Biomimetic Design of a Robot System to Investigate Pufferfish Geometric Circular Structures

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Abstract: This paper describes the work in progress, replicating the patterns that the pufferfish creates for mating. The robot designed and prototyped consisted of a mobile platform interfacing the medium via a magnetic attachment. Different considerations about the robot control and the mechanical setup of the medium are described. Further experiments replicating the experiment in water, with absolute positioning using computer vision and scaling the drawing size are discussed.

Keywords: biomimicry, robotic drawing, bioinspired design, pufferfish patterns, pufferfish circular patterns

1. INTRODUCTION

This paper describes the initial results experimenting recreating sand patterns utilizing a magnetic attachment with a robot mobile.

Kawase, Okata, and Ito in 2016 describe how the first scientific data of these patterns are from 1995, where a 2m in diameter "mystery circle" was found and linked to the mating behavior of the *Torquigener* sp., measuring only 120mm[1]. As shown in the center of Fig. 1, the author of these drawings is the male pufferfish. The mechanisms that the fish uses are uncertain, but there is no dispute in their beauty and their algorithmic regularity inspired the development of a drawing system.

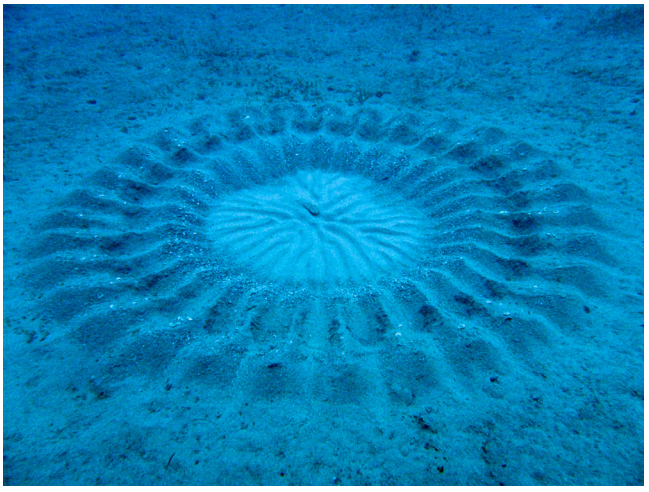

Fig. 1 - A male pufferfish (center) made this nest to lure females in japan in 2012. Photography by Kimiaki Ito.

The present work takes into consideration commercial models readily available of machines that reproduce drawings and patterns on the sand. E.g., the company Sisyphus produces artifacts that can draw on the sand for decorative purposes[2]. In Fig. 2, one of them is shown to illustrate the difference with the current set of experiments. The research described in this paper used these mechanisms as a proof of concept of an actuator mechanism that could draw on the sand of a controlled symmetrical pattern. The link to the fish and the behavior were the source to refine the precision of the movements and the algorithms utilized to execute the drawings. The model chosen at the end of the research is an efficient demo structure: easy to build, correct with drawing, and replicable. A robot used as the actuator can be coded to draw different patterns with magnets.

Fig. 2 - Commercial model of a decorative table that has a CNC to draw circular patterns on the sand

2. EXPERIMENTS

2.1. Initial Prototype: Open Feedback Loop

The initial tests were aimed to recreate the movement of the fish, with an initial proof of concept pulling from a mobile platform and utilizing an X-Y rigid frame to articulate the movement on the sand. The first working

prototype consisted of a vehicle capable of dragging an actuator through a magnetic attachment. The movement was achieved thanks to two geared motors differential. For this purpose, a wooden table was designed to have the height of the robot. The size of the table was initially 80cm x 80cm, and it had four supports on its corners of 22x22cm. The sand on the surface was 5kg.

Fig. 3 - Repetitive concentric patterns were not possible given that changing the angle and speed were not correctly tracked by the encoders

The movement of the mobile demonstrated the principle of operations as a direct relationship to the way that the pufferfish draws on the sand. The only areas where the movements were restricted were on the four corners of the square table, leaving a reduced area of operation. The geared motors used[3] did not have any kind of feedback, and the initial approach was to balance their speed and timing using software to calibrate their behavior. But this proved to be an obstacle to produce patterns that contained the repetitiveness of the ones from the fish, concluding that only spirals or circular patterns could be drawn, but it could not reproduce concentric figures.

2.2. Optimization Through Relative Positioning

To address the accuracy of the movements, the mobile robot hardware was upgraded to use Hall sensor magnetic encoders[4] and configured to move in straight lines. This improvement in the precision of the movements showed that the robot could create patterns as the ones seen in Fig. 4.

Fig.4 - Repetitive concentric patterns were not possible given that changing the angle and speed were not correctly tracked by the encoders

Nevertheless, this approach could not allow for rotating accurately given that there was no absolute positioning system and the robot initial acceleration and movements produced slipping on the wheels that were challenging to calibrate any sort of compensation. One of the factors that were decisive on this lack of control of the movement was the fact that the voltage affected nonlinearly the torque[5] of the motors, hence causing the wheels to slip more or less according to the remaining battery capacity and charge.

2.3. Mechanical Considerations

The size of the table was increased to 2.2m x 1.8m, leading to an increase of sand, trying to replicate the physical size of the pufferfish drawings. Unfortunately, the 5mm thick Multi Density Fiber (MDF) panel used for this did not have a structure to support the weight of the sand (7kg) and bent in the center of the table. This did not allow the mobile robot to have enough space to drag the magnetic attachment.

The panel size was reduced to 1.2m x 1.2m and included 16 supports of 5cm x 2cm, allowing the mobile robot to move freely under the table and giving enough structure to support 5kg amount of sand.

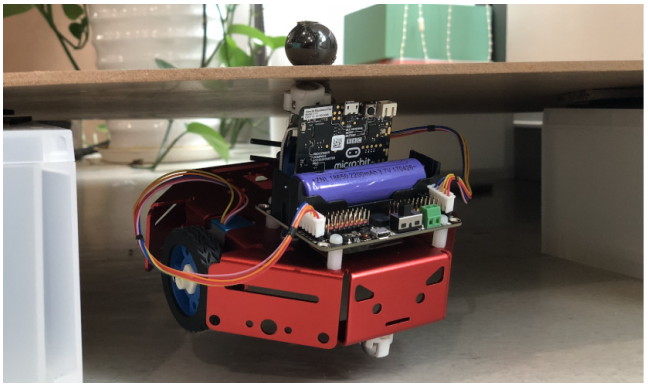

Fig.5 - The thickness of the table and the height of the magnet attached to the robot were carefully chosen to allow movement while still being able to drag the magnetic attachment displacing the sand for the drawing.

2.4. Final Setup

The final setup included geared stepper motors[6] that very precisely moved the robot and a magnet. Given the gear ratio and the steps per revolution, the final setup included geared stepper motors that very precisely moved the robot was also much slower than other models built so far. This seemed to be an advantage when the audience observed the robot drawing. In Fig. 6 and Fig. 7, we can see the display format. The whole setup has been exhibited during the IMA Spring Show 2019 in Shanghai, China and the ICRA-X 2019 in Montreal, Canada.

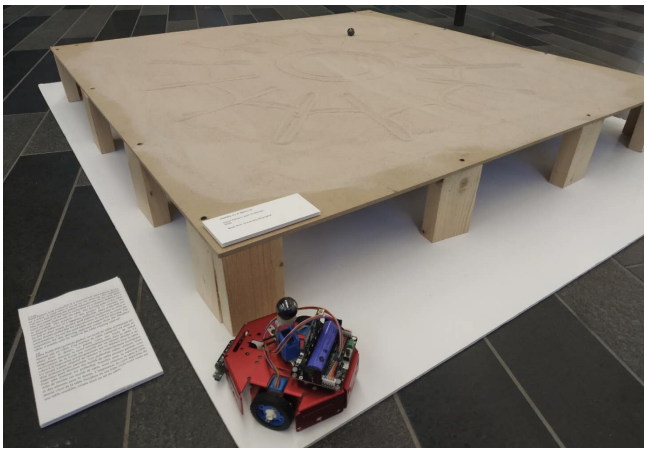

Fig.6 - Exhibit with the mobile robot next to the drawing table.

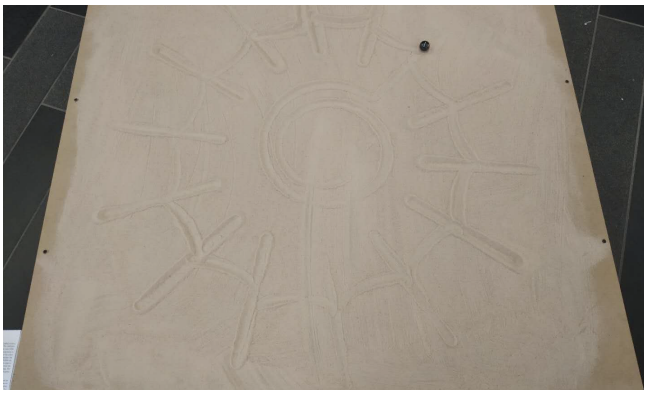

Fig.7 - Final patterns drawn during ICRA-X 2019

3. CONCLUSIONS & FUTURE WORK

"*This work in a way contains the sense of Zen: How a simple ball is moving automatically and slowing on the sand, leaving a symmetrical pattern for the audience to admire and reflect on.*"

--Weidong Chen, associate dean of the Institute of Medical Robotics of Shanghai Jiaotong University

"*I really like how this artwork is representing the mating process of pufferfish. This reminds people of how magnificent mother nature is and the awe we should always give to natur*e."

--Sam Bourgault, Research Assistant at University Concordia

"*The work presented evokes the audience's curiosity to figure out what drives the ball on the sand to move. It first looks like magic. Then, when people bend down to find that there is a robot underneath, they begin to realize the mechanism behind. .*"

--A presenter at ICRA 2019

The feedback collected from academics and professionals has been encouraging, and the initial inspiration of the pufferfish drawing has opened many relevant questions. For our future improvement, we are planning to experiment with different ways to draw patterns with depth, so that we can test the relationship between water speed and the pattern shapes.

An interesting conclusion to this project has been that the experiment might help to understand from another perspective the aquatic effects of the pufferfish geometric concentric figures. Next steps are to improve the current experiment but with a medium that is not only a table but a container with water and sand.

In order to improve precision in the movement, we see that the use of Computer Vision as a method of absolute positioning would be a solution to improve the precision of the drawings. Also, it would be important to increase simultaneously the size of the table to match the 2m diameter circular pattern.

4. ACKNOWLEDGEMENT

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