The importance and purpose of simulation in robotics

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Abstract

Research on autonomous robots that are capable of operating in an assisted living situation is often done with physical human size robots. Working with these robots however, is a very time consuming task which also provides a monetary constraint. In addition, the robots are often inconsistent while testing as there are many unexpected variables. Simulating the robot is a solution to provide a low cost, easy accessable environment for the development of robots. This thesis intends to determine the importance and purpose of simulation software for research into robots and propose an experiment to prove the capabilities of simulation software SIGVerse including the obstacles and the appliance in the RoboCup@Home tasks.

Contents

1 Introduction

> "By 2050, a team of fully autonomous humanoid robot soccer players shall win a soccer game, complying with the official FIFA rules, against the winner of the most recent World Cup of Human Soccer."[1]

This quote describes the goal of the RoboCup. First proposed in [Kitano et al., 1997], the RoboCup was a new approach to the creation of robots that are able to solve dynamic problems. In this initiative soccer is used as a benchmark for comparing the designs of the different teams because it provides a broad spectrum of challenges for teams to face in order to create a functioning team able to compete. For example, the obstacles that the RoboCup team has to overcome include the perception of video images and information from other sensors such as infrared or touch, the teaching of behaviour and movement and the creation of the possibility for collaboration between multiple agents.

In addition to the broad spectrum of challenges, soccer has also been chosen because it can be used to facilitate the embodiment hypothesis which by the 1950s had already been theorized by the British pioneering computer scientist Alan Turing by stating:

> "It can also be maintained that it is best to provide the machine with the best sense organs that money can buy, and then teach it to understand and speak English. This process could follow the normal teaching of a child. Things would be pointed out and named, etc."[Turing, 1950]

The embodiment hypothesis was formulated more precisely in [Brooks, 1995], by stating that the embodiment hypothesis means that for a robot to be truly intelligent, it has to possess a physical body that experiences and is part of, a dynamic world. Playing soccer requires the agents to be physical and since the field, the agents and the ball form the dynamic world and the agent within this world can observe and influence the world it can be called a truly intelligent agent. This makes soccer a fitting choice as a scenario.

Besides the challenges and obstacles that soccer provide, there are more significant research barriers within artificial intelligence that have to be overcome. To also facilitate this research, several other domains have been added to the RoboCup competition. One of these domains is @Home. In the @Home challenges teams have to design an autonomous robot capable of everyday household tasks to be done in an assisted living situation. This competition still complies with the embodiment hypothesis since the robot possesses a physical body. However, this competition has been constituted to provide an approach for the problem that is, human robot interaction. The promise of the @Home challenges is best described in [Wisspeintner et al., 2009]:

> "At the moment the focus is on physical capabilities such as manipulation, human recognition and navigation. In the future, more focus will be put on artificial intelligence and mental capabilities

[1] http://www.robocup.nl

> in the context of Human Robot Interaction. This includes situational awareness, online learning, understanding and modelling the surrounding world, recognizing human emotions and having appropriate responses."

This statement refers to the difference between the RoboCup and the @Home competition because whereas in the RoboCup the computer vision and navigation are fundamental, the communication with humans is of more importance for @Home. Therefore, @Home broadens the scope of the fields of research and consequently adds these fields to those already being exerted in the RoboCup Soccer League.

In RoboCup competitions, the teams have to provide their own robots for the demonstration. Every separate domain has specific rules describing the format of the competition as well as how teams will be graded and penalized in the event of errors or unintended behaviour of the robot. Each team has to design its own robot complying with these rules. And it is here that a problem arises: designing, building and maintaining robots is a time (and money) consuming task. In addition, not many researchers can work with one robot at the same time and finally, physical robots are also often rather fragile which may result in technical failures. A solution to these phenomena is to simulate a robot in a virtual world, instead of making a physical one. In simulation the environment is controlled and predictable which provides another advantage over real world testing: reproducibility. If the research and its conclusions drawn from it is done in a simulated environment, the reproduction of this research is guaranteed since all the variables involved in the research can be precisely recreated. This thesis intends to determine the importance of simulation software for research into robots and propose and experiment to prove its capabilities.

The structure of this thesis is as follows. Chapter two supplies a history of simulation followed by related research regarding simulation in robotics. Chapter three describes the RoboCup@Home division, the example scenario used throughout this thesis, along with the challenges and important obstacles. Subsequently, chapter four will describe the simulation software SIGVerse, the tool used in the experiment, which is described in chapter five. Chapter six is devoted to the conclusion and discussion of the experiment from previous chapter and finally chapter seven will discuss the future directions of research.

2 Literature review

To assess the importance of simulation software for research into robots, this study will use robot simulation software SIGVerse. Introduced in [Inamura et al., 2010] SIGVerse is conceived as an environment simulation tool to dynamically simulate bodies, senses and social communication. Upon the basis of the SIGVerse system introduced in 2010, the authors published a paper three years later in which the functionalities as well as the feasibility of SIGVerse in the RoboCup@Home challenges were published [Inamura and Tan, 2013].

History of simulation

The concept of simulation as used in this thesis has not been around for longer than a decade, however simulation is not a new concept. In ancient Rome, the military were trained by sparring in mock battles using training weapons. This was done primarily in one on one combat but steadily grew to battles between several units. The purpose of these battles was not to injure the opposing side, nevertheless the individuals on each side gained significant combat experience. Experience from simulating battle provided the Roman army an important advantage over any other army. Consequently, this contributed to the rapid expansion of the Roman empire[Goldsworthy, 2003].

Centuries later, the Renaissance era (1300-1600 AD) marked the start of important scientific research. Scientists such as Leonardo Da Vinci and Copernicus used scale models of their ideas to represent their functionality on a small scale. For example Da Vinci made sketches and models of several flying machines [Da Vinci,] while Copernicus made a model representing the solar system placing the sun in the centre of the system with the planets revolving around it [Kuhn, 1985]. The Renaissance also marks the period in which the strategic game of chess got its actual form. Throughout the 16th century articles and books on chess strategies were published, an early form of game theory. Eventually in 1997 IBM created Deep Blue, a computer capable of defeating world champion Garry Kasparov. Deep Blue was capable of simulating and analysing long movement sequences with an average rate of 100 million moves per second [Campbell et al., 2002].

In the 20th century simulation became a more significant element of education. In the twenties the first flight simulator, the Link Trainer, was built to train pilots. This simulator consisted only of wooden boards and a steering system. Further developed in the thirties, four pneumatic bellows were added to provide the simulator with feedback to the student. Modern flight simulators are exact replicas of an entire cockpit complete with instruments and controls [De Angelo, 2000].

Simulation is used in practically every form of education or research. Within the research of artificial intelligence, simulation is widely used. One of the first simulators that could recreate complex worlds in 3D is Gazebo. In [Koenig and Howard, 2004] the architecture of Gazebo is described. The difference between Gazebo and different 3D simulation software of that time is that Gazebo was one of the first to focus on resembling the world as realistic as possible for the robot instead of for the human. Originally, it was designed for large outdoor environments while currently, after years of development, Gazebo is also capable of simulating indoor scenarios. However, the initial focus on outdoor environments made Gazebo the simulator of choice for the Virtual Robotics Challenge, part of the DARPA Robotics Challenge. This challenge aims to develop autonomous robots that provide help and assistance in disaster situations. The difference between Gazebo and SIGVerse, used in this thesis, lies in the possibilities to interact with the simulated robot. While Gazebo is made to test manipulations to the world through sensors and actuators, SIGVerse is made with the purpose to let the user interact with the simulated robot. The user of Gazebo is simply a spectator while the virtual robot executes the algorithms. SIGVerse on the other hand, allows the user to enter the world and give commands to the robot.

A second alternative to SIGVerse is USARSim, where *USAR* abbreviates *Urban Search and Rescue*. As presented in [Carpin et al., 2007], the purpose of USARSim is to provide an open source, highly configurable and extensible environment for robot simulation. Furthermore, USARSim is established as the simulation engine for the Virtual Robots Competition within the RoboCup initiative, not to be confused with the Virtual Robotics Challenge, part of the DARPA Robotics Challenge. The simulator is designed as an extension of the Unreal Engine. Primarily designed as a game engine, the Unreal Engine is a rendering engine for first-person shooter games. The rendering of the 3D world is completely handled by the Unreal Engine providing USARSim with superior graphics and physical modelling. Although widely used in the Rescue division of RoboCup, it is less suitable for use in the @Home division because of the poor human robot interaction within the simulator.

The context in which SIGVerse will be used in this project is the RoCKIn@Home competition. A critical view of the relationship between competitions and experiments is given in [Amigoni et al.,] where the RoCKIn competition is discussed in particular. Although this article is indecisive whether competitions are a reliable benchmark for experiments, [Lima et al.,] argue that it an ideal instrument of benchmarking scientific experiments. Both articles however confirm the suitability of competition as a method of experimenting.

3 @Home

The @Home competition has been conceived to extend the previously existing RoboCup Soccer League by providing a way for the development of practical AI solutions and applications where the focus is mostly on human-robot interaction. This idea has been initiated in [van der Zant and Wisspeintner, 2006] as the RoboCup X-games. In this work the X-games are described as a set of tests that provide the teams with a limited complexity of the assignment and where the environment can be modified. This ensured a low entry level for new teams in the competition. Furthermore, the tests can be changed each year to prevent the X-games from getting repetitive. The following abilities can be tested:

- recognizing humans from their face or bodies in unknown and varying light conditions.
- supporting an elderly person while walking
- climbing a stair
- carrying an object and following a human while avoiding collision

The first competition in this format, was as a demonstration competition at the RoboCup in 2006 in Bremen, Germany. In this demonstration the participating teams had to carry out the tests. The scoring could be either pass or fail. The following year, this format became an official league under the name RoboCup@Home, where the competition was held in the same fashion as in Bremen the year before. After evaluation of the @Home competition in 2007, the Technical Committee decided to change the testing of the robots. Instead of scoring a pass or fail, the teams were rated a pass or fail for each individual subtask. This procedure facilitates comparing the performance of the different teams.

3.1 RoCKIn

As well as the RoboCup, RoCKIn also hosts an @Home competition, which is funded by the European Union. RoCKIn, *the Robot Competitions Kick Innovation in Cognitive Systems and Robotics*, aims to encourage and stimulate research and scientific progress in robotics and has in that respect the same goals as the RoboCup@Home. A secondary goal is to provide entertaining demonstrations of autonomous robots to increase public awareness and exposure of the state of the art technology. The tests and the grading system of RoCKIn both comply with the rules of the RoboCup. In this competition participating teams create a robot capable of operating and completing the tasks within a scenario that is changed each year. In the RoCKIn scenario, the robots have to operate within the apartment of a fictional elderly named *Granny Annie*. Granny Annie suffers from the usual problems people of her age face: her mobility is limited, she forgets things and she lacks energy. The participating teams create robots to assist Annie in three different situations that are simulated at RoCKIn.

The first task the robots have to complete consists of little chores given by Annie. This includes opening and closing the blinds according to her wishes, finding and retrieving her reading glasses or bringing Annie a glass of water. These tasks all involve object recognition, different forms of reasoning and communication in the form of speech recognition and synthesizing.

The second task involves mapping the apartment and localizing different objects such as furniture. The robot must navigate through the apartment and find the desired object without colliding with other objects in the room. There are several ways allowed to teach the robot. Firstly, the robot can autonomously move through the rooms, creating a map of the position of the different objects. As an option, the robot can ask a team member the name of an object. A second option is to let a team member guide the robot through the apartment while pointing out meaningful objects. Obviously, the execution of this task requires speech recognition for communication and the ability to create a map of the environment. Mapping the environment creates a representation of the room from which information can be gathered such as the number of chairs in that room or the location of the kitchen.

The third task tested at the RoCKIn competition is welcoming visitors. Because Granny Annie is not always capable of answering the door, the designed robot has to be able to perform this task. When a person rings the doorbell the robot has to be able to recognize this person and to decide whether he or she is allowed to enter the apartment or not. This task makes use of the ability to recognize the face or clothes of that person and speech recognition to ask the person at the door for his or her identity in the event that the recognition software is indecisive.

3.2 Welcoming Visitors

For this thesis the welcoming visitors task from the RoCKIn scenario is used as an example problem. In this task the robot is confronted with a visitor and has to decide an appropriate action. The task starts at the sound of the doorbell. First the robot has to access the video intercom to observe the screen or connect to the video feed from the camera at the front door. There are four possible visitors within this scenario and the robot has to respond on each person in a different manner. Below is a list of the four possible cases when the doorbell rings.

- The deli man. This person delivers breakfast for Granny Annie. The person always wears the same uniform, but the actual person may change each trial. The deli man has to be escorted to the kitchen where he can place the groceries on the counter. Next, he has to be escorted out the apartment.

- The postman delivers the mail and a parcel. Similarly to the deli man, the postman can be a different person each trial, but will always wear the same uniform. The robot has to accept the post and the parcel at the door and close the door after the exchange is completed.

- Dr. Kimble. If Granny Annie does not feel well, her doctor may visit. Dr. Kimble is a known acquaintance and has to be recognized from his face because he could wear different clothes each day. The doctor has to be escorted to Granny Annie and back to the door when the visit is at its end.

– A stranger. The door may not be opened and the stranger can be asked to leave.

Figure 1 shows images provided by RoCKIn, of the three to be recognized persons. A mock-up image of the deli man is shown in figure 1a. Figure 1b shows the uniform of the postman and the face of Dr. Kimble is shown in figure 1c. RoCKIn provided more images of these three guests. The image collection of Dr. Kimble is extensive, including images from multiple angles with different facial expressions. The collection of the deli man and postman is relatively minimal. The appearance of the deli man is illustrated in only two images, one a low quality but high resolution (3508 by 2480 pixels) mock-up image shown in figure 1a and the second image is a single front view photo of a person wearing the deli man uniform shown in figure 1d. This second image is, in contrast to the mock-up image, represented in a low resolution (500 by 1116 pixels). Even though the deli man has a front view photo of a person wearing the uniform, the photo of a person wearing the postman uniform, shown in figure 1e, is a rear view photo. The resolution of this photo is 500 by 1245 pixels which is close to, but different from the deli man photo.

(a) The deli man

(b) The post man

(c) Dr. Kimble

(d) Person wearing deli man uniform

(e) Person wearing postman uniform

Figure 1: RoCKIn images of the visitors

4 SIGVerse

Since human-robot interaction is of great importance for the RoboCup@Home tasks, SIGVerse should provide a sufficient simulating environment containing the required features and components. This chapter illustrates the architecture of SIGVerse and discuss where and discusses how it is used.

4.1 Configuration of the software

SIGVerse is a system consisting of a client and a server application which allows users to connect from the client onto the server to join in the simulated experiment as an observer. Figure 2 represents the architecture of the system.

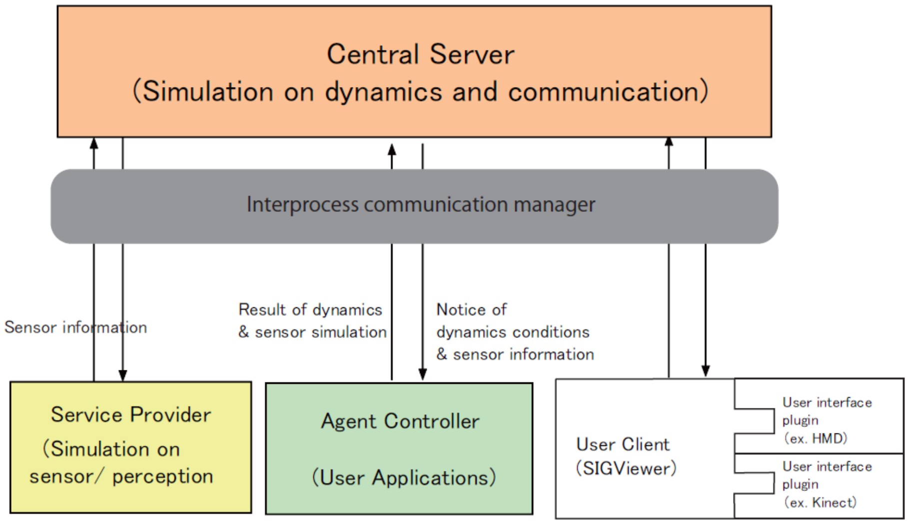

Figure 2: Configuration of SIGVerse from [Inamura and Tan, 2013]

The central server, called the SIGServer, is a Linux based application that performs all the calculations for dynamics and physics. Connected to this server is the service provider module which provides the system with the simulation of the senses and perception and contains three separate modules: dynamic simulation, perception simulation and communication simulation.

For the simulation of dynamics the Open Dynamics Engine (ODE) is used. ODE is an open source physics engine that provides SIGVerse with the capability of rigid body dynamics and collision detection. The component for rigid body dynamics calculates the motions of body parts that are connected through joints. This allows the engine, and thus SIGVerse, to simulate the movement of solid objects and bodies. The collision detection component provides the ability to detect the moment and location of impact when two objects make contact.

OpenGL is used for the perception simulation module which SIGVerse utilizes to render the graphics of the interface. It provides each agent with an image of that agent's point of view therefore simulating the sense of vision. Touch is also simulated in this module by the force and location where objects touch the agent. This module acquires the information of object location and collision detection calculated by the ODE.

The communication simulation module provides the sense of hearing to the agents by enabling audio data for each agent. This allows the agents to send audio messages to each other in the simulation. The volume of these audio messages is inversely proportional to the distance between the agents, which is calculated in the ODE, resulting in creating a virtual hearing range. The size of this range can be altered within SIGVerse.

In addition to the service provider, the central system also utilizes an agent controller which is a dynamic link library (DLL) on the Linux SIGVerse server. In this DLL application programming interfaces (APIs) in C++ can be added to implement autonomous actions and sensing functions.

Finally, the user can connect to the central server through a Windows user client, called the SIGViewer, which provides a virtual camera to move through the environment and a user interface to communicate and interact in real time with the simulated agents.

SIGVerse currently consists of one server that can simulate a virtual world allowing one client to connect. However, many-to-many human-agent interaction scenarios are mentioned in [Inamura and Tan, 2013], which could mean SIGVerse might be able to support multiple virtual worlds in which users can implement and upload their agents simultaneously in a future updated version.

A recent update (24th of April, 2015) provided several extra functions for SIGVerse. First of all a new 3D model for the iCub robot has been added. This robot has been designed according to the embodiment hypothesis, resulting in this one meter tall humanoid robot. Capable of facial expressions, object manipulation and crawling, the iCub robot contains all the abilities to be part of human-robot interaction experiments that can be simulated in SIGVerse. In addition to the iCub model, an extra view option has been added that allows the user to connect an OculusRift virtual reality head-mounted display to view the virtual environment. This adds extra immersion to the experience of viewing the simulated world.

4.2 In practice

SIGVerse was designed in 2010, and many additions have been made. For example the SIGViewer, which distinguishes SIGVerse from different simulation software, was added in the 2013 version proposed in [Inamura and Tan, 2013]. In that year, a new RoboCup competition was created for the yearly Japan Open contest; the RoboCup@Home simulation. This competition follows the rule set made for the RoboCup@Home competition, however the physical robots have been replaced by simulation software. Since the team from the Tagawa University, where SIGVerse has been created, has won the regular @Home competition in 2008 and 2010, the use of SIGVerse in the simulation competition was approved. Figure 3 shows an image of the robot as seen through the SIGViewer during the RoboCup@Home simulation 2014.

Figure 3: Simulated robot used in RoboCup@Home simulation 2014

5 Experiment

To prove the capabilities of SIGVerse, in this chapter an experiment is proposed to combine a state of the art recognition algorithm, the Viola & Jones object detection algorithm, with SIGVerse to recreate the RoCKIn RoboCup@Home scenario.

5.1 The algorithm

The suggested algorithm is the Viola & Jones algorithm. Made as an object detection algorithm in 2001 by Paul Viola and Michael Jones, this algorithm was originally only capable of detecting the location of an object in an image [Viola and Jones, 2001]. The benefits of using the Viola & Jones algorithm are that it provides a very fast computation of the features, allowing real-time computation, while still producing very accurate results. The algorithm was extended by adding a classifier making it, in addition to detecting, also able to recognize objects. Training of the algorithm makes use of Haar-like features, which also facilitate real-time computation. Each Haar-like feature provides a weak classifier for the algorithm which does not provide enough certainty for classification. Therefore, Viola & Jones organized the Haar-like features in a *cascade*, combining it to one strong classifier. The training algorithm can be found in OpenCV under the name *cvhaartraining.cpp*.

5.2 Obstacles

The obstacles encountered while executing this experiment are mostly caused by the @Home scenario or involve the use of SIGVerse. While Viola & Jones and Haartraining are well documented algorithms, the functioning of SIGVerse is still relatively unproven. This results in uncertain factors regarding the execution of the experiment.

The first obstacle to overcome is the gathering of training data. To train the algorithm two sets of images are needed. The first set is a collection of positive images containing the object that has to be recognized, in this case RoCKIn RoboCup@Home, thus these have to be images of the deli man, the postman and Dr. Kimble. The second set of images required for training is a collection of negative images that do not contain the object. Since the distinction has to be made between a person wearing one of the uniforms and a person wearing different clothing, the negative image set consisting of images of people in different clothing is recommended. The gathering of each training set however, provides a problem.

The set of positive images requires images of a person in the deli man or the postman uniform. RoCKIn provided for each of those uniforms just two images. Earlier discussed in chapter 3.2 these images are not sufficient for training. The mock-up images shown in figure 1a and figure 1b are not useful in training since they do not resemble the images presented while testing because it is only an illustration. The image in figure 1d is useful for training of the deli-man uniform, while the image in 1e is not useful since it is an image from behind, something not occurring while testing. At the RoCKIn competition the teams get to opportunity to create their own datasets before the demonstration starts. These datasets are not publically available so a different approach to the gathering of a large enough dataset is required.

Gathering a set of negative images results in a different problem. These images have to contain a person wearing different clothing than both uniforms, however they have to be in the same form as presented in the simulation. In the simulation the person will stand close and will be looking at to the observing robot, resulting in a front-view image from the waist up. Since the virtual world in SIGVerse does not have to include objects in the background, the background colour of the image will be blue by default. Because so many specific properties are required for this set of negative images, possibly the best way to create this set will be to photograph subjects from the correct angle and in front of a clear and even coloured background.

Other than the gathering of required training data, the testing data present an additional complication. When gathering testing data, images will be made of the simulated avatar of a person in SIGVerse. This avatar represents either a recognizable person or a stranger. The performance of the recognizing algorithm however, depends on the level of detail in which the appearance of the avatar is depicted.

Figure 4: Deli man represented in SIGVerse

Figure 4 is a representation of the deli man recreated as a 3D model in SIGVerse. The 3D model in SIGVerse however, is not an anatomical correct representation of the human. The problem this could present is that the avatar cannot be recognized because it is not similar enough to a human. A solution to this could be to create a new 3D model and import it into SIGVerse. This also allows the possibility to add the apron and cap, seen in figure 1d, which are missing in the current model.

6 Conclusion and discussion

In this thesis we have discussed the importance of simulation for robotics and the capabilities of SIGVerse. After providing the theoretical background a proposal has been made for an experiment to determine the feasibility of SIGVerse when executing a state of the art algorithm. From this study of simulation and specifically SIGVerse we can conclude the following.

SIGVerse provides an excellent platform for research into autonomous robots since it allows robots to make use of the sense of touch and hearing. Furthermore, the ability to send audio messages in the simulation enables communication with a human avatar. From the research point of view SIGVerse provides a multitude of functionalities to facilitate easy implementation of existing work. Since C++ is used for the APIs controlling the agents in the simulation, a direct implementation of interfaces from libraries such as OpenCV is possible. Finally, XML files containing 3D models can be imported to allow the smooth addition of required avatars such as robots, humans or objects.

In addition, we can conclude that simulation can be an important intermediate step between the creation of an algorithm and the testing in a real world scenario. Because a simulated environment is controllable, troubleshooting a misbehaving algorithm is simplified since less factors play part in the results of the algorithm. Furthermore, a simulated environment is not unpredictable which ensures the reproducibility of research, since the results of every experiment will always be constant.

After this study of simulation questions are raised as to how is speculated about the purpose of imitating reality in a simulated world. For example if an algorithm works in a controllable environment, will it be capable to perform equally as good in a real world scenario since many more factors are involved?

On the basis of this thesis can be stated that a different understanding has to be found as to how simulations function since they do not have to mirror reality, but they have the purpose to be an open environment in which new problems can be found and solved in an uncomplicated way. This does not require every real world factor to be simulated since keeping the simulated world simple, results in a simplified way of finding solutions.

7 Future Work

Future work regarding the experiment proposed in this thesis will arise with time. As for the simulation software SIGVerse, a list of points of further investigation is described below.

- Improving the Windows user client to provide more customizability in layout and accessibility in functions can help the user to observe the experiment in his or her desired way. For example adding the possibility to reset the simulated world through the Windows user client allows the user to instantly start over the experiment without restarting the Linux server. Furthermore, including the required packages in the Linux server installation simplifies the process and ease setup of the software
- A many-to-many extension to allow multiple users to load their own agent into one of many virtual worlds. Earlier discussed in chapter 4.1, the many-to-many implementation could allow multiple users to observe one agent. SIGVerse currently only allows one client to connect to a server. Allowing multiple clients on one server can make multiple researchers able to control multiple agents to study collaboration and communication between robots.
- Currently the server makes all the computations for the agent in the world. Whenever a user wants to make an adjustment in the agent controller, the server has to restart. If the user was able to make adjustments from the Windows user client and reupload the controller to the server, the research process would be greatly simplified.
- The textures of the 3D models in SIGVerse are currently stored in the install directory of the client application. However if multiple clients can connect to one server in the future, the textures might have to be stored on the server side instead. Whenever a vision application is used, and different users use different textures, discrepancies might occur in the results. Storing the textures on the server might be needed to prevent this, however it could also result in high data traffic.

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