with the remote control was controlling the movements of the robot using a joystick. The remote control, integrated with the joystick, provides a means for the user to interact with the system. It acts as an interface between the user and the robot, by accepting the movement instructions from the user and displaying the current characteristics of the robot back to the user. The remote control could also be used for controlling multiple robots at the same time. This chapter discusses in detail the simulation of the remote control module.

4.2 Methodology

The remote control is responsible for obtaining inputs from the user by two ways. One is by using a Graphical User Interface, which receives basic instructions like accelerate, decelerate, turn right, turn left, and acquire various sensor readings. The other is by using a joystick, which the user can operate in order to move the robot within the environment. In addition to receiving inputs from the user, the remote control should also display the various sensor readings relative to the current position of the robot. This can be done in a live manner, where in the information displayed is updated whenever the position of the robot is changed, or in a request based manner, where in sensor information is updated only when the user requests it. The implementation of the remote control is discussed in the next section.

4.3 Implementation

The main classes in the Remote Control Module are the `RemoteControl`, `RemoteControlRobot` and the `RemoteControlMessage`. They are implemented as a part of the `edu.ksu.cis.cooprobot.simulator.applications.maze` package. The `RemoteControl` class implements the remote control, waiting for input from the user. The `RemoteControlRobot` class simulates the robot that is controlled by the remote control. The `RemoteControlRobot` and `RemoteControl` use the `RemoteControlMessage` class for exchanging control and sensor information between each other. Figure 6 gives a high-level view of the remote control module. The functioning of the system can be explained in detail as follows.

For every robot controlled by the remote, the `RobotConfigFile` file should contain information regarding the IP address of the `RemoteControlRobot` system and the port number at which it will connect to the `RemoteControl`. This is given as input to the `RemoteControl` thread. The `RemoteControl` implements the abstract class `JoyStickListener`⁸. It first initializes the `JoyStickListener` and then it loads the information of all the robots and determines the primary robot it will be controlling, identified using the tag `primary` in the `RobotConfigFile`.

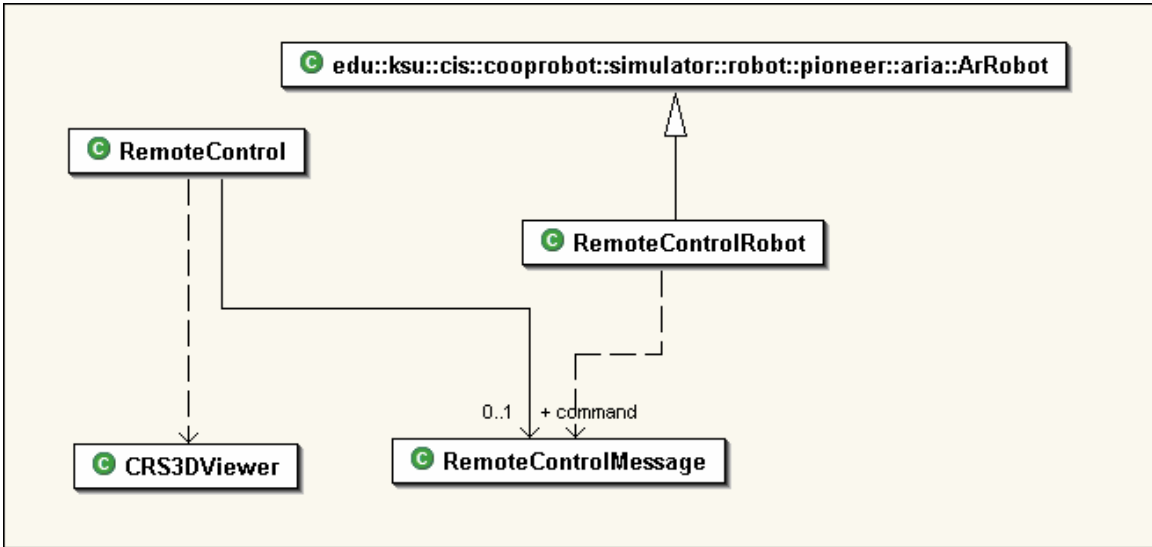


Figure 6. RemoteControl Module - High Level Class Diagram

On loading the information of all the robots, the `RemoteControl` initializes and starts the `CRS3DViewer` (a type of `Viewer`) thread. The `CRS3DViewer` is used for displaying 3D view of the environment and its objects. The view shown will be relative to the robot. It will capture the picture as that of a camera placed on top of the robot. This helps the user in navigating through the environment. Therefore, the user can move the robot around the environment and request sensor data even from a remote system. The effectiveness of the `Viewer` module was seen during the testing phase when navigating through the Maze.

The `RemoteControl` and `RemoteControlRobot` use the `RemoteControlMessage` for communication between each other. The types of messages that can be used for communication are shown in Figure 7. They are the `INIT`, `INIT_ACK`, `ACCELERATE`, `DECCELERATE`, `TURN_LEFT`, `TURN_RIGHT`, `REQ_HEAT`, `REQ_LASER`, and `REQ_SONAR`. The type of the message

⁸ `JoystickListener` [10] is a vendor API which is used for receiving input from the joystick in a similar way to an `ActionListener` in Java.

is indicated by the attribute `messageType` of the class `RemoteControlMessage`. The `INIT` message is sent when a connection is established. The `INIT_ACK` message is sent from the `RemoteControlRobot` when it receives an `INIT` message and from the `RemoteControl` when it wants to inform a robot to switch between executing autonomous control code and remote control commands. The `ACCELERATE`, `DECCELERATE`, `TURN_LEFT`, and `TURN_RIGHT` are messages representing movement commands sent by the `RemoteControl`. The `REQ_HEAT`, `REQ_LASER`, and `REQ_SONAR` are messages which represent, sensor reading request if sent from `RemoteControl`, and sensor reading replies if sent from `RemoteControlRobot`.

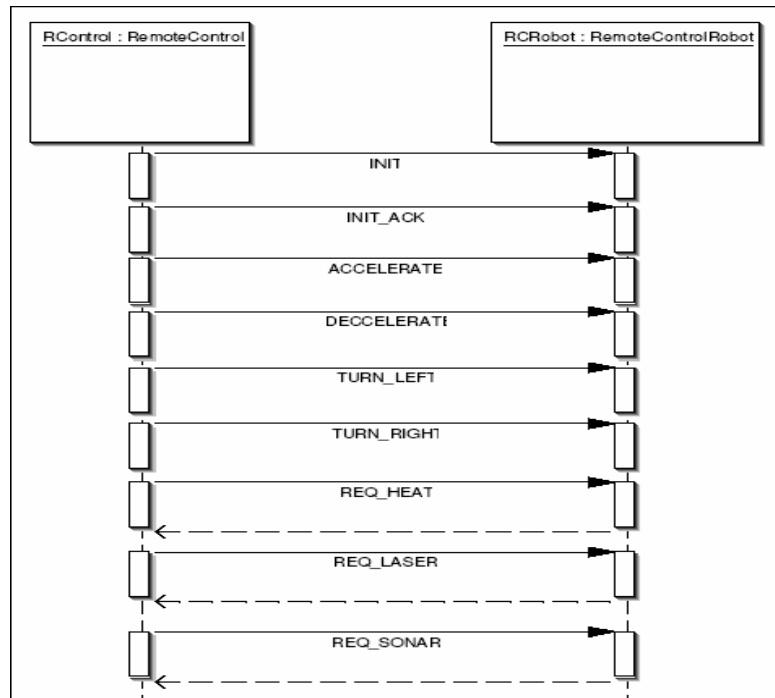


Figure 7. Remote Control - Robot Protocol Diagram

Figure 8 represents a detailed view of the classes of the Remote Control module. After starting the `Viewer` thread, the `RemoteControl` waits for all the secondary robots to connect with it. As soon as it connects to each secondary robot, it sends an 'INIT' message to it with the attribute `autonomous` set to `TRUE`. On receiving the message, the secondary robots start executing the autonomous control code⁹. Finally, the `RemoteControl` connects with the primary robot and

⁹ Autonomous control code is present in the `autonomousControlCode()` method of the `RemoteControlRobot` class.

sends an INIT message with the attribute `autonomous` set to `FALSE`. On receiving this, the primary `RemoteControlRobot` is set to execute the remote control code¹⁰. The system now enters the main loop, where the `RemoteControl` waits and receives commands from the user and sends it to the primary robot. The primary robot then processes the requests and action commands by sending it to the `HardwareSimulator`.

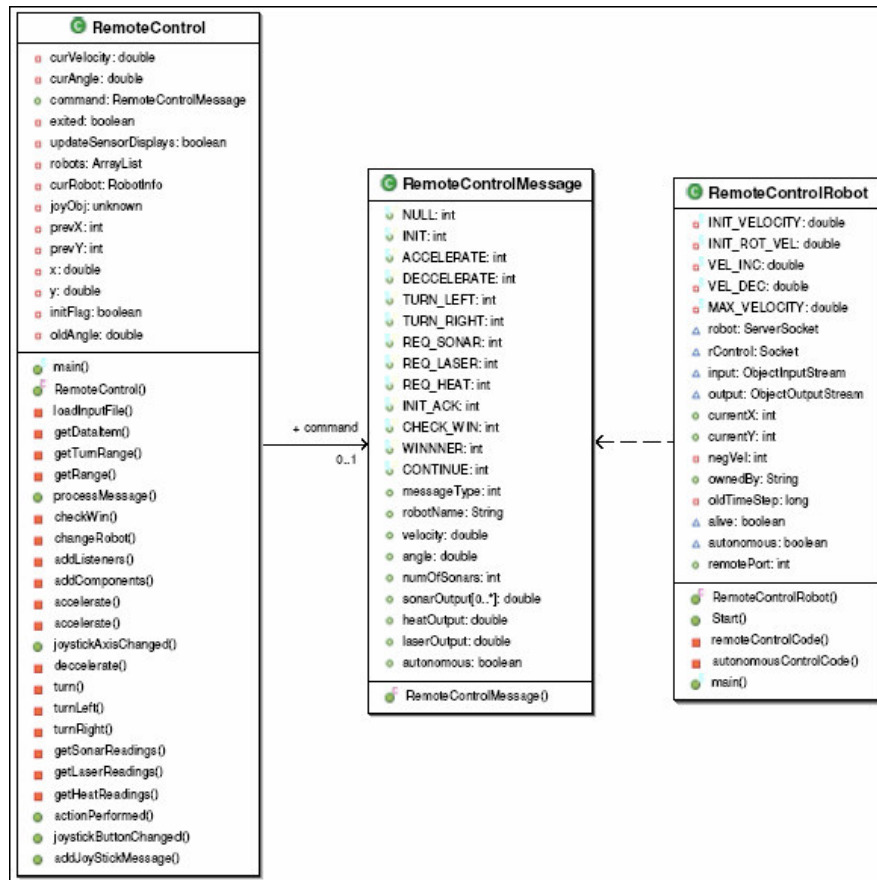


Figure 8. RemoteControl Module - Detailed Class Diagram

The user can change the primary robot controlled by the `RemoteControl` by clicking the appropriate button¹¹ in the joystick. When the user presses this button, the `RemoteControl` sends an `INIT_ACK` message to the primary robot, sets it to execute the autonomous control code, and puts it in the tail of the list of secondary robots. It then selects the first robot in the list

¹⁰ Remote control code is present in the `remoteControlCode()` method of the `RemoteControlRobot` class.

¹¹ Refer to section Appendix A for operation configuration of the application.

and sends an 'INIT_ACK' message to sets the selected robot to listen to the commands from the RemoteControl.

Chapter 5 Testing & Results

5.1 Introduction

The modules that were developed were successfully integrated into the RoboSim. In order to test the correct functioning of these modules, an application was developed which uses the information obtained from these modules. This chapter discusses in detail the two versions of the Maze application that was developed in order to test these sensor and the `RemoteControl` modules.

5.2 Testing Sensor Module

5.2.1 Methodology

The Version 1 of the Maze application was used for testing the sensor modules. In this application, a group of robots search through a large Maze for finding gold kept at an unknown location. The robots move through the maze and find the gold by using their sensors and they communicate with each other for passing information if the gold has been detected by any of the robots.

5.2.2 Implementation

The `GoldFinder` class, derived from the Aria robot interface, simulates the gold finding robots. The main loop of the `GoldFinder` can be seen in Figure 9. The robot gets the readings from the SONAR and the HEAT sensors. The `Gold` class simulates the presence of gold inside the Maze. It generates heat at a temperature specified in the XML file.

The HEAT sensor calculates the reading based on the temperature of objects within a specified range. The robot checks the temperature obtained from the HEAT sensor against a threshold temperature that identifies the Gold. As soon as it detects the presence of Gold, it sends a GOLD message to its neighboring robot. The robots transfer messages in a cyclic manner. When the application is started, for each robot, the robot to which it can send message is given as input. Hence, when a message is to be sent across, it is sent to only one robot at a timestep. If a GOLD message is received by any robot in the application, it sends a GOLD message with the source of the message and information to its neighboring robot and halts at that point. Hence, the application comes to a stop once any of the robots detect gold inside the Maze. In addition to the SONAR and the HEAT sensor, the application also made use of the LASER sensor for navigation inside the Maze. The readings that were obtained from the sensors at various locations in the

environment are displayed in Table 1. These readings were obtained for the EnvironmentConfigFile OpHo2_1.xml. These readings were compared against manual calculations and they were found to be consistent.

```

while(run){
  //Get the sonar readings
  acquireSensorReadings(AriaUtil.SONAR);
  while(!isSonarNew(3));
  //Get the sonar readings
  acquireSensorReadings(AriaUtil.HEAT);
  while(!isHeatNew());
  //Check if gold has been found
  if(this.temperature > Threshold){
    //Send message to other robots and break from look
  }
  //Decide on next move
  if(sonarArray[4].getRange() >= 5.0 && sonarArray[3].getRange() >= 5.0
  ...

  //Check if any other robot has found gold
  while(!messageQueue.isEmpty()) {
    message = (Message) messageQueue.remove(0);
    MazeMessage receivedMessage = (MazeMessage)message.getContent();
    if(receivedMessage.messageType==MazeMessage.GOLD){
      run=false;
      //Send message to next robot in chain
      ...
    }
  }
}

```

Figure 9. Maze Version 1 - Main Loop

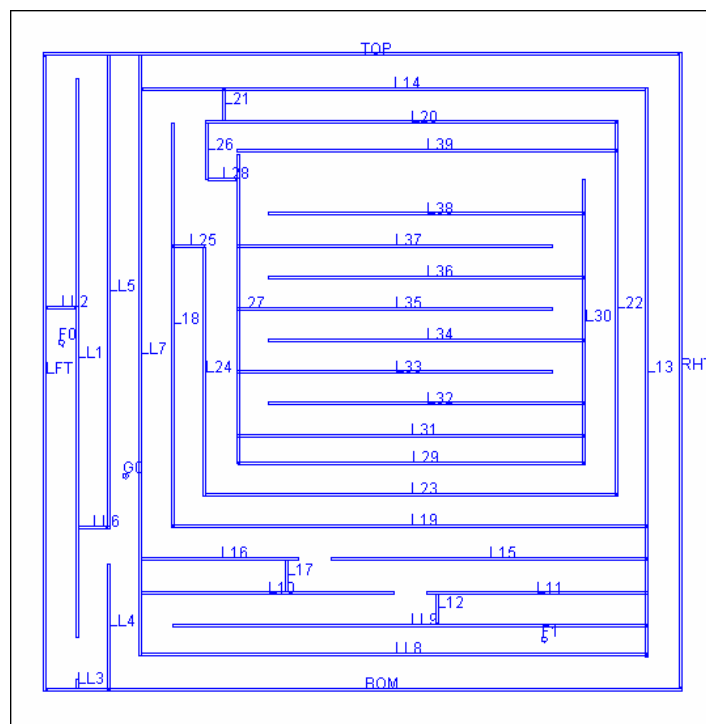


Figure 10. Maze - Testing Sensor Module

No.	Robot Position and Angle				Sonar Readings																Laser Readings	Heat Readings
	X	Y	Z	Θ	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16		
1	-10	-89.5	5	90	6.5	8.3	12.4	16	16	16	16	16	16	11.1	8.3	7.5	7.5	8.3	8.3	6.5	13.6	0
2	-30.6	-85.7	5	170	11.9	13	16	16	16	16	16	11.6	11.4	12.3	16	16	16	16	16	12.1	21	0
3	-47.9	-82.7	5	170	8.8	9.8	13.3	16	16	16	16	14.6	14.5	16	16	16	16	16	13.3	9	21	0
4	-81.7	-72.9	5	150	16	16	16	16	16	16	16	16	16	16	16	16	16	16	9	12.1	17.9	0
5	-78.6	-40.6	5	70	5.1	16	16	16	16	16	16	16	16	16	16	16	16	16	10.2	5.8	21	0
6	-62	-35.3	5	330	12.8	16	16	16	16	16	16	16	16	16	16	16	16	16	16	7.1	21	0
7	17.4	-47.7	5	60	13.9	5.9	5.3	11.7	16	16	16	16	16	16	16	16	16	16	16	16	19.28	0
8	4.4	0	5	100	12.4	16	16	16	6	6.9	16	16	16	16	16	16	16	16	13.3	12.2	21	5.39
9	3.5	4.9	5	40	16	12.9	12.9	14.2	16	16	16	1.1	1.4	16	16	16	16	16	16	16	17.8	11.7
10	-1.1	15.7	5	170	16	16	16	16	16	16	16	0.8	1.3	16	16	16	16	16	16	16	15.6	12.2

Table 1. Sensor Data from application

5.3 Testing RemoteControl Module

5.3.1 Methodology

The Version 2 of the Maze application was used for testing the RemoteControl module of the simulator. The application involves the controlling of robots by an external user by using the joystick. The robots are placed within a maze and the ultimate goal of the user is to move the robot within a suitable distance from the gold that is placed in the Maze. The first robot to reach the gold is termed as the winner.

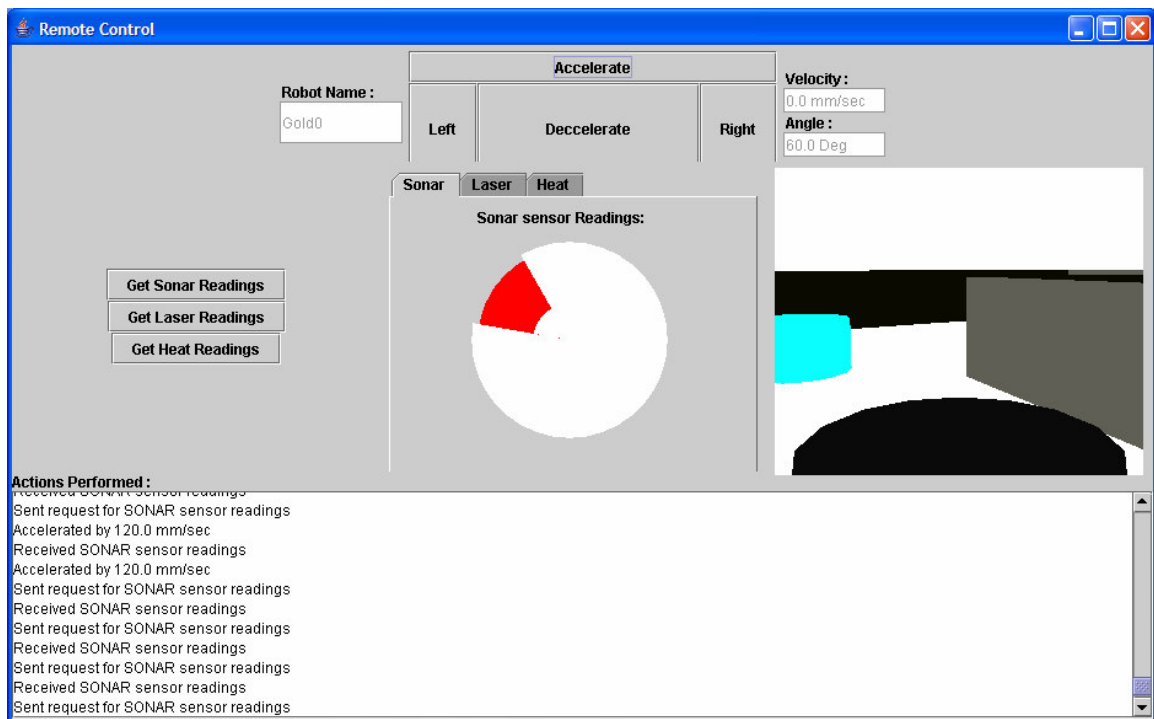


Figure 11. Maze - RemoteControl Module

5.3.2 Implementation

The RemoteControl class is responsible for receiving the joystick input from the user. It sends the received requests and commands to the RemoteControlRobot instance that it controls. On reaching within a close vicinity of gold, if the user requests to check for a win situation, the robot sends a request to the environment, which determines if the user has won. If so, it sends the win information to all the robots. On receiving this information, all robots are made to come to a halt. The display of the RemoteControl can be seen in the Figure 11 below. The user moves through the Maze by using the 3D display shown in Figure 11. The remote control was displayed at the 'Spring Open House 2005' at Kansas State University. The readings obtained from the sensors

were checked for consistency with the graphical display shown on the GUI. At various locations in the maze, the sensor information obtained was found to be consistent with the readings derived from manual calculations.

Chapter 6 Conclusion

The `Sensor` and `RemoteControl` modules were integrated with the environment and tested using the two versions of the Maze application. The Version 2 of the Maze application was displayed for user at the Open House 2005 event at Kansas State University.

The SONAR, LASER and HEAT sensors consistently provided accurate information, which was used by the robot for navigation through the maze. The current system uses the 3D Sonar simulator, present within the `GeometryServer`, for sensor readings for the robot.

The `RemoteControl` in the system is capable of receiving input from the user through a Joystick, as well as the Graphical User Interface, for controlling the movements of the robot.

6.1 Future Enhancements

During the course of development of the project, there were some ideas that I thought could be considered as future enhancements in the project. They are explained below.

In the current system, for sending back sensor responses to the robot, for each sensor request sent by the robot, a sensor response packet is sent back to it. In future if all the sensor requests for a particular robot at each timestep could be packaged together and sent, it will minimize the network traffic between within the system. For this to be implemented, the `processSensorRequests()` method of the `Environment` and the corresponding `doSensorUpdate()` method of the `HardwareSimulator` should be modified appropriately.

The three sensors that have been simulated perform the operations based on perfect geometric calculations. However on the real robot, the readings that are obtained from the sensors may be corrupted and prone to errors. An example of one such error could be noise disturbance. Since the simulator should behave in an exact manner as the original system, in future the sensor readings that are sent from the sensors should be error prone and these errors should be introduced in a calculated manner based on the real robot sensors.

The current `RemoteControl` interface was developed with the `RemoteControlRobot` extending the `ArRobot` interface of the `Pioneer` robot class. Hence the remote control feature is not available for the Scout robot interface, the `Scout`. In future, this feature should be extended to the `Scout` robot's interface too.

The code that is written on the simulator has not been tested on the actual robots. A significant advancement in the simulator could be to solve the porting problems that will be faced when using the code from the simulator on the actual robots.

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Appendix A Users Manual

RoboSim is a distributed system that can be run on network of systems. The simulator consists of a minimum of four modules that need to be started. They are the `Environment`, `GeometryClient`, `3D/2D Viewer`, `RemoteControlRobot`, and `RemoteControl` started in the given order. The detailed steps for running the simulator with the `RemoteControl` are explained in this appendix.

A.1 Starting Simulator – With RemoteControl

The step-by-step procedure for starting the simulator is given as follows:

1. Check out the RoboSim project from the CVS repository. The CVS is located at the server `fingolfin.user.cis.ksu.edu`¹². A login is necessary to check out.

The `RoboSim\scripts\` directory contains the executable files for Windows and Linux based systems. They are written to load pre-defined environment configurations. Samples of the `EnvironmentConfigFile` are located in the `RoboSim\TestLoadFiles\Environment` directory (e.g. `OpHol.xml`). The `RobotConfigFile` given to the `RemoteControl` is also located in this directory (e.g. `RobotInfo.xml`). Using these files as templates, you can create new files based on the applications specifications.

The `Environment` is the first module that should be started. The file given as input is the `Environment` configuration file. The command is:

```
start java edu.ksu.cis.cooprobot.simulator.environment.Environment
                                         <EnvironmentConfigFile>
```

2. The next two modules to be started are the `2D/3D Viewer` and the `GeometryClient`. They can be started in any order using the following commands:

```
start java edu.ksu.cis.cooprobot.simulator.viewer.Viewer2D <EnvHostname>
                                         <EnvWaitPort = 3000>

start java edu.ksu.cis.cooprobot.simulator.viewer.Viewer3D <EnvHostname>
                                         <EnvWaitPort = 3000>

start java edu.ksu.cis.cooprobot.simulator.geometry.GeometryClient
                                         <EnvHostname> <EnvWaitPort = 10000>
```

¹² Server will be moved to `macr.user.cis.ksu.edu` in future

In the previous commands shown, the `EnvHostname` is the hostname or IP address of the system in which `Environment` module is running and `EnvWaitPort` is the port at which the `Environment` is waiting for a connection with the corresponding module.

3. The `RemoteControlRobot` module is the next one to be started. It can be done using the following command:

```
start java edu.ksu.cis.cooprobot.simulator.applications.maze.RemoteControlRobot 0
      <EnvHostname> <EnvWaitPort = 8000> <No. of sonars> <x-pos> <y-pos> <RCPort>
```

In the previous command, the `EnvHostname` and `EnvWaitPort` represent the same as mentioned in step 4. The next input is the size of sonar sensor array present in the robot. The `x-pos` and `y-pos` are the starting x and y coordinates of the robot. They can be used in future for any mapping applications. The `RCPort` is the port at which the `RemoteControlRobot` will be waiting for a socket connection from the `RemoteControl`.

4. Finally the `RemoteControl` is started using the following command:

```
start java edu.ksu.cis.cooprobot.simulator.applications.maze.RemoteControl
      <RobotConfigFile> <EnvHostname>
```

In the above command, the `RobotConfigFile` is the configuration file containing the information about the robots that will be controlled by the `RemoteControl`. The `EnvHostname` is the hostname of the system in which the `Environment` is running.

A.2 Configuration File Formats

```
<?xml version="1.0"?>
<RobotInfo>
  <robot>
    <hostname><IP Address></hostname>
    <port><RCPort></port>
    <name><Robot Name></name>
    <primary><1/0></primary>
  </robot>
  ...
</RobotInfo>
```

Figure 12. RobotConfigFile Format

Figure 12 shows the general format of a `RobotConfigFile` given as input to the `RemoteControl`. The information that should be specified in the file are the `Hostname/IP Address` of the `RemoteControlRobot` system, the `Port` at which the `RemoteControl` connects to it, the `Robot - Name` and a '1' to indicate this robot is primary else a '0'. Only one `RemoteControlRobot` specified in the file can have a '1' value in the `primary` tag.

```

<?xml version="1.0"?>
<world>
  <surface>
    <type>smooth</type>
    <size>
      <xmin>-500</xmin>
      <xmax>500</xmax>
      <ymin>-500</ymin>
      <ymax>500</ymax>
    </size>
    <object>
      <shape>
        <robot>
          <cylinder>
            <direction>0.0</direction>
            <name>Gold1</name>
            <x>30.0</x>
            <y>0.0</y>
            <z>0.0</z>
            <radius>10.0</radius>
            <height>1.0</height>
            <color>1.0 1.0 1.0</color>
            <hot>0</hot>
            <stationary>0</stationary>
          </cylinder>
          <sensor>
            <id>1</id>
            <type>heat</type>
            <range>15</range>
          </sensor>
          <sensor>
            <id>2</id>
            <type>sonar</type>
            <mode>2</mode>
            <position>
              <x-relative>1.5</x-relative>
              <y-relative>0.0</y-relative>
              <z-relative>3.0</z-relative>
              <range>15</range>
            </position>
          </sensor>
          <sensor>
            <id>3</id>
            <type>laser</type>
            <position>
              <x-relative>1.5</x-relative>
              <y-relative>0.0</y-relative>
              <z-relative>3.0</z-relative>
              <dir-relative>0.0</dir-relative>
              <range>20</range>
            </position>
          </sensor>
        </robot>
      </shape>
    </object>
  </surface>
</world>

```

Figure 13. EnvironmentConfigFile Example

Figure 13 shows an example for the EnvironmentConfigFile. This particular example contains the information about a robot named Gold1, facing an initial angle of 0.0radians at location (10,-90,5) with a radius of 3units, a height of 10 units, temperature of 0 degrees and is not stationary. It has a laser range finder with ID = 3, RANGE = 20, the position relative to the robot is (1.5, 0, 3). The

parameters for the stationary objects are also specified in a similar manner, but sensor section will not be present and the tag `<robot>` will be replaced by `<primitive>` and a value of 1 for the `<stationary>` tag.

A.3 Controlling Buttons on Joystick

The Joystick buttons that are used for controlling the robot motions and their corresponding actions are:

- BUTTON 2 - Send CheckWin message to Environment
- BUTTON 3 - Accelerate the robot
- BUTTON 4 - Decelerate the robot
- Joystick Handle moved left - Turn the robot left
- Joystick Handle moved right - Turn the robot right

Appendix B Programmers Manual

This appendix discusses the information required for modifying the modules developed for this report. It addresses the programmer's point of view of the system developed.

B.1 Sensor Module

The `Sensor` classes that have been implemented are a part of the `edu.ksu.cis.cooprobot.simulator.environment` package. The main logic of the sensor is implemented in the `generateSensorResponse()` method of each sensor class. The parameters of the sensors are loaded in the `EnvironmentFileLoader` class. If any new sensors are added to the system or the current ones are modified, these issues have to be taken into consideration.

B.2 RemoteControl Module

The `RemoteControl`, `RemoteControlRobot`, and `RemoteControlMessage` classes make up the module. They are implemented as a part of the `edu.ksu.cis.cooprobot.simulator.applications.maze` package. Any additional commands that are to be used to control the robot can be implemented by modifying the protocol existing between the `RemoteControl` and the `RemoteControlRobot`. If any new application are developed, which require the robot to function in either of `Autonomous` or `RemoteControl` mode, can be implemented by adding autonomous control code to the `autonomousControlCode()` method and the remote control code to the `remoteControlCode()` method of the `RemoteControlRobot` class.