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# Water Strider Robot with Superhydrophobic Surface Coated Feet

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**Abstract:** We have developed the fabrication process of superhydrophobic surface with micro/nano texturing method. The contact angle of micro-pyramid was 165.1° after the PTFE coating. The textured surface was applied to feet of Water Strider Robot (WSR). The proposed WSR has Micro Controller Unit (MCU), servo motor and wireless communication module and for the remote control, any PC with Bluetooth module can be used. The control command is given by a user in the hyperterminal which is a default program in the windows operating system. From the results, we know that the moving time was improved in 0.32 s because of the hydrophobicity coating. Therefore, the Poly Tetra Fluoro Ethylene (PTFE) coated surface can be successfully applied to reduce the moving time of the water strider robot.

**Key words:** Water strider robot, superhydophic surface, RIE, PTFE, Bluetooth, hyperterminal

## INTRODUCTION

Surface wettability is one of the most important properties of the material application. Superhydrophobic surfaces such as the leaves of the lotus plant are extremely difficult to wet. The contact angle of a water droplet exceeds 150° and the roll-off angle is <10° (Wang and Jiang, 2007).

The hydrophobic surfaces can be formed by producing micro/nano structures by creating a layer of solid surface etching and low surface energy chemical coating (Wang and Jiang, 2007; Yan *et al*., 2011; Bhushan *et al*., 2009). However, the chemical coating itself is difficult to obtain with a high contact angle. On the contrary, the surface etching technique with high contact angles requires high cost, complexity and long process time (Kwon *et al*., 2009).

Recently, in surveillance and reconnaissance system, the biomimetic robots satisfying various conditions are main research targets. Among them, the robot that can take the place of the human observer is required to monitor the effective surveillance of water pollution and the sea state. For this surveillance, Water Strider Robot (WSR) is one of the good solutions. Especially, when a water strider moves the legs, a driving force of the vortex occurs under the surface of the water. The leg acts as a paddle and the menisci research as wings of the paddle. The strength of this vortex is converted into fluid motion and makes the water strider be slipped on the water surface. Therefore, the water strider will be utilized effectively for various monitoring in water.

Several biological research results have been applied to the characteristics of the WSR and its configuration (Basso *et al*., 2005; Ozcan *et al*., 2010) and more robots are developed (Irawan *et al*., 2014; Wang *et al*., 2010; Takonobu *et al*., 2005). Water dancer IIa robot can rotate and have a speed control function. Furthermore, Water Dancer IIa also can be controlled remotely by infrared light and has been designed to be light weight and low power consumption (Irawan *et al*., 2014). In contrast there is a water strider robot operated by separate parallel mechanism (Wang *et al*., 2010). On the other hand, strider II uses a circular footpad in order to keep the robot on the water surface. A robot with a light and compact structure is appeared in another configuration which uses the three piezoelectric unimorph actuators and has low power consumption (Takonobu *et al*., 2005). PSpHT is focused on the four main legs for walking on the water surface and its structure based on the wind shield enables the buoyancy function for all the components.

In this study, we propose a WSR that can be used for data collection and monitoring of pollution in various waters. Particularly to improve the mobility of the proposed WSR, Micro-Electro Mechanical Systems (MEMS) manufacturing technology is applied to the foot portion of the WSR. As improvement of MEMS technology, this study shows the superhydrophobic surface and its application to water strider robot. We have developed superhydrophobic surface obtained by a Reactive Ion Etching (RIE) textured micro/nano structure and Poly Tetra Fluoro Ethylene (PTFE) processes. We applied the structure for the water strider robot to test the performance of the structure.

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## MATERIALS AND METHODS

As previous reported by Lee *et al.* (2013) and Kim *et al.* (2013), the micro/nano structure was formed nano-needle structures on the micro-pyramid structures as shown in Fig. 1. The contact angle of micro-pyramid was 94.6°. After the RIE etching for 20 min process, the contact angle was then 138.5°. After the PTFE coating, the contact angle increased up to 165.1° as shown in Fig. 2.

Using the increased hydrophobicity by PTFE coating, the WSR developed for the experiments is described in chapter 3. The WSR consists of two main parts, body and legs (legs and paddles). The body is for control and communication and legs are for floating and moving on the water.

**Water strider robot:** Overall system configuration is made of a command window PC which gives an instruction and a WSR which receives and performs the given instruction. Considering the mobility of the WSR, the communication is accomplished wirelessly and enables the remote control. The Bluetooth communication is applied for wireless connection between PC and WSR and we use the RS-232C serial communication method for simple open loop remote control. Configuration of the entire system is in the Fig. 3 where the left side is the command window PC, the right side is WSR with Micro Controller Unit (MCU), servo motor and remote control, yellow line describes the signal and the red line is for power.

As an MCU, we used ATMega 128 which is recently utilized in various environment and PWM (Pulse Width Modulation) is applied to control the servo motor. ATMega 128 have many ports and among them port D is used for PWM output and port E is used for RS-232C serial communication. For communication, pins of Bluetooth module and ATMega 128 should be connected reversely which means RXD in ATMega 128 to TXD in Bluetooth and vice versa. Main power is 6V which is made of four 1.5 V batteries by series connection and the power required for the Bluetooth module is derived from the voltage regulator which converts the main power into 3.3 V as shown in Fig. 4.

As a command window PC, any desktop and laptop is available if it has a Bluetooth communication. And based on the configuration in Fig. 4 and in the functional viewpoint, the proposed WSR is made of mobility unit (servo motor, driving and supporting legs), communication unit (remote control, Bluetooth), Control Unit (MCU) and power unit (battery) as shown in actual figure in Fig. 5.

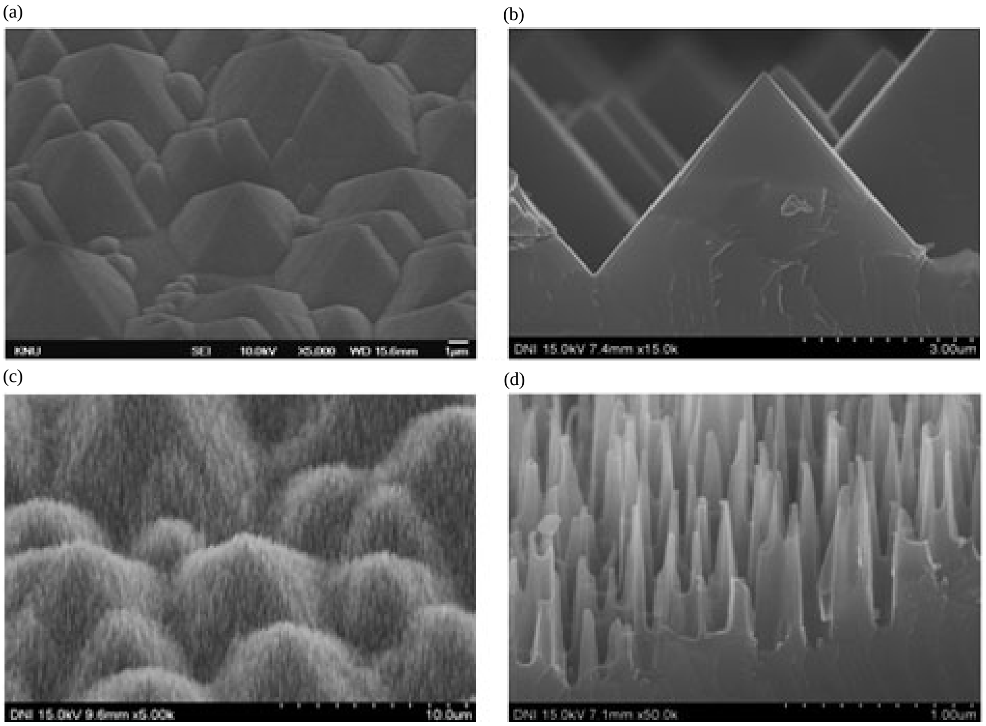

Fig. 1: SEM image of nano-needle structure on the micro pyramidal structure; a, b) Potassium hydroxide (KOH) solution for 20 min and c, d) RIE for 20 min

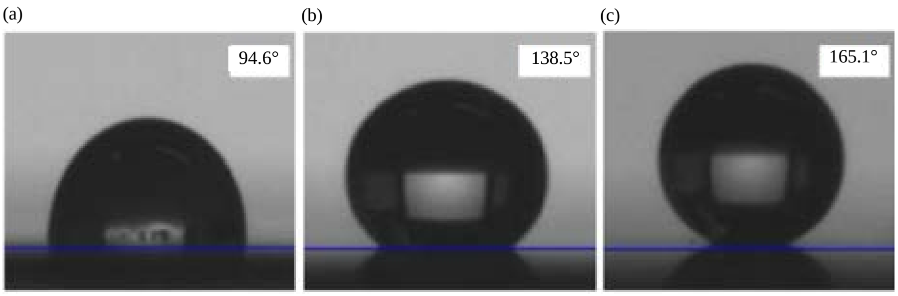

Fig. 2: Contact angle after wet etching, RIE etching and PTFE coating; a) KOH solution for 20 min (94.6°); b) RIE for 20 min (138.5°) and c) PTFE coating (165.1°)

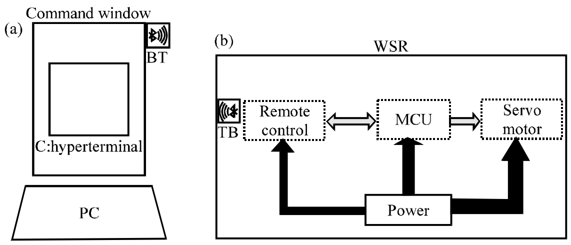

Fig. 3: Overall system configuration; a) Command window PC and b) WSR)

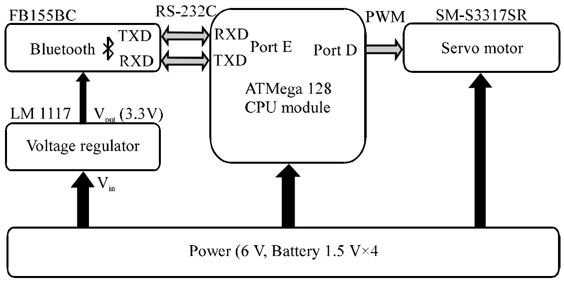

Fig. 4: WSR configuration

The supporting legs are four as shown in Fig. 6 and especially, the bottom of the supporting legs are coated PTFE which raises micro/nano structure to increase hydrophobicity. This hydrophobic property leads to the reduction of friction on the water surface and brings the moving speed increase and the experimental result in this study shows the difference.

For mobility, the driving legs are attached to two servo motors. SM-S3317SR is used which is an analog servo motor with small four plastic gears and one metal gear and single ball bearing. There are three connection terminals and they are GND (black), $V_{cc}$ (red) and the other (white) which is connected to the Pulse With Modulation (PWM) signal.

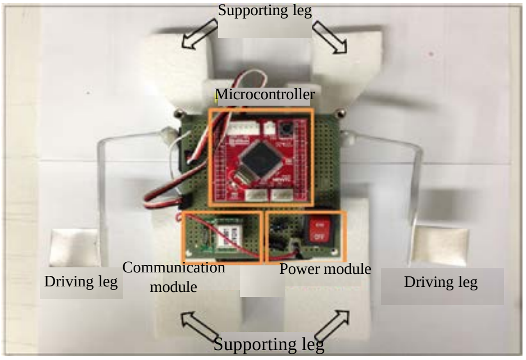

Fig. 5: Functional units of the proposed WSR

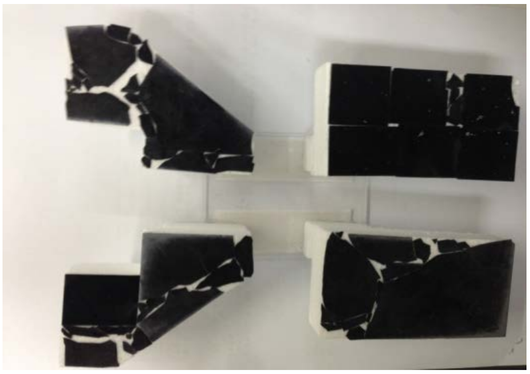

Fig. 6: PTFE coated micro/nano structure attached under the four supporting legs

Servo motor is directly controlled from the command window and this control is one of open loop control method which does not require feedback. In other words, the remotely transmitted command from the master (command window PC) is transferred to the WSR and according to the received command, the WSR is moving. For example, if command is go straight then the right servo motor rotates CW (Clock Wise) and the left servo motor rotates CCW (Counter Clock Wise). For the

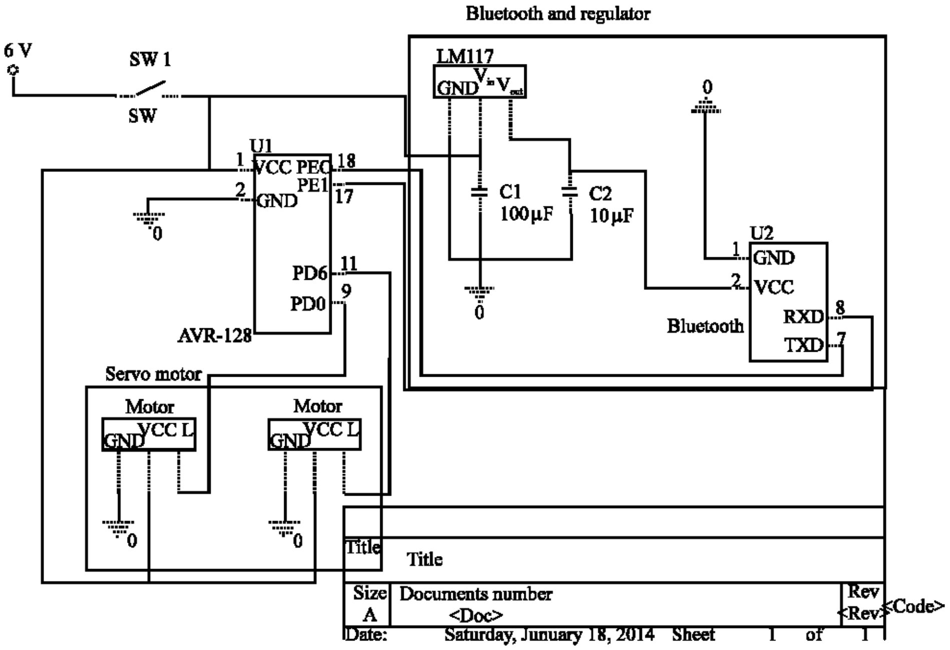

Fig. 7: Circuit diagram of WSR

transferred command, PWM generates control signal to have a constant speed but the rotation direction depends on the given command (forward, backward, left and right). For the comparison, constant speed and direction control is important because relatively, speed and position control of WSR is irrelevant to observe the effect of the moving speed increase by super hydrophobic. Therefore, open loop control without feedback is applied to the direction remote control.

Including two servo motors and ATMega 128, the circuit diagram of WSR is given in Fig. 7 and main power supply is made of four batteries with serial connection. There are also FB115BC Bluetooth module and LM1117 voltage regulator for Bluetooth power in Fig. 7.

RXD and TXD of Bluetooth module are connected to the ATMega 128 and for 3.3 V Bluetooth DC power supply, the used voltage regulator has three terminals (GND, OUT, IN) and IN is connected to the 6 V and the regulator supplies 3.3 V to the Bluetooth module through OUT terminal.

WSR is controlled directly by user via. the Bluetooth communication and RS-232 C is utilized between Bluetooth module and command window PC. To deliver the command through RS-232 C, hyper-terminal which is a default program in windows operating system is used. The commands are forward (W), backward (S), left (A), right (D) and four diagonal directions are also considered and implemented the functionality by combining two key buttons which are W+D (forward-right), W+A (forward-left), S+D (backward-right) and A+S (backward-left) as shown in Fig. 8.

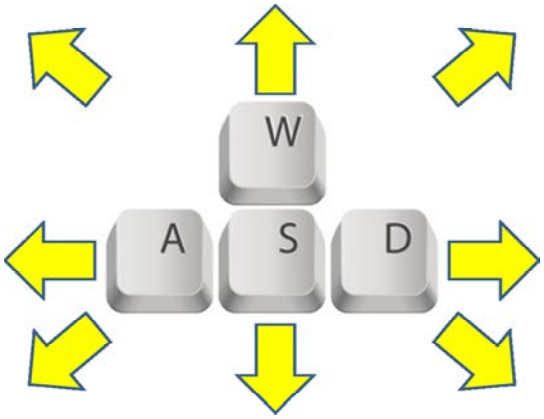

Fig. 8: Keyboard control for WSR

## RESULTS AND DISCUSSION

The motion performance evaluation of robot was conducted to evaluate the performances of the water stride robot with micro/nano textured PTFE coated structure. During the experiments, the water strider robot moved on a water tank surface measuring about 115×115 cm areas. Figure 9 shows the comparison results of moving times between two water strider robots. Figure 10 shows the actual WSR.

From the results, we know that the moving time was improved in 0.32 sec because of the hydrophobicity coating. Therefore, the PTFE coated surface can be successfully applied to reduce the moving time of the water strider robot.

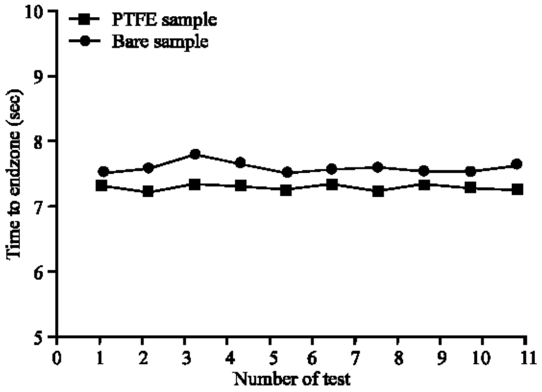

Fig. 9: Comparisons of moving time between two water strider robots

Fig. 10: WSR moving in the water tank

## CONCLUSION

In this study, the WSR is proposed with feet of superhydrophobic surface which is obtained by a RIE textured micro/nano structure and PTFE processes. And the tests are accomplished for comparisons of moving time between two water strider robots with or without superhydrophobic surface. As a result, the moving time is improved in 0.32 sec because of the hydrophobicity coating. Therefore, the PTFE coated surface can be successfully applied to reduce the moving time of the WSR but the figure of the proposed WSR is less like a water strider in nature. So, more biomimetic WSR implementation is investigated for the future study.

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