MULTI-AGENT COLLABORATION WITH HUMANOID NAO ROBOTS

ECE 486 Midterm Report

by

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ODU Honor Pledge

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ABSTRACT

The purpose of this project is to use humanoid NAO robots to simulate a problem setting where one robot, Robot A, will model two or more behavioral states, and another robot, Robot B, will communicate and perform behaviors to move Robot A toward a target state. This project has implications in improving human/robot relations and interactions. The Vision Lab has two NAO robots, which will both be used in this project, each equipped with two five-megapixel cameras, four omnidirectional microphones, temperature sensor, gyroscope, accelerometer, and multiple position, tactile, force-resistive, and ultrasonic sensors. The NAO robots are fully programmable using Python 2.7 and the NAOqi API; there is also a GUI application called Choregraphe that can be used to make block diagrams with programmable blocks. Test controllers for the behaviors of each robot will be designed and implemented. Each controller will require a behavior module that manages behaviors and communications performed by the robot, a recognition module to classify the behaviors of the other robot, and a reinforcement module to adjust behaviors based on feedback from the other robot.

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CHAPTER 1

INTRODUCTION

1.1 DESIGN PROBLEM

The objective of this project is to design and implement a problem setting where two NAO robots communicate and perform behaviors to reach a target state.

The design approach will involve using Choregraphe and the NAOqi API to build each controller and their respective modules. Many of the NAO robot's sensing technologies will also be employed to accomplish the design task.

1.2 DESIGN FUNCTIONALITY

This design will use two NAO robots, each connected to a separate computer. The programs built in Choregraphe will be uploaded to each robot through an ethernet connection between the computer and robot. Each robot will have their own block diagram program designed in Choregraphe tailored to what the robot will be doing; robot A will display some random initial behavior and robot B will try to move robot A toward some target state. Both robots will adjust their behaviors based on what the other robot does.

1.3 QUANTITATIVE PERFORMANCE OBJECTIVES

The robot should be moved to the target state in a realistic amount of time based on how complex the set of behaviors are. When using three basic behaviors that only control the color of the eyes on the robots, the interaction should take no more than a minute to complete. When using more than three complex behaviors that control eye color, movement and speech, the interaction should take no more than five minutes.

CHAPTER 2

DESIGN APPROACH

2.1 REALISTIC CONSTRAINTS

2.1.1 ECONOMIC CONSTRAINTS

An analysis of the economic constraints associated with the use of the NAO robots reveals that the cost of equipment is not accounted for. The equipment that ranges from the robots and their wires to the softwares used in the design are purchased and provided prior to the beginning of the project. Due to this, the project has no budget. According to RobotLAB (an educational robotics market), the price of the latest NAO to that of older models ranges from \$9000 to \$6500 [1]. Therefore, in a hypothetical scene, if an organization wanted to make use of the robots in their own manner, the cost to obtain them is affordable.

2.1.2 ENVIRONMENTAL CONSTRAINTS

The programming of the NAO robots took place in the Vision Lab. The wires used to establish an internet connection between the robots are of a certain length. This means that there is a restriction in the amount of movement the robots can perform. To accommodate this, the two robots were always used in close proximity. The NAO robots are not innately programmed to avoid collision so a room with many obstacles must be accounted for.

2.1.3 TECHNOLOGICAL CONSTRAINTS

One huge constraint for this project is that the NAO robots and NAOQI do not support the latest version of Python. Python 2.7 is the only version of python supported [2] . Python 2.7 went out of support on January 1, 2020. Therefore, many libraries do not support it. This limits what we can do with this project without extra complex systems to support Python 3 code. In addition, the NAO robots are lacking novel GPUs in their hardware. This additionally limits the complexity of any potential networks unless other methods are implemented such as streaming data to a nearby GPU.

2.2 ALTERNATIVE DESIGNS

Our first opportunity to choose between designs was when choosing to program the virtual or real robots. After sticking with the real robots, we had to choose between using C++ or Python. We went with Python. After that, we had to choose between Choregraphe and just using raw Python. We chose Choregraphe. Consequently, we had to make a choice on whether to use built in functionalities or implement ours from scratch. We went with the Choregraphe built in functions. Details and reasons for these choices are explained in the next section.

2.3 ANALYSES USED TO SELECT AMONG THESE ALTERNATIVE DESIGN CONCEPTS

here are and were multiple opportunities to implement alternative designs. In the beginning we had to decide whether to program virtual NAO robots or the actual NAO robots. The virtual NAO robots would have been programmed with the virtual WeBots environment [3]. We decided to go with the physical NAO robots as the NAOqi is no longer supported in WeBots. This meant that any code written for a virtual robot would not work for the real ones.

After making that choice, we had to decide between C++ and Python 2.7. We made the choice to go with Python 2.7 as the developer website warns against going with C++. Additionally, machine learning libraries and computer vision libraries support Python 2.7 more than C++.

Afterwards, we had to choose between using just raw Python 2.7 or using Python in the context of Choregraphe. We decided to use Choregraphe as it is simpler to use and we experienced some seemingly non deterministic behavior with just using Python 2.7. In addition, if some custom python modules are required, then we can implement them.

Another alternative design we could have is implementing our object classifiers and natural language modules from scratch. We decided to go with the built-in NAO robot modules as these have been proven experimentally to be capable of performing simple object classification and voice recognition.

2.4 TEAM ORGANIZATION AND PERFORMANCE

When splitting up the work of the 6 modules we naturally considered each team member's own skills and interests. Stephen and Jacob chose the recognition modules due to their own experience with machine learning. Zeph and Seth chose the behavior modules due to their own experience with programming. Who is exactly working on the reinforcement modules is not determined at this point. Whoever is finished with their respective module first will then move on to their robot's reinforcement module.

CHAPTER 3

PROJECT DELIVERABLES

3.1 TASKS AND RESPONSIBILITIES

Stephen's responsibilities were researching the feasibility of NAOs recognizing each other's voices and to develop a detailed plan for the fusion of various mobile nets for recognition or navigation. After further testing of the NAO Robots, he was able to get the NAO Robots to recognize each other's voices and decided that the NAO robots are capable of performing the required tasks. Therefore, a custom mobilenet was not required.

Zephaniah's responsibilities were looking into NAO robot behavior to determine if the NAO Robots were able to overlap emotions and movement at the same time. After testing, the NAO Robots were able to detect multiple emotions at once but are not able to physically do multiple tasks at the same time.

Seth's responsibilities were to do research on all the sensors on the NAO Robot and to see how well they responded. Overall, all sensors on the NAO Robot were in good shape and were able to fully do the designed job they were intended for.

Jacob's responsibilities were to organize the shared drive and documents, troubleshoot issues with installing Choregraphe and NAOqi, help Stephen test the NAO robots' capabilities, and develop a recognition module for Robot A. The recognition module still needs to be tested with other sensors other than just vision recognition.

Overall, all team members worked together closely on all tasks and responsibilities. We worked together over Zoom meetings to complete all assigned tasks on blackboard on time and in-person meetings to test the NAO Robots functions.

3.2 TEAM ORGANIZATION

Together as a team we met every Wednesday at 2PM via Zoom along with Dr. Khan PhD student Megan, Dr. Khan assisted us when needed. Also, as a team we met in person one to two times a week to work on the NAO Robots. We kept a shared google drive open between all group members to complete assignments in a timely manner. Furthermore, the team has a group text chat to be able to get into contact with one another when needed.

TASK	Start Date	End Date
Broader Impacts	20-Sep	23-Sep
Engineering Design Process	27-Sep	30-Sep
Slides for General Public	4-Oct	7-Oct
Engineering Ethics	11-Oct	14-Oct
Engineering Standards	18-Oct	21-Oct
Mid-Term	20-Sep	28-Oct
System Reliability	1-Nov	4-Nov
Progress Presentation	1-Nov	4-Nov
Risk in Engineering	25-Nov	2-Dec
Final Proposal	20-Sep	6-Dec

Fig. 1: Assignment Deadlines

Here is a table 1of all our meetings so far this semester . Unless explicitly stated, it can be assumed that we also worked on that week's assignment during the weekly meeting on Wednesdays. Every meeting lasted approximately an hour.

3.3 MILESTONE TIMELINE

All tasks we completed/will complete are listed in figure 1. The start date is when we started or intend to start on a specific task and the end date is when we plan to finish the following task.

TABLE 1: Past Meeting Schedule

Meeting Date (Members)	**Topics**
9/1/21 (Everyone)	Introduction to project. Determine whether we want to program real or virtual NAO robot. Relevant literature given.
9/8/21 (Everyone)	Discussed whether to go with the virtual or physical robot based upon Stephen's findings. Decided to go with the real robots.
9/15/21 (Everyone)	Discussed overall project design. Made plans to meet day after.
9/16/2021 (Everyone except Megan)	Developed overall project design. Sent it to Megan for feedback.
9/22/21 (Everyone)	Split up project based upon everyone's strengths and comfort levels with various modules.
9/29/21 (Everyone)	Discussed possible method to implement the recognition module. Creating our own network from scratch or using built-in functionality.
9/30/21 (Jacob, Stephen, Zeph)	Experimented with the NAO robots and tried to get familiar with the API.
10/6/21 morning (Everyone)	Further discussed the implementation of recognition modules either from scratch or using built-in functionality.
10/6/21 afternoon (Jacob and Stephen)	Built flow charts for the different recognition modules.
10/12/2021 (Everyone except Megan)	Used the flow charts to implement one large master plan for the entire project. Went very into depth on every module. Proposed multiple alternative designs and decided to perform feasibility tests to determine which design is the best.
10/13/21 (Everyone and Dr. Khan)	Met with Dr. Khan. Discussed our progress with him. Decided to be more rigid and unforgiving with our deadlines. Decided that we have to implement and follow deadlines for ourselves.
10/14/21 (Jacob and Stephen)	Were able to get the NAO robots to recognize each others voice.
10/19/21 (Everyone)	Experimented with getting the NAO robots to recognize and classify each others eye color.
10/20/21 (Everyone)	Discussed environmental impacts of the NAO robots. Discussed making robot behaviors realistic
10/21/21 (Jacob, Stephen, Seth)	Were able to get the robots to recognize each other's eye color. Decided on the following implementation for moods Red-¿Mad Green-¿Happy Blue-¿Neutral

CHAPTER 4

DESIGN SPECIFICATIONS

4.1 DETAILS OF THE ENGINEERING DESIGN

There are two robots. Robot A is supposed to simulate an autistic child. Robot B is supposed to simulate a therapist providing scaffolding for the autistic child. Each robot has three modules: a reinforcement module, a behavior module, and a recognition module.

4.1.1 REINFORCEMENT MODULE

The reinforcement module for each robot will be implemented essentially as a state machine and is essentially the main function that calls other functions for each robot. Below are flow charts for how each robot's reinforcement should be implemented. Later on, these will need to be converted into Choregraphe block diagrams and/or Python programs to be executed on the NAO robots.

The flow chart diagram for how robot B will behave is shown in figure 2. The robot will be initialized with some random state and then will attempt to locate robot A. Once robot A is located, its behavior will be recognized and checked if it is the target state. If the target state is not achieved and the state of robot A has not improved, then the robot will try a new behavior. When the correct rectifying behavior is achieved a +10 will be added to child A or the child robot's mood. Otherwise a -10 will be added until a minimum of -100 is reached.

The flow chart diagram for robot A's behavior is shown in figure 3. Similar to the previous diagram described, robot A will be initialized with some random state, and then robot B will need to be located and its behavior will need to be recognized. If robot A prefers the behavior of robot B, then it will move closer to the target state, else it will move away from the target state.

4.1.2 BEHAVIOR MODULE

There will be essentially three behaviors per robot. The behavior for robot A, the child robot, will be implemented in the form of a variable ranging from -100 to 100 with -100

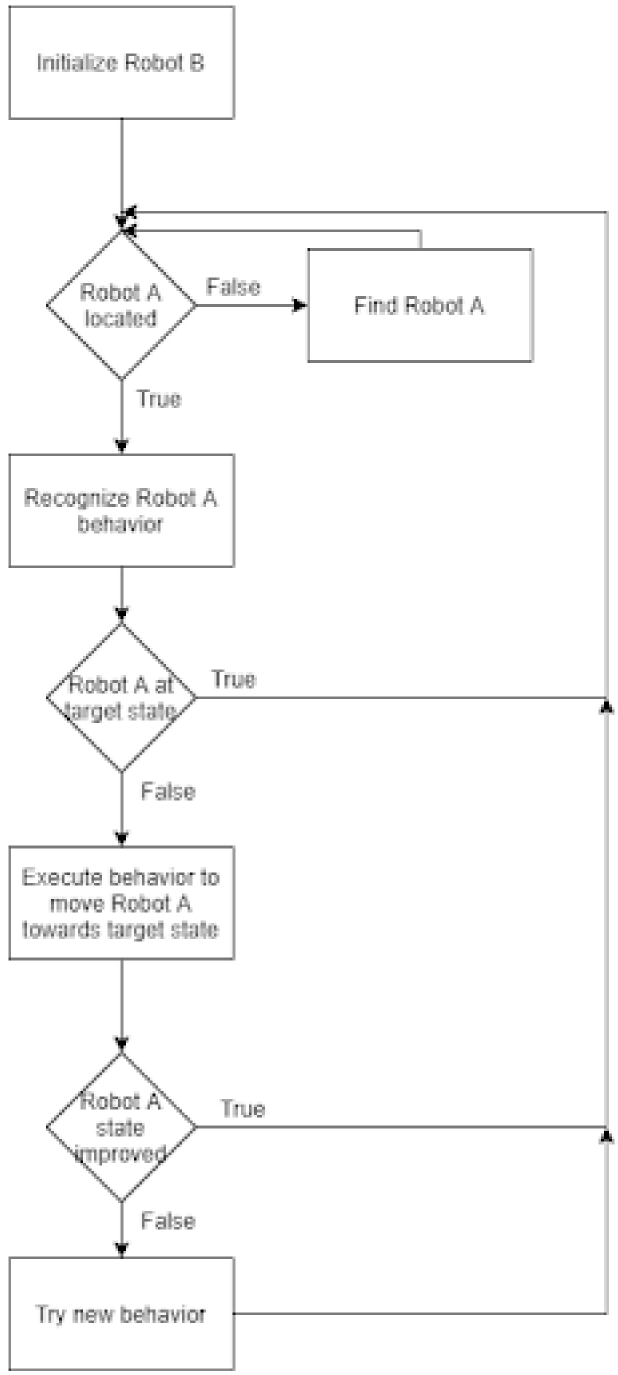

Fig. 2: Robot B Reinforcement

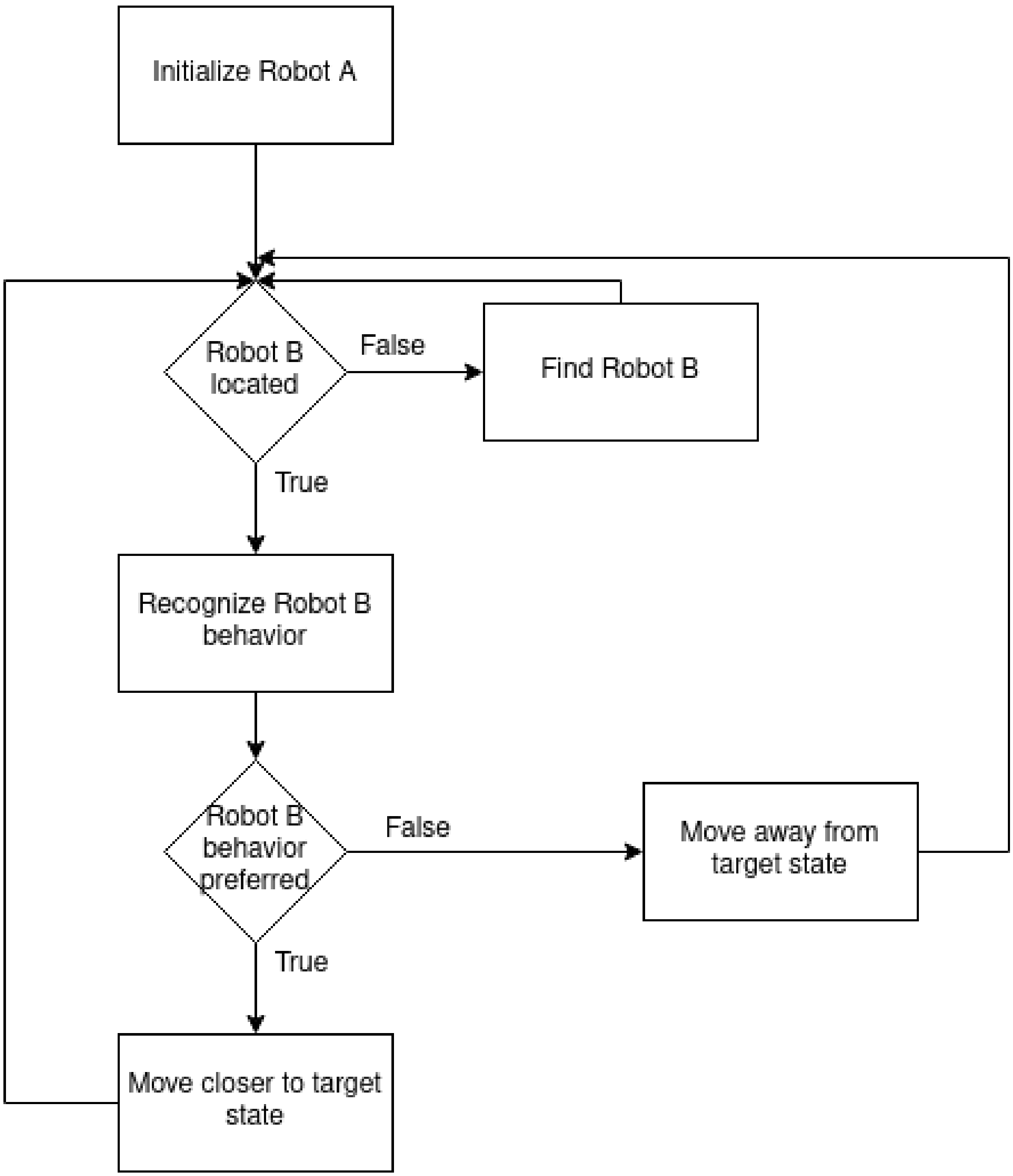

Fig. 3: Robot A Reinforcement

TABLE 2: Robot A Moods

Mood	**Eye Color**	**Voice**
-100 (negative)	red	irreponsive
0 (neutral)	blue	Responds to prompts normally
100 (positive)	green	Responds to prompts positively

TABLE 3: Robot B Moods

Robot A Mood	**Eye Color**	**Voice**
-100 (negative)	green	Tries to console robot A
0 (neutral)	blue	Tries to cheer up robot A
100 (positive)	red	Makes small talk with robot A

being negative mood, 0 being neutral mood, and 100 being positive mood. This behavior will be exhibited in several different ways according to the table 2. These are implemented in Choregraphe.

The behavior for robot B, the therapist robot, will be based upon the behavior for the child robot or robot A. This is as follows in table 3.

4.1.3 RECOGNITION

The recognition module for each robot will be implemented by using the voice recognition functionality in the Choregraphe as well as the object recognition module. Each robot will be trained to recognize the other's eye color as well as speech. For robot A the robot will monitor the therapist robot for the appropriate speech and respond if its correct. Additionally, robot A will also monitor robot B for the appropriate eye color. If both conditions are met, then the robot's mood will improve.

Similarly, robot B will monitor robot A for the appropriate mood. It will monitor the responses to it's questions as well as its eye color. It will monitor these factors through the use of the object recognition module and the voice recognition functionality. It will then output the expected mood of robot A as well as the appropriate behavior for robot B.

4.2 PARTS LIST / SOFTWARE COMPONENTS

Required components for this project are rather limited. They are as follows. If any additional software is determined to be required, we will add it to this section.

- 2 NAO Robots
- 2 Laptops with Choregraphe installed
- 2 Ethernet Cords

4.2.1 ENGINEERING STANDARDS

The first IEEE standard that applies to this project is the standard for Ontologies for Robotics and Automation. The purpose of this standard is to provide a methodology for knowledge representation and reasoning in robotics and automation together with the core ontology for the robotics and automation domain [4]. In this project, the NAO robots are expected to execute complex behaviors; therefore, the robot's capabilities and knowledge representation must be precisely defined to abide by this standard. Two NAO robots are expected to interact with each other with certain forms of data through vision recognition (i.e., colors, visible behavior states) and speech recognition when the robots are communicating with each other. This data will be facilitated and integrated through this robotic systems standard.

The NAO robots used in this project apply audio and video recognition for the means of communication. One robot will be given instructions to deliver a certain sound that will trigger an action from the other robot. In terms of video recognition, one robot must also be able to react to movements performed by the other. Due to these concepts, the IEEE standard for Advanced Audio and Video Coding is applied to this project. The purpose of this standard is to provide the tool sets for functions such as the compression, decompression, and the packaging of video data. The standard also includes in-depth descriptions of video coding as well as intra prediction and interpretation. These are used in the storage of the video which contains the actions performed by one of the robots, ultimately enabling the other NAO robot to perform the adequate response. The information presented in the standard will be used in detail in the completion of the project. [5]

The third IEEE standard that applies to this project is the Standard for Ethically Driven Robotics and Automation Systems. With having the capability to program the NAO Robots to do almost any task, we must make sure to ethically guide the NAO Robots in the correct direction. Throughout the project the NAO Robots must complete many tasks such as changing emotions, communicating with one another, assisting one another and doing specific body emotions such as moving the Robots arms and legs. It is crucial that the NAO Robots do not do anything unethical and cause any harm or damage to oneself or one another. For this to happen we must make sure the automation system of the robot is designed flawlessly; if the design for the automation system is not done correctly, the risk of the NAO Robot doing something unethical increases significantly. This is how the Standard for Ethically Driven Robotics and Automation Systems applies to this project.

As this project requires the use of Python 2.7, either by using Python itself or by using Choreographe which relies on Python 2.7, Python 2.7 is an important and relevant engineering standard. Python 2.7.18 is the latest version of Python 2.7 that will be used on this project. Even though Python 2.7 is antiquated and out of support, it must be used for this project as the newer (and better) versions of Python 3.10 are not supported on the NAO robot. This also ties into project restraints as most libraries support Python 3 with limited or no support for Python 2. Despite this, Python 2.7 is still an important standard. It is necessary to have a standardized version of any programming language when its use is widespread. This ensures that any interpreter written for Python 2.7 can also process other Python 2.7 code. This also ensures that code is readable and standardized between users. If the standard version of Python 2.7.18 was not applied to this project, this would make using libraries very difficult as they rely on the standard Python version. Additionally, porting the written code to another platform would also be more difficult and it would make our results harder to reproduce. [2]

CHAPTER 5

PRELIMINARY DESIGN PERFORMANCE

Some testing is naturally required to test whether our design, so far, is effective. So far, the robots are capable of recognizing and classifying the eye color of the other robot. This is important as this eye color is one of the ways we will communicate robot moods. Additionally, these robots are also capable of recognizing the voice of the other robot. This is also an important part in our proposed communication system between the robots.

CHAPTER 6

PROJECT BROADER IMPACTS

6.1 ETHICAL IMPLICATIONS OR ISSUES OF THE PROJECT

The robots used in this project are very versatile in their ability to perform various tasks. The robots have a face recognition system that allows them to follow the movements of a person they have detected. For this project, the NAO robots must recognize and perform actions in response to one another. If this recognition system does not prove to be consistent, it could take action against the wrong individual. In other instances, NAO robots are utilized in the fields of healthcare and education where they are specifically programmed to interact with people. This is where the consistency in recognition becomes a requirement. If this feature is not accurate, the NAO robots can pose a threat to the safety of those around them.

To prevent the implications of risk and danger to the participants of this project, the IEEE Code of Ethics is being thoroughly observed and practiced. It is understood that failure to comply with this code could cause harm to students, halt the completion of the project, and ultimately stain the image of the institution.

6.2 KNOWLEDGE OF CONTEMPORARY ISSUES

One of the biggest contemporary issues this project faces is the ethics behind the robots and the Artificial intelligence behind them. AI that can learn complex tasks on its own with minimal training data is critical. With this we have to make sure AI does not erode human freedom [6]. Robots and AI grow increasingly every year as technology advances and trying to use them ethically is a challenge engineers face daily. Is it right for us to replace humans with robots on simple tasks which increases unemployment and the de-skilling of the workforce [6]?

6.3 LIFELONG LEARNING

Jacob - From my experience of working with many different Python libraries prior to this project, I am able to apply that knowledge by learning an entirely new library and software in NAOqi and Choregraphe. I hope to continue learning new techniques and software to aid in my future career/studies.

Zeph - I have two goals that I plan to accomplish with the help of this project. The first being to understand how robots can be programmed to assist the lives of people. Secondly, I wanted to learn how to be more proficient in working in groups. Prior to being an engineer, I never thought I would be working with robots, however, being a part of this project is an experience that will assist in any future endeavour in robotics. I have never worked on a project of this scale before but it has been a great experience for me. It has taught me that with good collaboration, the hardest of assignments become simplified. Working on this project will definitely assist me in my career and the job market.

Seth - With taking many Engineering classes at ODU, it has made me a better critical thinker and problem solver when it comes to new material such as working with the NAO Robots. I plan on using what I learn from this project to further my career with robots, artificial intelligence and autonomous vehicles as they are one of my favorite things to work on; it will also benefit me as I have to communicate with my group daily and use teamwork to complete tasks. This is a very common thing in the Engineering field, you are almost always in some type of small group working together to achieve a common goal.

Stephen- I have been working in Dr. Khan's vision lab for over a year at this point in semantic segmentation of flooding research. In my major, I have been focusing on machine learning, data analysis, and computer vision. It is always nice to see applications of machine learning and computer vision beyond use in a pure academic setting. I have no doubt that this project will help broaden my knowledge of what is possible with machine learning and artificial intelligence.

6.4 IMPACT OF ENGINEERING SOLUTIONS IN A GLOBAL, ECONOMIC, ENVIRONMENTAL, AND SOCIETAL CONTEXT

6.4.1 GLOBAL

One very important tool the NAO robot has is its language barrier. The NAO robot can recognize up to 20 languages and also communicate with dialogue with the correct programming [7]. This is an extremely important feature and with this feature it can connect with almost anyone around the world.

Growingly, NAO robots are being used to help children learn their primary language with a second language [8]. With more people becoming bilingual it will connect different cultures around the world with the help of a robot. One thing a robot has over a language teacher is consistency and reliability. Also, NAO robots can be specifically programmed for certain students with learning disabilities which can help guide and motivate them. The NAO robots can also be placed as a security system or an alarm which can be used globally; the possibilities are endless with its ability to recognize multiple languages.

6.4.2 ECONOMIC

It is quite easy to realize the economic impact of developing such a robot. A NAO robot programmed in this manner has the potential to supplant preexisting jobs in the workforce that relate to the caretaking of kids with autism. For example, kids with autism may require caretakers with specialized education that also require a salary. While, NAO robots are expensive (around $10,000) this is not even close to the potential salary of one full time caretaker. Consequently, those organizations that employ NAO robots for autism intervention and caretaking instead of specialized employees could see reduced expenses and make them more efficient and productive [9]. However, such caretakers with specialized skills will find themselves out of a job. This same trend can be found in other industries such as car manufacturing where robots replace skilled workers and the workers are now unemployed [9].

6.4.3 ENVIRONMENTAL

The impact many forms of technology leave on the environment can be negative. The pollution of land and air that occurs from the disposal of chemicals affects more than just agricultural yield. The short and long term exposure to pollutants comes with adverse health effects ranging from infections to cancer. The disposal of batteries used to power a variety of machinery plays a big part in the pollution process due to how they are absorbed in the environment. The NAO robots' use of a lithium-ion battery greatly reduces the amount of this adulteration. Lithium is not expected to bioaccumulate and its human and environmental toxicity are low [10]. To add to that, lithium in certain doses can stimulate certain plants [10]. Compared to other types of batteries, lithium is considered less toxic to the environment.

To reinforce the NAO robots' innocuousness to the environment, it is important to state the versatility of the robots. NAO robots make use of tactile sensors. These are devices that gather information based on physical interactions that include touch, pressure, and force. These are a big element to what allows the NAO robots to function, however, the chemicals used in the creation of these sensors are in question of being harmful to the environment. PVDF (Polyvinylidene fluoride), ZnO (Zinc Oxide), PZT(Lead Zirconate Titanate) are some of the materials used in the production of these sensors. This is where the versatility of the NAO robots comes into play. Even though the sensors are important, the robots can operate without them. Using a measure of the Instantaneous Capture Point, it is possible to develop an equilibrium-based interaction technique that does not require force or vision sensors [11]. The NAO robots are designed in a manner to not be hazardous to the environment.

6.4.4 SOCIETAL

In a societal context, robots are seeing increasing use in homes, work, and healthcare. More specifically, in healthcare, NAO robots can be used to simulate an Autism intervention, where one robot can be the child and another could be the parent. Eventually, this could lead to using the NAO bot as the "parent" and performing an intervention with a human child. There is currently evidence of other robots created by Softbanks Robotics being used in elder care homes, where the elderly interact with a robot instead of staff. In this case, the robot being used is called Pepper, a 4 foot tall robot that is built to interact with residents, as opposed to just carrying out manual tasks [12].

As stated before, the use of NAO robots is popular in aiding children with Autism either in the classroom or at home; this will be made more popular through the use of mobile apps being developed to control the NAO robots [13]. Having an easily accessible software application for non-technical professionals, such as therapists and teachers, to use can increase the level of comfort in using the NAO robots, thus increasing human and robot relations and helping children with disabilities.

6.4.5 EXPECTED OVERALL EDUCATIONAL BENEFITS FROM THIS PROJECT

The overall study of the NAO robots greatly assists in the mastering of the Python API. The ability of the programming language to automate tasks, conduct data analysis, etc. is what makes it so useful. Due to this however, the language is very complex. It is quite in-depth in terms of syntax and can be difficult to produce results with if a user is not efficiently using it in its entirety. The programming of the NAO robots is a very thorough project which also implements the use of the Python language. The robots require well designed behavioral, recognition, and reinforcement modules to run properly. The completion of these will give the user a very extensive understanding of the language.

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APPENDIX A

EXECUTIVE SUMMARY

Stephen Lamczyk (CpE), Jacob Strother (EE), Seth Cummings (EE), and Zephaniah Amonoo-Harrison (CpE) were the group members for this project. Megan Witherow was the PhD student advisor while Dr. Khan Iftekharuddin was the faculty advisor. The goal of this project is to program two NAO robots to simulate an autism intervention situation. One NAO robot simulates the autistic child and the other tries to move it to a desired state. Our results so far have proved that there are many different effective ways for the robots to communicate with each other. We program these robots using the Choregraphe and the NAOqi. This has applications in autism intervention. Of course, the modules that we design will have to be modified for this to work with a real child.