A Survey on the Structures of Current Mobile Humanoid Robots

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Abstract—Many types of mobile humanoid robots combining both the characteristics of mobile robot and humanoid robot have been developed in the literatures in the past two decades. This paper is aimed at presenting a survey of robotic structures for the mobile humanoid robots. The most used ones are wheeled mobile humanoid robots with their salient features of the human-like upper body normally containing two arms, the waist, neck and head mounted on a wheeled mobile platform. The whole-body structure and different parts are all analyzed in detail by comparing among similar mobile humanoid robots. This work will be meaningful for the design of future promising mobile humanoid robots.

Index Terms—Mobile humanoid robot, Biped humanoid robot.

I. INTRODUCTION

Service robots that have to operate in many different and unstructured environments will be of great technological and economical importance. Humanoid robots(HR) offer great potential for assisting human with a variety of tasks. By definition, HR will work autonomously or in cooperation with humans in a dynamic, relatively unstructured environment as assistance or guidance and they will need a high degree of robustness, adaptability and advanced communication abilities in order to deal with unexpected situations.

As far as the structures of the humanoid robots are concerned, they can be divided into two categories: the biped humanoid robots(BHR), like ASIMO[1] and H7 as well as the mobile humanoid robots(MHR)[2]-[21]. The BHRs have been developed mainly to investigate the fundamental functions of biped locomotion such as walking and turning whereas the MHRs have been developed mainly to study human-robot interaction and cooperation[3].

In recent years, the MHRs have been widely applied as service robots although they can not climb stairs, jump or step over obstacles where humans can walk around without consuming too much energies, they can access most of the in-door environment. MHRs will be indeed a much better choice not only because wheels would suffice but also because batteries and computers, as well as additional hardware could be easily built into the base without limiting its usability but enormously increasing autonomy. These MHRs always take the structure of upper-human-like body mounting on the mobile base, providing a good mobility and flexibility.

The design of these robots requires a high integration of mechanics, electronics and computational technologies.

There are many successful examples of MHRs which are built and designed to study different subjects. HERMES[4]-[5] made by Bundeswehr University demonstrates several key technologies such as locomotion, manipulation, HRI and learning. WENDY[6]-[7] developed by Waseda University can pick up the objects and do cooking tasks of egg breaking and cutting vegetable with a kitchen knife successfully. MR Helper[8] made by Tohoku University can handle an object in cooperation with humans. Cog[9] constructed by MIT is an upper-torso humanoid robot with 21-DOF and a variety of sensory systems, including visual, auditory, vestibular, kinesthetic and tactile sensors. ARMAR-III[10],[11],[12],[13] made by Karsruhe University has a full of 43-DOF which can realize complicated HRI in a household environment.

Robonaut[14][15] developed at the NASA Johnson Space Center is the first HR specifically designed for space while Centaur[16] is created by pairing Robonaut with a new four-wheeled mobility platform. YIREN[2][3] developed at Shenyang of China applies an advantageous waist mechanism. Robovie[18][19] made by Osaka University can accomplish exhibit-guiding and free-play interaction at the science museum.

The aim of this work is to remind primarily the reader of the development related to the structures of MHRs after inspecting numerous published papers, and provide readers with some typical and promising mechanisms of MHRs. More and more research works are focused on MHRs for the manipulation capabilities, while intelligence of current MHRs are still far away from the human ability in solving complex manipulation tasks. This paper presents the whole structure of the MHRs in section II, and analyzes the basic parts of the MHRs with comparisons in details in section III. The paper is summarized at the last section.

II. WHOLE STRUCTURE OF WHEELED MHRS

The purpose of most MHRs is for friendly HRI as service robots so they commonly apply the structure with the human-like physical upper body. Almost all the MHRs have the similar design of the upper body mounted on the mobile base and the basic upper body consists of one head and two arms with simple gripper or dexterous hands. Based on different purposes...
Fig. 1. A typical prototype of the MHR

<table>
<thead>
<tr>
<th>MHR</th>
<th>base</th>
<th>waist</th>
<th>arms</th>
<th>hand</th>
<th>head (neck)</th>
<th>eyes</th>
<th>total</th>
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<td>3</td>
<td>3</td>
<td>2</td>
<td>7</td>
<td>2</td>
<td>8</td>
<td>4</td>
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<tr>
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<td>7</td>
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<td>3</td>
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<tr>
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<tr>
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<td>3</td>
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<td>7</td>
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<td>7</td>
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<tr>
<td>YIREN</td>
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<td>2</td>
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</tbody>
</table>

Table I: The DOF numbers of different MHRs and their basic parts

and applications, some MHRs will add the waist and have more flexible DOFs in the arms, neck, head and hands. A typical MHR prototype includes the basic parts of mobile base, waist, head and arm[20], which is shown in Fig. 1.

Due to multiple tasks and good cooperative interactions with human beings, some MHRs are required to have many DOFs. By summarization, the numbers of DOFs of several whole MHRs and their parts are listed in Table 1, so it is clear to obtain the flexibility and complexity of their structures.

III. SUBSYSTEMS OF THE MHRS

This section discusses about different subsystems of MHRs in details, provides the most typical structures and other aspects of considerations during the design.

A. Upper-body

The upper body contains most components of MHRs and its weight will have a great influence on the manipulation in addition to the space restrictions and mechanical limitations. So the design of upper body structure should consider not only the human-like configuration, but also the mechanical aspects of motors, cable routing and location arrangement of sensors.

As shown in Fig. 2, ARMAR-III[11] has the typical MHR upper body with two 7-DOF arms, two 8-DOF hands, 3-DOF waist, 4-DOF neck and 3-DOF eyes. Fig. 2(a) shows the human-like upper body and Fig. 2(b) shows its kinematics.

B. Mobile base

The bases of mobile robot usually have types of tracked base, gantry base and wheeled base whereas the wheeled base is applied mostly in the field because it provides the great mobility and can be used in most of human friendly environment.

Normally, the wheeled base has the structure of two wheels, three wheels and four wheels. The Segway\textsuperscript{TM} Robotic Mobility Platform (RMP) is a two-wheeled motorized vehicle for transportation combined by Robonaut as a mobile base[17]. Most MHRs use the three-wheeled mobile platform with two driven wheels and one passive wheel, as shown in Fig. 3(a). The Centaur lower body applies a rugged four-wheeled rover with rear wheels driven and independent front steering and suspension. HERMES’s mobile base consists of four wheels that are placed in the middle of each side, two driven and steered wheels and the others passive castor wheels as shown in Fig. 3(b). Above mobile bases are all nonholonomic while for some narrow environment, holonomic mobile base is used by ARMAR-III with three passive rolls known as Mecanum wheels or Omnidirectional wheels at the circumference as shown in Fig. 3(c).

C. Head

A head subsystem of MHRs should act as not only visual information sensor, but also an interface for collaborative tasks with human beings. Normally, the head has the flexible neck and eyes for more vision, and if facial expressions are necessary, more DOFs are required for the ears, eyebrows, mouth, and eyelids.

The typical head of ARMAR-III features human-like characteristics in motion and responses with 4-DOF neck mechanism and two eyes shared a common tilt DOF. Each eye is equipped with two digital color cameras (wide and narrow angle) to
allow simple visual motor behaviors such as tracking and saccadic motions towards salient regions, as well as more complex visual tasks such as hand-eye coordination[11]. As shown in Fig. 4, Fig. 4(a) is the prototype of ARMAR-III head and Fig. 4(b) is the 4-DOF neck mechanism.

D. Arm

The arm of the MHRs should be flexible and anthropomorphic for better adaptation to typical human environments and to allow for human-like behavioral strategies in solving complex tasks. In order to achieve a high degree of flexibility and to allow the simple and direct cooperation with humans, most MHRs apply two 7-DOF arms assembled symmetrically on both sides of the upper body.

Some MHRs like HERMES apply the arm structure as shown in Fig. 5(a) with shoulder of 2-DOF, elbow of 2-DOF, wrist of 2-DOF and a simple gripper as the end-effector. Some MHRs like ARMAR-III apply the arm structure as shown in Fig. 3(b) with 3-DOF shoulder, 2-DOF elbow, 2-DOF wrist and a dexterous hand. Some MHRs like WENDY and YIREN apply the arm structure with 3-DOF shoulder, 1-DOF elbow and 3-DOF wrist equipped with a five-fingered hand as shown in Fig. 3(c) and a simple gripper as shown in Fig. 3(d). The reachable workspace of these different structures of arms is compared carefully with the consideration of the inverse kinematics and dynamic properties in[3].

E. Waist

As the center of the whole body, the waist of human is a typical super-redundancy system with high flexibility that plays an important role in adjusting the center of gravity (COG) and maintaining the humans equilibrium. The waist mechanisms of MHRs are utilized for expanding the working spaces and improving the flexibility and stability during the tasks with human or cooperative interactions with external environment.

The design of waist mechanisms should include not only the requirements of function, but also the features of structure, such as cable routing, motor position, drive transmission, etc. Based on different functions, some MHRs build the 3-DOF waist mechanism like AMAR III in Fig. 6 and YIREN in Fig. 7, whereas some MHRs apply the waist mechanisms with less than 3-DOF or no waist.

The waist of ARMAR III has a typical structure with 3-DOF of Rot. 1, Rot. 2 and Rot. 3 as shown in Fig. 6. The driving train for the DOFs of Rot. 1 and Rot.3 consists of Harmonic Drive transmissions and toothed belt transmissions. The driving train for the DOF of Rot. 2 is different from most of the others as it consists of a toothed belt transmission, a ball screw and a piston rod which transforms the translational motion of the ball screw into the rotational motion for moving the upper body sideways. This solution is chosen because a high gear ratio can be achieved and the motor can be placed away from the driven axis and away from the point of intersection of the rotational axes[13]. The design of waist mechanism in YIREN[2] has many advantages: 1)The COG falls off and the body becomes more steady; 2) The actuating systems and differential mechanisms arent fixed on joints and moving parts directly, which will decrease the load of motors and improve the dynamic property of joints; 3) Two differential mechanisms are fixed in closed chains to decrease the power of motors; 4) The cable and compliant elements can adjust the stiffness of the waist to meet the needs for the compliance and safety of the waist.

F. Hand

The human hand is a very complex grasping tool that can handle objects with different sizes and shapes, so in order to imitate human hands and cooperate with human beings in dynamic unstructured environments, many research activities have been carried out to develop artificial robot hands with light-weight, high flexibility and high intelligence. Normally, in consistency with the human hand, the design of humanoid hand considers the subjects such as the number of fingers and
the placement and motion of the thumb, the proportions of the link lengths and the shape of the palm. Besides, the design and modeling of a sophisticated hand faces other challenges in the design of humanoid robots and artificial arms. Firstly, it is difficult to place the complex mechanism of the hand into a narrow and limited space. Secondly, the weight of the hand has a great impact on the actuators used to construct the robot arm or the artificial arm. In fact, the weight of the hand increases the power consumption of the robot, gives a load on every joints and causes unstable behavior of the arm[21].

Some MHRs install the end-effectors with the dexterous hands which can cope with the wide variety of tasks and objects while some MHRs applies the simplified structure of hand for some special tasks. As shown in Fig. 8(a), the Robonaut’s hand[14] is one of the first developed explicitly for EVA use and is the closest in size to a suited astronauts hand. As Fig. 8(b) shows, the hand is divided into a dexterous set used for manipulation and a grasping set used to maintain a stable grasp while manipulating an object.

IV. CONCLUSION

This paper classifies the HR into MHR and BHR according to their features and structures, which is helpful for the progress of MHR as a separated class since MHRs are working recently in human friendly environment. The main part of this paper presents a survey of similar MHRs by inspecting the whole structure as well as the upper body, mobile base, head, arm, waist and hand in details through careful comparisons and summarizations. This survey work will provide preliminary knowledge of state of art research works on HR and lay a good foundation on the development of MHR our Mechatronics Laboratory.

REFERENCES