C951 – Introduction to Artificial Intelligence

BubbleRob – The Disaster Relief Robot

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CONTENTS

A. DISASTER RECOVERY ENVIRONMENT

Hurricane Sandy was one of the deadliest hurricanes to affect the United States during the 2012 Atlantic hurricane season. It is estimated that the storm led to the deaths of 233 people across eight different countries, including the United States (Diakakis, 2015). Disaster relief robots can aid in search-and-rescue efforts following hurricanes and other extreme weather events.

The disaster recovery environment simulated in this project represents a town located in a low-lying area near a river that was just devastated by a tornado rated with an F4 intensity as measured on the Enhanced Fujita scale (National Weather Service, 2001). The storm has resulted in widespread devastation across the area, with debris and flooding causing emergency personnel to have limited access to the area. Therefore, the BubbleRob disaster relief robot is being deployed to the area to search for survivors.

1. OBSTACLES

Within our simulated layout of the disaster environment, a perimeter of cylinders has been organized to enclose the entire area. This represents an area cut off to emergency personnel due to debris from destroyed buildings, telephone and electrical wires, and trees.

The first obstacle that must be handled by our disaster relief robot is the bridge crossing the river. The river is represented by the inaccessible area in the center of our simulated environment. The bridge is represented by the two sets of columns organized parallel to one another which traverses the simulated river. The disaster relief robot must be able to traverse this narrow bridge to search for survivors on either side of the river.

The second obstacle that must be handled by the disaster relief robot is the wreckage of a home that was located on the other side of the river from the initial deployment coordinates of the robot. The wreckage is represented in our environment by a cluster of cylinders extending from the river into the enclosed environment. The cube within the simulated wreckage represents a victim who is trapped and must be located by our disaster relief robot.

2. IMPROVED RECOVERY OPERATIONS

The BubbleRob disaster relief robot will enhance recovery efforts in the area affected by the tornado in several ways. As described in the previous sections, initial access of emergency personnel to certain disaster recovery locations may be limited by distribution of debris, floodwater, or other obstacles. Following a storm, the remaining debris and floodwater can be treacherous and unpredictable, putting emergency personnel at unnecessary risk. The BubbleRob disaster relief robot can traverse these obstacles that would otherwise be too dangerous for humans to traverse. Once deployed, the robot can immediately begin search-and-rescue efforts. Emergency personnel can use BubbleRob's on-board camera to map out the disaster recovery zone and determine the safest strategy for extraction of surviving victims. In addition, while BubbleRob searches for victims of the storm, emergency personnel can work to create a clear and safe path for extraction of victims. Finally, BubbleRob allows emergency personnel to focus their recovery efforts on areas where victims are located, allowing faster access to medical attention for victims.

B. ROBOT MODIFICATIONS

Several modifications to the base BubbleRob model were applied to make the robot more suitable for post-tornado disaster recovery operations.

1. MOVEMENT SENSORS

The first modification to the movement sensors made to the base BubbleRob model was the conversion of the main object detection sensor of BubbleRob from a cone sensor to a disc sensor. This sensor was renamed "bubbleRob_sensingNoseC" and its volume parameters were adjusted to detect objects in a 120-degree arc in front of the BubbleRob robot. Two additional object detection sensors were added to BubbleRob – one on the front-left face of the robot and one on the front-right face of the robot. Both sensors were set up as disc-shaped sensors with 60-degree angle of detection. These additional sensors made it possible to add turning to the existing movement operations supported by BubbleRob. In addition, these sensors allowed for customization of the curve that BubbleRob takes when in reverse. For example, if both the central and right object detection sensors are triggered, then BubbleRob will shift into reverse and curve to the right to avoid the obstacle. The time that BubbleRob spends in reverse after its central object detection sensor is triggered was also shortened. This is because with a longer time spent in reverse, BubbleRob would sometimes repeatedly trigger the central object detection sensor and end up traveling in a circular path. These additional movement operations allow the BubbleRob robot to have finer control over its movement operations when moving through the disaster recovery zone, which can allow the robot to navigate areas it may not have been able to previously.

2. VICTIM SENSOR AND INDICATOR SPOTLIGHT

A final object detection sensor was added to BubbleRob for the sole purpose of detecting survivors during disaster recovery operations. This sensor was set up as a disc-shaped sensor with a 160-degree angle of detection oriented in the direction that the robot is facing. The sensor has a much wider range than the movement sensors which prevents interference with the movement sensors. In addition, a spotlight was added to the top of the BubbleRob robot. When the victim sensor detects a survivor, all movement operations are halted, and the spotlight is turned on to highlight the position of the survivor. A message is also broadcast to the disaster recovery team to inform them of the survivor (in the simulation this is represented by a message printed to the console) and allow them to respond to the situation by isolating BubbleRob's coordinates.

C. ROBOT OPTIMIZATION

Several methods of optimization were employed when designing the BubbleRob disaster relief robot. The most obvious example of optimization would be the modification of the movement logic to decrease the length of time that the robot spends in reverse when one of its object detection sensors is triggered. This allows the robot to both respond to the encountered object more quickly as well as prevents the robot from entering an infinite loop of turns (which would lead to the robot traveling in a circle).

1. REASONING

The BubbleRob disaster relief robot exhibits the capability to perform basic reasoning through its ability to navigate around and through obstacles. The Lua code that governs the robot's movement capabilities allows the robot to reason about what is considered an impassable obstacle versus navigable terrain. The code also provides the robot with instructions for how to reason through encounters with various obstacles (i.e. whether the robot should shift into reverse or turn to the right or left).

2. KNOWLEDGE REPRESENTATION

The BubbleRob disaster relief robot has several methods for representing knowledge. First, its object detection sensors allow it to organize and categorize terrain into two categories – navigable or non-navigable. In addition, the robot can justify ceasing all movement activities when it locates a disaster survivor. Finally, it can represent the fact that it has found a victim by engaging its victim indicator spotlight and can transfer this information to the emergency personnel responding to the disaster.

3. UNCERTAINTY

The BubbleRob robot operates with a constant level of uncertainty about its environment. It does not have any prior knowledge of the environment that it is being deployed into, or whether disaster victims may be present in said environment. Instead, it is equipped with the sensors to handle this level of uncertainty and respond to events in an appropriate manner.

4. INTELLIGENCE

The BubbleRob robot can be classified as a simple reflex agent – it selects its current action based on the current percept of its environment. Because of this, the intelligence of the BubbleRob robot is primarily driven by the condition-action rules embedded within its custom Lua code. The triggering of a condition will result in the BubbleRob robot taking a predetermined action. For example, triggering the left object detection sensor without triggering the center object detection sensor will result in the robot turning slightly right for 1 unit of simulation time.

D. ADVANTAGES AND LIMITATIONS

There are several advantages as well as several limitations to the chosen design of the BubbleRob prototype.

1. ADVANTAGES

Use of the BubbleRob robot prototype to traverse and explore disaster zones has several advantages over using human disaster recovery personnel. As outlined in Section A.2., the BubbleRob prototype can be deployed into areas that are otherwise too dangerous or too unpredictable for human emergency personnel to enter. This has the dual advantage of preserving the safety of the emergency personnel as well as allowing them the time to secure the disaster scene while the disaster relief robot takes on the risk of traversing the disaster zone. The BubbleRob prototype can also allow emergency personnel to visualize and map out the disaster recovery zone through its on-board vision sensor. Emergency personnel will also be alerted if the BubbleRob prototype locates a victim of the disaster and will illuminate the victim with its spotlight, making it easier for emergency personnel to assess and rescue the victim. Finally, the BubbleRob prototype as described is capable of successfully completing the simulation in the attached file entitled “Disaster

Recovery Simulation.ttt". The prototype successfully explores the disaster zone, locates the "Victim", and alerts emergency personnel that a victim was found.

2. LIMITATIONS

There are two major limitations to the BubbleRob prototype in its current form. First, because the prototype does not keep track of previously visited locations, it can traverse the same location more than once. This leads to inefficiency in the prototype's use of battery power, as well as a decrease in time to location of victims. This also means that the robot may not traverse all available paths in the disaster zone, thereby missing potential victims. This is a significant limitation because any delay in the location and recovery of a disaster victim can be detrimental to the health of the victim in question. Second, due to the fact that the robot lacks rear object detection sensors, it is possible for the robot to shift into reverse and back itself into debris or floodwater, causing it to either become lodged in the debris or short-circuit, rendering it unusable. This means that the disaster recovery team now must handle search-and-rescue efforts for disaster victims and also recover the prototype as part of their search-and-rescue effort.

3. CRITERIA FOR SUCCESS

The minimum criteria that the BubbleRob prototype must meet to be considered successful are as follows:

1. The BubbleRob prototype must be able to move throughout the simulated disaster zone environment, traversing all areas that are unimpeded by obstacles.
    a. The prototype should move forward when no object detection sensors are triggered.
2. The BubbleRob prototype must be able to reorient itself when encountering an obstacle to allow for continued exploration of the disaster zone.
    a. The prototype should shift into reverse and back up to the left for 1 unit of simulation time when encountering an obstacle that triggers both the left and central object detection sensors.
    b. The prototype should shift into reverse and back up to the right for 1 unit of simulation time when encountering an obstacle that triggers both the right and central object detection sensors.
    c. The prototype should shift into reverse and back up straight for 1 unit of simulation time when encountering an obstacle that triggers only the central object detection sensor.
    d. The prototype should turn slightly to the left for 1 unit of simulation time when the right object detection sensor is triggered.
    e. The prototype should turn slightly to the right for 1 unit of simulation time when the left object detection sensor is triggered.
3. The BubbleRob prototype must cease all movement activity and alert emergency personnel when a disaster victim is found.
    a. When a victim is found, the prototype should cease all movement activity.
    b. When a victim is found, the prototype should turn on its victim detection spotlight.
    c. When a victim is found, the prototype should broadcast a message to emergency personnel (simulated via printing a message to the console).

E. TESTING AND IMPLEMENTATION

Initial testing of the BubbleRob disaster relief robot will be conducted within the CoppeliaSim Edu, Version 4.1.0 (rev. 1) robotics simulation software. This allows us to mimic the environment that the BubbleRob robot may encounter when deployed into a disaster relief zone. Because the robot is specifically designed for tornado disaster recovery, the robot will be rigorously tested against a multitude of randomly generated tornado recovery scenarios. If an issue is identified during a simulation, such as the robot entering an infinite loop of turning or failing to cover a particular portion of the disaster zone during its sweep, testing will be paused and the robots condition-action rules will be modified. Once the robot is consistently passing all randomly generated scenarios within the simulation environment, a prototype of the robot will be constructed and tested in simulated real-life disaster recovery scenarios. Only when the robot is consistently passing all testing scenarios, both within the simulation software and the real-life simulations, will it be deployed to disaster recovery teams across the United States for use during tornado recovery efforts.

F. FUTURE IMPROVEMENTS

There are numerous future improvements that could benefit the disaster recovery efforts of the BubbleRob robot.

1. MECHANICAL

One potential improvement that could benefit the movement capabilities of the BubbleRob robot would be a rear object detection sensor. This would remove the need for the robot to shift into reverse for a set amount of time. Instead, when the frontal object detection sensors cause the robot to shift into reverse, we could engineer the robot to either back up for a fixed duration of time or until it detects an object within a certain proximity behind it (whichever happens first). In addition, flattening of the BubbleRob chassis and replacing the wheels with treads would allow the robot to be more flexible in terms of the terrain that it can traverse.

2. LOGICAL

In a real-world scenario, the BubbleRob robot will not have prior knowledge of its environment, and so it will not be able to determine *a priori* what effect the actions that it takes will have. To avoid disastrous consequences such as the robot missing detection of a disaster victim in need of aid, we could embed a reinforcement learning algorithm into the movement system logic of the robot. First, we will need to enhance the robot with a system that allows it to keep track of the previous coordinates that it has visited within the disaster recovery zone. Then, to allow the robot to "learn" what locations within the disaster recovery zone are more likely to contain a disaster victim, we can incorporate a reinforcement learning algorithm. Our reinforcement learning algorithm will be unsupervised, given that we have no knowledge of the environment ahead of time. We can also consider BubbleRob to be a Q-learning agent – the robot will learn an action-utility function (Q-function) which will provide the robot with the expected utility of taken a given action based on a given state (Russel, 2021). In this case, the utility would be finding a disaster victim and the state would be the input from the robot's sensors as well as the history of traversed locations. The robot would be "rewarded" for finding a disaster recovery victim at a given coordinate and penalized for not finding a survivor at a given coordinate. Based on this information, the Q-function would naturally cause the robot to favor locations within a disaster recovery environment that it has not visited before that would be more likely to contain a disaster victim.

G. SOURCES

1. Diakakis, M., Deligiannakis, G., Katsetsiadou, K., & Lekkas, E. (2015). Hurricane Sandy mortality in the Caribbean and continental North America. *Disaster Prevention and Management: An International Journal, 24*(1), 132-148. Doi:10.1108/dpm-05-2014-0082.
2. National Weather Service. (2001, January 01). NOAA's NWS Storm Prediction Center. Retrieved September 27, 2020, from https://www.spc.noaa.gov/efscale/.
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