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Comparison of Moving Speed of Water Strider Robot with Hydrophilic and Hydrophobic Legs and Feet

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A R T I C L E I N F O

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A B S T R A C T

This paper proposes an application of hydrophilic surface for water strider robot (WSR). We have developed hydrophobic surface obtained by a reactive-ion-etching-textured micro/nano structure and polytetrafluoroethylene processes. We applied the structure for the water strider robot to test the performance of the structure. This paper tests moving speed of a WSR for the changing of driving legs with materials Cu, Fe, and Al and water composition such as NaCl, $C_6H_{12}O_6$, C_2H_5OH. As a result, the copper is the most suitable for the water which is the best environment for the moving speed and the experiments are accomplished for the various cases. Then we applied hydrophobic surface on WSR feet and tested the performance. From the results, the moving time was improved in 0.32 second because of hydrophobic coated surface. The hydrophobic surface can be successfully applied to reduce the moving time of the water strider robot.

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INTRODUCTION

Water strider robot (WSR) is a kind of very special mobile robot since it can be considered as bionic copy of insect water strider which stands and moves in a unique way of locomotion by surface tension. This makes it saving energy greatly by reducing almost all the water viscous drags which are the main resistance to hinder a boat, submarine and fish-like robot. WSR can also access to the very shallow water area, where boat, submarine and fish-like robot can't go. Moreover, it can also be operated with tiny drag, high speed, great agileness and small disturbance for the water. Some researchers have proposed that once equipped with a chemical sensor, it could monitor water supplies for contamination or other toxins; with a camera it could be a spy or an explorer; with a net or a boom, it could skim contaminants off the top of water (Forbes, 2004).

Ref. (Hu, D.L., 2003; Wang, S. and L. Wu, 2010) report calculation methods of surface tension force and relation between surface tension force and contact angle with the aims to propose that the foot surface of the supporting leg should be hydrophobic in order to obtain the maximum surface tension force. In Ref. (Wu, L., 2010) a discussion is reported on the deformation of a linear supporting leg in water and its maximum effective length. In Ref. (Wu, L., 2010) a discussion is reported on an approximate algorithm to optimize the leg's shape as based on a flexibility matrix.

In this paper, to achieve efficient and fast legged propulsion, a test for the selection of a material of the driving leg is accomplished and also water composition for the fast moving is tested. The body of the WSR is made of polystylene and wood for the buoyancy and the material of the driving leg is changed by zinc, steel, and copper and tested for the fast moving. Also water composition is also tested with salt, sugar, and alcohol. After selection the best material of leg and water composition, we apply hydrophobic surface on WSR feet and test the performance we comparing the moving speed of WSR. This robot has trapezoidal footpads that are designed to generate driving force. The robot consists of simple ATMega 128 CPU module, DC motors, and gearbox.

Principles of Water Strider Moving:

The principles of water strider moving are based on the hydrophobicity. A water strider can float on the water for a long time by using a surface tension that occurs in the hydrophobic legs. For the functions of water strider legs, front legs get claws and can catch the prey. Center legs do rowing and make propulsion for the forward movement. Hind legs help

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to change direction when a water strider moves on the water.

The rowing of the center legs generates the ripples in the opposite direction and the swirling movement of the hemisphere form, thus the water strider can move forward by its reaction. But the effect of the ripples is known to be insignificant. In other words, the main propulsion which can make a water strider move quickly is from the reaction of the swirling movement by center legs rowing. This is the same principle with cases of a bird and a fish. Forming a vortex by shaking wings of a bird or a tail fin of a fish from side to side makes a forward movement.

A water strider can float on the water by the buoyancy and can move forward by the reaction force of the water by legs shaking back which is the same with moving by arms shaking of the swimmer.

Forces for Water Strider Moving:

The forces affecting on a water strider in the static state are gravity and buoyancy which act in the opposite directions to each other. Buoyancy is the value by multiplying the specific gravity of the water and the entire volume of the legs submerged in the water and should be bigger enough than the weight of the water strider for floating on the water stably. In the dynamic state which a water strider is moving, the leg thrust comes from the resistance caused by the water. Water resistance can be divided into two forces by the direction of the action. The drag force D is in the direction of the action ant the lift force L is in the vertical direction and the equations are as follows:

$$F_d = \frac{1}{2}\rho v^2 A C_d \quad (1)$$

$$F_l = \frac{1}{2}\rho v^2 A C_l \quad (2)$$

where the C_d is the coefficient of the drag force and C_l is the coefficient of the lift force. The coefficients are dependent on the shape of the foot, the action direction, the foot surface condition, and the viscosity of water. ρ is the density of water, A is the cross-sectional area at the foot movement direction v is the relative speed of the foot against water.

In general, water resistance acts in a direction to prevent that a water strider moves forward. But when the leg of the water strider stirs water back, the water resistance is applied to the upper and front direction. The front direction will act as a driving force and the upper direction will act as a buoyancy aid. Therefore, when designing the shape of the water strider legs and feet, it should be considered that water resistance acts in the forward direction of the water strider movement.

Legs and Feet Design of the WSR:

For the moving action of the WSR, two methods are considered. The first is moving legs forward to the left and right simultaneously. The legs slowly pulled out and quickly push the water to gain driving force. However, this approach produces errors and problems in the measuring because of thrust in the opposite direction when return rowing.

The second one is rowing. Center legs work for rowing and results in the swirl of the hemisphere form and ripples in the opposite direction. And the reaction can make the WSR move forward. Rowing scheme is designed to reliably move forward like a canoe rowing and left and right oars are designed as center legs. For applying power to the left and right legs at the same time, one motor and gears are used and the constant speed is achieved.

Buoyancy of the WSR:

The buoyancy is equal to the weight of the fluid that has the same volume of an object in a fluid. The action point of buoyancy coincides with the center of gravity of the fluid which is extruded by the object. This action point is called the buoyancy center, and is a major factor in determining the resiliency of the tilted floating object.

If the weight of an object is greater than the buoyancy of the object, it will sink. Conversely, if the buoyancy of an object is greater than the weight of the object, it will float on the water. The iron chopsticks sink in the water and wooden chopsticks float on the water because the gravity of iron chopsticks is greater than the buoyancy of iron chopsticks and wooden chopsticks buoyancy is greater than the gravity of wooden chopsticks. The reason that the iron ship floats on the water is because large volume immersion creates greater buoyancy than the weight of the boat. In general, heavier materials than water, like steel and silver, sink in the water and lighter materials than water, like foamed styrene resin, float well. Floating on the water is called the positive buoyancy and sinking in the water is called the negative buoyancy. The similar specific weight with water is referred to neutral buoyancy which means the object does not sink, or float.

WSR Prototype:

This paper designs a body of the WSR with a polystyrene and acrylic, which is available easily in the daily life. In the body part of the WSR, a 6V DC motor is applied for the driving legs and a solar panel is used for the power source. An acrylic plate with 4cm width, 6cm length, and a thickness of 0.2cm is a body for connecting the motor, gears, and the center legs. Fore and hind legs are made of Styrofoam with 1.5 cm width, 3 cm length, and a thickness of 1.5 cm, and attached via an acrylic legs of the body for the buoyancy. Center legs are made of 8 cm plastic and connected to the motor of the body. At the end of the center legs, feet with trapezoidal shape with 1cm upper side, 2cm bottom side, and 4 cm height are applied for the measurement and three ingredients, such as aluminum, iron, and copper, are alternatively tested.

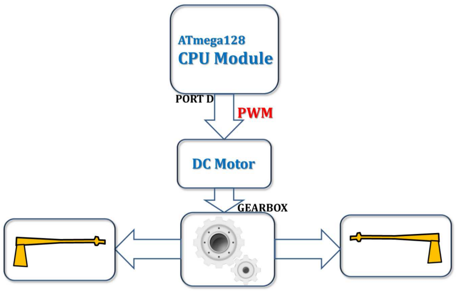


Fig. 1: Schematic block diagram of WSR.

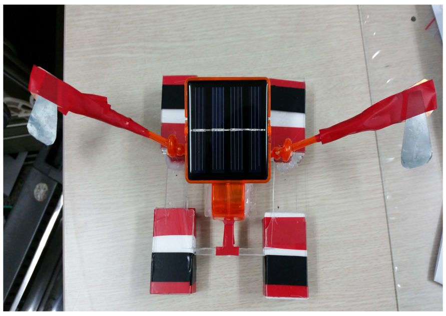


Fig. 2: WSR prototype.

Experiment Results and Discussion:

For the WSR prototype with center legs of copper, iron, and aluminum, various conditions are tested as follows:

1. 10L water
2. 200g salt + 10L water
3. 200g sugar + 10L water
4. 5L alcohol + 5L water

For the accuracy, three times are tested to run the same distance for each case and the results are shown in Fig. 3-7. These materials show hydrophilic characteristics on the water.

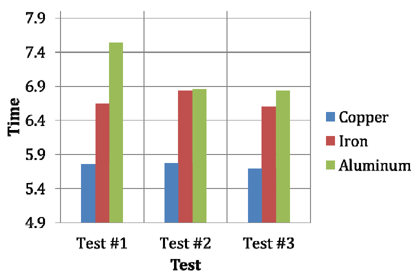


Fig. 3: Test in the 10L water. (case1).

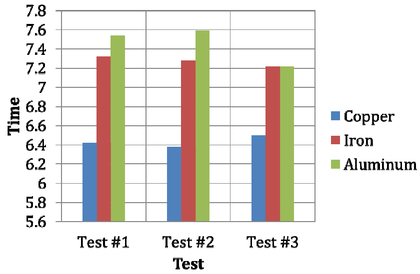


Fig. 4: Test in the 10L water with 200g salt. (case2).

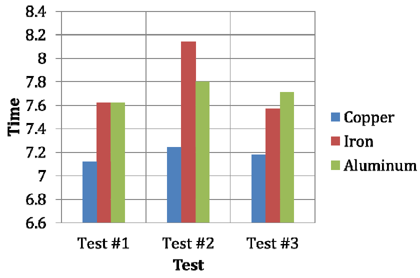


Fig. 5: Test in the 10L water with 200g salt. (case3).

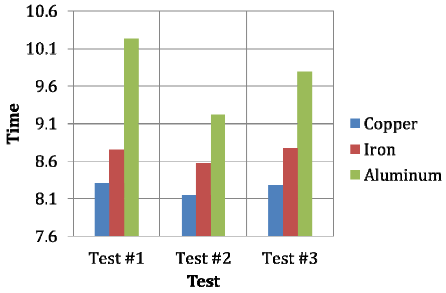


Fig. 6: Test in the 10L water with 200g salt. (case4).

As a result, the average of tested cases is as follows:

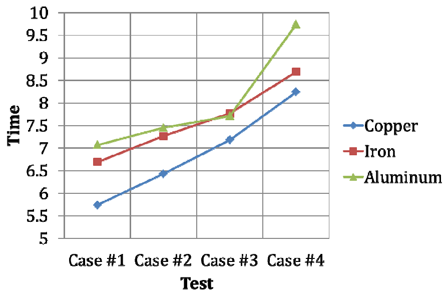
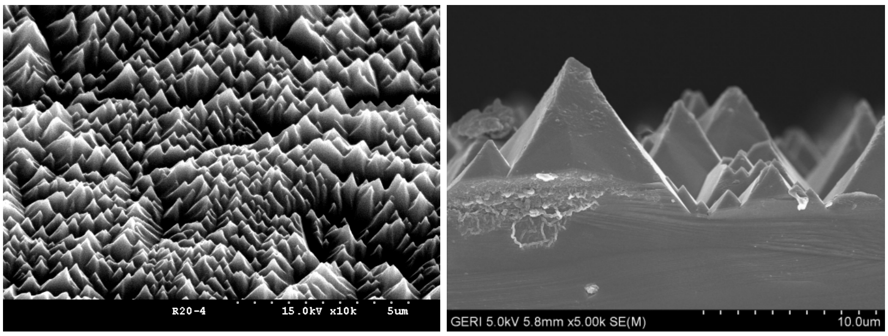


Fig. 7: Test in the 10L water with 200g salt.



(a) (b)

Fig. 8: SEM image. (a) 20 min RIE-etched Si surface and (b) 10 min PTFE coated Si surface on 20 min RIE-etched Si surface.

From the Fig. 3 to Fig. 7, it can be shown that speed difference depends on the leg materials and also on the type of water. Therefore the speed of the WSR is influenced by both leg materials and types of water materials. These legs materials have hydrophilic properties because of oxidation on surfaces.

We also applied hydrophobic surface as a legs and feet materials. As previous reported (Lee, D., 2013), we have developed hydrophobic surface with micro/nano structures by RIE (reactive ion etching) and PTFE (Polytetrafluoroethylene) coating.

We compared the moving speeds between PTFE-coated hydrophobic surfaces on the feet. Figure 8 shows the SEM image of micro/nano textured structures and PTFE coated surface. Figure 9 shows the results of the test. From the results, the moving time was improved in 0.32 second because of hydrophobic coated surface. Therefore, hydrophobic surface can be successfully applied to reduce the moving time of the WSR.

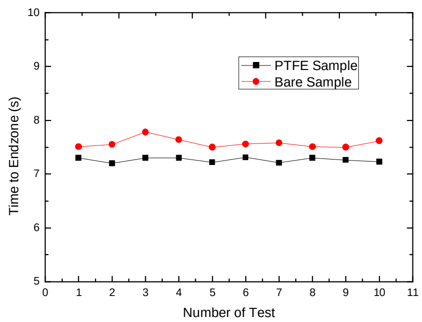


Fig. 9: Comparison of moving speed with hydrophobic surface (PTFE coated surface).

Conclusion:

In this paper, the WSR prototype is proposed by the principles of the water strider movement and various cases are tested for the selection of leg materials and types of water. This paper shows the WSR movement by using the surface tension of the water and the speed depends on the leg materials and types of the waters.

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