Cooperative Negotiation and Control Strategy of A Shape-shifting Robot

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Abstract—The complex environment requires mobile robots to possess high capability of obstacle negotiation. Cooperative negotiation is proposed to endow the AMOeba-I robot with capability of obstacle negotiation and to reinforce the adaptability of the robot in unstructured environment. A mathematical model is established. The relationship between the height that the robot can overcome and angle with gravity offset’s variation is analyzed theoretically. The maximum heights that conventional negotiation method can reach and cooperative negotiation method can reach are compared. Control strategy of autonomous negotiation is presented. The emotion model is established and the robot’s control strategy is fine-tuned according to the change of emotion. Experimental results prove the validity of the cooperative negotiation method and autonomous control strategy.

Keywords: shape-shifting robot, cooperation, negotiation, emotion

I. INTRODUCTION

As a result of earthquakes, terrorism and other reasons, disasters happen frequently. Therefore, relief activities need to be started rapidly after disasters. According to the needs of the relief missions, the rescue robots not always need to avoid obstacles or complex terrains, but are required to adapt to and traverse them. This requires robots to have strong abilities to negotiate obstacles. At the same time the robot’s motion control in obstacle negotiation is much more complicate than that of moving in the plane. When the robot is required to climb obstacles with a certain posture, its remote operation is very difficult. In recent years, the important role played by the intelligent emotion control has attracted researchers much attention. Professor Minsky in the "brain-society" indicated that "the problem is not whether intelligent machines have emotion, but whether machines without emotion can realize intelligence." Therefore emotion can be introduced to support the control throughout the process of negotiation.

According to the deformable mobile robot AMOeba-I’s features, a cooperative negotiation method is introduced to enhance the adaptability to complex environment for the robot so as to make the robot cross the barrier successfully. And we analyzed the relationship between the negotiation height and robot’s center of gravity position. At the same time, control strategy of autonomous negotiation is put forward. Changes of the emotional state are included in the control strategies, in order to help completing control of the whole process of cooperative negotiation. We identified a kind of cooperative negotiation method through experiments. This method can adapt to barriers of different heights. The experiments also verified the effectiveness of the control strategy of autonomous negotiation.

II. THE FEATURES OF AMOEBa-I

AMOeba-I is a kind of shape-shifting robot. The key advantage of AMOeba-I is its adaptability to the environments through various configurations.

AMOeba-I is composed of three modules. A single-module is mainly composed of a link arm, a track driving system, an offset Yaw joint driving system, a Pitch joint driving system. The module in Fig.1 is a standard one and its main specifications are shown in Table I.

![Diagram of AMOeba-I module](image)


Fig. 1 Structure of a single standard module of the improved prototype
TABLE I

SPECIFICATIONS OF A STANDARD MODULE

<p>| | |</p>
<table>
<thead>
<tr>
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<th></th>
</tr>
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<tbody>
<tr>
<td>Length</td>
<td>316–539mm</td>
</tr>
<tr>
<td>Height</td>
<td>126mm</td>
</tr>
<tr>
<td>Breadth</td>
<td>176mm</td>
</tr>
<tr>
<td>Mass</td>
<td>5Kg</td>
</tr>
<tr>
<td>Power</td>
<td>DC24V, 2.5Ah</td>
</tr>
<tr>
<td>Geared motor</td>
<td>20W x 3</td>
</tr>
</tbody>
</table>

AMOEBA-I is repetitively composed of such kind module. It is a tracked robot which can overpass various terrains by transforming its configurations. The key advantage of this type over other link-type vehicle is its adaptability to environments through various configurations. The structure of the AMOEBA-I is shown in Fig.2.

Nine kinds of configurations are available and among them, linear, triangular and parallel are the most fundamental symmetrical configurations as shown in Fig.3.

III. ROBOT NEGOTIATION METHODS

A. A conventional negotiation method

In the process of climbing obstacles, the pitch joints of the deformable robot are fixed, and the whole negotiation process becomes the negotiation of conventional crawler robot. The procedure is shown in Figure 4.

By using the above-mentioned parameters of the deformable robot, from formula (1) we can get the relationship between the robot’s climbing height and the location of the center of gravity, shown in Figure 6.
it can climb to the maximum height of 21.16 cm, with a climb angle of $\theta \geq 55^\circ$. When the robot’s front end crosses the tread line, the robot’s gravity center’s location will keep rising. There will be two situations here: one is the robot’s G position locates over the wall line in the x-axis direction, realizing tread-crossing; the other is in the process of climbing, the robot’s G position keeps being difficult to climb over the wall line so as to lead to the erection of the system and up to overturn.

B. Cooperation negotiation methods

From the above conclusions we can get: if the robot does not change its size and we want it to climb higher vertical obstacles, we need to adjust the centre of gravity of robots in the process of crossing. Therefore we put forward the cooperative negotiation method as shown in figure 7. In the dynamic process of crossing obstacles, the pitching joints in the deformable robot constantly change the configuration of module 2 and adjust the centre of gravity of the entire robot. And modules 2 can also provide the impetus for climb in the process, making crossing easier.

\[ y = \tan(\theta) x \]  
(3)

According to equation (2) and (3), the maximum height of tread can be climb is 35cm, theoretically 13.84 cm larger than the height reached by the method shown in figure 5. In fact, the height is less than this due to insufficient driving force. In order to protect the electromotor and make sure the robot can climb safely, usually the maximum climb height in practice is set to be $H_m = 30$ cm.

As the tread-crossing process only uses the obliquity sensor’s information, in order to avoid a "dilemma" phenomenon of being unable to climb up or down after climbing to a certain altitude, whether the robot can climb obstacles early before the process should be predicted, which is to say we should make sure the height of obstacles is less than $H_m$. Therefore, at the moment of starting to climb, the robot’s ascending angle is measured to evaluate whether it can climb over the obstacle. The rule is: in the process of climbing up, when $\alpha + \theta = [\gamma \Delta \varepsilon, \gamma + \Delta \varepsilon]$ adjust center of gravity by rotating two modules clockwise at the same time in the course of the motion. $\gamma$ is the maximum angle that the obliquity sensor can sense when climbing the height of $H_m$, and $\Delta \varepsilon$ is adjusted value. By this rule, there are only two situations when the robot climbs barrier: one is the robot can successfully cross the barrier, the other is that the robot can not climb up the obstacles, and can not fall into a "dilemma" phenomenon. As figure 9 shows, $\beta$ is $45^\circ$, from calculation we can get $y_{\max} = 53^\circ$.

IV. CONTROL STRATEGY OF AUTONOMOUS NEGOTIATION DECIDED BY EMOTION CHANGE

A. Emotion Model

As a form of reflecting the objective world, emotion is an important component of artificial psychology. A robot can act by a certain degree of emotional state, and emotion affects the final decision to a certain extent. Emotion model basically includes three kinds of feelings: tired, nervous and happy; these three kinds of emotions make full use of robot perception, and are closely related to the behavior of the robot.

(1)Tired

Such a sentiment expresses the duration of an action. If a movement sustained, as time passes by, the robot’s motion control plus wanes and finally adjusts its movements.
\[ E_t = c_t \cdot \exp\left(1/(t_2 + 1)\right) \]  
(4)

Where \( c_t \) is a coefficient and \( c_t > 0; t_2 \) is the time duration of the action.

(2) Tension

Emotion model better adapts to the environment by adjusting the tension status. In the process of negotiation, many accidents are easy to happen. Such as slippage of robot, control error, change of sliding speed, and different adhesion between track and obstacles, which cause the robot’s departure from a scheduled track and cornering phenomena. Emotional tension can respond to this phenomenon to adjust the robot’s trajectory to the due course. The intensity of tension increases by the cornering angle. Therefore, the definition of emotional tension is:

\[ E_t = \frac{\theta_t}{\left| \theta_t \right| \left( 1 + \exp\left(\psi - \left| \theta_t \right| \right) \right)} \]  
(5)

Where \( c_t \) is a coefficient and \( c_t > 0; \psi \) is the cornering safety threshold; \( \theta_t \) is the angle of cornering measured by obliquity angle sensor. A positive \( E_t \) means deflection left, and a negative one means deflection right.

(3) Happy

In the course of negotiation, if the return value of the sensor is within the scope as time passing by, happy emotion will be activated. Therefore, the happy feelings can be expressed as:

\[ E_h = \begin{cases} 
1 & \text{when } |\theta - \gamma| \leq \Delta \gamma; t/T_1 \leq 1 \text{ or } \text{ otherwise} \\
0 & \text{other}
\end{cases} \]  
(6)

Where \( \theta_t \) is the pitching angle measured by obliquity angle sensor; \( \phi \) is the threshold for the clockwise rotation, and \( \Delta \phi \) is an adjustment angle; \( t \) is the time variable, and \( T_1 \) and \( T_2 \) are time thresholds.

B. Autonomous control in cooperative negotiation

Cooperative negotiation control process is shown in Figure 10. In the process of crossing obstacles, the pitch joints of Module 1 and 2 rotate 45° anti-clockwise, this process is named as rising head. After the front end of module 2 lifts, the three modules start to climb at the same speed. When the angle returned by obliquity sensor achieves \([\gamma - \Delta \gamma, \gamma + \Delta \gamma]\), module 1 and 2’s pitch joints rotate clockwise to make module 2 fall down, and this is named as bow. Here \( \gamma \) is 50°, \( \Delta \gamma \) is 3°. When the angle of obliquity sensor is within \([\phi - \Delta \phi, \phi + \Delta \phi]\), Module 2 began to restore to be parallel with module 1 and 3. Here \( \phi \) is -25°, \( \Delta \phi \) is -5°. At the same time, emotion model’s does auxiliary control according to affective changes. In the climbing course the intensity of \( E_t \) increases with duration of action 1. When \( E_t \) reaches a certain value the robot stops at the current movement. That means robots cannot climb the obstacle. The robot adjusts module 1 and 3’s speed according to the intensity of tension \( E_t \), thereby adjusting the balance of robot. Here \( \psi \) is 4°. The state of \( E_h \) shows whether the climbing process is all right.

V. EXPERIMENTS AND ANALYSIS

As shown in Figure 11, the deformation robot can complete the process of whole cooperative negotiation indoor. Vertical height of the obstacles is 32.5cm. Experiments show that this height is the actual maximum vertical height of obstacles that the deformation robot can climb over.

Figure 12 shows the whole process of autonomous cooperative negotiation outdoor. Even though there is a certain deflection angle between the robot and the vertical plane of obstacles, this control method can also complete the whole process of negotiation. Robots will not fall over because of a bit cornering when beginning to climb.
VI. CONCLUSION

According to the structural features of deformable robot, we proposed a cooperative negotiation that improves the deformable robot’s negotiation capacity, and theoretically analyzed the relationship between robot’s negotiation height and its center of gravity’s position. Theoretically, by conventional methods the largest vertical barrier height that the deformation robot can climb over is 21.16 cm, while by cooperative negotiation method the height is 35 cm. At the same time the barrier of self-control have been adopted in the process of autonomous cooperative negotiation by making minor adjustment to control strategies of robot in accordance with the changes in the emotion state and a corresponding emotion model is established. Experiments show that the cooperative negotiation method enhances the robot’s ability of negotiation, and validates the effectiveness of robot autonomous negotiation strategies that are combined with emotion. This will provide important references for the robot’s obstacle negotiation in future when the deformable robot completes task in non-structure environments.

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