A CPG Based Biomimetic Robot Control for a Multi Link Mobile Robot

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Abstract—Robots and robotics technologies are expected as new tools for inspection and manipulation, especially in the extreme environments where are very dangerous for human beings to access directly such as underwater environments, volcanic areas, nuclear power plants. Robots for such the extreme environments should be robust and strong enough against disturbance and breakdowns. We have focused on the functions of creatures and being finding out solutions to realize robust robot systems. One solution is to take advantage of nervous systems of animals, rhythm generator mechanisms called the Central Pattern Generator (CPG), which has been proved to control the motion patterns, such as walking, respiration and flap. In this paper, a robot motion control system using CPG is proposed and applied to a multi link mobile robot.

I. INTRODUCTION

Robots and robotics technologies are expected as new tools for inspection and manipulation, especially in the extreme environments where are very dangerous for human beings to access directly such as underwater environments, volcanic areas, nuclear power plants. Robots for such the extreme environments should be robust and strong enough against disturbance and breakdowns. We have focused on the functions of creatures and being finding out solutions to realize robust robot systems. One solution is to take advantage of nervous systems of animals, rhythm generator mechanisms called the Central Pattern Generator (CPG), which has been proved to control the motion patterns, such as walking, respiration and flap. In this paper, a robot motion control system using CPG is proposed and applied to a multi link mobile robot.

II. MULTI LINK MOBILE ROBOT

In the previous work[7], we developed Multi Link Mobile Robot (MLMR shown in Fig.1) as a test bed for the evaluation of a motion control system using CPG. We realized wriggle motion for forward and turn motion using periodical output signals of CPG control system. However, MLMR is not developed for evaluation of the hybrid-dynamics systems in which the dynamics of robot transfer from a certain mode to others, which is one of interesting application for CPG system, we developed “MLMR II” (see Fig.2) as a new test bed of motion control and adaptation to environments so as to have two dynamics; on land and in underwater. Table 1 shows the specification of MLMR II. In this paper, we evaluated basic performance of MLMR II and CPG based biomimetic control system is applied to MLMR II.

A. Mechanism

MLMR II is able to move on both environments, ground and underwater. Therefore, Waterproof is very important point in development of robot. The robot is constructed by 8 cylinders which consist of joint that are able to rotate around yaw axis using DC motors, gearbox and control circuit as shown in Fig.3. Each cylinder is put O-rings on shaft of joint...
and lids of cylinder for the waterproof of robot.

Pressure capacity \( P_k \) of each cylinder is calculated using Eq.1 and we obtained the \( P_k = 0.156 \) [MPa], therefore, the maximum operation depth of the robot is approximately 15[m] which is enough depth for experimental pool test.

\[
P_k = E \left[ \frac{\pi}{n^4(n^2-1)} \left( \frac{r}{l} \right)^4 + \frac{n^2-1}{12(1-\nu)} \left( \frac{t}{r} \right)^2 \right] \frac{t}{r} \tag{1}
\]

Here, \( P_k \) is Elastic buckling stress, \( E \) is Young’s modules (3060[MPa]), \( n \) is Bucking mode (2), \( \nu \) is Poisson’s ratio (0.23), \( t \) is thickness of cylinder (3.0 \( \times \) 10^{-3}[m]), \( r \) is radius of cylinder (5.0 \( \times \) 10^{-3}[m]) and \( l \) is length of cylinder (17.5 \( \times \) 10^{-2}[m]).

In underwater, hydrodynamic forces caused by fins and body produce thrust forces and passive wheels are used on ground (Fig.4).

**B. Electrical system and communication**

MLMR II consists of two kinds of cylinders; a cylinder for head (head module) and seven cylinders for joints (motor modules). A motor module has a motor to control joint angle and a circuit board. The circuit has a MPU(PIC18F452), a potentiometer to measure the joint angle, a RS485 transceiver (MAX1487) for communication and a current sensor to measure joint torque. For protection of MPU from noise of motor, the MPU ground is isolated from actuator ground by photo couplers. The block diagram of the circuit is shown in Fig.5. The MPU calculates the target trajectory using the neuron potential of CPG, controls the motor using PID, manages sensor information; (current data, angle data, etc.) and communicates to circuits of other modules using RS485. The head module is the interface device between the robot and the host PC, and transfers the target behavior to other modules.

Token-Passing method is used for the communication. The head module sends a token from head to tail and controls data flow. If a target module gets the token, the module sends its measured data such as joint angle, current, potential of neuron and other modules read and store the data for CPG calculation. The output of neural oscillator is used as the target joint angle. The token flows every 6.25 ms and each module has a chance to output their data every 50 ms.

### Table 1 Specification of MLMR II

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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<tr>
<td>Length [m]</td>
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<td>Weight [kg]</td>
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<td>Number of joint</td>
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<tr>
<td>Operation depth [m]</td>
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<td>MPU</td>
<td>PIC18F542</td>
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<td>Communication</td>
<td>RS485</td>
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<td>Sensors</td>
<td>Current sensor (LTS 6-NP) Potentiometer</td>
</tr>
<tr>
<td>Actuator</td>
<td>DC motor (0SD-SU TUKASA)</td>
</tr>
<tr>
<td>Motor driver</td>
<td>TA8440H</td>
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Fig.1 Overview of MLMR

Fig.2 Overview of MLMR II

Fig.3 Internal architecture of cylinder

Fig.4 Front view of cylinder
III. BASIC MOTION PERFORMANCE OF MLMR II

The sinusoidal target angle is given to MLR II to investigate basic performance in underwater and on ground by measuring the position of each joint using a motion capture system. The weight and buoyancy are adjusted as to swim on the surface. Markers are put on the joints of MLMR II and the motion capture system tracks each marker and calculates the position and the velocity of each link. If you see the motion of real snake, the body of snake is controlled to have a certain phase difference using eq.(2).

A. Application of CPG network to motion control

The robot has 7 joints; therefore, a set of neural oscillators is assigned to each joint. The CPG for the multi link mobile robot is shown in Fig.11. A neural oscillator consists of an extensor neuron(EN) and a flexor neuron(FN). Extensor neurons are connected to flexor neurons of the neighbor neural oscillator, and flexor neurons are connected to extensor neurons of the neighbor neural oscillator. The network architecture is designed having closed loop to generate periodical successive signals with a certain phase. After CPG simulations, we carried out some sets of CPG parameters for generating waves with a certain phase difference. Table 2 shows parameters in forward motion and Fig.12 shows outputs of each neural oscillator. We found out these parameters through a trial and error process using MATLAB.

IV. BIOMIMETIC MOTION CONTROL

A. Matsuoka model

Matsuoka model is expressed in Eqs. (3)-(5), where $u_i$ is the membrane potential of the $i$-th neuron, $v_i$ is the variable that represents the degree of adaptation, $w_j$ is the external input with a constant rate, $f_i$ is the feedback signal from a sensory input, $\beta_i$, $\tau_e$, $\tau_c$ are parameters that specify the time constant for the adaptation, $w_j$ is the weight between neurons, and $n$ is the number of neurons Neural oscillator is able to generate periodical signals by combining neurons with mutually inhibitory connections. Figure 10 shows output of neural oscillator. We developed neural oscillators based controller for biped walking, and the simulation results of biped walking show that the parameters/weights of the controller is able to be optimized by a Genetic Algorithms approach [8].

Matsuoka model’s neural oscillator wave can entrain external oscillatory input using sensor input $f$. Neural oscillator wave is able to entrains to wave that match resonance frequency. Williamson[9], Bailey[10], Ijspeert[11] and Inoue[12] developed robot control system which is able to adapt change of the environment and own dynamics using sensor input $f$. Additionally, Matsuoka model’s wave is able to change amplitude and bias adjusting $u_0$. We adjusted parameter $u_0$ and realizes motion such as forward, right turn and left turn. Then, these motions are analyzed using motion capture system.

B. Application of CPG network to motion control

The robot has 7 joints; therefore, a set of neural oscillators is assigned to each joint. The CPG for the multi link mobile robot is shown in Fig.11. A neural oscillator consists of an extensor neuron(EN) and a flexor neuron(FN). Extensor neurons are connected to flexor neurons of the neighbor neural oscillator, and flexor neurons are connected to extensor neurons of the neighbor neural oscillator. The network architecture is designed having closed loop to generate periodical successive signals with a certain phase. After CPG simulations, we carried out some sets of CPG parameters for generating waves with a certain phase difference. Table 2 shows parameters in forward motion and Fig.12 shows outputs of each neural oscillator. We found out these parameters through a trial and error process using MATLAB. If $u_0$ of each oscillator is adjusted, CPG can output increasing amplitude wave as shown Fig.13. $u_0$ parameters are set as $u_0_e = u_0_f = 0.45, 0.5, 0.55, 0.6, 0.65, 0.7, 0.75$ form head oscillator. Other parameters are same as Table 2. The multi link mobile robot can change heading and to rotates by changing the parameter $u_0$ so as to shift neutral position. If parameters are set as Table 3, robot rotate and changing heading toward right. Fig. 14 show output of CPG network in right turn motion. And, if parameters are set as Table 4, robot rotate and changing heading toward left. Fig. 15 show output of CPG network in left turn motion.

We analyzed motion of robot using motion capture system in underwater and on ground. Figure 16 show motion capture data in forward motion on the ground and in the underwater. Setting parameters are shown as Table 2. Figure 17 show motion capture data in right turn motions when parameters are set as Table 3. And, Fig. 18 show motion capture data in right turn motions when parameters are set as Table 4.

In forward motion, the robot is able to go forward on ground more than in underwater as shown in Fig.16. In underwater, robot was able to move through a distance of about 2.0 meters, but on ground, about 5.5 meters. In right turn motion, the robot is able to go round on ground, but, is not able to go round in underwater. Turning radiuses are 1.6 meters on ground and 1.2 meters in underwater. In left turn motion, the robot is able to go round on ground, but, is not able to go round in underwater. Turning radiuses are 1.6 meters on ground and 1.2 meters in underwater.
\[ \tau_i \dot{y}_i = -v_i + y_i \]  
(3)

\[ \tau_i \ddot{u}_i = \beta_k y_i + \sum_{j=1}^n w_j y_j + \eta_i + f_i \]  
(4)

\[ y_i = \max(0, u_i) \]  
(5)

V. CONCLUSION

Multi link mobile robot which has 7 joints and moves on ground and in underwater is developed. Distributed control system which is implemented biomimetic motion control system using CPG are developed. The system was applied to MLMR II, and motion control were carried out on the ground and in the underwater with adjusting CPG parameters. Additionally, the motions of robot are analyzed using motion capture system. In future work, we will implement sensor feedback to biomimetic motion control system. And dynamics simulation will be carried out.

ACKNOWLEDGMENT

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REFERENCES


Table 2 Parameters of CPG network in forward motion

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<th>$\tau_v$</th>
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<th>$W_{ef}$</th>
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<th>$u_{0,e}$</th>
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Table 3 Parameters of CPG network in right turn motion

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Table 4 Parameters of CPG network in left turn motion

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Fig. 9 Output of neural oscillator

Fig. 10 CPG Network for biomimetic motion control

Fig. 11 Output of CPG network in forward motion

Fig. 12 Increasing amplitude wave using CPG

Fig. 13 Output of CPG network in right turn motion

Fig. 14 Output of CPG network in left turn motion

Fig. 15 Motion capture data of forward motion on ground and in underwater using CPG waves for target joint angle
Fig. 16: Motion capture data of forward motion in underwater using CPG waves for target joint angle.

Fig. 17: Motion capture data of turn motion on ground using CPG waves for target joint angles.