University of Hertfordshire UH

School of Physics, Engineering, and Computer Science

School of Physics, Engineering, and Computer Science

Bachelor of Engineering Honours in Robotics and Artificial Intelligence

Applied Robotics and AI project (5FTC2068)

(2023/2024) Semester 1/ Year 2

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Report on Robot Simulation in a Homeostasis Environment

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Abstract

This project is intended to simulate a robot operating and surviving in a homeostasis environment for the duration of 10 mins using the Webots simulation software. The E-puck robot (the chosen robot for this project) is well-equipped with sensors such as proximity and ground sensors as its distance sensors and a camera as its visual sensor, LEDs for the increased interaction with the environment. An arena image with a water source and food source is provided and the robot is coded in such a way that it maintains homeostasis stability, and successfully performs obstacle avoidance, and adaption to the motion such as accelerating and decelerating throughout the designated time frame.

Introduction

In a world of rapid developments in science & Technology, robots play a vital role in many areas. They can perform dangerous jobs for humans as they can work in risky and unsafe environments. In the medical field, intricate surgeries such as prostate cancer surgery and additionally they can reduce pain for the patients while recovering as they can be less invasive, Greater accuracy can be achieved by robots as they can reach the places where human hands may not deem fit. In manufacturing industries, robots can increase productivity by performing challenging tasks in challenging environments.

However, for the robots to perform to the expectations, robot simulation is necessary. We also need to perform certain trial-and-error experiments with the components of the robot and test if it works out with the idea in various desired scenarios. Robot simulation is a process that helps to achieve a better as well concise understanding of the project before building a robot.

In this project of ours, we aim to make a robot survive in a virtually simulated homeostasis environment for a duration of 10 mins. Homeostasis in an environment refers to the ability of an organism to maintain its internal needs and conditions regardless of the external environment. In this project, we aim to simulate a robot that can dynamically change its behavior and respond according to it maintaining its homeostatic variables. In this project, we need to show and exhibit obstacle avoidance behavior and incorporate the concepts of behavioral robotics to let the robot survive on its own in a homeostatic environment.

In this report, we go through the literature review to know more about the work which has been done before in this robot simulation and its real-life uses, the methodology on what was our approach for this project, the experimental results which we found out through the trial-and-error process and a conclusion to summarize everything.

Literature Review

Ligot et al (2022) compared various simulation-based predictors in application to robot swarms. They have used classical approach and pseudo reality predictors which rely on simulation model used int eh design process. And concluded that that the pseudo-reality predictor yielded perfect values to the real-world performance. Fabio et al (2022) provided a comprehensive review of sim to real research for robotics, with a strong focus on technique of domain randomization, method which they followed from randomized simulations. Yang et al (2022) in their research concluded that artificial synaptic devices such as neuromorphic robots could be used for the construction of artificial neural pathways which control artificial muscle reflexes with a strong relationship with the ion homeostasis in the human body.

HeeSun Choi (2021) discussed the effects of simulation in robotics and how it is useful in preventing its broad adoption and proposed some steps to eliminate these barriers in robotics. They have also discussed widely about the impact of simulation in robotics, and the barriers that prevent for broad adoption and possible steps to eliminate those barriers. In their article, they discussed the importance of simulation of the dynamics of the robot, simulation to the virtual world and cited about the human the robot.

Kingson Man (2019) proposed a new set of machines that was inspired by Homeostasis which would result in exhibiting human feelings & consciousness, intellectuality, and investigating the environment through its interactions with it. They concluded that these machines have abilities to evaluate processes based on the principles of homeostatis and soft robotics and observed an improvement in their functionality across a range of environments. Nagahama et al (2012) experimented with simulations using LED lighting systems and concluded that these systems were able to achieve stable control of environments without any complications.

Akiba & Mita (2013) experimented with a proposed algorithm, a robot could recognize a human's behavior toward the homeostasis environment and use that information to determine the preference for the lighting control system.

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Methodology

The method of approach we took to achieve the desired outcome of the robot maintaining its homeostasis variables like hunger, thirst, and sleep.

Setting up the Environment

We first set up the homeostatic environment by importing the floor image provided which consists of a water source in blue and a food source in green.

Then we add and size the obstacles according to the requirements.

Control Algorithm

We define a few functions, which indicate the robot's odometry (orientation and position) based on its wheel position.

We use Finite State Machine (FSM) to show the different behaviors of the robot, such as

State 0: Rotate to observe the environment, if it sees a goal then transits to state 1.

State 1: Robot adjusts its odometry and trajectory in the path of the goal, if the goal is detected then transits to state 2.

State 2: The robot uses its distance sensors and camera to see and detect obstacles and moves toward the goal. If any obstacles are detected, then it transits to state 3.

State 3: Moves randomly in the environment, after around 30-40 steps it transits back to state 0 and repeats the process.

Goal Detection

We define a function for goal detection using the camera functions, to detect the color of the obstacle.

We color code it using the goal function, such as when it is thirsty, it looks for the source in blue, when it is hungry it looks for the source in green or when it sees an obstacle in red (predators) it moves away from it. We use the sensors to detect the obstacle distance and give enough time for the robot to change its trajectory.

Time Management

We have added a variable in the code known as 'Time_step' which allows us to keep track of the time so that it can act accordingly while changing the states of the FSM.

It increments every time the loop has been run.

Along with time, the position and orientation variable has been added to keep track of the robot’s position and to use functions such as ‘slowing down’ or ‘stopping’ using this variable.

Testing

Run the sections of the code to see if the robot is functioning the desired behaviors and then run the entire code to check for any sort of errors.

Take the readings and errors and then move on to the next stage for the improvement of the robot's behavior.

Experimental Results

While experimenting with the values and the code, we did the following experiments:

1) **Optimizing E-puck Robot Speed**

During the experimentation phase involving the E-puck robot, a comprehensive analysis of its velocity was carried out. Initially set at a constant 6.28 meters per second, this velocity was found to be suboptimal for achieving precise movement and optimal performance. To ensure a balanced operation of the left and right motors, a series of tests were conducted with varying speed values.

Initiating the investigation, both wheels were set to a speed of 0.7, which resulted in irregular and jerky movements along with incomplete sensor data acquisition. Subsequent tests were conducted using different speed settings, leading to the identification of an optimal velocity range for the E-puck robot. Specifically, speeds ranging between 0.5 to 0.1 were observed to yield the best results. Notably, the ideal range was found to vary based on the robot's motion dynamics.

The process of fine-tuning the robot's velocity proved to be intricate and time intensive. Nonetheless, the efforts invested in meticulously adjusting the speed yielded substantial enhancements in the robot's overall performance and movement capabilities. The resultant improved functionality justified the meticulous nature of the velocity calibration process.

2) **Calibration of Camera Sensor for Color Detection**

A rigorous calibration process was undertaken to enhance the color detection capabilities of the camera sensor. This meticulous calibration facilitated the sensor's ability to accurately detect a wide spectrum of colors. Notably, the sensor exhibited the capability to detect colors such as R=140, G=160, B=135 at varying distances. Moreover, up-close color detection was achieved for colors with attributes such as R=180, G=137, B=160.

The advanced calibration mechanism applied to the camera sensor ensured the precision capture of color information relevant to food sources. This capability holds significant promise for research and analytical purposes, offering a reliable means of gathering data from the robot's environment.

3) Observations on 'Steering' Behavior in Webots:

In the context of our experimentation with the 'Steering' behavior, which encompassed the Seek and Arrive behaviors, intriguing insights into the robot's movement dynamics were uncovered. The movement towards a goal or obstacle was accomplished through a process of averaging the velocities of both the right and left motors. An interesting observation emerged as the robot's initial position was set to 0.1 rather than 0.0, ensuring a correct start to its motion once the simulation commenced.

Challenges were encountered particularly in fine-tuning the arrival behavior. Modifications to the behavior's parameters, particularly the arguments set to values of 0 or 1, were necessary to facilitate appropriate deceleration when the robot approached obstacles or goals. This endeavor provided valuable experiential learning as the team gained insights into the intricacies of implementing these behaviors within a simulated environment.

4) Enhancing Robot Lifespan through Iterative Adjustments:

Making the E-puck robot last as long as possible was a key goal of our research. This was accomplished by making iterative modifications that involved increasing the number of loop iterations for certain important variables. During this endeavor, a startling realization emerged that highlighted the crucial importance of the number of iterations necessary for homeostatic behavior.

Unexpectedly, it was found that the loop iterations required for homeostasis were greater than those required for hungry behaviors. This asymmetry brought home how crucial homeostasis is to the longevity of the robot's operation. Robot premature termination because of insufficient iterations for this behavior further emphasizes how crucial this parameter is to maintain the robot's functionality and survival.

5) Utilizing Lookup Table for Obstacle Avoidance:

The 'get' function was employed to acquire the lookup table, a critical component for effective obstacle avoidance. This table contained distance range data detected by the robot's distance sensors. Notably, the lookup table played a crucial role in decelerating the robot's motion when near obstacles.

In-depth experimentation revealed that the optimal distance range for effective deceleration was approximately 0.4 units away from an obstacle. This insight underscores the significance of precise sensor data in facilitating safe and efficient navigation within the robot's environment.

These findings collectively contribute to a deeper understanding of the E-puck robot's behaviors and capabilities, fostering advancements in both its performance and functionality within various contexts.

6) Algorithm Performance with Obstacles:

An important experiment was undertaken to evaluate the 'localise' function's performance in the context of assessing the algorithm's performance in the presence of impediments. We focused on settings that mimicked real-world congested surroundings, where prospective food sources were partially hidden by well-placed impediments. The goal was to determine whether the algorithm could correctly recognise and locate items even when some of them were partially obscured.

Surprisingly, the 'localise' function showed a respectable capacity to deal with the challenges presented by obstructions. Even when partially obstructed, it was still able to determine the locations of objects. This experimental project demonstrates the robustness and adaptability of the algorithm, both of which are crucial qualities in handling the complex problems present in real-world robotics applications. The result highlights how well the system handles dynamic and complicated settings, which are common in the robotics industry.

7) Evaluating Sleep Threshold Impact on Energy Consumption:

The dramatic effect of the robot's sleep threshold on its overall energy usage was a key aspect of our work. Our methodical research aimed to understand the complex connection between shifting sleep threshold values and the robot's subsequent energy consumption rate. We discovered a direct association between these variables after careful investigation.

The results revealed an interesting finding: the robot's energy consumption pattern was strongly influenced by the alteration of the sleep threshold. We established a delicate balance between prolonging the robot's operating lifespan and carefully controlling its energy consumption by fine-tuning this parameter. This optimization technique has a great deal of potential for extending the robot's useful life and assuring its energy-efficient operation, which will support sustainable and successful robotic behaviors.

Future Scope

In this project, here are some findings/plans of action for future work:

1) In my code, I have a function called "localize()", this function allows the robot to see the arena, analyze it and then autonomously remember the coordinates of the food source. If given more time I would have incorporated the navigation towards the location of the food source either by using the wheel encoders or the mathematical equations such as the use of tangent angles and distance formulas, so that the robot would know how to navigate to the location on its own.
2) If the above was a success, the same logic would have been incorporated for the water source as well, for going back to the location when it needs to such as whenever it's thirsty and in need of getting its thirst value higher than its threshold value.
3) The same could have been done, using the "opencv" module, where we can segment and filter the image so that the robot could detect our sources better, later adding the navigation part for the robot to navigate back to the source it desires to go.
4) Implementation of the concept "Slam", using slam as an additional behavior would have resulted in giving the robot more autonomous behaviour as we allow it to map the arena on its own and let it remember where it wants to go.
5) Exploration Behavior:

   This behavior allows the robot to see and explore its arena by getting close to any new object and lets it explore the new object in the arena.
6) Predators:

   When the E-puck robot sees another robot or any other human in the simulation, it would immediately seek the hiding behaviour, where it would run away from the predator and hide in a spot till the predator is no longer near the robot.

Conclusion

To successfully achieve the main intention of the project which was to create a homeostasis environment and make a robot capable enough to survive in it for a duration of 10 mins by maintaining its internal needs, we have used the concepts of Control Algorithm in Braitenberg-style behavior and incorporated it with the simulated robot. The E-puck robot used its proximity and ground sensors (distance sensors) to detect any obstacle in its course, and its camera sensor as its eyes to look for the goal, at the same time, the use of LED to enhance its interaction with the homeostasis environment. Throughout the experiment, the robot exhibited obstacle avoidance behavior by adjusting its trajectory and path when and if any obstacles were detected. In the absence of any obstacle, the robot showed an exploring behavior by interacting with the environment and maintaining its homeostasis variables.

This project helps us to gain insight into the concepts involved in training and incorporating behavior in a robot, as well as opens the world of simulation and Webots software to us.

Not only has this project helped me to learn about the behavior of a robot but also the firm usage of Python coding language and how to incorporate behavioral robotics into coding through the usage of control algorithms, finite state machines, etc.

We were trained in the aspects of the principles of homeostasis and what are the variables which are supposed to be taken into consideration while building a homeostasis environment. It gave us the know-how for understanding, experimenting, and how to balance between maintaining stability and balance within a dynamic environment.

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