Using Elastic Plate Vibration Actuation for a Cheap Underwater Swarm Robot

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1 Introduction

A DEMO swarm is a large group of similar agents, natural or unnatural, that work in a self-organized group to complete a task that one agent alone would be unable to do. Examples of these swarms in nature include animals such as termites, which build mounds up to 17 feet tall and tuna, which form a well-coordinated Baitball to confuse predators when threatened. These swarms operate using only local information such as the position of the agents around them and use a set of simple rules to decide how work together with their fellow swarm-mates.

In robotics, swarms provide a more versatile and robust alternative to a single large robot. Robotic swarms are more scalable because the algorithms do not change based on the number of agents and more fault tolerant because there is no single point of failure. Testing swarm algorithms in the physical world requires anywhere from hundreds to thousands of robots. Therefore, as a lab platform, these robots need to be cheap, simple, and maintainable.

Previously, swarm robots have cost over $100 each and require individual attention to switch on and off, charge, and program. The first robot to break with this trend was the Kilobot [1], which uses two vibration motors to move on the surface of a table, was only $15 and took 5 minutes to assemble and can be operated without individual attention, making swarms of a thousand practical for a university research lab. The focus of this paper is to investigate using a vibration motor as an actuator to create a cheap miniature underwater robot. An underwater robot of this scale would allow the exploration of large swarm behavior in three dimensions or allow operation in small spaces inaccessible to humans.

Current underwater actuators with the potential for swarm applications include the dielectric elastomer actuator (DEA) [2] and the magnet in coil (MIC) actuator.[3] A MIC actuated underwater robot costs about $300 and still includes [a fair amount of moving parts] making it difficult to scale down in cost or size. The DEA is also costly in terms of power and production costs. Takesue [4] proved the concept of using a vibration motor to actuate an elastic fin and proved the possibility of steering by selectively actuating fins of different resonant frequencies.

In this paper, we replicate the results of previous work in vibration motor actuated fins and quantify the performance of different fin lengths using a cheap torque based thrust-measurement system. The results of this paper. Results, collected across a range of frequencies and fin lengths, will allow design of a more robust steering for resonance of elastic plate (REP) actuation.

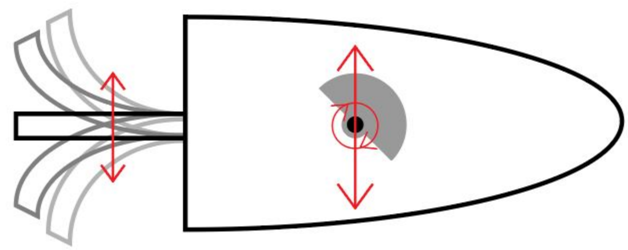

Fig. 1. Principle of locomotion

2 Principle of Locomotion

The proposed design uses a vibration motor and an elastic plate fin for propulsion. The vibration motor will vibrate both the hull and the fin when powered, but because the fin is less stiff than the body, it will vibrate more than the body and propel the robot forward.

Steering will be achieved by using the resonant frequency of the fins. Each fin has a natural frequency and matching that frequency with the motor will cause it to vibrate at a higher amplitude. The natural frequency of the fin is based on the equation for resonant frequency of a cantilever beam, below, where t is thickness of the elastic plate, l is length, E is Young's modulus, ρ is density, and λ i a vibration mode constant.

$$f = \frac{\lambda^2}{4\pi}\sqrt{\frac{E}{3\rho}} * \frac{t}{l^2} \quad (1)$$

3 Design

For the purpose of testing, the design, shown below, was a positively buoyant hull with a slot for a fin and a hole for a vibration motor.

The boat-like shape allows for a stronger drag force on the sides of the robot than the front. This is essential for movement. The testing of a spherical design showed that without this drag, the robot will move back and forth in place. To increase buoyancy, the hull is deeper than it is wide and the walls were only 1 mm thick. The back of the

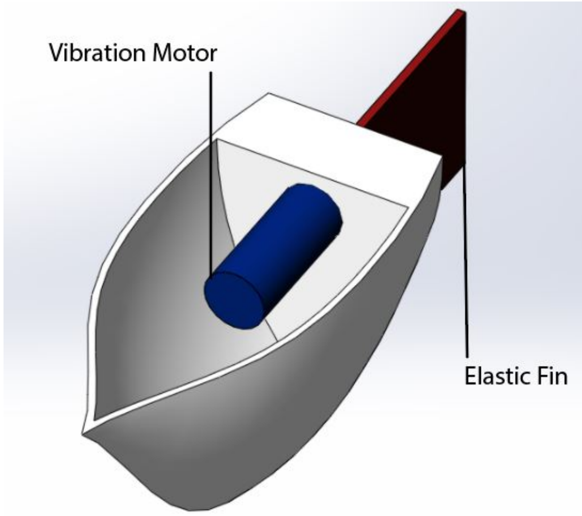

Fig. 2. CAD model of test platform

hull is flat to allow as much contact between the body and fin as possible. The motor was placed in the back of the hull, as close to the fin as possible. The press fit that holds the motor fully contacts both sides of the hull. If the press fit for the motor does not have enough contact with the hull, the vibrations would be absorbed by the body and not transferred to the fin.

We first tried a .8G amplitude coin vibration motor but found that it could not produce a strong enough thrust to overcome the force of the measurement system, described below. For simple forward propulsion, the fin is placed on the back of the hull. A possible design for steering puts a fin on front left or right of the hull to maximize the torque the fin produces and allow the hull to turn on the spot. The limitation with this design is that the vibrations did not transfer equally to both fins.

The design used for data collection had only one fin on the back of the hull and used a 7G encapsulated vibration motor.

4 Build

The hull was 3D printed from white polyjet ABS. The fins were made of rubber or spring steel. Spring steel was both faster and had resonant frequencies closer to the frequency range of our motor. The fin was attached to the hull with epoxy.

5 Test

To characterize the resonance effect across fin lengths, we measured the thrust across the range of motor vibration frequencies. Because this method of locomotion produces very small amounts of thrust, we measured thrust using the set-up below. A long stiff rod attached to a spring was clamped to the tank. The farther along the rod the robot is, the larger the angular displacement. With a significant enough angular displacement, we can measure that displacement, which correlates with the thrust of the fin.

To find the specific thrust we will calibrate the set up by attaching weights on a pulley to the rod. From this, we will find the nature of the relationship between angular displacement and thrust and find the significance of the resonance effect on each length of fin. From these results we can choose the correct fin length for selective actuation of multiple fins and determine the number of fins one vibration motor can control.

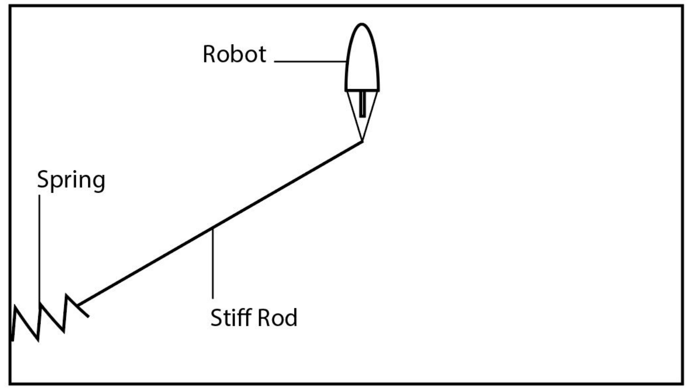

Fig. 3. Thrust measurement set-up

6 Results and Future Work

As a result of this summers work, we created and tested a basic design for forward motion, achieving a proof of motion and a replication of work done in the Takesue [4] paper. We also designed and built a successful thrust measurement system. The rod and spring set-up exerts a small enough force for a robot with a 7G motor to overcome. We also developed and tested a Matlab computer vision script to locate two colored stickers in the picture and calculate the change in angle between the two images. One current limitation with the set-up are that after the motor is engaged, the spring does not always restore to the same position. This may indicate that the measurement system is degrading over time and would make the results unusable.

Once this problem is solved, we will use this set-up to collect data over a range of motor frequencies and over a range of fin lengths. This data will illustrate the relative thrust values over fin lengths and frequencies, but to calculate absolute thrust values, this measurement system must be calibrated with known thrust values. To do this, we will set up a pulley on the side of the tank. A string tied to the rod is fed over the pulley. A known weight is placed in a water-permeable mesh back tied to the other end. The force on the rod will be determined by the gravitational force on the rod. However, the buoyancy force must also be accounted for. To that end, we will need to calculate the volume of each weight and calculate buoyancy force.

The next step is to use the resonance data to design a steering system using the optimal fin lengths. To do so, it will be essential to design an energy transfer system that effectively transfers vibrations equally to both fins. In future versions it may be possible to print both the hull and the fin using flexible material to decrease assembly time.

References

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