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Honda humanoid robots development

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Honda has been doing research on robotics since 1986 with a focus upon bipedal walking technology. The research started with straight and static walking of the first prototype two-legged robot. Now, the continuous transition from walking in a straight line to making a turn has been achieved with the latest humanoid robot ASIMO. ASIMO is the most advanced robot of Honda so far in the mechanism and the control system. ASIMO's configuration allows it to operate freely in the human living space. It could be of practical help to humans with its ability of five-finger arms as well as its walking function. The target of further development of ASIMO is to develop a robot to improve life in human society. Much development work will be continued both mechanically and electronically, staying true to Honda's 'challenging spirit'.

Keywords: humanoid robots; biped walking; applications

1. Introduction

Following in the steps of Honda's motorcycles, cars and power products, in 1986 Honda took up a new challenge in mobility—the development of a two-legged humanoid robot that could walk. The main concept behind Honda's robot R&D was to develop a more viable mobility that would allow robots to help and live in harmony with people.

The research began by envisioning the ideal robot form for use in human society; the robot would need to be able to manoeuvre between objects in a room and be able to go up and down stairs. For this reason, it had to have two legs, just like a person.

In addition, if a successful two-legged walking technology could be achieved, the robot would need to be able to walk on an uneven ground and be able to function in a wide range of environments.

Although considered extremely difficult at the time, Honda set itself this ambitious goal and developed a revolutionary new technology to create a two-legged, or bipedal, walking robot. What follows is an outline of Honda's R&D into humanoid robots to achieve this ambitious goal.

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One contribution of 15 to a Theme Issue 'Walking machines'.

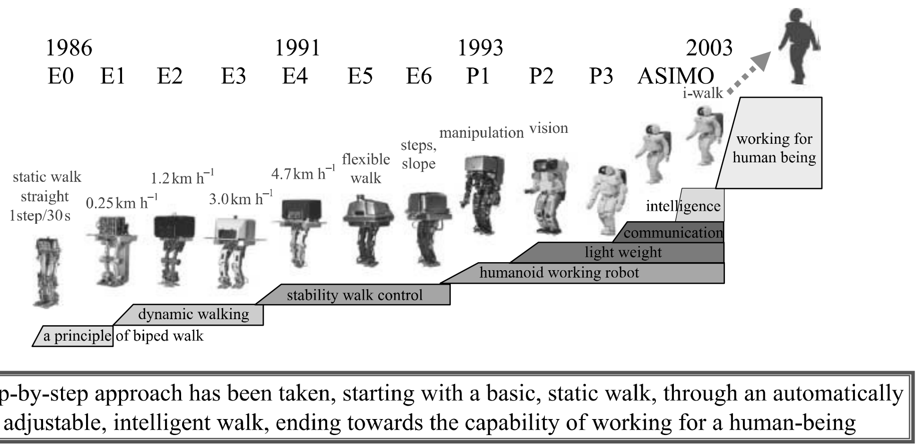

Figure 1. Evolution of a Honda humanoid robot.

2. Evolution of a Honda humanoid robot

(*a*) *Overview*

Honda's research into bipedal humanoid robots began in 1986, and as figure 1 demonstrates, we have made a steady progress ever since. The first milestone was to develop a bipedal prototype that could walk in a straight and static way. It was from this early progress that we were able to reach the next key stage of development, which was to develop a more dynamic and stable form of walking. Coupled with this was the need to master walking over uneven surfaces and then stairs. In 1993, a torso and two arms were successfully added to complete our first truly humanoid robot.

The next challenge was to modify the robot so that it could adapt and operate in real world environments. This stage of development saw the robot's structure and operating systems become smaller and lighter. It was also in this phase that communication aids were introduced as well as the early stages of intelligence, allowing the robot to recognize and interact with people.

Honda's research is continuing and with this we will bring further improvements, which will see ASIMO moving ever closer to becoming a real and viable assistant for people in our human environment.

(*b*) *Basic research in the 1980s and 1990s*

E0 was our first robot ('E' means electronics), and with this we took on the challenge of creating a two-legged robot that could walk. Walking by putting one leg before the other was successfully achieved, and this was assisted by the application of linear actuators (electronic 'muscles') to its joints. However, taking nearly 30 s between steps, it walked very slowly in a straight line. To increase this speed, and to allow the robot to walk on uneven surfaces or slopes, faster walking speeds needed to be achieved.

To achieve this faster walking pace, it was necessary to study how humans walk. So in the next stage, from E1 through to E3, human walking was thoroughly researched and analysed. It was through these studies that a faster walking

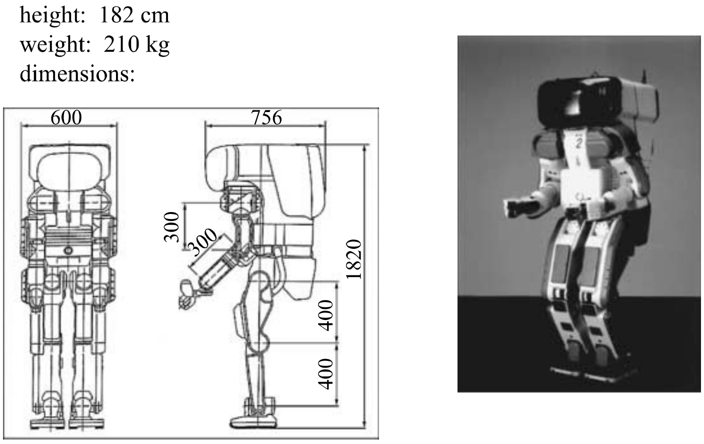

Figure 2. Prototype 2 (20 December 1996).

programme was created and input into the robot. For example, E1 saw the introduction of a basic joint structure; with E2, we achieved our first dynamic walking robot, which could also go up and down stairs; and with E3, we were able to increase the walking speed up to 4.7 km h^{-1}. It could also carry a payload of 70 kg.

From 1991 to 1993 (E4–E5–E6), the research focused on completing the basic functions of two-legged walking and establishing technology for stable walking. E6, the final robot in the series, was the last of Honda's robots with only legs and benefited from the integration of all the autonomous walking functions developed thus far into one self-contained system. Environment maps were also installed at this stage to aid navigation.

(*c*) *Prototypes 2 and 3*

From 1993, work began on developing a completely independent humanoid robot and in December 1996, we announced the world's first self-regulating, two-legged humanoid robot called P2 (prototype 2). This robot was 182 cm tall with a weight of 210 kg (figure 2).

Using wireless techniques, the torso contained a computer, 32 motors, a battery, a wireless radio and other necessary devices, all of which were built into the robot. In these early prototypes, independent walking, walking up and down stairs, trolley pushing and other simple operations were also achieved wirelessly, allowing the robot to be operated independently. These robots also benefited from the introduction of a number of sensors, including optical fibre gyros, inclination sensors, ground reaction force sensors and four cameras. Other advanced abilities were developed at this stage, including an ability to compensate against external forces (so when P2 was pushed, it would resist), zero moment point sensing (allowing the robot to step back if it was pushed further), collision avoidance (if someone stepped into the robot's walking line, P2 stopped autonomously and continued when they had passed) and improved systems to allow it to walk on an uneven floor.

P2's degrees of freedom were as follows: legs, 12 (6×2); arms, 14 (7×2); hands, 4 (2×2); and cameras, 4 (2×2).

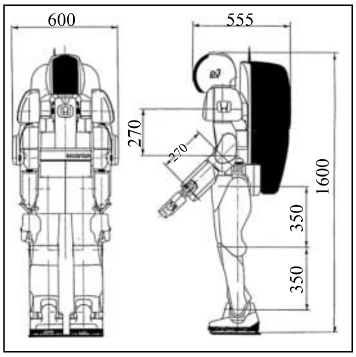

Figure 3. Prototype 3.

While P2 was a major advance in our robotics research, there were still many areas that required improvements. For example, P2 was far too large and heavy, and it had an operational time of only 15 min (owing to its high power motors and a heavy energy consumption of nearly 3 kW during walking). Improvements to the robot's reliability and maintenance were also required.

This led to the development of prototype 3 (P3). The major difference between this and our previous prototypes was its reduced size and weight (it was 160 cm tall and weighed 130 kg). We also replaced our existing motors with brushless DC motors to help with the robot's reliability (figure 3).

(*d*) *ASIMO*

Using the experience gained from the prototypes P2 and P3, the research then began on a new technology for actual use. ASIMO represents the fruition of this pursuit and is our latest biped robot. Its name, ASIMO, stands for advanced step in innovative mobility, and it is the collective name for all of Honda's humanoid robots.

In Japanese, there are many words that sound similar to ASIMO. For example, 'ashi' means leg and 'ashita' means tomorrow, so sometimes we say ASIMO is an abbreviation of 'asita-no' mobility. This means mobility in the future (figure 4).

ASIMO was conceived to function in an actual human living environment in the near future. It is easy to operate, has a convenient size and weight and can move freely within the human living environment, all with a people-friendly design.

3. Details of ASIMO

(*a*) *Concept of development*

As outlined previously, Honda's vision when it first embarked on its R&D into humanoid robotics was to create a new form of mobility that could be of practical help to humans (figure 5).

Figure 4. ASIMO (Advanced Step in Innovative MObility).

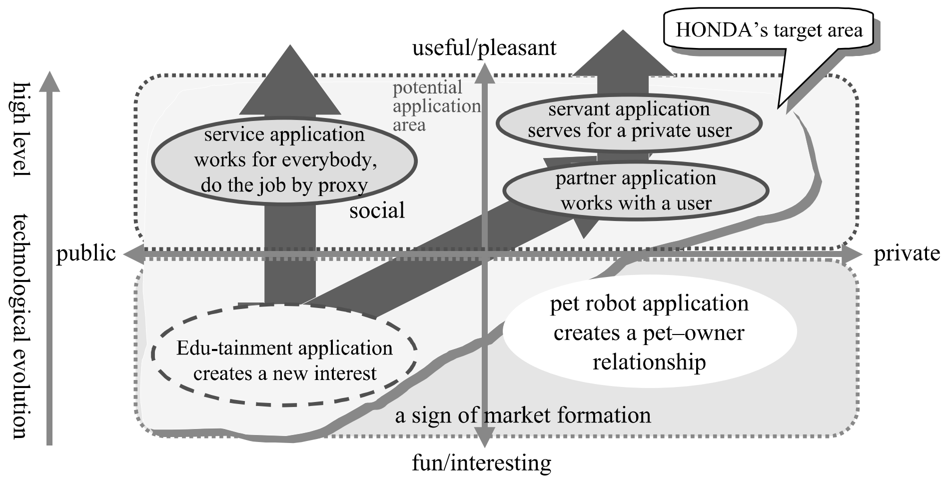

Figure 5. Honda's target consumer robot market aim. The pet robot market is developing and AIBO is a top runner. In the future, the work domain of the robot will expand. (Edu-tainment = education + entertainment.)

(*b*) *Configuration*

The robot's size was chosen to allow it to operate freely in the human living space and make it people-friendly (figure 6). When designing ASIMO, we studied the reach of the robot's hands and its squatting position to access things, such as doorknobs, light switches, electric outlets and other things in the daily life environment. The location of the robot's elbows and shoulders is also dictated by the normal height of desks and workbenches. The current ASIMO is also Honda's first prototype robot that is capable of tackling both off-road and indoor environments.

ASIMO's shoulders are positioned at a height of 910 mm, allowing it to benefit from an upper reach as high as 1290 mm. Its legs are 610 mm long, which enable it to go up and down stairs. In total, ASIMO is 1200 mm tall. ASIMO's width is set at 450 mm and has a depth of 440 mm, so that it can easily pass through narrow doorways and corridors. Figure 7 outlines the specifications of the current ASIMO in detail. ASIMO's joint–link configuration is partly modified from the previous

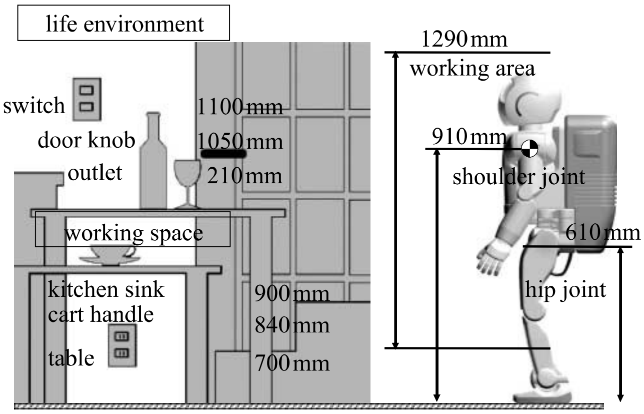

Figure 6. Environment and space.

height	1200 mm
depth	440 mm
width	450 mm
weight	43 kg
walking speed	0–1.6 km h^{-1}
walking cycle	cycle adjustable, stride adjustable
grasping force	0.5 kg/hand (5-finger hand)

actuator	servomotor + harmonic speed reducer + drive unit
control unit	walking/operating control unit wireless transmission unit
sensors	foot: 6-axis force sensor torso: gyroscope, acceleration and sensor
power system	38V/10AH (Ni-MH)
operating system	workstation and portable controller

Figure 7. Specifications of ASIMO. The optimum adjustable walk is shown for ASIMO in the first prototype, which is an integrated humanoid robot able to assist humans indoors.

prototypes. For the legs, this configuration is the same as P3. For the arms, the shoulder angle has been extended to allow it to function in a wider operational space, and while the degrees of freedom in its wrists have been reduced, it is fitted with motor-driven five-finger hands; the movement of which allows ASIMO to make familiar expressions and gestures, such as waving and shaking hands (figure 8).

(c) *Control system*

To help with the movement and control of ASIMO, approximately 20 central processing units (CPUs) and a large number of sensors are installed into the robot. Several of these are used in each of the robot's several sub-systems, including audio–visual sensing and recognition, communication with the operator, the

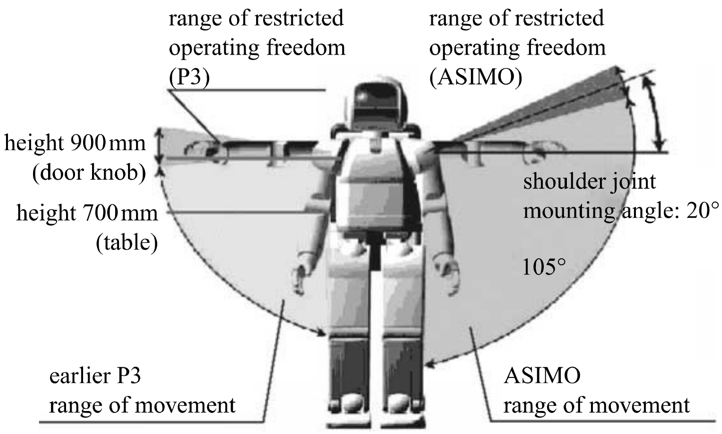

Figure 8. Operation space of P3 versus ASIMO.

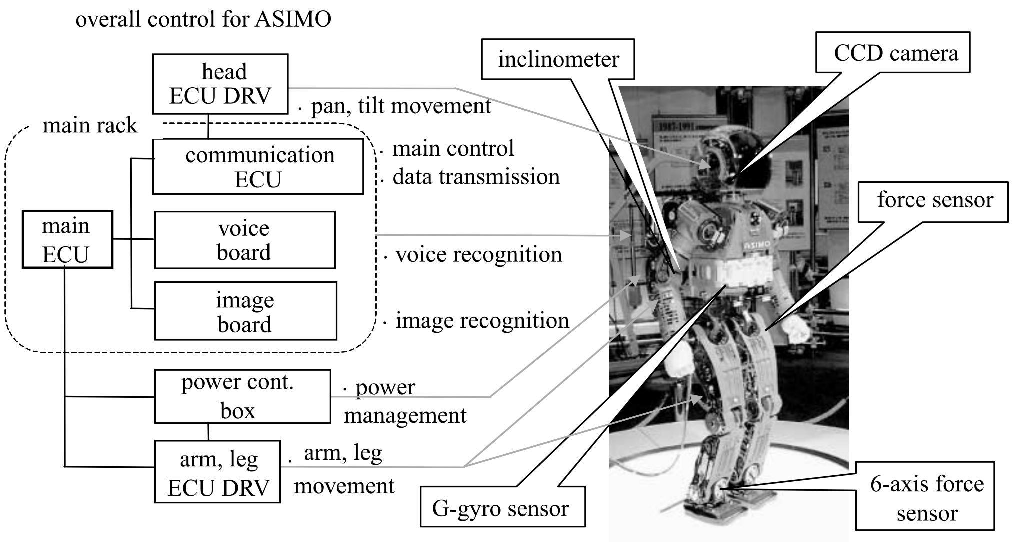

Figure 9. CPUs and sensors of ASIMO where some 20 CPUs and many sensors are installed.

actuation of its arms and legs and power management. They are also installed in various places around its body, including a number of CPUs in the robot's 'back-pack'. Thanks to these, the current ASIMO has greatly improved its interaction and communication with both its operators and environments (figure 9).

(*d*) *Physical functions*

ASIMO's walking functions, allowing it to walk in a smooth, flexible and stable way, have been enhanced from the previous prototypes and are an important part of what helps the robot to successfully interact with people in their daily life conditions.

For example, its predictive movement control allows ASIMO to change its walking pattern smoothly, freely and flexibly at any moment without stopping first. Figure 10 shows an example of this predictive movement control in action,

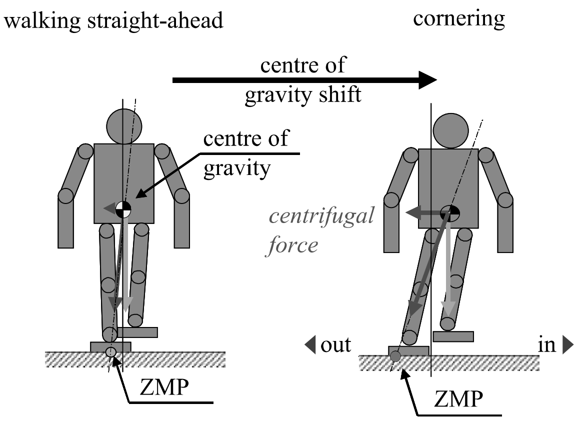

Figure 10. Continuous transition of ASIMO from walking in a straight line to making a turn.

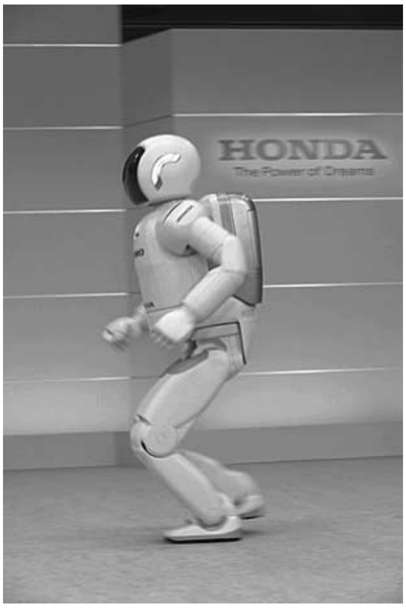

Figure 11. ASIMO running at $3\,\text{km h}^{-1}$.

with ASIMO making a continuous transition from walking in a straight line to making a turn. As can be seen, it is necessary for the robot to shift its centre of gravity towards the inside of the turn to balance the centrifugal force.

When ASIMO makes the transition, predictive calculations have already begun before the robot makes the turn. These calculations determine the optimum shift of the centre of gravity at every instant, while generating a walking pattern in real time.

With these walking technologies, ASIMO can walk in a straight line, on a circle, turn and even slalom, enabling ASIMO to operate in most common human environments. As well as improving the complexity of its walking direction, Honda also aims to increase ASIMO's moving speed, including developing its ability to run—its current running speed is as high as $3\,\text{km h}^{-1}$ (figure 11).

Figure 12. Potential applications of ASIMO in the future.

Making a robot that can run is no easy challenge. Indeed, there are three major obstacles: a higher floor reaction force; slipping on the floor while jumping ahead; and the spinning force reaction generated by the faster movement of legs.

Therefore, in order to address these challenges, we have improved the robot's actuator driver with a higher control response, enhanced the robot's body stabilization with whole-body coordination and coordinated the robot's arms and upper body against the above spinning force. Research does not stop here. Indeed, both the complexity and the speed of movement will need to be improved further, as will the dexterity and skill of the robot's hands and whole body.

4. Future research and development

Honda's dream is that ASIMO will one day help improve life in human society. There is still much to do to reach this goal, and ASIMO will be improved mechanically and electronically. However, by staying true to our 'challenging spirit' Honda's research and development will continue with ASIMO, to realize our dreams for the future (figure 12).