YCP Robot

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Abstract

The project that was completed in fulfillment of the CS481 requirement was the design and implementation of software that made a robot both mobile and autonomous. The group members for this project are Tori Bare, Cory Boyle, Jason Cluck and Drew Wicke. Using the Robot Operating System (ROS), algorithms were developed for obstacle avoidance, and 3D navigation. Additionally, a simulator was created in OpenGL that was used as a testbed for these algorithms.

Introduction

One of the goals of the Robot Operating System (ROS) is to provide roboticists a software platform for specific robots. ROS is beneficial in this way because it creates "a wide variety of frameworks to manage complexity and facilitate rapid prototyping of software for experiments, resulting in the many robotic software systems currently used in academia and industry"[6]. This paper addresses the construction of a new ROS package that controls the X80SVP robot. The package, which already implements obstacle avoidance and wandering behavior, provides low level drivers up to a robust development framework that can be extended.

Another goal of the ROS community is to provide simulation software to test the robot. For example, the player project consists of Player, a robot interface, Stage, a two-dimensional robot simulator, and Gazebo, a three-dimensional robot simulator. The paper describes a new simulator for ROS that can be extended and provides a Kinect sensor.

The paper is organized as follows: the first part provides a background detailing the devices, algorithms and libraries that were used; the second part discusses the design of the system following with implementation details; finally, it concludes with an overview of future work.

Background

Various devices, technologies and algorithms were used to create an autonomous robot. The robot that was used was an X80SVP. A Beagleboard hosted the software and acted as a bridge to the robot while the Robot Operating System provided a framework for the software. Braitenburg aggression behavior was used to provide obstacle avoidance and a Kinect was used to provide vision. Lastly, graphics libraries were used to provide 3D graphics for the simulator.

Devices

The X80SVP Robot has a max speed of 75 cm/s, weighs 3.5 kg, has a max payload of 15 kg, and has a three hour battery life. The robot also has IR and ultrasonic range sensors, as well as pyro-electric human motion sensors as seen in Figure 1.

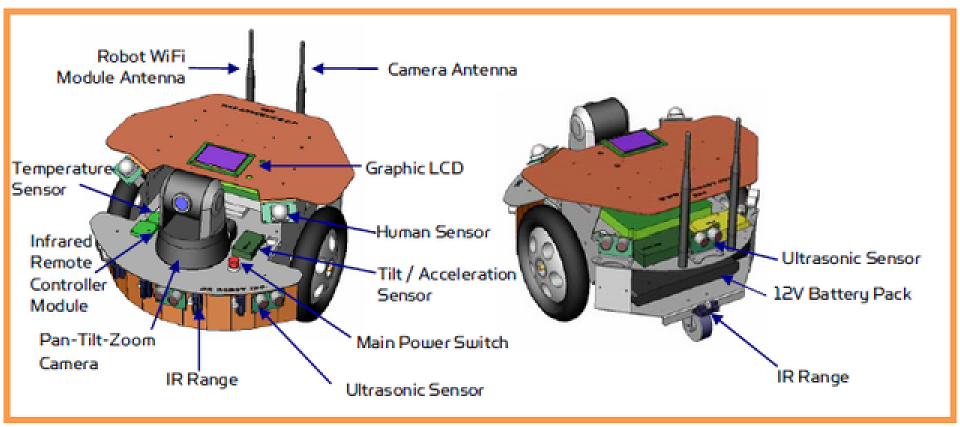


Figure 1: X80SVP Robot [3]

The Beagleboard XM was chosen as the computer for the X80SVP. Some of the major advantages to this is that the Beagleboard has many peripheral options, a 1 GHz CPU, a DSP, and it is very popular in the open source/ROS communities. The initial plan accounted for the DSP being able to process the Kinect vision data while the CPU handled the overhead associated with ROS. The major components on the board are shown below in Figure 2.

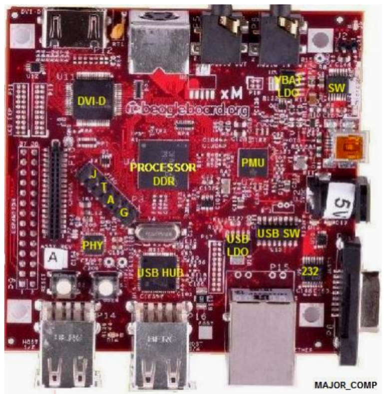


Figure 2: Beagleboard's Main Components [1]

A Kinect was used to generate maps of the robot's surroundings and to allow the robot to navigate intelligently through his environment. The OpenNI drivers for ROS, created by the makers of the Kinect, would enable the Kinect to be used in this manner. One of the main concerns with using the Kinect was the processing power that it would require. The Kinect produces a message that is roughly 10 MB at a rate of 30 frames per second, this equates to the Kinect sending about 300 MB of data each second. At first, it was expected that the DSP on the Beagleboard would have been able to handle the Kinect's processing; however, due to the overhead of ROS, the processing will most likely have to be offloaded to a netbook.

Technologies

ROS is a framework that facilitates the construction and execution of applications for robots. There are implementations of ROS in C++, Python, Lisp, and Java. ROS executables are called nodes. ROS provides a master node that oversees running nodes and a parameter server, it also acts as the matchmaker for nodes and topics. ROS nodes communicate over topics or services using ROS methods. Nodes publish messages on topics which other nodes can subscribe to in order to receive the information. The message's fields are described in a data file using the yaml language which ROS converts into a file that the targeted language can use, such as a header file in C++.

ROS also provides a hierarchy to group common elements. Nodes that perform common functions are grouped into a package. Packages that share a common purpose are grouped into stacks. Therefore, ROS's goal is to build a complex system out of simple, single-purpose parts.

The rosjava stack is an implementation of ROS in Java; therefore, rosjava nodes work with the rest of the nodes in ROS. In order for rosjava nodes to communicate, ROS messages are converted to classes and made into jar files;

this allows for easy integration of message data types into rosjava nodes.

Obstacle Avoidance Algorithm

There are two ways to implement obstacle avoidance. One implementation is motor fusion, which uses a direct correlation between sensor readings and motor velocities. The second implementation, sensor fusion, uses the sensor data to reconstruct the surroundings to produce motor commands. For the X80SVP robot, obstacle avoidance was accomplished by a motor fusion algorithm utilizing Braitenburg's aggression behavior.

Braitenburg behaviors are a form of synthetic psychology described in Valentino Braitenberg's book[5]. These behaviors were thought experiments into how different emotions, such as fear, aggression, and love, can provoke movement based on sensor stimulation. Aggression behavior is caused by pairing the sensors and motors on opposite sides through a non-decreasing function.

To implement aggression behavior for obstacle avoidance, modifications to use a centered sensor were made to the algorithm presented in [7]. The algorithm computes both the linear and angular velocity for the robot given the normalized sensor readings as shown in equations 1 and 2. Accounting for the center sensor separately allows the robot to avoid deadlock while in symmetric corners. The value of the sensor increases as an obstacle gets farther away and as the velocity becomes greater in that direction, providing a smooth wandering movement that effectively avoids obstacles.

$$\alpha_S(t_k) = \sum_{i \in L \cup R} w_i^{\alpha_S} \hat{r}_i^S(t_k) \tag{1}$$

$$\beta_S(t_k) = \sum_{i \in R} w_i^{\beta_S} \mathfrak{D}(\theta_i') \hat{r}_i^S(t_k) - \sum_{i \in L} w_i^{\beta_S} \mathfrak{D}(\theta_i') \hat{r}_i^S(t_k) \tag{2}$$

α_S and β_S are the normalized translational and rotational speeds in the range [0,1] and [-1,1] respectivley. $w_i^{\alpha_S}$ and $w_i^{\beta_S}$ are constant weights corresponding to the i^{th}sensor defined in equations 3 and 4. $\hat{r}_i^S(t_k)$ is the current normalized filtered range value of the i^{th} sensor. $\mathfrak{D}(\theta_i') = 90 - |\theta_i|$ the angular distance. Where θ_i is angle from the x-axis to the sensor assuming the x-axis lies on the axle and y-axis divides the robot in half.

$$w_i^{\alpha_S} = k_i^{\alpha} e^{-\frac{\mathfrak{D}(\theta_i')^2}{2\sigma_\alpha^2}} \tag{3}$$

$$w_i^{\beta_S} = k_i^{\beta} e^{-\frac{\mathfrak{D}(\theta_i')^2}{2\sigma_\beta^2}} \tag{4}$$

k_i^{α} and k_i^{β} are normalizing constants so that the speeds are normalized. σ_α^2 and σ_β^2 are the variance chosen here to be 1400 and 350 respectively.

Simulator Libraries

The simulator uses a number of libraries to make the OpenGL API more manageable. FreeGLUT is used to provide the basic windowing functions for the GL application. GLU provides utility functions for computing projection matrices, used to create the perspective camera views. SOIL is used to provide texture-loading capabilities. The simulator also interfaces directly with the Xorg APIs for some functions in handling mouse and full-screen controls. A custom loader was written to load DirectX format mesh files exported by Blender. This allows environments as well as movable obstacles of completely arbitrary design and complexity to be modelled quickly.

Design

The design model favors modularity and simplicity to create a complex system. The goal was to follow the subsumption control architecture to create a robust and fault tolerant system. By following the model view controller design pattern, the implementation is extensible. The model is based on the ROS parameter server in which the model of the robot and communication layout is stored. The view is the world or the virtual world as created by the simulator. The controller classes act to move the robot, changing the robot's view.

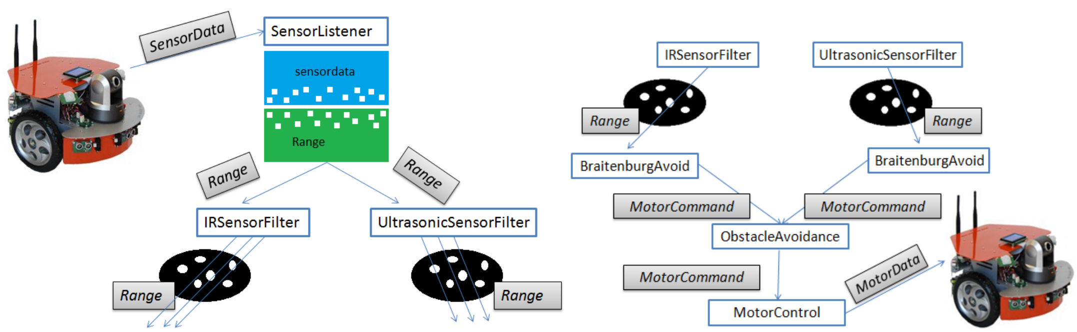


Figure 3: Simplified Design and Communication Model

The design is centered around the Converter and the RobotActor classes. Converter and RobotActor are interchangeable bridges between the view and the control, they publish the sensor data and send commands to actuate the robot's motors. The SensorListener class subscribes to the sensor messages published by a bridge class and publishes converted sensor data in the ROS standard Range message type. The SensorFilter classes filter the sensor data so that the data is more useful and the BraitenburgAvoid class uses the filtered sensor data to publish a MotorCommand message based on the Braitenburg aggression behavior algorithm. The ObstacleAvoidance node publishes a linear combination of the MotorCommand sent by the infrared and ultrasonic based on BraitenburgAvoid nodes. Finally, the MotorController acts as both an arbiter of motor commands and as a gateway back to the bridge nodes. The full design diagram is in Appendix A.

The initial design of the simulator relied on existing code which supported only one "Player" with one graphical view; this was adapted to support an arbitrary number of "Actors", each with any number of "Sensors". This was then used to implement each of the ultrasonic and infrared sensors as well as the graphical displays. Multiple actors allow the user to view the environment from the perspective of the robot or from an independent Camera actor, it also allows Obstacle actors to be positioned in real-time. A diagram of the simulator appears in Appendix B.

Implementation

The implementation of the design was completed in both C++ and Java. C++ was used for the simulator and the serial communication between the robot and Beagleboard while Java was used to implement the rest of the design.

The serial library used the PMS5005 protocol which allows any processor, DSP, or PC to control the robot through the Universal Asynchronous Receiver/Transmitter (UART) communication interface. The basic packet outline, shown in Figure 4, handles both the sensor and motor data transmission. The library that implements this interacts with ROS by subscribing to motor controls and publishing sensor data. Using this packet structure, a large amount of information can be processed every tick.

STX	RID	Reserved	DID	LENGTH	DATA	CHECKSUM	ETX

Figure 4: Packet format for serial library

The sensor and motor data from the packet structure were not ideal for our purposes and needed to be converted to useful formats. The data for the sensors needed to be handled differently for each type of sensor. The ultrasonic sensors were the most straightforward since the control board returned the distance in the range of 0 - 255 cm, which is already in the correct units for the message. The infrared sensors needed to be converted since they return a non-linear voltage value corresponding to a range of 10 - 80 cm. The voltage output with respect to distance is shown in Figure 5. This voltage output needed to be linearized using an interpolation equation [4]. The result of such an equation with respect to Analog/Digital Converter (ADC) values is shown in Figure 6. After testing the human sensors, it was decided that these will not be used at this point due to unreliable results.

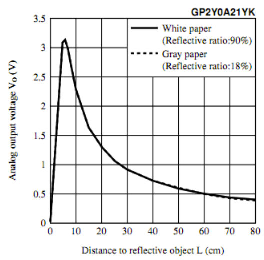


Figure 5: Infrared sensor voltage output [2] values [4]

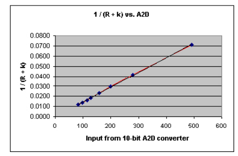


Figure 6: Linear interpolation of Voltage with respect to ADC

Once the serial library and sensor conversions were implemented on a desktop system, the next step was to achieve this functionality on the Beagleboard. The Beagleboard was loaded with Ubuntu 11.10 since this OS works best with ROS. Some of the configuration scripts for ROS require Internet access so a wireless internet connection was part of the Beagleboard setup. ROS was compiled from source on the Beagleboard because cross compiling is not recommended for ROS yet. After configuring the installation, it quickly became apparent that the overhead associated with ROS was more than expected. At the moment, the Beagleboard is unable to support ROS at 10 Hz and further testing will conclude whether this can be fixed or not.

The obstacle avoidance algorithm produces linear and angular velocity values, but the robot requires left and right wheel velocities. Using the differential drive kinematics equations 5 and 6, the conversion is possible. Note that $\alpha_S(t_k)$ and $\beta_S(t_k)$ are normalized linear and angular velocities and d is the wheel base of the robot.

$$V_L = \frac{2\alpha_S(t_k) + d\beta_S(t_k)}{2} \tag{5}$$

$$V_R = V_L - d\beta_S(t_k) \tag{6}$$

Ultrasonic sensors were used to provide obstacle avoidance, however the sensors can overestimate the distance to a flat wall due to specular reflection. These readings can be improved by applying an incremental filter (Equation 7) as described in [7]. The filter works by acting as a short term memory to ensure that a current reading of free space is correct based on the previous range.

$$\tilde{r}_i(t_k) = \begin{cases} r_i^s(t_k) & \text{if } r_i^s(t_k) < r_{nr}^s \\ Min\{\tilde{r}_i(t_{k-1}) + r_\triangle, r_{nr}^s\} & \text{if } r_i^s(t_k) = r_{nr}^s \end{cases} \tag{7}$$

$r_{nr}^s$is the max range of the sensor, $r_i^s(t_k)$ is the current range measurement, $\tilde{r}_i(t_k)$ is the current filtered range value and $\tilde{r}_i(t_{k-1})$ is the previous filtered value. $r_\triangle$ is a constant which is used to offset the previous value and was chosen to be 20cm as descibed in [7].

One issue of using rosjava was the overhead of creating new nodes, since each new node started a new JVM process. After implementing the design of the rosjava nodes, rosjava released documentation detailing how using a NodeRunner object can start the nodes as threads rather than as new processes. This significantly reduced the memory overhead and launch time of the rosjava nodes.

RGBDSLAM was selected as the main algorithm to implement mapping. In order to take advantage of RGBDSLAM, the entire project had to be downgraded from using ROS Electric to ROS Diamondback and from using Ubuntu 11.04 to Ubuntu 10.10. RGBDSLAM allows a point cloud of the environment to be created from the Kinect data as seen in Figure 7. Once a point cloud was generated, it could be converted to an OctoMap as seen in Figure 8, a 3D occupancy grid map that is developed from an octree. The OctoMap is then sent to the 3D navigation algorithm so that the robot can utilize the map.

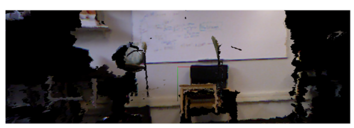


Figure 7: RGBD point cloud

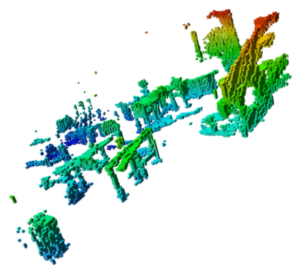


Figure 8: Octomap

The original goal was to have the robot using a static OctoMap to navigate his environment, and eventually implement dynamic mapping so the robot would have been able to map his environment while he wandered. Due to issues with ROS running in a timely matter on the Beagleboard, it is unsure as to whether the OctoMaps will be usable. At this point, a sign language feature may be replacing the OctoMaps, but that will be more-so determined in the final paper.

One of the initial challenges encountered in writing the simulator was that the position of the robot was represented as a point on an X-Y plane, but the input coming in from ROS would be in the form of differential wheel movement commands. Finding the necessary equations proved to be a challenge. It was also difficult to test initially since the ROS interface had not yet been implemented to a working degree. Some revisions and corrections had to be done once it was possible to send specific commands from ROS and to observe whether the resultant location of the robot in the simulation was correct.

Figure 9: Simulator in third person view

There were some problems to overcome in terms of speed and optimization. One of these problems was in computing a linear representation of the depth map because GL uses a logarithmic representation when rendering, but the one provided by the Kinect is linear. The initial implementation of this conversion required doing up to two million floating-point logarithm operations per frame. This was improved significantly by making the simulator initially render at the Kinect hardware's resolution, then scaling it to fit the actual size of the visualization window. Performing the conversion in this manner provided a nearly seven-fold reduction in the number of required operations when running in fullscreen mode.

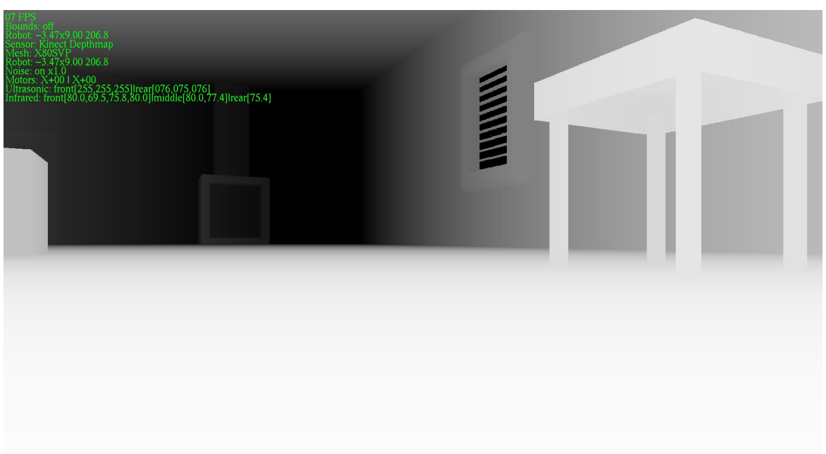


Figure 10: Simulated Kinect depth map

There were also some modifications in what is rendered during each pass. The simulator visualization targets a frame rate of 60 fps, but was unable to attain that rate on the workstation. Since the Sensing/Motion Controller on the actual robot only functions at 10 Hz, it is only necessary to broadcast data to ROS at that rate; thus, the sensor rendering passes could be skipped on 5/6ths of the frames, saving processing resources and boosting frame rate.

Future Work

In the future, there are plans to implement features such as gesture recognition, a multi-agent system, and unit testing for the simulator.

Gesture recognition is one of the more immediate future plans for the robot. A ROS stack called hand_interaction, created by the Massachusetts Institute of Technology, appears to be the best option for implementing this feature. Using hand_interaction, the location of the hands can be determined. As a gesture is made, the movement of the hands will be tracked and then the robot can react accordingly. At this point, it is unknown as to whether the gestures should be hard-coded into the robot or if the robot should learn these gestures manually. The most beneficial of these options will be determined and mentioned in the final paper.

The system could be extended by adding TurtleBots to create a multi-agent system. Capture the flag could be a way to explore algorithms involved in multi-agent systems. However, due to the limited processing power of the Beagleboard, there would be considerable challenges implementing efficient navigation, SLAM, and learning algorithms. One solution would be to use a remote computer to perform these features.

Another way the system could be extended is by using the Kinect for facial and object recognition. This would allow for high level behavior and learning rather than the current reactive-based system; however, the processing capabilities of an on-board computer may be overwhelmed.

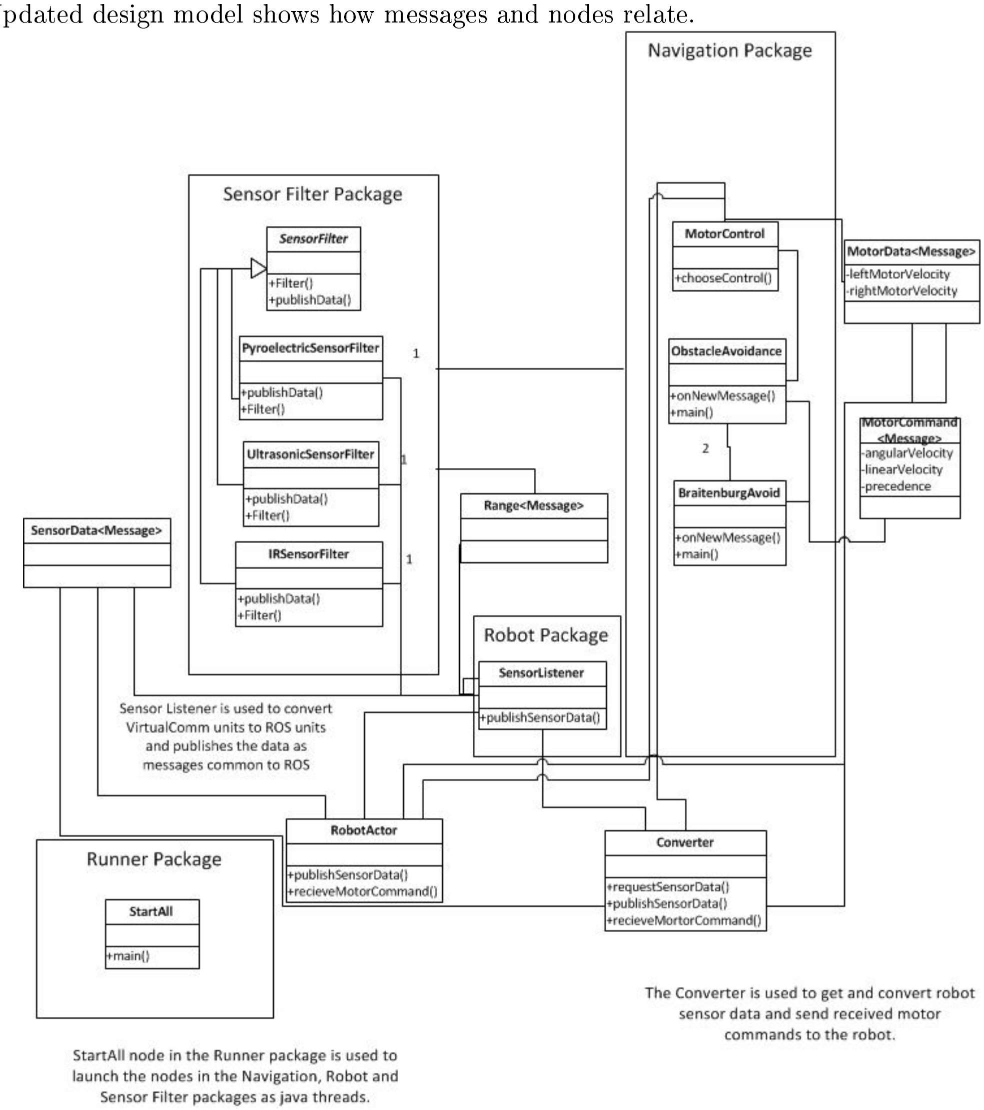
A future system could also utilize rosjava's ability to operate on Android to provide a user with the ability to teleoperate the robot or provide the robot access to the cloud.

A way to implement unit testing in the simulator may be useful. This would allow some of the previous problems encountered, such as inaccuracies in the wheel movement equations and rendering pipeline issues causing inaccurate sensor outputs, to be tracked down more quickly. Implementing this may be difficult, as the correct values would have to be computed manually by some other reliable method, and one of the primary motives for developing the simulator was to not have to do these tedious calculations manually.

Appendix

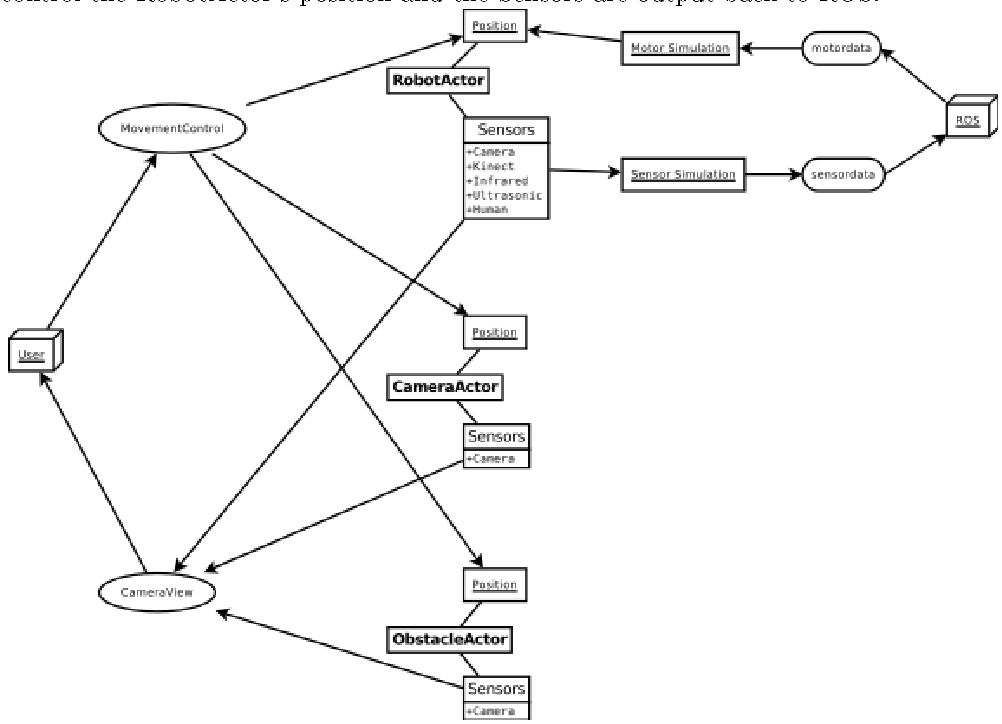
Section A

Updated design model shows how messages and nodes relate.



Section B

The User can select to control any Actor's position. The specific sensor the CameraView is rendered from can also be selected. Data from ROS is also used to control the RobotActor's position and the Sensors are output back to ROS.



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