HAIBAO Intelligent Robot Developed for Shanghai World Expo 2010

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Abstract—This paper describes the design and techniques of HAIBAO intelligent robot which is developed for Shanghai World Expo 2010. Compared with previous exhibition service robots, the HAIBAO robot has a more flexible motion ability, a more anthropomorphic interactive ability and a more intelligent cognitive and decision ability. Some key techniques including a four-wheeled omni-directional mechanism and its motion control and compensatory algorithm, the anthropomorphic interaction design, and the architecture of multi-tasks scheduling are introduced. During the Expo, totally 184 days, 37 HAIBAO robots have successfully serviced for the tourists by providing information, photography, hall guiding, chat and various entertainments. Their robust, stability, flexibility and friendliness have been greatly commended.

I. INTRODUCTION

Robot has become a highlight in various exhibitions, especially some large scale exhibitions. In Hanover World Expo 2000 [1], Swiss National Fair 2002 [2], Aichi World Expo 2005 [3] and 2008 Beijing Olympic game, intelligent robots have been developed to provide various kinds of services for tourists. Their advanced and entertainment have great attraction to the audience.

In 2010, we developed 37 HAIBAO intelligent service robots for Shanghai World Expo. During the Expo, they worked for information providing, photography service, hall guiding and various entertainments. Compared with previous exhibition service robots, the HAIBAO robot has following characteristics.

1) A more flexible motion ability. The HAIBAO intelligent robot employs a four-wheeled omni-directional mobile mechanism, so that it can move agilely in any direction on the plane. In addition, the suspension designed makes it has a good capability to adapt the uneven ground and the motion planning and control algorithm makes it move smoothly and quickly.

2) A more anthropomorphic interactive ability. According to the image design of HAIBAO, we endow the HAIBAO intelligent robot with a role of young boy, a lovely character and several moods by the ways of expression, dialogue and action. This greatly promotes the affection of the interactive person.

3) A more intelligent cognitive and decision ability. Using the algorithms of human detection, face and objects detection, learning and recognition, speech recognition, localization, navigation, motion planning and multi-tasks scheduling, the HAIBAO robot can successfully carry out various services, such as welcoming, guiding a tour in some exhibition hall, planning the best route from his location to the destination in the Expo Garden, taking photo for and with tourists, and providing information about Expo, Shanghai and China.

This paper introduces some technologies related with above three characteristics. It includes the system design, the multi-directional motion mechanism and control, the anthropomorphic interaction design and the multi-task scheduling.

II. SYSTEM DESIGN

Fig.1 shows the external image and internal structure of HAIBAO robot. It has a height of 155cm and a weight of 70KG. Besides of the motion chassis, there are totally 12 DOFs, 1 for the yaw of neck, 1 for the roll of waist, 5 for per arm. 2 cameras mounted on the head and chest respectively are used to detect and identify human body and face and various objects. A wireless microphone is adopted to capture the speech voice. A laser ranger finder, SICK LMS-100, is used to get the environment information for mapping, localization and navigation. There are also 8 infrared and 8 ultrasonic sensors for navigating safely and 1 gyro for computing the orientation. The tactile sensor in its fringe makes the robot can feel people’s touch. 2 high brightness LCD fixed respectively on the face and chest are used to show the expression and information. The printer below the chest LCD is used to print the download address of the photo took. There are two ways for the communication between the robot and the external monitor and control equipment. One is WIFI, the other is 3G network. Computer, PDA and iPhone all can be used to communicate with the robot.

The Circuit subsystem includes dual master computers, dual master controller units, one sensor measurement unit, one power management unit, and various kinds of motor driver module. The software subsystem consists of voice detection and recognition unit, body detection and recognition unit, face and object detection, learning and recognition unit, map building unit, localization unit, navigation unit, chassis motion control unit, joints motion planning and control unit, human-robot interaction unit, multi-task scheduling unit, multi-robots coordination unit, and monitoring unit.
TABLE I

<table>
<thead>
<tr>
<th>Parameter</th>
<th>DC-motor parameters</th>
<th>Gear-reducer parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage</td>
<td>24V</td>
<td>44N.m</td>
</tr>
<tr>
<td>Rated speed</td>
<td>3000rpm</td>
<td>20:1</td>
</tr>
<tr>
<td>Holding torque</td>
<td>0.4N.m</td>
<td>Max radial force</td>
</tr>
<tr>
<td>Output power</td>
<td>125W</td>
<td>Max axial force</td>
</tr>
<tr>
<td>Peak torque</td>
<td>1.2N.m</td>
<td></td>
</tr>
</tbody>
</table>

B. Motion Control and Compensatory

Based on the motion analysis of single wheel and the geometry of four-wheels arrangement, the relationship between the speed of robot mass center \((\dot{x}, \dot{y}, \dot{\theta})\) and the speed of each wheel \(W_1, W_2, W_3, W_4\) can be gotten.

\[
\begin{bmatrix}
W_1 \\
W_2 \\
W_3 \\
W_4
\end{bmatrix} =
\begin{bmatrix}
\cos(\omega_1) & \sin(\omega_1) & l \\
\cos(\omega_2) & \sin(\omega_2) & l \\
\cos(\omega_3) & \sin(\omega_3) & l \\
\cos(\omega_4) & \sin(\omega_4) & l
\end{bmatrix}
\begin{bmatrix}
\dot{x} \\
\dot{y} \\
\dot{\theta}
\end{bmatrix}
\]

where \(\omega_i\) is the angle between the orientation of \(i\)-th wheel and the orientation of the robot, \(l\) is the distance from the wheel to the robot’s center.

Then the inverse kinematic equation can be calculated by inverting (1), that is

\[
\begin{bmatrix}
\dot{x} \\
\dot{y} \\
\dot{\theta}
\end{bmatrix} = A^{-1}
\begin{bmatrix}
W_1 \\
W_2 \\
W_3 \\
W_4
\end{bmatrix}.
\]

Because \(A\) is not a square-matrix, its inverse is calculated by Moore-Penrose pseudo-inverse,

\[
A^{-1} = (A'A)^{-1}A'.
\]

However, due to the inaccuracy in motion modeling, the discontinuous contact between the rollers on the wheel and the ground, as well as the additional resistance and impact caused by the rollers, the actual motion usually deviates the expectation. To achieve expecting speed, the bias must be corrected by compensating.

From experiments, we found that the implementation bias is only related with the moving orientation and speed. So the method of black-box modeling is adopted. Two three-layers forward BP neural networks are trained and used respectively for the translation motion and rotation motion. The input is the actual speed, while the output is the expecting speed.

Here the actual speed is measured by a vision system we developed. It has the ability to identify and locate the moving objects in an area of 6.5m \(\times\) 4.5m with a speed of 60fps. Its positioning accuracy is less than 1cm and the orientation precision is less than 3° [6]. Fig.3 gives the comparison of before and after applying compensatory, where Fig.3(a) is for the translation motion and Fig.3(b) is for the rotation motion. The dash line indicates the expecting speed, the diamonds and cycles line respectively are the actual speed before and after applying compensatory. It could be seen that our compensatory plays a significant effect, especially on the translation motion [5].

III. OMNI-DIRECTIONAL MOTION

A. Motion Mechanism

To meet the high requirements on motion flexibility and stability to achieve quick, agile and lively navigation and dance, HAIBAO robot adopts a four-wheeled omni-directional motion mechanism which is shown in Fig.2(a)[4]. The wheel designed is shown in Fig.2(b). It composes of two Swedish wheels with a diameter of 15cm. This kind of wheel do not has the non-integrity constraint, which is inherent in standard wheel, that can not move laterally. Using this wheel, the robot can move easily in any direction on the ground. To ensure the long time walk and adapt the uneven ground, the roller’s rubber and curve are extremely important. They are determined by repeated calculations and experiments. The motion chassis consists of three parts, that are a frame which is produced by the sheet metal based on the finite element analysis, a suspension which employs a non-independent form, and 4 drive structures where each structure composes of a DC motor and a gear reducer. Table 1 lists the parameters of the DC motor and gear reducer.

With the configuration described above, HAIBAO robot has a maximal speed of 1.0m/s, a maximal acceleration of 0.6m/s² and a load capacity of 75Kg. It has a good performance on uneven ground. After 184 days’ running, all wheels are still in a good condition.
IV. ANTHROPOMORPHIC INTERACTION DESIGN

The feature of anthropomorphic interaction is very important for some service robots such as the domestic robot, office robot, exhibition robot and etc. As a favorable impression from guest helps much to the interaction between the guest and the service man, winning the favorable impression from human is also important for the robot. If the robot is just a machine that could complete the work human ordered and provide information human needed, people will feel boring quickly and then do not have any desire to communicate again. So what kind of interactive way people accept and love of it? We believe that is the analog of thinking and logic of the speeches.

Firstly, to endow the ability of cognition and reaction, various detection, identification and planning modules are developed. So HAIBAO robot could identify persons in communication, distinguish objects people show him, recognize the words people say, localize itself in the environment and autonomously navigate to somewhere ordered. However, limited by the techniques, the robust and adaptability of these modules are still not reach people’s expectation.

Secondly, we endow a role to HAIBAO robot because the role of a person determine the person’s speech, expression and gesture. According to the image of HAIBAO and the appearance that child is more favored by all kinds of people, HAIBAO robot is designed as a young boy with a humorous appearance that child is more favored by all kinds of people, acting in concert with the speech make HAIBAO robot more lovely and popular. And China, popular movies, stars and activities are also frequently asked. So we design more than 4000 dialogues, one half is about the former three items and the other half is about the knowledge. Because different people has different speech habit, keywords techniques are used here to improve the adaptability. We also design the logic in speech, thus after hearing the answer of HAIBAO, many times the people will ask next questions we have estimated. The popular and humorous words used in the answer also prompt people’s acceptance.

Expression plays a considerable role in the interaction because people is accustomed to look at the face in talking. Sweet expression will make people pleasure. To make the expression plenty and pretty with a low cost, we employ the FLASH technique. A high light LCD is fixed on the head to play the expression. Totally 19 expressions are designed, including normal, talking, smile, laugh, unhappy, cry, tired, sleepy, etc. Some of them are illustrated in Fig. 4. There are also 7 auxiliary elements could be add on those expressions, such as sweat, sunglasses, beard, and etc. These expressions acting in concert with the speech make HAIBAO robot more lovely and popular.

V. MULTI-TASKS SCHEDULING

The multiple ways of interaction between human and robot make the robot have a variety of trigger mechanisms for the tasks. For HAIBAO robot, there are four kinds of trigger mechanism. They are by voice, interface on the chest LCD, network remote command, and automation. The former three kinds are triggered by human, the last one is triggered by the program itself who repeatedly detects the information around the robot and generates new task according to current scene and the errand required. For example, the robot is set in the welcome mode, thus the program detects repeatedly if there is tourist coming or not, when there is a tourist, the program generates a task to speak “welcome”, do a welcome gesture and play a welcome page on the chest LCD. The multiple trigger mechanisms would cause multiple tasks generated simultaneously, sometimes they are conflict because they require a same device. So the scheduling for multiple tasks is absolutely necessary.

The architecture of multi-tasks scheduling is given in Fig. 5.

There are two situations in which some tasks could be executed concurrently. One is there is no device conflict absolutely. For example, navigating autonomously and talking with people do not involve any same device, they completely
could execute simultaneously. The other is there is some device conflict between two tasks, but the device is not necessary for some task, thus the two tasks could execute concurrently after competition. For example, when the robot in the welcome mode detects a tourist, a task described in above is generated, at the same time, the tourist also touches the chest LCD and trigger a query task, thus playing a welcome page is not necessary, other action in the welcome task could be executed concurrently with the query task. If after device competition, the tasks still could not execute simultaneously, they will be arranged according to their priority.

The scheduling module must correctly analyzes tasks’ interruptibility. Some tasks could be interrupted when in execution and continued after some time, such as the task of guiding. Some tasks could not be interrupted, such as the task of speak a sentence, and some tasks could not be continued after interrupt, such as dance for which restart is a better choice.

The scheduling module considering the three properties of tasks makes the robot act more naturally and humanly.

VI. RESULTS

Fig. 6(a) shows the developed HAIBAO robot. During the Expo, totally 184 days, 37 HAIBAO robots have serviced for the tourists at the sites of China Pavilion, Expo Axis, Culture Center, Recreation Bay, Pudong Airport, Hangzhou Museum and etc. Almost every day, there were a very large amount of tourists in the Expo Garden, especially at the service sites of HAIBAO robots. To release the tourists’ impatience, HAIBAO robots chat with the tourists waiting in line, provide information about Expo, Shanghai and China, take photo for them, and do some performances such as dance, singing, as shown in Fig.6(b) and (c). Even in the summer, under a high temperature over 40°C, HAIBAO robots still worked for 8 hours per day. In addition, the robot in Hangzhou Museum acted as a guider to introduce the culture and view of Hangzhou.

In addition, HAIBAO robots successfully participated some large publicity campaigns, for example, on May 1st, 4 HAIBAO robots simultaneously danced for the famous singer Zuying Song when she sang the song of "Spicy Girl" (as shown in Fig.7(a)), and on June 1st, 20 HAIBAO robots lined up to show in the big parade in which the whole walking distance is 1.8Km (as shown in Fig.7(b)).

184 days of operation proved the robust and stability of HAIBAO robots. During the Expo, only 4 technician was working for maintaining and repairing, volunteers on site were just in charge of powering on/off, maintaining order, and sometimes controlling the robot. The main weakness of these robots is the motors of the elbow joint and wrist joint on the arm were easily broken when some people pull the arm with a big force. After Expo, 30 robots are still in working condition. Thus for an interaction service robot, arm’s flexibility to adapt the extern force must be considered.

VII. CONCLUSION

This paper describes the HAIBAO intelligent robot designed for Shanghai World Expo 2010. During the Expo, the 37 HAIBAO robots have successfully serviced for the tourists and brought a lot of happiness for everyone. Their flexible motion ability, anthropomorphic interaction ways, humorous conversation, lively character, and comprehensive services have been greatly commended by the tourists. In the future, we will further advance the techniques, improve the performance of the robot and apply it into other fields.

REFERENCES