Historical Development of BHR Humanoid Robots

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Abstract. This paper presents the historical development of the humanoid robots of the BHR series, ranging from the first Chinese humanoid robot BHR-1 to the current sixth generation BHR-6P. The early BIT (Beijing Institute of Technology) activities in robotics have laid a foundation for the development of the BHR series. The success of the first prototype of BHR-1 in 2001 gave the start of Intelligent Robot Institute and the technological and social influence attracted proper funding for continued development of the next BHR generations. Several challenges have been overcome by fully independent efforts of BIT, and future designs of the BHR series will aim at breaking through more challenging technological difficulties in the field of humanoid robotics.

Keywords: History of humanoid robotics · History of BHR series
BHR humanoid · History of IRI-BIT

1 Introduction

Most of the robot laboratories can date back to the 70s of last century. But for humanoid robots, the activities started later. Nowadays, more and more laboratories are founded to work researches and experiments on humanoid robots, with significant development of humanoid robots as outlined for example in [1–3].

Since the start of the third technology revolution, the emergence of automation and intelligence has paved the way for robots. After half a century of development, both the number and quality of robots have increased greatly all around the world, thanks to the ever-increasing number of robotic laboratories as summarized in [4]. So far, most countries in the world have established several robotic laboratories, and academic exchanges between laboratories from all over the world have become more and more frequent. Humanoid Robotics is an important branch of Robotics, since humanoids show special advantages over other robots due to their close similarity to the human body. They can operate in complex environments for a wide variety of complex tasks. Therefore,

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more and more countries have gradually increased their researches on humanoid robots like in Japan, America, China, and some European countries. Today, most of the humanoid robot laboratories are interested in the research of robot capabilities such as walking on various terrains, fall protection, and interaction with the environment, [4].

To a certain extent, Robotics reflects a country's scientific and technological strength. China began to attach the development of the robot industry at the end of the last century, and it has made great achievements not only in industrial robots but also in service robots. Humanoid Robotics has attracted more and more attention in China. Many Chinese colleges and universities have carried out researches on humanoid robotics, such as Harbin Institute of Technology, National University of Defense Technology, Shanghai Jiao Tong University, and Beijing Institute of Technology. Among them, Beijing Institute of Technology has succeeded in ranking in the world's top level in terms of robotic research. The BIT Biomimetic Robot Laboratory was born in 2000, and since then the research team in the laboratory has developed six generations of humanoid robots, known as the BHR (Beijing Humanoid Robot) series, as outlined for example in [5–9].

This paper introduces the history with main achievements of the laboratory. The IRI (Intelligent Robotics Institute) of BIT plays an dominant role and has made significant contributions in the field of humanoid robotics in China, and its success in the BHR series is believed to serve a guiding role for future development of humanoid robots not only in China.

2 Preliminary Work

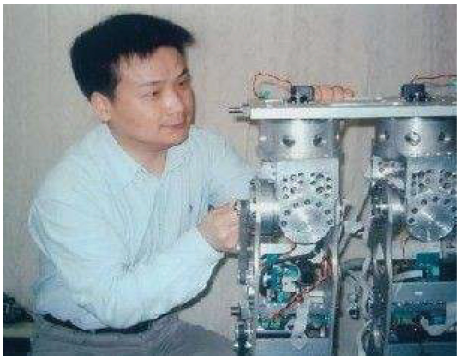
The robotic laboratory was founded in 2000 by Prof. Qiang Huang, Prof. Li Kejie and other professors at BIT, see Fig. 1. For promoting the development of humanoid robotic technology. Prof. Qiang Huang received his bachelor degree and master degree from Harbin Institute of Technology, China in 1986 and 1989, and started his Ph.D. study at Waseda University, Japan in 1991. Since then he has been engaged in research on Robotics within international frames.

Fig. 1. The establishment ceremony of the intelligent robot institute, at BIT in Beijing in 2000

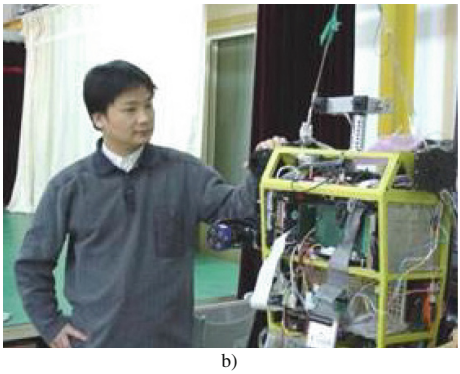
Since 2000, many scholars who have expertise in robotics have gathered together to contribute to the development of humanoid robots in China. Meanwhile, a large number of postgraduates in Beijing Institute of Technology have been recruited. This brought the laboratory with a very powerful research team, yielding achievements as for example shown in [10]. The laboratory is located in Beijing Institute of Technology, which is one of the top universities in China. The aim of the IRI is to develop experience, teaching and research in the field of robots, with main focus on aspects of complex motion intelligent control.

3 The BHR-1 Design

In 2002 the first generation (BHR-1) of the BHR series came out, as supported by the Chinese national 863 Plan of the Tenth Five-Year Plan of the Ministry of Science and Technology and the National Defense Department, see Fig. 2 [14, 15]. It represents that the research team has made breakthroughs in the system integration technology of humanoid robots and developed the first humanoid robot that can walk independently without external cables. The success of BHR-1 represents that China's humanoid robot



a)



b)

Fig. 2. Prof. Xiang Huang, the leader of the **IRI**; (a) during activity for design and assembly of BHR-1 (b) during a test of the motion control

technology has entered the international advanced ranks. It took two years from design to completion into a successful prototype. The BHR-1 robot was designed with the height of 1.58 m, weight of 76 kg and 28 degrees of freedom. With integration of control unit, sensors, power unit in one system. BHR-1 was the first humanoid robot in China that can walk independently without external cables. Since then, China has become the second Asiatic country after Japan with a humanoid robot capable of walking without external cables. At present, the BHR-1 robot is displayed in the History Museum of Beijing Institute of Technology [11], as shown in Fig. 3.

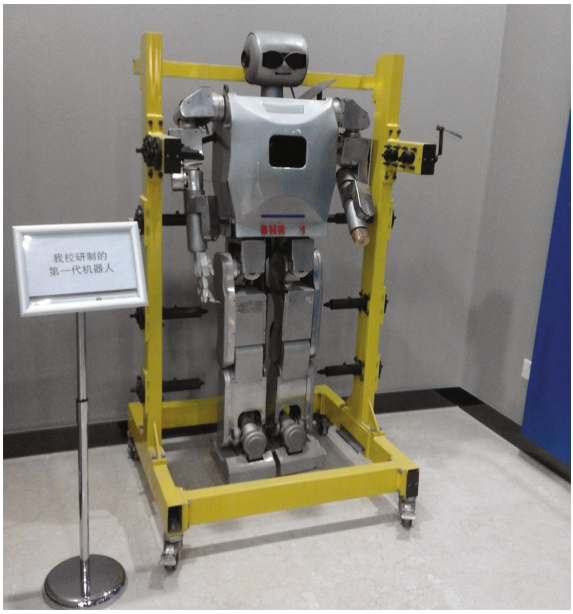


Fig. 3. BHR-1 exhibited today at BIT Museum in Beijing

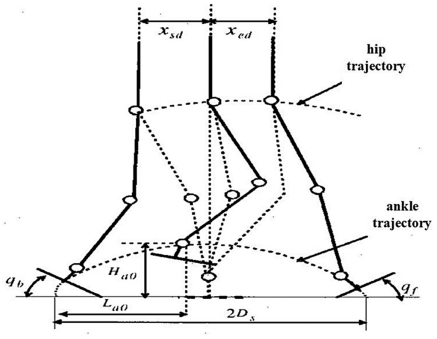


Fig. 4. Walking trajectory generation of BHR-1

The BHR-1 humanoid robot is designed with complex mechanical structure and control system. There are six degrees of freedom in each leg and arm, so the robot can perform most motions that humans can do. By analyzing human motions through a motion-capture system, the robot trajectory can be planned offline and its operation can be controlled for robot stability online which can make the robot able to perform complex motions accurately and quickly. The BHR-1 robot can walk at a speed of 2 km per hour. It was the first time that a fast-dynamic walking of a humanoid robot was operated in China. The gait planning of the BHR-1 is shown in Fig. 4. The ankle trajectory can be generated when the walking parameters are determined, such as the walking cycle, walking step and the maximum lift height. The hip trajectory is generated by a linear inverted pendulum model. The stability criterion is ensured since the zero-moment point is always in the supporting area when the BHR-1 walking at a speed of 2 km/h, as shown in Fig. 5.

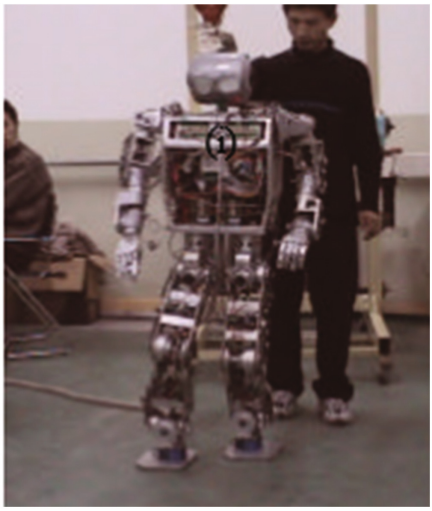


Fig. 5. BHR-1 walked in 2002 at a speed of 2 km per hour

4 The BHR Series

After the BHR-1 success, the team in the IRI has developed five more generations of the BHR series successively, as summarized in Fig. 6.

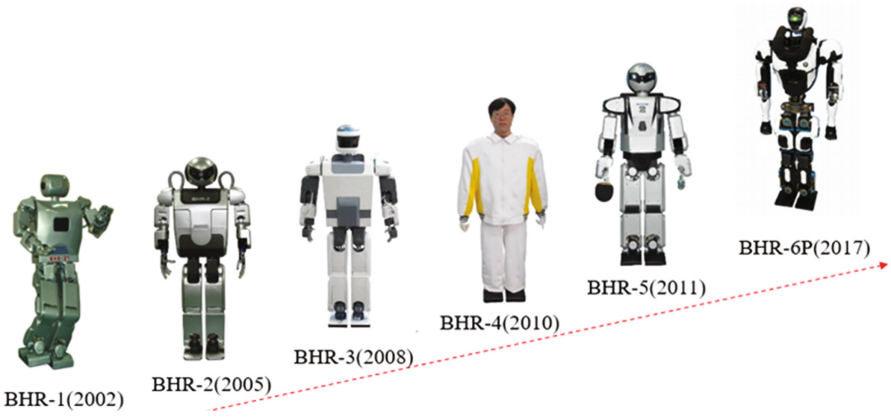


Fig. 6. Development of BHR series from 2002 to 2017

In 2005, with the key support in the advanced manufacturing field of the Chinese national 863 Plan of the "Tenth Five-Year Plan" of the Ministry of Science and Technology, the second generation (BHR-2) of the BHR series was developed. The IRI made a big progress in the humanoid robot's stable walking and complex motion Planning so that IRI achieved a leadership in the international community. The BHR-2 is capable of performing the traditional martial arts such as Tai Chi and broadsword match, as shown in Fig. 7. The BHR-2 robot caused a great sensation and became a highlight in the "National 15-Year Science and Technology Plan Major Achievements Exhibition", "National Science and Technology Innovation Achievement Exhibition", as well as CCTV "Innovation China".

From 2007 to 2009, the IRI has developed the third generation (BHR-3) of the BHR series. The third generation is mainly designed for scientific education. In this period, the third-generation multi-modal humanoid robot was developed and oriented to science popularization education. The project focused on system engineering design and research reliability. It was the first time in China that a humanoid robot was brought into practical application and education instead of standing in a laboratory.

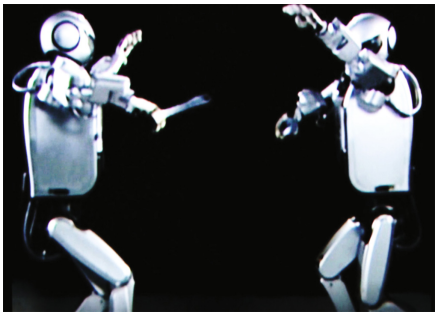


Fig. 7. BHR2 performing martial arts in 2002

Fig. 8. BHR3 performing in public in 2009 at China Science and Technology Museum in Beijing

The BHR-3 was exhibited in China Science and Technology Museum and Guangdong Science Center successively. See Fig. 8. This indicated that the BHR humanoid robot had walked out of the laboratory and taken a solid first step toward market valorization, breaking the monopoly of foreign robot industry technology and making China the second Asiatic country after Japan whose robots can be put into practical application.

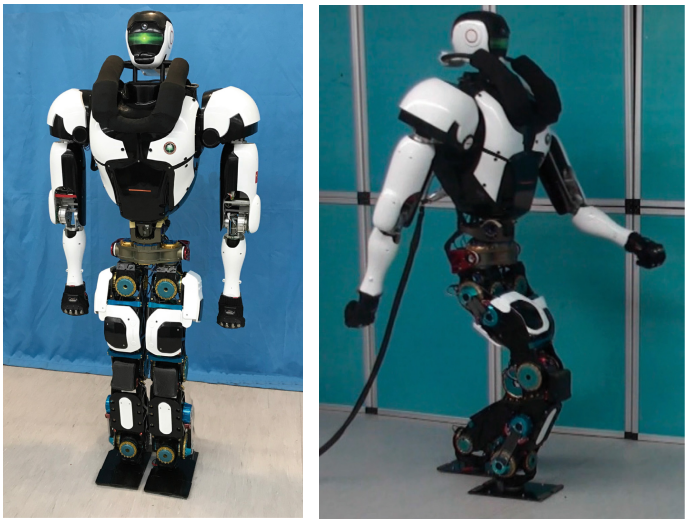
In 2010, the fourth generation (BHR-4) of the BHR series was developed, with the height of 1.7 m, the weight of 65 kg, and 46 degrees of freedom. The BHR-4 robot was designed with the capabilities of human expression simulation and mobile job planning. See Fig. 9 [16]. It is not only capable of walking autonomously and performing Tai Chi, but also of greeting and making facial expressions such as joy, anger, and sadness.

Fig. 9. BHR4 in human shape in 2010

Fig. 10. BHR-5 playing ping-pong in 2012

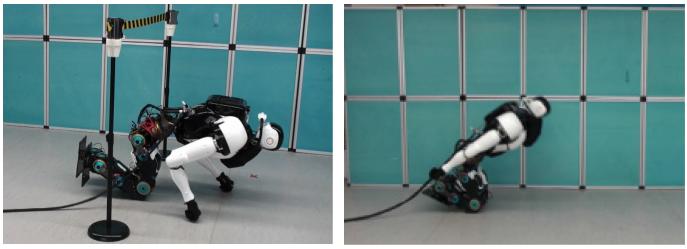
In 2011, the fifth generation (BHR-5) of the BHR series was developed by using the key technologies of smart motion control, as based on high-speed vision and whole-body coordination with autonomic reaction. The BHR-5 robot can hit ping-pong up to 200 rounds, manifesting its high capability in perception and motion control. See Fig. 10. The BHR-5 robot was considered as having reached the international advanced level as reported for example in [12, 13].

In 2017, the sixth generation (BHR-6P) of humanoid robot was launched. At present, most of the humanoid robots around the world are able to walk but cannot perform athletic motions like humans. Humanoid robots fail to continue working after a fall-over, which means that the robots can only adapt to flat environments. Thus, BIT started the research on the theories and methods for robots to adapt to complex environments. The research objectives are to design a humanoid robot that can assist or replace humans for operations in dangerous environments, or for emergency rescue, anti-terrorism and other dangerous tasks. Thus, by incorporating the key technologies of multi-modal motion and transition, bionic drive units, dexterous mechanism designs and fall protection, the prototype of BHR-6P was developed, with the height of 1.65 m, the weight of 55 kg, and 23 degrees of freedom, as shown in Fig. 11. The BHR-6P has the abilities of fall protection, rolling, walking, crawling and other multi-modal motion, and can stand up and resume working after falling over. See Fig. 12. The development of BHR-6P humanoid robot has expanded the application range of humanoid robots, so that it is expected to assist or replace human for tasks in complex environments, such as disaster relief, mineral exploration, home service and special care, and realize the practical application of robot Leap-forward development. The relevant results are expected to lead the forefront development of intelligent robots in China.



(a) (b)

Fig. 11. BHR-6P in 2017: (a) the new prototype; (b) during a walking test



(a) (b)

Fig. 12. BHR-6 in a test of multi-modal motion: (a) crawling motion (b) falling down

5 Achievements and Open Issues

The BHR series robots have profound influence in the Chinese society. The BHR-1 humanoid robot is housed in the History Museum of Beijing Institute of Technology, the BHR-2 robot is on display at the Guangdong Science and Technology Museum, and the BHR-3 is on display at the Chinese Science and Technology Museum. Through the exhibitions and performances, the public can get to know more about humanoid robots from their first-hand experiences. After years of display and demonstration, the performance of the BHR-1 is still efficient and reliable. As is shown in Fig. 13, the

BHR-2 performed Chinese martial arts in public in 2005. The two BHR-1 robots can cooperate with each other. As shown in Fig. 14 [17], the public, including the state Chinese leaders, visited the BHR-3 robot.

Fig. 13. BHR-2 performing complex motions as featured by CCTV-1 in 2005

Fig. 14. BHR-3 interacting with the public at China Science and Technology Museum in Beijing

The IRI has received high reputation thanks to the BHR-1, BHR-2 and BHR-3. Many foreign well-known scholars came to the IRI to discuss the academic achievements. Some foreign scholars have joined the lab's research team, improving the strength of the laboratory.

People from many countries visited the humanoid robot exhibition and paid great attention and recognition as reported for example in Figs. 15 [18] and 16. There were more than 20 thousand people visiting the exhibition, including the leaders and people from different Chinese provinces and cities. As is shown in Fig. 17, Professor Huang introduced the BHR series robots to state leaders of China. In addition, BHR series was covered by Chinese media such as the 'BEIJING DAILY', 'NEWS CONTENT' and 'China Central Television', like for example in Figs. 16 and 18. These media reported greatly on the BHR series robots and the efforts made by the IRI. This not only improves the popularity of the IRI but also gives the public a better understanding of the development of humanoid robots.

Fig. 15. BHR-4 interacting with visitors

Fig. 16. BHR-5 playing ping-pong as featured by CCTV-4

a)

b)

Fig. 17. Presentation of BHR-5 by prof Huang: (a) at national exhibition; (b) CCTV-13 news, [12, 13]

At present, the Beijing Municipal Government has set up an Advanced Innovation Center for Intelligent Robots and Systems, based on the IRI, BIT. The government invests one hundred million every year as the funding for research and development of robots. Through introduction of high-level talents in the field of robotics at home and abroad, the center has accumulated technological capabilities to run in parallel with international advanced laboratories. Besides, the supporting projects and relevant funding received every year greatly promoted the development of the BHR series humanoid robots.

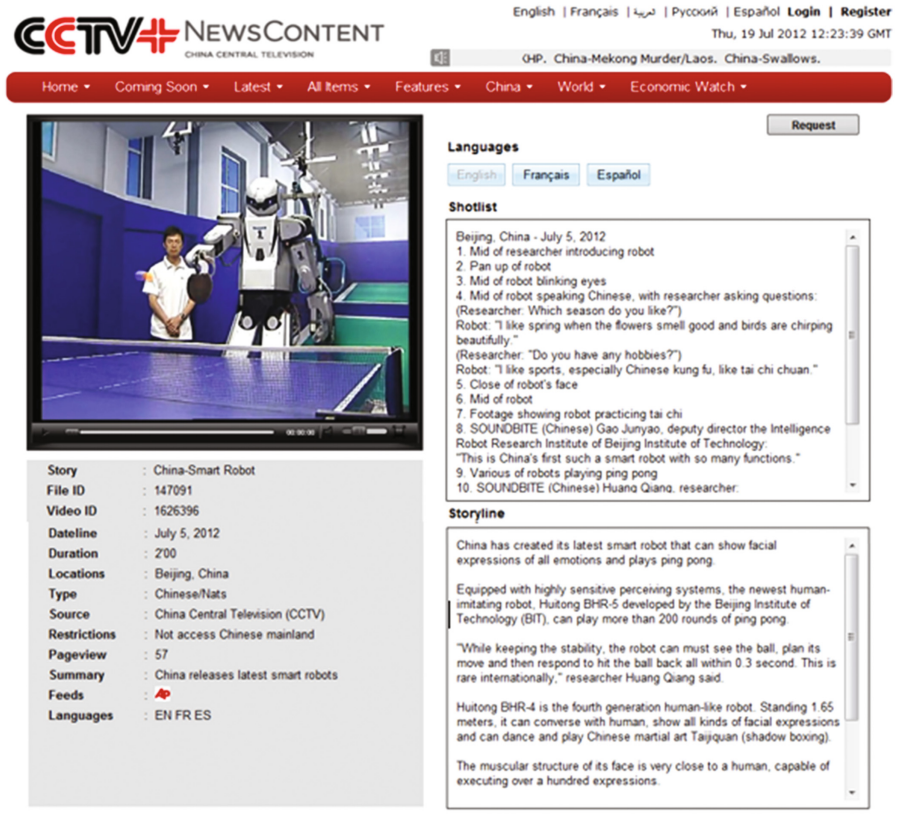


Fig. 18. TV news about BHR-5 on Chinese CCTV network

6 Conclusions

The historical development of BHR humanoid robots is outlined by stressing the inventiveness in design and comprehensiveness in functions of the robots.

The prominence and impact of BHR-1 that has started in 2000 is proved by the continued development of improved versions up to the present sixth generation.

As a modern laboratory, the IRI has made great achievements in the field of humanoid robots. Since 2000, the IRI has developed six generations of the BHR series humanoids robots. The achievements of the BHR series has driven China's humanoid robotics a big step forward, narrowed the gap between China's humanoid robotics development level and the international advanced level, and expanded the breadth and depth of the research on humanoid robots in China and Asia at large, making a significant contribution to the development of the world's Robotics.

Now the team in the IRI is developing a new generation of robots which is capable of walking, crawling, fall protection, rolling and jumping. All the performance indicators will be greatly improved as compared to the previous generations. It is expected to be the first humanoid robots in the world integrating a variety of functions in one system.

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