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Unmanned Autonomous Cockroach

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Abstract

Cockroaches are a resilient species that could provide assistance to humans in numerous hazardous scenarios such as emergency rescues and nuclear disasters. By outfitting cockroaches with the appropriate control mechanisms and sensing equipment we can increase the effectiveness of such cockroach "biobots." A procedure for applying stimulation to cockroaches as a means to control movement was designed and tested. A prototype system was implemented using an Arduino Uno and basic electronic components. By exploring more natural stimulation methods, we can design systems to better employ unmanned autonomous cockroaches (UACs) to aid humans.

Contents

1 Introduction

The common cockroach is considered a pest and a sign of unsanitary conditions. However, the cockroach is one of the most resilient species on the planet, and has much to offer to humans. The cockroach has survived millions of years of drastic climate changes, and is known to be able to withstand much higher doses of radiation than humans. It strong biological build, as well as its simple nervous system make the cockroach an ideal candidate for electrorheological experimentation.

Insect biobots have long been a source of imaginative thought. Compared to mechanical robots, insects are cheaper and more efficient. Research done at the University of California has shown that a flying beetle can be manipulated using electrical stimuli to turn and fly in certain patterns [1]. In addition, [2] explains a patented method of implanting electrodes for such stimulation. The cockroach has also been experimented on in a similar manner. The Madagascar Hissing Cockroach was successfully driven using signals sent into the antenna of the roach as described in [3], and have numerous uses in these capacities.

Madagascar Hissing Cockroaches were selected for this project not only because previous studies have shown that they are effective, but also because of their large size and lack of wings. These roaches have a hard exterior and a mantle that covers their head. The thorax is protected by a weaker exoskeleton which allows for locomotion without resistance [4]. The cockroaches antenna act as a guidance system for the roaches. When coming in contact with surfaces and other chemicals the antenna can inform the roach of any hazards or obstacles in their way. They send signals which are interpreted and the roach reacts to the obstacles detected. Cockroaches are also an ideal candidate for this type of experimentation because they are not know to feel pain as humans perceive it [3]. Instead, electrical stimulations simply guide the roachs by motivating motion. This project makes use of this characteristic to direct cockroach motion by applying electrical stimuli to the antennae.

2 Methods

The procedure employed in this study followed directly from the instructions laid out in [5]. Electrodes were implanted in each of the cockroach's antennae, and a third, ground electrode was implanted in the cockroach's thorax. Once these were in place, an Aruino micro-controller was used to apply electrical stimulus to the cockroach based on commands from a computer.

2.1 Electrode Implants and Surgical Procedure

In order to be able to send signals to the cockroach, a surgery was performed to implant electrodes into the cockroach's antenna. Like most cockroaches, the Madagascar Hissing

Cockroach can be anesthetized by submerging it in ice water for a period of five to ten minutes. This renders the roach relatively immobile for the duration of the surgery. During several surgeries, cockroaches began to show signs of regaining consciousness, and were submerged back into the ice water for several more minutes. To further ensure that the cockroach did not interfere with its surgery, it was restrained to an operating table with a strip of masking tape. Madagascar Hissing Cockroaches have a waxy coating over the mantle that covers their heads. This coating must be removed so that a set of three female header pins could be attached there. Both the cockroach and the connector were sanded with 400 grade sandpaper. This allowed for two abrasive sides that super glue could adhere to. Before the connector was fastened to the cockroaches mantle, silver wires were soldered onto the connector, with the silver coating at each end melted off using a lighter.

Once the connector was firmly glued in place, the electrodes were inserted into the appropriate channels. To serve as a ground, one of the silver wires was inserted into the thorax of the cockroach. This was done by using microscissors to remove a small triangle of exoskeleton to reveal the soft interior. A 5ml syringe was then used to puncture the roaches thorax and provide an opening for the silver wire to enter. The silver wire was placed into the hole created by the syringe about 5mm deep, and then super glued into place. The other two wires were placed into the roaches antennae. The antennae were snipped at about 10 mm from the base. This short antenna length was chosen because the antennae are thick enough to allow the wires to enter at that length, and longer antennae allow the cockroach to attempt to pull out the silver wire more easily. Once each silver wire was inserted into its respective antenna they were super glued to ensure that they would not be removed. Finally, to ensure that no connections would be broken the silver wires were hot glued on top of the connector. The header pin connector, as can be seen in Figure 1, allowed easy connection to the stimulation device using three wires soldered to a set of three male header pins. After surgery the roaches were placed in separate habitats to prevent other cockroaches from interfering with the wiring.

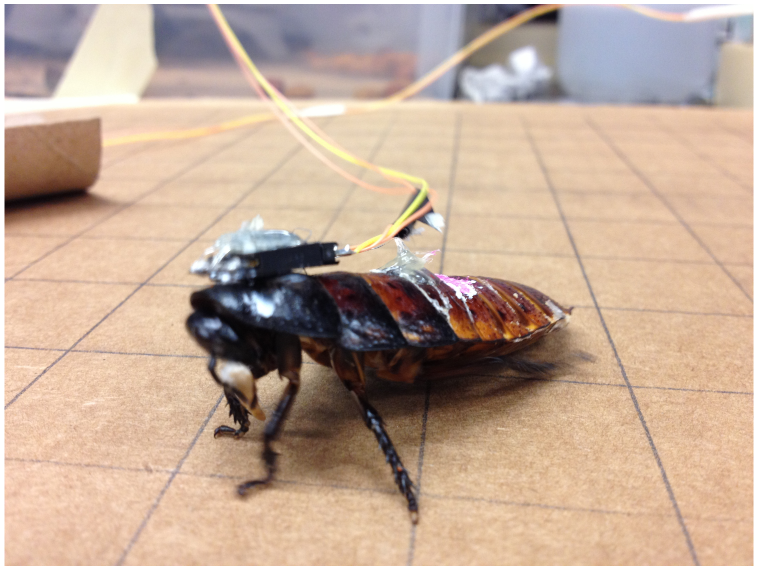

Figure 1: Cockroach with Implanted Electrodes

2.2 Arduino Control System

The Arduino Uno micro-controller was chosen for this study because of its ease of use and because it was easily accessible. The initial goal of the project was to employ a control system that is activated remotely in order to prevent wires from obstructing the movement of the cockroach, as well as to provide a proof-of-concept of the applicability of UACs. The Arduino Mini Pro and the Femptoduino were chosen for this task because they are lightweight, small-scale versions of the Arduino micro-controller, and could easily have been carried by the Madagascar Hissing Cockroach. However, due to technical difficulties, the Arduino Uno was used to demonstrate the overall concept that cockroaches can be easily manipulated using electrical stimulus.

The basic control system used for this demonstration allowed the user to provide three single character commands - ‘a’,‘d’, and ‘s’, which applied a stimulus to the left, right, and to both antennae respectively. The commands were transmitted via serial communication to the micro-controller, where they were decoded. The actual stimulus that was generated in each of these cases was a one second pulse train of random frequency between 40 Hz and 200 Hz duty cycle between 1.2% and 20% with a constant peak-to-peak voltage of 5V. This was based off the stimulus used in [1] on moth biobots, which ranged from 20 Hz to 50 Hz at a 50% duty cycle. The code to execute this functionality can be found in section 7.1.

3 Analysis and Results

The project was successful in demonstrating its primary goal of motivating cockroach motion through electrical stimulus. After one failed surgery, the following two cockroach subjects could easily be controlled using the stimulation system described above. Each cockroach moved right or left as stimuli were applied. However, their reactions to the stimuli were not regular, and controlling the motion of the cockroaches exactly was difficult for the user.

The focus of this project was to overcome the engineering challenges associated with designing an effective UAC system. These challenges can be separated into surgical and stimulation related issues, each of which must be addressed in order to improve the UAC system.

3.1 Analysis of Surgical Methods

Madagascar Hissing Cockroaches, like most living things, do not like to have foreign objects forcibly attached to them. After initial surgery, the roaches immediately noticed something different in their surroundings. The surgery effectively removed all use of their antennas for use in locomotion and other daily tasks. The silver wire connections were constantly under threat of being ripped out by the cockroach. Because of the cockroaches anatomy, their first set of limbs gives them the ability to stroke their antenna and clean them. This allows for the roach to attempt to forcibly remove the foreign object from their antennas. One cockroach was so determined that she forcibly removed her whole antenna. This poses a serious problem, because if the cockroach removes its antenna during testing all signal will be lost. Getting the silver wire into the cockroachs antenna is no easy feat in itself, and the fact that it is under constant threat of being destroyed adds an additional problem. One of the main focuses of the repeated surgeries was to find a suitable way to make sure the antenna are safe from tampering.

After the first surgery, there were no safeguards in place for antenna connection protection. The first cockroach took advantage of this and cleaned herself of all foreign objects (i.e. the connections). The second surgery was much more successful. The first solution was to splint the roaches antenna with fragments of toothpicks, which in turn were hot glued to the roaches mantle. This provided satisfactory protection for the antenna, but the roach was still able to reach and attempt to clean its antenna. The third method utilized was based off the second. Instead of splinting the antenna, the antennas were folded back onto the roaches mantle and fastened to the connector. This placed the antennas out of reach of the roaches front legs. The antenna fastening methods of the second and third surgeries can be seen in the left and right cockroaches respectively in Figure 2. As an added security measure, the roaches frontmost legs were clipped off. During initial trials, the lack of front legs did not impact locomotion. However, these methods could be improved. Other locations for electrodes to be fastened are worth exploring, as the current method is dependent on the cockroaches disposition.

Figure 2: Cockroach with Implanted Electrodes

3.2 Analysis of Stimulation Methods

The basic stimulation methods applied in this system are, in general, insufficiently complex for UAC applications. The stimuli we applied to the two cockroach subjects allowed the user to control movement, but did not produce continuous motion. The cockroaches turned left or right with sudden movements, indicating that the stimulus did not seem natural to them.

In order to find the most natural stimulus, we could have followed two research paths: measuring actual action potentials in the antenna, or measuring the effects of varying stimulation characteristics such as peak-to-peak voltage, frequency, duty cycle, and the output impedance of the stimulation circuit. A major issue with the former path is that action potentials are already very difficult signals to measure, especially in the noisy environment of the lab. With motion artifacts from constantly moving antenna added to the measurement problem, measuring these signals may have been even more difficult. However, given accurate action potential measurements, a stimulation model could have been constructed to evoke the most natural response from the cockroach subjects. The latter path would have been easy to follow, however time constraints did not allow for sufficient measurements.

Finally, a major issue in evaluating the success of stimulation methods is the lack of a suitable numerical metric for UAC systems. Because of the relatively erratic movement of the cockroaches, it is difficult to judge the effectiveness of a given system. During the short experimental period, we found no suitable solution to this issue.

4 Conclusions and Recommendations

With the methods and analysis provided above, the locomotion of a Madagascar Hissing Cockroach was controlled by a user sending single character commands to a stimulation circuit. A surgical procedure for tapping into the roaches existing nervous system allowed for stimulation of the roaches sensory structures. A prototype system was implemented using an Arduino Uno and basic electronic components, which sent stimulus to the cockroaches antenna and evoked a reaction in the roach that influenced the direction it which it moved.

However, this is not to say that the cockroach was controlled perfectly. The cockroach displayed a jagged, almost piecewise response to the stimulus. Further explorations should be focused on a smoother response to the stimulus. This could be achieve by closely mimicking the natural stimulus of the cockroachs antenna. In addition, using this procedure, the cockroach could not be moved forward by stimulation alone. Reliable forward motion is essential for a fully functional UAC, and can be explored by stimulating the cockroachs rear splines. Because of the unmanned nature of the UAC, a remote control system must be implemented to allow for untethered control from a safe distance. This could be implemented by a smaller micro-controller and a wireless transceiver. A camera would further allow for full control and application of the UAC from anywhere within range of the cockroachs transmitter. This allows for the user to see and adjust to the cockroachs environment in real time. However sensors are not limited to a camera alone. A microphone could be attached to the cockroach to record audio from a remote location. A geiger counter could be placed on the cockroach to measure radiation levels as cockroaches do not have the same reaction to radiation as humans do. Beyond these basic applications, the UAC has countless uses, and can truly be used to improve human life.

5 Acknowledgements

We would like to acknowledge Professor Damian Williams, Dionne Lutz, and Uyen Nguyen for the expertise and support they provided during the course of this project.

6 Bibliography

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7 Appendix

7.1 Arduino Code

```
/************************************************************
 * Unmanned Automated Cockroach
 * Tethered Stimulation
 * Sharang Phadke & Marcello Ricottone
 * PH 330
 * 05/12/2013
 *
 * Stimulate a cockroach with commands from the serial monitor
 * 'a' - stimulate left antenna
 * 'd' - stimulate right antenna
 * 's' - stimulate both left and right antennae
 ************************************************************/

#define leftPin A0
#define rightPin A1
#define stimLen 40

int C = 0;
boolean ready = false;
int pulseWidth = 0;
int stimDelay = 0;

void setup() {
  Serial.begin(9600);
  randomSeed(analogRead(0));
  pinMode(leftPin, OUTPUT);
  analogWrite(leftPin,0);
  pinMode(rightPin, OUTPUT);
  analogWrite(rightPin,0);
}

void loop() {
  C = readCommand();

  // Use 'p' to pause and unpause
  if(C == 'p'){
    if(ready){
      Serial.println("Paused");
    }
    else{
      Serial.println("Ready");
    }
    ready = !ready;
```

```
  }

  if(ready){
    switch (C){
      case 'a':
        activate('a');
        break;
      case 'd':
        activate('d');
        break;
      case 's':
        activate('s');
        break;
    }
  }
}

// Command reading function
// sends '---' while active
// polls the serial bus ever 300 ms for new characters
char readCommand() {
  while (Serial.available() ≤ 0) {
    Serial.println("---");   // send --- while
    delay(300);
  }
  return Serial.read();
}

// Stimulating function
// Stimulate the appropriate pin at a random frequency
// within a range for 1 second in total
void activate(char c){
  digitalWrite(leftPin,LOW);
  digitalWrite(rightPin,LOW);

  Serial.println(stimLen,DEC);

  if(c == 'a'){

    pulseWidth = random(300,1000);
    stimDelay = random(5,25);
    printStuff(pulseWidth,stimDelay,c);

    for(int i = 0; i < stimLen; i++){
      digitalWrite(leftPin,HIGH);
      delayMicroseconds(pulseWidth);
      digitalWrite(leftPin,LOW);
      delay(stimDelay);
    }
    Serial.println("done stimulating LEFT");
  }
  else if(c == 'd'){

    pulseWidth = random(300,1000);
```

```
    stimDelay = random(5,25);
    printStuff(pulseWidth,stimDelay,c);

    for(int i = 0; i < stimLen; i++){
      digitalWrite(rightPin,HIGH);
      delayMicroseconds(pulseWidth);
      digitalWrite(rightPin,LOW);
      delay(stimDelay);
    }
    Serial.println("done stimulating RIGHT");
  }
  else if(c == 's'){

    pulseWidth = random(300,1000);
    stimDelay = random(5,25);
    printStuff(pulseWidth,stimDelay,c);

    for(int i = 0; i < stimLen; i++){
      digitalWrite(rightPin,HIGH);
      digitalWrite(leftPin,HIGH);
      delayMicroseconds(pulseWidth);
      digitalWrite(rightPin,LOW);
      digitalWrite(leftPin,LOW);
      delay(stimDelay);
    }
    Serial.println("done stimulating BOTH");
  }

  digitalWrite(leftPin,LOW);
  digitalWrite(rightPin,LOW);
}

// Print to Serial Monitor
// Print relevant info upon stimulation
void printStuff(int pWidth,int sDelay,char C){
  Serial.print("Stimulating ");
  Serial.print(C);
  Serial.print(" at ");
  Serial.print(1000/sDelay,DEC);
  Serial.print(" Hz, ");
  Serial.print(pWidth/(sDelay*1000),DEC);
  Serial.println("% Duty Cycle");
}
```