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Research paper

Simple RAM Control for Water Strider Robot

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Abstract

In this paper, we propose a RAM (Rotate and Move) controller by considering the WSR (Water Strider Robot) with two wheels. The proposed controller commands to move straight after rotating to track the desired trajectory by applying the two wheel WSR characteristics. In this paper, a proportional controller is applied to make the error zero and there is a room to apply many other nonlinear controllers. For a given target point, the rotation angle is computed at first and the shorter rotating angle is chosen between CW (clockwise) and CCW (counterclockwise). After accomplishing rotation, the WSR moves straight toward the target point. The proposed controller is noble and simple and easily track the target point and the simulation results proves the good performance and this controller will be applied to the developing prototype WSR.

Keywords: *Two wheels; tracking; WSR; RAM*

1. Introduction

Recently, biomimetics is one of the strong research interests in robotics and the water strider robot is one of biomimetic applications of robotics [1]. For example, Suhr et al. [2] developed a controllable water strider robot utilizing three piezoelectric unimorph actuators. Song et al. [3, 4] studied the numerical modeling of the supporting legs by respectively developing a rigid-leg model and a compliant-leg model, and built a non-tethered water strider robot with two miniature DC motors and a lithium polymer battery. Suzuki et al. [5] showed two water strider robots with hydrophobic microstructures on the surface of the supporting legs respectively driven by a vibration motor and a slider-crank mechanism. Shin et al. [6] developed a water jumping robot that is able to achieve a vertical jumping motion on the water surface with a latch mechanism driven by a shape memory alloy actuator.
But the present studies have not achieved its autonomous walking, meanwhile there are no such details about motion control in relevant documents. To develop the new generation of robot with certain autonomous walking ability, it becomes so important to study robot's dynamics modeling and motion control problems. Although water strider robot has the similar motion mode to wheeled mobile robot, the latter also has a matured research and related technique is worth learning, control of wheeled mobile robot mainly based on kinematics model [7]. This method ignored the influences of dynamics characteristics (e.g. mass, moment of inertia) to the system. Furthermore, water strider robot works in a special operating environment, water surface. Thus it is required to solve the controller design problem to achieve better effect.
To make water strider robot walk on the water, the robot's dynamics modeling and control algorithms are discussed in the paper. Simple rotate and move (RAM) control method is proposed because the buoyance of the water strider robot (WSR) is well affected by the system dynamics variation and also the variation makes WSR unstable and sinking into the water. So simple action is required to reach the target point and RAM is selected. Especially, to rotate fast, the rotating force is designed and the shortest rotation direction is chosen by proposed method, which is clockwise (CW) or counter clockwise (CCW). P control is applied to verify the control method and Matlab/Simulink is used to simulate autonomous motion of water strider robot. Simulation results show the effectiveness and accuracy of the approach.

2. Model

The prototype of the WSR is shown in Fig. 1 and it has ten supporting legs and two driving legs. Ten supporting legs are coated for super-hydrophobic surface. But the lifting weight limit is strict, so the motor with light weight is required. For the light weight, a vibrating motor was used, which was a part of the smartphone. WSR is two wheeled robots and moves on the water surface. The water surface can be the 2nd dimensional plane, so the dynamics is composed of x and y motion and the angle is added to show the rotation.

Figure 1: Prototype of WSR.

The dynamics can be formulated as Eq. (1).

$$\ddot{x}=\frac{2F}{m}\cos\theta$$
$$\ddot{y}=\frac{2F}{m}\sin\theta \qquad (1)$$
$$\ddot{\theta}=\frac{2W}{I}F$$

And the control input comes from two driving motors in Eq. (2).

$$2F=F_R+F_L \qquad (2)$$

In WSR rotation, the angel error is Eq. (3)

$$\theta_e=\theta_d-\theta \qquad (3)$$

For the movement, the distance is the position difference between starting point and target point. The distance error is Eq. (4).

$$r_e=r_d-r \qquad (4)$$

3. RAM Control

To track the desired trajectory is the common task in control problem, but the desired trajectory is generally curved and it results in the frequent direction change. The two wheeled robot can do one action at one time, which is moving or rotating. Thus if direction changes more times, more rotations are required and the moving time is relatively shorter than rotating time. Furthermore, the frequent rotation means the angular momentum change and it will affect WSR float on the water surface.

So the desired trajectory is assumed only straight line and in this case, tracking means simply to track the end point of the straight line and only requires one rotation and movement (RAM) toward the end point. The curved trajectory also can be tracked by divided many piecewise lines.

Now in RAM control, the tracking is to track the target point as shown in Fig. 2. If the WSR direction is toward the target point, the control problem is only to go straight toward the target point. So the fast rotation toward the target point is the last problem to handle.

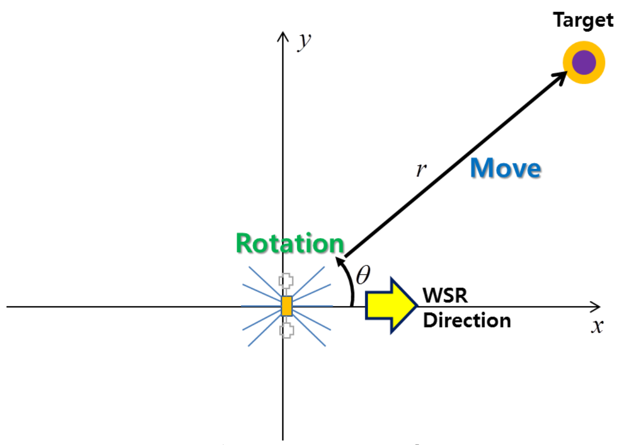

Figure 2: RAM Control.

The WSR rotation can be classified into two cases by the angle absolute magnitude. One is the rotation of angle under π and the other is the rotation of angle over π. Under π ($|\theta_e|<\pi$), the rotation force is applied just to the proportional to the angle error as shown in Fig. 3 and the force is given as Eq. (5) for clockwise (CW) or counter clockwise (CCW) rotation.

$$\text{CW: } F_R=-K_\theta\theta_e,\ F_L=K_\theta\theta_e$$
$$\text{CCW: } F_R=K_\theta\theta_e,\ F_L=-K_\theta\theta_e \qquad (5)$$

Over π, the force is proposed as Eq. (6)

$$F=-sqn(\theta_e)K_\theta\left[2\pi-|\theta|+|\theta_d|\right] \qquad (6)$$

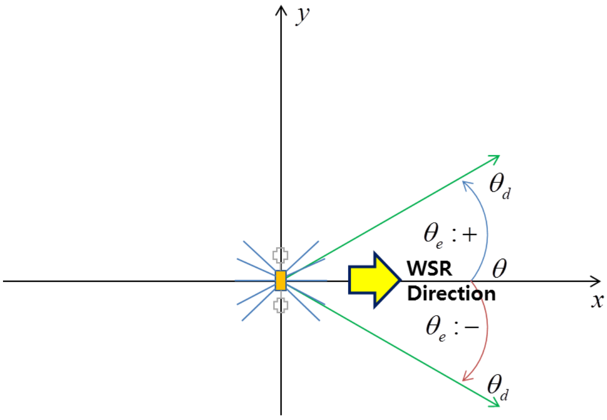

Figure 3: Normal case (< π).

This force just changes the rotation direction oppositely and takes the shorter rotation as shown in Fig. 4. Two examples are described in the Fig. 4 to show the direction change in rotation. Fig 4(a) is that CW changes into CCW and Fig. 4(b) is vice versa.

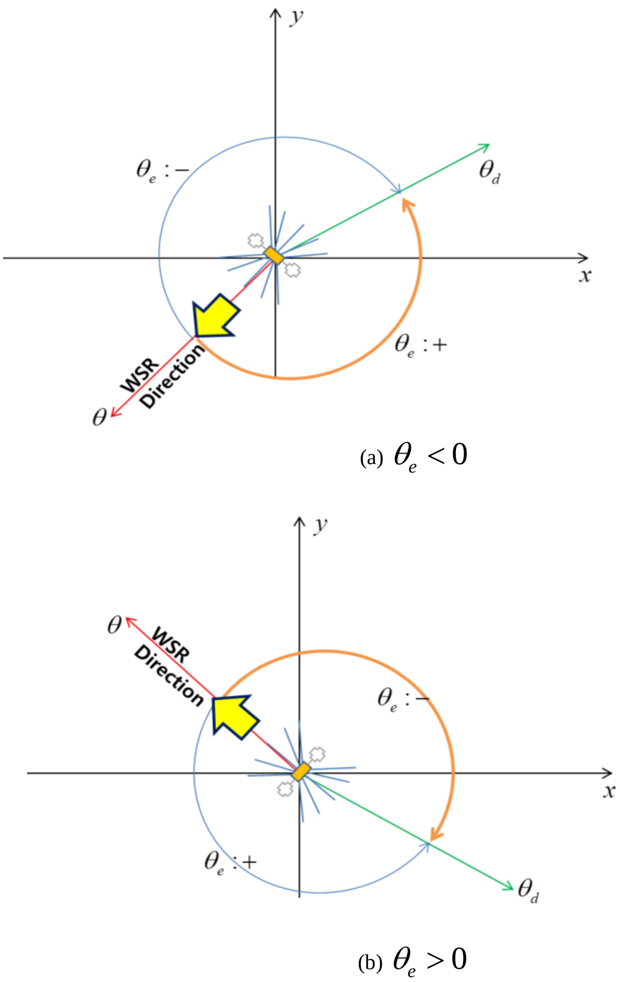

Figure 4: Fast (shorter) rotation (> π).

4. Simulation

For WSR simulation, the model is Eq. (1) and the control force by a motor is given by Eq. (7)

$$
\begin{aligned}
F &= m_R\left(1-a\right)\frac{hn}{60}\times\frac{an}{60\theta_{uw}} \\
&= \frac{m_R\left(1-a\right)ah}{60^2\theta_{uw}}n^2
\end{aligned}
\tag{7}
$$

and the fitted speed curve (r/sec) for the input electric voltage, Eq. (8), is applied [8].

$$
n\left(U_N\right)=\begin{cases} 336.8U_N-61.8 & ,U_N\geq 0.5 \\ 0 & ,otherwise \end{cases}
\tag{8}
$$

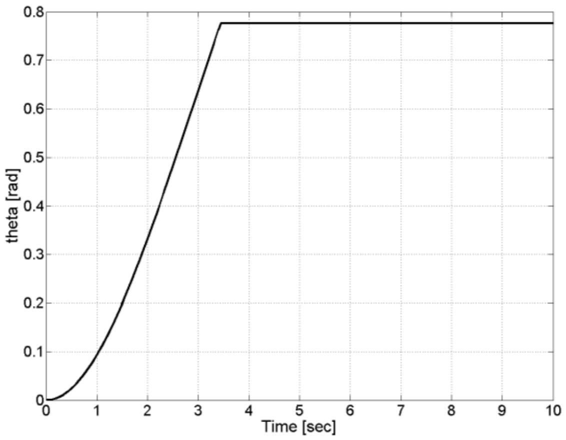

Figure 5: Rotation.

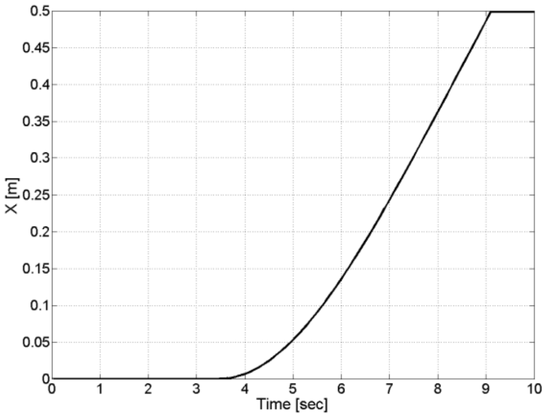

Figure 6: Moving – x position.

For verifying the RAM steps in the control process, the angle and the x, y positions are measured and displayed in the Fig. 5, Fig. 6, and Fig. 7. In Fig. 5, the angle is increased at first toward the target angle which is computed from initial position and target position. After arriving target angle at about 3.4 sec, the angle control method is switched OFF and as the next step, the moving control starts in Fig. 6 and Fig. 7.

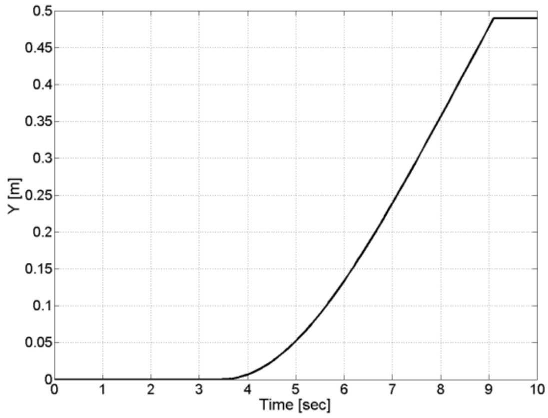

Figure 7: Moving – y position.

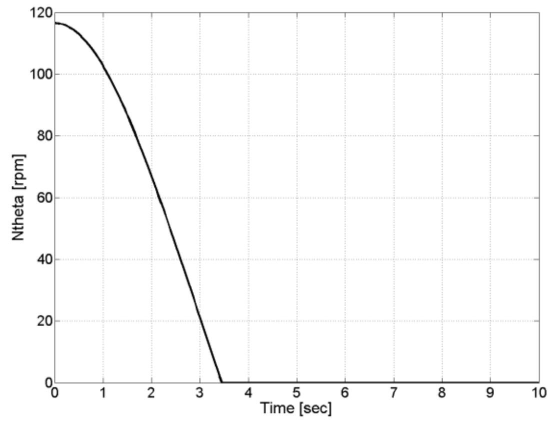

Figure 8: Angle control input.

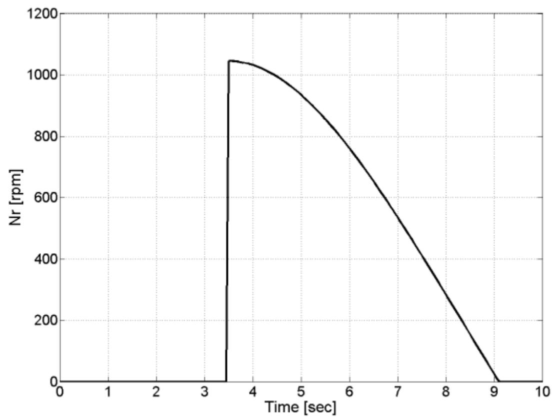

Figure 9: Moving control input.

After finishing angle control, the moving control starts and because the WSR direction is now toward the target point, two driving legs only work for the moving action. In Fig. 6 and Fig. 7, as we assumed that the target point x and y have the same values, the changing positions of x and y are almost the same and after arriving target point, the moving control is also switched OFF at 9.1 sec. There is some gap in y position and it may come from sampling rate for the simulation and the switch ON/OFF with boundaries to check the arrival may also cause that result. In Fig. 8 and Fig. 9, control input also confirms the RAM method. The angle control input in Fig. 8 works for changing angle at first and at 3.4 sec, angle control input is switched OFF and after 3.4 sec in Fig. 9, the moving control input starts to work for changing x and y position and at 9.1 sec, moving control input also stops because the WSR arrives the target point.

5. Conclusion

In this paper, we propose a simple method for controlling the movement of a biomimetric robot and considering the characteristics of the model. In the proposed method, the two-step movement method is used in consideration of the characteristics of the two-wheel drive system. By applying the RAM method called Rotate and Move to achieve the optimal speed while simplifying it, it is possible to minimize the change in the operation of the system and speeds up the operation. We simulate the proposed method through Matlab / Simulink. We can confirm that the proposed method can simplify the motion and predict the motion at the best speed. In this study, we applied the simple P control to this method. In the next study, we will use the sliding mode control with robust characteristics to determine the desired tracking control regardless of the ambient disturbance, that is, we will make it possible to improve the controller.

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