CHOOSING A CHARGING STATION USING SOUND IN COLONY ROBOTICS

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ABSTRACT

This research is part of a study that is investigating methods for supplying power to autonomous robots in remote locations. One possibility is to provide autonomous charging stations fueled through solar power. This paper reports preliminary results for a system being proposed to help a robot determine which station, among those available, would be its best source of power. The system uses distinct sound frequency bands to determine the available stations and uses the characteristics of sound and the environment as a type of analog computer to help compute, considering each station's distance and available energy, the best station to track towards.

KEYWORDS: autonomous robots, power supply, remote environment, charging station, colony robotics, sound propagation

1. INTRODUCTION

An important aspect of the design of an autonomous robot system is sensor selection. Sensors are used for detection of the environment and for communication. In both cases, the entire system must be considered in the selection of sensors. Although considered in some previous research, audible sound is a common part of the environment that is not commonly used in autonomous robots. There are difficulties with using audible sound; most notable is that there is often an abundance of noise in the environment. Nevertheless, sound has some interesting attributes that we believe make it worth pursuing as a means for environmental detection and communication. One of its major assets is that it is commonly used by humans for communication and is a good medium for human-computer communications. Another aspect of audible sound that makes it attractive is that its amplitude is reduced by obstacles, yet it can still be heard. In other words, if an object with dimensions larger than the wavelength of the transmitted sound is between a robot and a sound source, the robot can still hear the sound although its amplitude will be less than if the object were not present. Use of sound in different frequency ranges allows communication between many source-listener parties to be carried out in parallel. Even when all sources are active simultaneously relevant information contained in the resultant sound can be decoded by means of signal processing at the listener's end. Several factors affect the propagation of sound. Some of these are geometric spreading, temperature and wind effects, air absorption, reflection, and surface absorption. In a free field, most of these contribute to the weakening of sound intensity with increasing distance. In particular, geometric spreading of sound causes the weakening of sound intensity as the listener moves away from the source. Sound intensity is defined as the sound power per unit area and obeys the inverse square law under ideal conditions where there are no reflections or reverberation. Reduction in sound intensity with distance is often considered detrimental, but can also be used as an asset. We believe that this can be used to give the robot additional information. The proposed method uses the environment, with the propagation properties of sound, as a kind of analog computer.

Several researchers have used sound for localization. MIT Labs is using sound as a means for localization of a humanoid robot [1,2]. The direction of sounds is determined by using spectral cues and time delays. They make use of visual information, along with sound, to further assist in object localization. Deniz et al [3] used sound for localization on a robot head by processing signals gathered by two robotic ears. Blank et al [4] used standard PC sound cards and microphones mounted on their robot to locate simulated victims during the Urban Search and Rescue Contest sponsored by AAAI. Pissokas and Malcolm [5] also used sound sensors to help locate victims during a USAR competition. Stoytchev and Arkin [6] used a binaural microphone on a service robot to locate users who are trying to draw its attention. Baldassarre et al [7] used sound sensors on a group of simulated Khepera robots to help the robots locate one another so that they could move together toward a light source. Sound has also been used to model cricket phototaxis on actual robots that can track over natural terrain toward a simulated male cricket song [8].

Although not directly related to our research, sound has been used for several other interesting applications dealing with autonomous robots. Human-computer communication was done through natural language processing for the Jijo-2 mobile office robot [9] and through the use of musical elements and robot motion sounds for a service robot at the IMAT-Lab [10]. Another interesting application of sound processing in robotics was the use of acoustic signals and case-based reasoning to predict faults in industrial robots [11].

The research presented in this paper has similarities with the localization research, but steps out in a new direction. The unique characteristics of sound are exploited to help in doing the computation through a kind of analog computing. This reduces the needed computation on board the robot while enabling the robot to make a key decision concerning the choice of which location is the most desirable for it to track towards.

2. POWER SUPPLY PROBLEM

The use of a colony of autonomous robots can be very advantageous in remote dangerous environments. One of the major obstacles in the use of autonomous robots in remote environments has to do with power supply. A colony of electric powered robots that is operating outside of the area where electrical power is available requires that some method of supplying power is available in the local area. One possibility for supplying power is through the use of solar panels to collect energy. The difficulty with this method is that the robots would require very large solar panels to operate continuously.

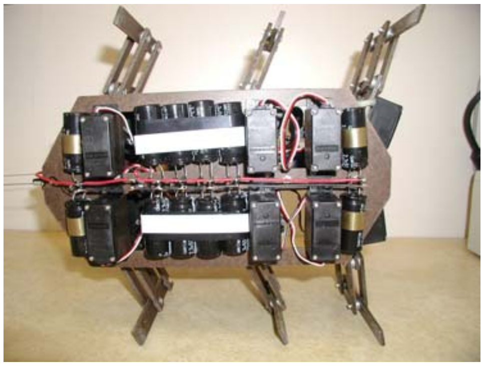

Figure 1. ServoBot equipped with 6 pairs of high capacitance capacitors.

We propose the use of charging stations, which are stationary, with the power supplied through large solar panels. The robots, which are operating autonomously, will go to these charging stations when they are low on power. The charging stations will be equipped with high capacitance capacitors to hold the charge. The robots will also have capacitors that can be charged from the charging stations. In previous work, we designed the robots equipped with capacitors (Figure 1) and charged them using a constant power supply charging station. The solar panel charging stations will require no connection with continuous power. They are a proposal and have not yet been constructed. At this point, we are considering a method that will allow each robot to find the appropriate charging station that it should track towards when it is low on power.

The real world problem involves a distribution of autonomous robots in an area. These robots are to be performing some function in the area and will require a power supply available in the area. Our proposed power supply, charging stations being powered by solar panels, will also be distributed in the work area. Although the boundaries of this real world area are not specified, our model of the problem is set up in a colony space in the laboratory. When tests determine that our system is a viable means of selecting a charging station, we will need to address the issue of an unbounded operating space. A method of ensuring that robots do not wonder to a distance of no return needs to be determined. One option is to not allow a robot to move to a point where it can hear less than three stations at some minimal amplitude. Other options are being considered and will be discussed in future works.

There is a colony space set up in the Artificial Intelligence and Robotics Lab at Connecticut College. It is populated by ServoBot (hexapod) robots that are to be performing some function. The robots are equipped with high capacitance capacitors (Figure 1) to store power to run their servo motors [12,13]. The controllers and sensors need minimal power, which is provided by a 9 volt battery. The robots recharge by approaching a charging station [12]. Making contact with the plates of the charging station through probes on the robot, they can recharge in approximately 3 minutes [13].

Figure 2: ServoBot with charging station (power supplied by a power supply). The ServoBot charges its capacitors through probes (can be seen on the front of the robot) that are aligned to make contact with charging plates.

At this point, the charging stations (Figure 2) are powered by a constant power supply, which is not appropriate for a remote environment. Our proposed charging stations, powered with solar power, will allow the system (robots and charging stations) to be usable in remote locations, but will not always have sufficient power to charge the robots in need. The object of this research is to find a method for each robot in the system to determine which charging station is the best for it to move towards when it is in need of power.

To model the environment, we are using standard PC speakers for the charging station and a small microphone that will be mounted to the robot. At this point, we are considering a single robot operating in the colony space with two charging stations to choose from. More charging stations will be added and eventually they will be equipped with an array of speakers so that their transmission will be omnidirectional. However, since the initial tests were done with a single microphone, simple speakers directed at it were sufficient. These tests were done with the microphone connected to a PC so that the experimental results could be easily recorded and analyzed.

3. CHOOSING A CHARGING STATION

The robot needs to consider several factors in determining which charging station to track towards. Assuming that it is considering only charging stations that it can reach with its available power, the most important factors are how far away is the charging station and how much power is available at it. We believe that both of these can be considered by the robot and the charging station chosen through the use of a system employing audible sound. The idea is that each of the charging stations will emit band-limited noise. The center frequency of this signal will be unique to that charging station and the robot will be capable of separating concurrent signals in these frequency bands. Each station will emit its signal with amplitude that is relational to the energy that it has available. In other words, a fully charged charging station will transmit a predetermined maximum amplitude signal. A charging station below some minimum will transmit no signal. The amplitude transmitted between the two extremes will be directly related to the energy available. Band-limited noise is used instead of single frequencies to alleviate the effects of reflective surfaces that might cause standing waves in the environment.

The function that maps the stored energy to the output amplitude can vary depending on the environmental circumstances and the needs of the robot. This function is the same on all stations and changing it biases the robot's decision process. Due to the propagation properties of sound, as a sound wave moves away from the speaker, its intensity decreases. When sounds from all stations reach the robot, it is being supplied with both key elements of its decision with one piece of information. It is being supplied with a result, computed through the use of the environment, that tells it the best charging station to track towards considering its distance and energy available. It will choose the charging station with the strongest signal that reaches its microphone. The nature of this decision can be controlled through the transmission function. Using it, the system designer can bias this decision to have the robot track toward the nearest station, to track toward the station with the most power, or balance the two.

4. TESTS

Tests were conducted with two speakers and a single microphone to determine if this method is plausible. The space used for the tests had walls covered with absorptive material to reduce reverberation. The dimensions of this space were approximately 8x8 meters. Two small PC speakers, which were facing each other, were positioned at the center of opposing walls at locations that were almost 8 meters apart. A single omnidirectional microphone was placed at different locations in the test area to determine the boundary points. The microphone was placed, measurements were taken to find which speaker was producing the stronger signal at the present location, and then it was moved toward the speaker giving off the weaker signal. This procedure was repeated until the boundary points were found.

Each station (speaker) was set to emit band-limited noise in a frequency region unique to that station. The frequency regions of participating stations need to be non-overlapping to ensure that they are distinguishable. A band pass filter for each station was used on the receiver. The energy outputs of these filters were compared with each other to determine which station's received signal was stronger. This indicated the station that the robot would choose to move towards.

For the actual tests reported in this paper, the experiments were carried out using two stations. The two frequency ranges used in this experiment were 220Hz - 660Hz and 660Hz-1100Hz. Initially, the system was calibrated by positioning the receiver in the middle of the two stations and equating their received energy outputs. This was to offset many of the nonsymmetrical qualities of the sound production and reception systems.

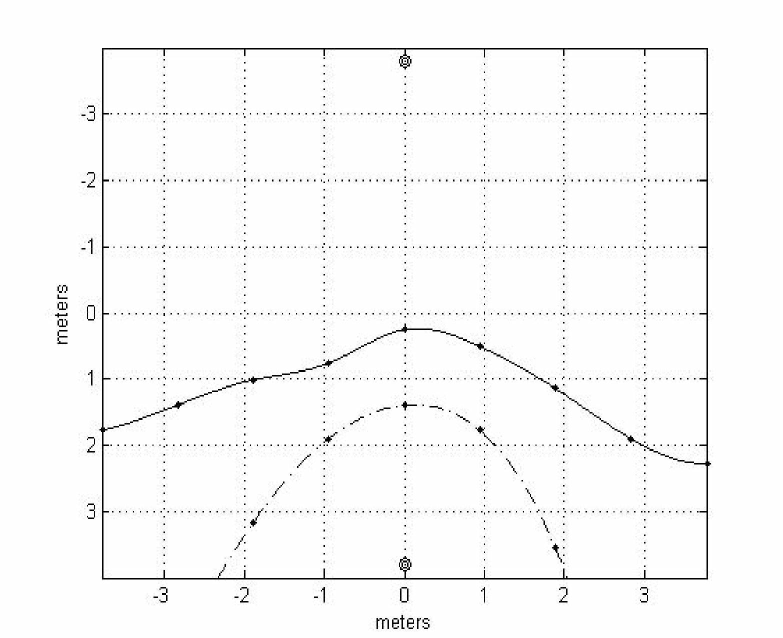

Figure 3: Actual test results showing speaker placement and the boundary lines for two of the tests. The solid line indicates the boundary when the bottom speaker's amplitude is ¾ that of the top speaker. The dashed line shows when the bottom speaker's amplitude is ½ that of the top speaker. The points on the lines show actual microphone locations found on the boundary line.

5. RESULTS

Figure 3 shows the results of the experiment in the space we selected for this purpose. The location of each speaker is shown by two small concentric circles. For equal power outputs from the two stations the boundary is a straight horizontal line at 0 on the vertical axis. Hence, in this case the robot selects the closest station. This can be achieved by maintaining equal power outputs and making these power values independent of the energy available at the charging stations. The continuous line in Figure 3 represents the boundary when the station at (0,4) was emitting a signal at 75 percent of its original amplitude. The station at (0,-4) continues to transmit at the original amplitude. It can be seen that the region of attraction of the weaker station has diminished. The dashed line represents the boundary when the station at (0,4) was emitting a signal at 50 percent the original amplitude (again with (0,-4) at original amplitude). This resulted in further diminishing of the attraction area. The tolerable amount of reverberation in the test environment has inevitably caused some deviations from ideal conditions of propagation. These deviations are space dependent and it will be useful to carry out a preliminary analysis of the environment to assess applicability of this method. Reverberant rooms have been observed to result in more complex boundaries or in some cases disjoint decision regions.

6. CONCLUSIONS

These preliminary tests indicate that a receiver equipped with a microphone and band pass filters can recognize reasonably curved boundary lines between speakers emitting noise in distinct frequency bands. A mapping function between the station's energy and the output amplitude gives the system designer the capability of biasing the system. Through this method, these curves can be adjusted to make reasonable boundary lines for robots making decisions as to which charging station they should move towards in order to recharge. Once the robot chooses a station, it can use localization techniques as referenced in Section 1 to find the station.

In future work, tests will be done with multiple stations to determine if the boundary lines are appropriate. Experiments will also be done with directional microphones which can give the decision system a bias as to the heading of the power station. This will be useful for robots that cannot easily rotate in place. In addition, tests will be done to determine the effects of obstacles in between the station and the robot. Our hope is that an obstacle will disrupt the sound by creating a sound shadow resulting in reduced amplitude received from that station. This will bias the robot away from choosing stations with large obstacles in the path between the robot and the station.

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