Emergent behavior in a zoomorphic autonomous agent

Group 9
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Introduction

The growing interest in Artificial Intelligence and the increased development and implementation of social robotics prompt researchers and manufacturers to create functional autonomous agents that can act according to explicit goals or principles in a dynamic social environment. The aim of this project, though on a much humbler scale, is to develop an autonomous agent that will emulate the actions and reactions of a wild, young, and inexperienced animal. The higher goal is demonstrating seemingly intelligent behavior from simple control rules based on the phenomenon of emergent behavior. It will take the role of those animals commonly thought of as prey. Consequently, the robot will be named 'Bambi.'

Bambi navigates through the environment, ostensibly foraging. It treads carefully, avoiding any major obstacles in its path, and, when encountered, looks to both sides to choose the unobstructed one. Sound is the modality of focus. While Bambi forages, any sound of a higher amplitude than what the agent is used to - resembling a predator running towards him - will initially trigger a flight reaction. This will take the form of Bambi turning in the opposite direction of the stimulus to flee from the potential danger. After successfully escaping the source of potential peril, the agent will resume foraging.

As triggers present themselves repeatedly, due to Bambi remaining unharmed from all previous encounters, it will get confident and start to flee less and less, reaching the point where it will do so no more. Namely, it will habituate to the loud sounds from the environment.

Theoretical implementation

Since Bambi has a physical body, comprising sensors, actuators, and a considerable amount of cardboard, that interacts with the physical environment, embodiment is present as one of the main concepts. Embodiment refers to agents that have a physical body, which consist of parts varying in material qualities, functionality and complexity (Nolfi, 2021).

Bambi's behavioral control takes inspiration from the Braitenberg vehicle 2a, with an additional layer of control for obstacle avoidance. Braitenberg vehicles are architectures possessing simple internal structures that exhibit behavior potentially described and considered, for the onlooker, to be only possible if the agent was *alive* (Braitenberg, 1986). For Bambi, the quality of being perceived as so will afford it autonomy.

Vehicle 2a is the architecture corresponding to fear. It has a sensor and a motor, each placed on both sides, which are ipsilaterally connected to one another. The vehicle turns away from a source emitting a modality in question, sound waves in the case of Bambi. The architecture has slight alterations explained in the Practical Implementation section.

Braitenberg vehicles utilize a behavior-based approach, and so does Bambi. The behavior-based approach expands on the sense-plan-act layout from deliberative-approach models by dividing the control/planning module into multiple layers, each dedicated to a particular behavior. Therefore, Bambi has two levels of control: (1) based on an alternate Braitenberg vehicle 2a and (2) the control module for object avoidance. (see the Practical Implementation section for a thorough description of the layers). Due to the layers having somewhat overlapping functions, namely that they both control movement, a hierarchy is established. Because of Bambi's inexperience, fleeing from a potential prey may make him react in reflex and could, therefore, crash into obstacles. For consistency, Braitenberg's 2a reactions take authority over obstacle avoidance.

Emergent behavior refers to the phenomenon where the interaction of simple reactive components results in complex behavior (Hutt et al. 2006). An example of this is when an observer describes a Braitenberg vehicle's behavior in psychological terms, thus accrediting it with the quality of being autonomous or even alive. To further enhance emergence, a rudimentary version of habituation is implemented. Habituation in neuroscience is the decrease in neurotransmitter release elicited by a stimulus. The repeated occurrence of a harmless stimulus will reduce the intensity of the reaction, fleeing to less and less in the case of Bambi. This concept is a simple model of long-term memory (Purves et al., 2013), making Bambi exhibit behavior that indicates remembrance and consideration, thus learning from experience.

Zoomorphism is the process of ascribing animal characteristics to non-animal entities. It is evoked in numerous social robotics projects due to its effect in eliciting positive social responses and acceptance (Venkatesh & Davis, 2000). Due to Bambi emulating basic prey animal behavior and bearing some resemblance to the appearance of a small creature in nature (for instance, its size, the four wheels representing legs, and the sensors in the front taking after eyes), it can be considered a zoomorphic agent.

Practical Implementation

Bambi is an autonomous robot that mediates sensor and actuator information via the Arduino UNO microcontroller board (henceforth referred to as Arduino). Due to the energy needed, a separate battery pack (exerting a max of 6 volts) powers the Direct Current (DC) gear motors, with the Arduino (powered by a 9-volt block battery) itself powering the other components. Thus two separate circuits are needed (see Appendix 3, Figure 1). A breadboard facilitates this task. All mentioned components are mounted on a wooden chassis (see Appendix 1, Figure 1). Due to its length, adding a caster wheel eases maneuvering without the need for control (see Appendix 1, Figure 2), thus, offloading further computations from the Arduino. This case is a prime example of morphological computation.

Altered-Braintenberg

The main modification of our Braitenberg implementation is that there is a discontinuous indirect proportional connection between the sound sensors and DC motors. In our robot, a sound threshold (the threshold variable was the same for both sensors) mediates the robot's reactions. When the sound detected in one of the sensors, located lateral to the robot (see Appendix 1, Figure 3), surpasses it, it triggers the common Braitenberg 2A reaction (see Appendix 2, lines 31-42). This reaction decreases the output voltage to the DC motor contralateral to the sound sensor, halting it, thus reorienting the robot 90 degrees to the opposite direction of the triggering source (see Appendix 2, lines 32-33 & 38-29). Unfortunately, DC motor and sound sensor proportionality cannot be achieved due to the necessary implementation of habituation in a simple manner, making the reorientation of the robot a quasi-independent component from the sensor. In our implementation, a delay parameter mediates reorientation (see Appendix 2, lines 35 & 41). The ideal delay parameter was found through thorough testing, eventually leading to the value of 600ms; the closest to an almost perfect opposite reorientation from the source.

Habituation

Bambi getting overconfident requires: (1) making Bambi indifferent to sounds quieter or equal to the previous trigger and (2) making it flee less and less from the source. The former was done by incrementing the threshold by 100ms every time it was surpassed (see Appendix 2, lines 34 & 40), and the latter by mapping the values of said threshold (0 - 1000) to a range of values spanning from 0 up to the original delay (0 - 600) (see Appendix 2, line 27). These values subtract the delay, decreasing it and making Bambi reorient itself in a decreasing order from 90 degrees to 0 degrees (see Appendix 2, lines 35 & 41). In a nutshell, previous sounds that would trigger the reaction would not do so afterward, and the next sound that triggers it would not make Bambi flee as much. It keeps going until it reaches the maximum value for the threshold in the mapping function, which would map into the same value as the original delay, and make Bambi unresponsive to sounds.

Obstacle avoidance

It is executed by having an ultrasonic sensor mounted onto a micro servo motor (see Appendix 1, Figure 4). When the ultrasonic sensor detects an obstacle less than 35cm away, both DC motors are halted for a safe and smooth measurement (see Appendix 2, lines 53-55). Then the micro servo motor turns 90 degrees to the right, the ultrasonic sensor measures the distance, and ditto for the left side (see Appendix 2, lines 57-65). The corresponding distances are compared to select the less obstructed path. After the decision, the DC motor contralateral to the selected side starts while the other remains halted for 600ms, enough of a delay to reorient the robot correctly (see Appendix 2, lines 67-75). Once the robot reorients, it continues moving forward.

The code is written hierarchically (in the same order as the implementations explained above) to implement the mentioned naivete by setting the obstacle avoidance as an “else” statement within the Alt-Braitenberg conditional statement (see Appendix 2, lines 31, 37 & 43). Therefore, if the sound triggers the Braintenberg reaction, obstacle avoidance is ignored.

Discussion

The project aimed to design and build an embodied zoomorphic autonomous agent that can adapt to its dynamic environment. There is much debate about the relevance of embodiment in reaching autonomy, which is increasingly leaning towards highlighting the importance, if not the necessity, of having the physical body sense and act in a physical environment (Pfeifer & Bongard, 2006; Cangelosi & Asada, 2022). The simplified behavior of prey animals serves as an example to be emulated, due to its potential for emergence, while still being elementary. Despite the lack of interaction between Bambi and humans, there is enormous potential in observing and modeling animal behavior for social robotics (Miklósi & Gácsi, 2012).

Having the agent display complex behavior emergent from simple rules was not an initial goal of the project; nevertheless, it became focal. It proved to be an effective learning tool in understanding how one can create an autonomous agent from scratch, the challenges of building such an agent, and how the agent's interaction with the environment is vital in the process (Harlan & McClarigan, 2005). Furthermore, the suggestion that emergent behavior from models based on the behavior-based approach (such is the case for Bambi) may provide a hint as to designing and implementing robust agents in tasks requiring specialized skills of sensory-motor associations (Brooks, 1989).

Carrying the project out, however challenging at times, proved worth going through, gaining insight into the significance of embodiment in autonomous agents and an understanding necessary to make the goal easier to achieve and the outcome more applicable to the real world. Observing emergent behavior had a similar effect on grasping its role in making the process of creating autonomous agents achievable, accompanied by prospective applications in making these agents more relatable to an onlooker.

The main limitation of our robot was the lack of direct proportionality between the sound sensors and DC motors. Unfortunately, it was a necessary trade-off to implement habituation modestly and effectively. In addition, the sound sensors posed some problems due to their low granularity, but the threshold was a good enough implementation to solve this. Another limitation arises due to the lack of precision in ultrasonic sensor measurements, where obstacles that are not wide enough (table legs, etcetera) pose problems, inevitably causing the robot to crash.

Having more time to modify the robot, some further development could take the form of attaching touch sensors onto Bambi, which might prove beneficial in improving the adaptivity of the agent and implementing the concept of a counter-habituation (touching the robot would reset the habituation), thus also reaching a more realistic and complex outcome. We would replace all the cardboard with plastic counterparts (using 3D printing) to make it more robust and custom. The wooden chassis would also be replaced with a more compact and simplistic one. Substituting the ultrasonic sensor with a lidar sensor could further improve its obstacle avoidance, increasing precision and eliminating the ultrasonic limitation mentioned. Using deep learning could enable Bambi to present even more complex behavior, but it is more appropriate as a mid-future endeavor.

References:

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Appendix 1:

Figure 1. Picture A represents the isolated chassis of the vehicle, while Picture B represents the chassis with all the mounted components.

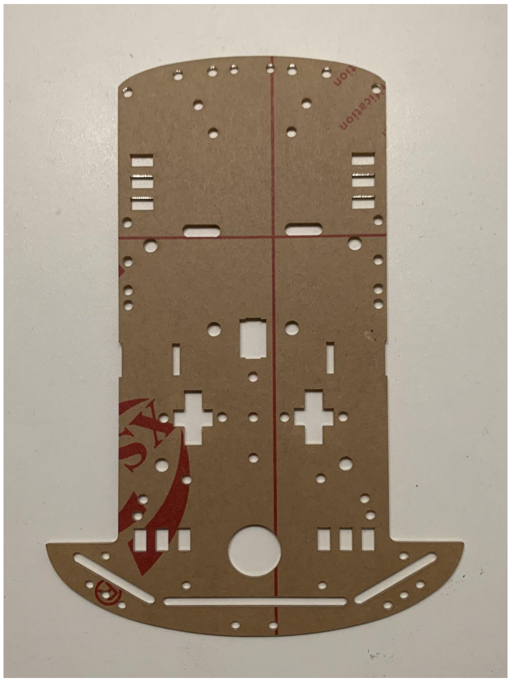

Figure A

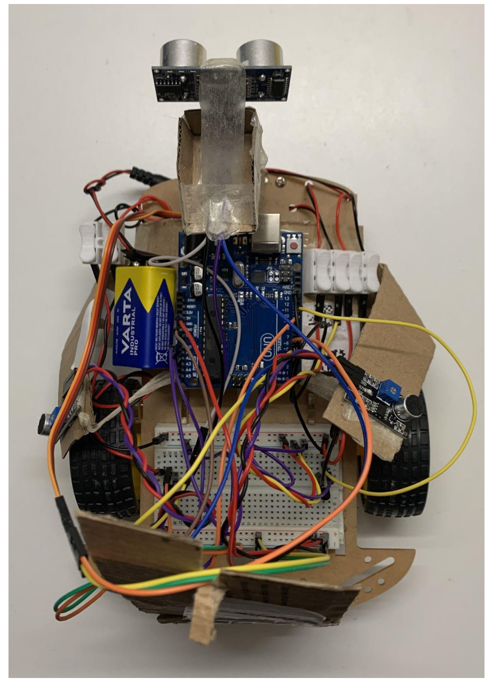

Figure B

Figure 2. Image of the caster wheel, located in the rostral of the robot.

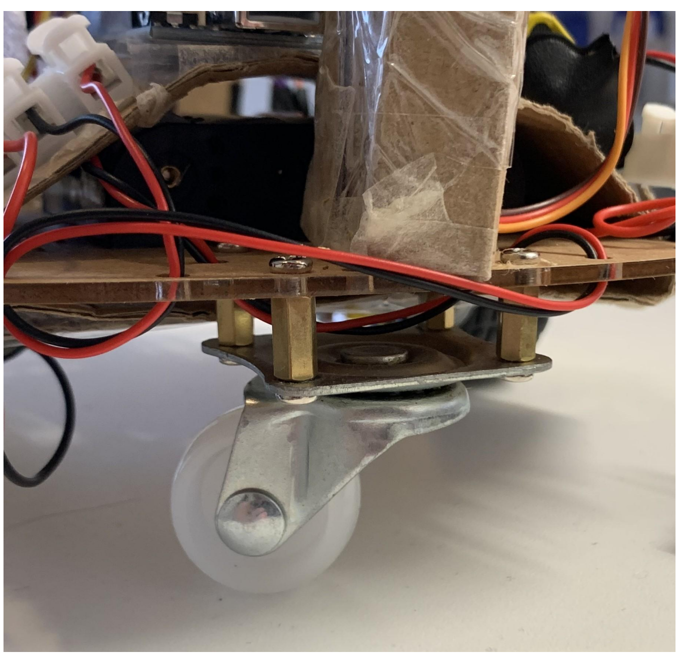

Figure 3. Image of the sound sensor located on the lateral side of the robot (the other sensor is located in the same manner, but on the other side).

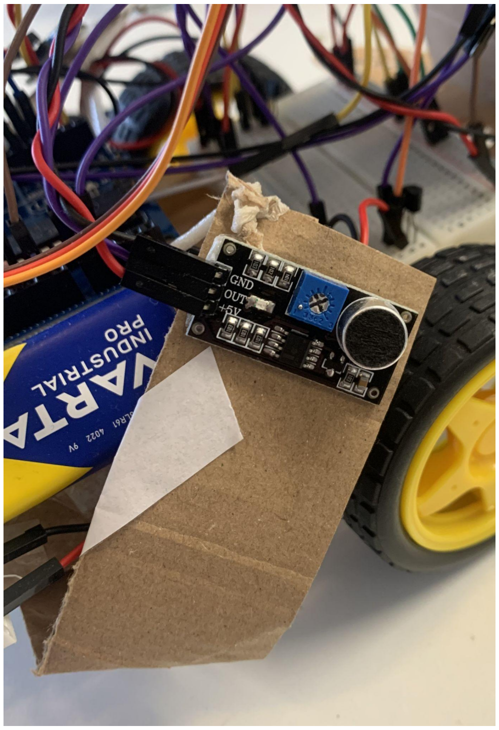

Figure 4. Picture A and Picture B show different angles of the ultrasonic sensor mounted on the micro servo motor.

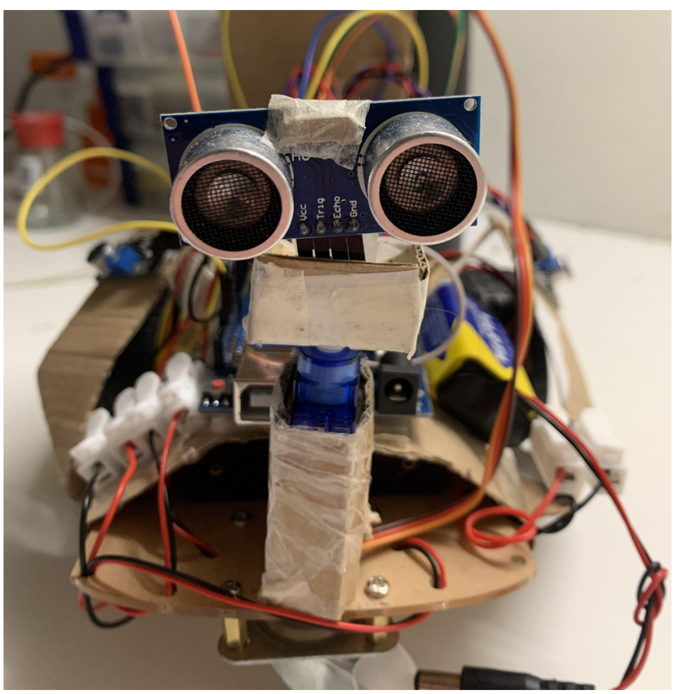

Figure A.

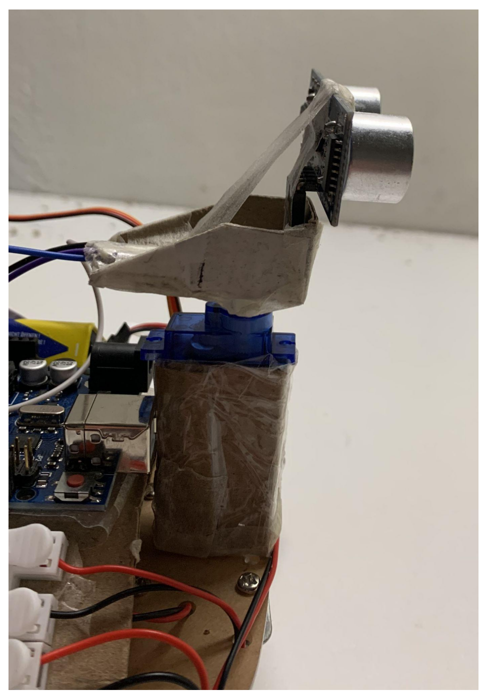

Figure B.

Appendix 2:

```
#include <SR04.h>
#include <Servo.h>

Servo s1;
SR04 sr04 = SR04(5, 4);
int motorpinRight = 11;
int motorpinLeft = 10;
int threshold = 0;

void setup() {

  pinMode(motorpinRight, OUTPUT);
  pinMode(motorpinLeft, OUTPUT);
  s1.attach(6);

}

void loop() {

  // braitenberg + habituation

  int soundLeft = analogRead(A1);
  int soundRight = analogRead(A0);

  // using the map function to map the threshold values to
  // the values used to subtract the delay.
  int d_delay = map(threshold, 0, 1000, 0, 600);

  // if the sound surpasses the threshold, orient the robot
  // opposite to the sound source.
  if (soundLeft > threshold) {
     digitalWrite(motorpinRight, LOW);
     digitalWrite(motorpinLeft, HIGH);
     threshold = threshold + 100;
     delay((600 - d_delay));
     }
   else if (soundRight > threshold) {
     digitalWrite(motorpinRight, HIGH);
     digitalWrite(motorpinLeft, LOW);
```

```
      threshold = threshold + 100;
      delay((600 - d_delay));
      }
    else {

    // bang-bang controller

    digitalWrite(motorpinRight, HIGH);
    digitalWrite(motorpinLeft, HIGH);

    // if distance is less than 35cm, halt the motors
    // and take measurements from both sides of the robot
    // in order to choose which side is the clearest.
     if (sr04.Distance() < 35){
       digitalWrite(motorpinRight, LOW);
       digitalWrite(motorpinLeft, LOW);

       s1.write(0);
       delay(1000);
       int rightDist = sr04.Distance();
       delay(1000);
       s1.write(180);
       delay(1000);
       int leftDist = sr04.Distance();
       delay(1000);
       s1.write(90);

       if (rightDist > leftDist){
         digitalWrite(motorpinRight, LOW);
         digitalWrite(motorpinLeft, HIGH);
         delay(650);
        }
       else if (rightDist < leftDist){
         digitalWrite(motorpinRight, HIGH);
         digitalWrite(motorpinLeft, LOW);
         delay(650);
        }
      }
  }
}
```

Appendix C:

Figure 1. Schematic circuit diagram of the whole robot (the infrared sensor represents the sound sensor since no sound sensor was available in TinkerCad).