OBSTACLE AVOIDANCE FOR MULTI-LINK INVERTED PENDULUM ROBOT USING VIRTUAL IMPEDANCE

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ABSTRACT
This paper introduces an obstacle avoidance methodology for inverted pendulum robots, which has been a basic function on general intelligent robots. General idea of obstacle avoidance system consists of revised trajectory algorithm and control system. We evolve general obstacle avoidance technique making use of the idea of virtual mechanical impedance. The virtual mechanical impedance is mounted at the robot and produces the enhance force to avoid obstacles and use a small avoided space. The method to obtain optimal equilibrium length from robot to obstacles and virtual impedance parameters are presented. Furthermore, smooth robot motion during avoidance is performed even if the mounted distance sensor is tilted.

Keyword: inverted pendulum robot, multi-link, obstacle avoidance, virtual mechanical impedance, enhance force.

1. INTRODUCTION
This paper introduces our latest research result related to obstacle avoidance control methodology on wheeled inverted pendulum robot. The robot has a head and it is located on the top of the body and some sensors are mounted on the face as obstacle detectors. As the obstacle detectors, vision sensor, laser range finder, and infrared sensors are selected. It means that the robot is intended to be a kind of multi-link intelligent robot. We think that the structure of the robot is better than the structure of normal single-link robot shown in Fig.1 (a). Such the single-link robot cannot find obstacles during movement with tilt, which is often generated at acceleration or deceleration of inverted pendulum robots. The basic structure of the robot is illustrated in Fig.1 (b).

In this paper, we focus on the design concept with respect to obstacle avoidance control technique for the robot making use of the idea of virtual mechanical impedance. In previous studies, number of virtual mechanical impedance systems have been introduced [1]-[4]. The developers have designed the obstacle avoidance systems for huge number of stabled mechanical systems such as four-wheeled robots and manipulators.

As mentioned above, we scope control function that the multi-link inverted pendulum robot avoids static obstacles and concurrently keeps stable during movement. The simulation results about obstacle avoidance performance are introduced with comparison between normal obstacle avoidance and obstacle avoidance using virtual impedance.

2. OBSTACLE AVOIDANCE SYSTEM
This section introduces a practical function of the presented obstacle avoidance. Basically, normal obstacle avoidance system consists of revised trajectory algorithm and the obstacle avoidance system making use of virtual mechanical impedance which consists of two functions with the revised trajectory algorithms and the algorithm performing virtual mechanical impedance.

We assume the situation that the inverted pendulum robot tends to contact obstacles but the position of the wheel is not always near obstacles. At the situation, the neck or head may contact obstacle as shown in Fig. 2. Therefore, the virtual horizontal mechanical impedances at head and body components should be considered to generate enhanced forces. The structure of the control system is overviewed in Fig. 3.

2.1 Virtual impedance system
The virtual mechanical impedance system consists of the virtual springs, dampers and masses. They are created around the position as horizontal circulars on the head, the neck joint, and the wheel of the robot as shown in Fig.4 (a) and (b). Then we define physical parameters of the multi-link inverted pendulum as shown in Fig. 4 (c)
and definition of the distance of virtual impedance \((dX^i_v)\) is given as
\[
dX^i_v = \begin{cases} R\alpha_i^i - D_0^i & : \|D^i\| < R \\ 0 & : \|D^i\| > R \end{cases} \tag{1}
\]
\[
D_0^i = (X_{0,i} - X^i) \cos(\theta_2)
\tag{2}
\]
where, \(D_0^i\) denotes the vector from center of virtual circular \(i\) to obstacle at \(\emptyset\) radian, \(X_{0,i}\) denotes the obstacle position from obstacle detector at \(\emptyset\) rad, \(X^i\) denotes the position of center of virtual circular \(i\), \(R\) denotes the radius of virtual circular or equilibrium length, and \(\alpha_i^i\) denotes the unit vector of vector \(D_0^i\). In addition, virtual force is computed by the mechanical impedance control algorithm as
\[
F^i_{v,\emptyset} = \begin{cases} m_i^i\dot{D}_0^i + c_i^i\dot{D}_0^i + k_v^i : dX^i_v \neq 0 \\ 0 & : dX^i_v = 0 \end{cases} \tag{3}
\]
The total virtual force \((F^i_v)\) of each virtual circular is combined to be virtual enhanced forces, which directly effects to the control input of the multi-link robot system as shown in Fig. 3.

2.2 Revised trajectory algorithms

When a range sensor, which is an example of obstacle detector, is mounted on the head of the robot, we define three-virtual circulars. The concept of this function is as follows: the range sensor detects obstacles, the system changes desired position to new revised position in order to keep the desired distance between robot and obstacle shown in Fig.5. The maximum of \(dX^i\) and the revised position by the presented algorithm are expressed as
\[
X_{RT} = \begin{cases} X_0 - R \frac{dX}{\|dX\|} : dX \neq 0 \\ X_0 & : dX = 0 \end{cases} \tag{4}
\]
Where, \(X_{RT}\) denotes revised position, \(dX\) denotes the direction of totally force of three virtual circulars.\(X_0\) denotes the desired position of user.
robot with virtual impedance force. The simulation result presents that the position of robot with virtual impedance avoids quickly and smoothly. While the magnitude of swaying of body and head components are larger than it.

Table 1 Simulation parameters.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desired position</td>
<td>1.00 m.</td>
</tr>
<tr>
<td>Obstacle position</td>
<td>1.00 m.</td>
</tr>
<tr>
<td>Equilibrium length</td>
<td>0.30 m.</td>
</tr>
<tr>
<td>Virtual mass</td>
<td>1.00 Kg.</td>
</tr>
<tr>
<td>Virtual damp coefficient</td>
<td>100.0 N.s/m.</td>
</tr>
<tr>
<td>Virtual spring constant</td>
<td>50.0 N/m.</td>
</tr>
</tbody>
</table>

5. CONCLUSION

From the above result, the presented obstacle avoidance system has good performance to avoid obstacles successfully and rapidly. Then the head and body of the robot are swinging largely during movement. The presented servo controller is designed based on the system modeling so that feedback gain is optimized. Furthermore, the multi-link inverted pendulum robot system is easily un-stabilized when disturbance force is applied. Therefore, the virtual force should be designed considering unknown disturbance force and it should be carefully designed that the magnitude of virtual force has to be smaller than the force of the current controller.

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REFERENCE


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