Current and Future Perspective of Honda Humanoid Robot

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1. Start of Humanoid Robot Research

Honda publicly presented a humanoid robot having two legs and two arms in December of 1996. The research and development of this robot was initiated 11 years ago of 1986.

The key words were «intelligence» and «mobility,» and our direction and thoughts were «to coexist and collaborate with human, to perform things that human is unable to do and to create a mobility which brings additional value to the human society.» That is to say, we aimed at developing a new type of robot to meet the consumer needs but not a robot for special limited purpose.

We first planed a practical wheeled robot having two arms and a video camera installed on the upper body for recognition research which we thought would be very convenient to study such intelligence as judgment and recognition research. However, as we gave a careful thought as to the meaning of a consumer type robot which we initially intended to develop, we came to a conclusion that it does not meet one of our key words «mobility». We then looked into a type of consumer robot which will better meet our initial objective.

If we were to look at a «Domestic Robot,» for an example, as a type of robot that consumers may use, it will be necessary for a robot to walk around the furniture and walk up and down the staircase inside of a house. We found that human with two legs is best suited for such movements. At the same time, if we were able to develop a two legged (biped) robot technology, we believed that the robot should be able to move around the majority of earth environment including rough terrain.

Consequently, we reached to a conclusion that the configuration of lower part of the robot would be better if it has two legged mobile mechanism which can walk like human than wheeled type and therefore decided to develop a robot by concentrating our effort on that objective. Once we established our direction, the next step was how to realize it.

We then began to conduct a study on two legged walking mechanism by first analyzing actual human walking by taking ourselves as a model.

2. Study on Robot's Leg Mechanism

Following 7 subjects were selected to study the leg mechanism.

1). Effectiveness of leg joints relating to the walking.

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2). Locations of leg joints.
3). Movable extent of leg joints.
4). Dimension, weight and center of gravity of a leg.
5). Torque placed on leg joints during the walking.
6). Sensors relating to the walking.
7). Grounding impact on leg joints during the walking.

In the following, we would like to explain the result of our initial experiment.

Regarding the subject 1) of the leg joints above, we found that the walking was not affected even there were no fingers and that the roots of the fingers and heel are more important for supporting the body weight.

As far as the ankle joint and walking function are concerned, if the ankle joints were fixed;

a). there will be a lack of contact feeling with ground surface and the fore-and-aft stability will be weak,
b). standing still is difficult if eyes were closed, and
c). when side crossing a sloped surface, the feeling of contact with ground surface and stability are weak.

As far as the knee joint, we found that if the knee joints were fixed, walking up and down staircase is not possible.

From the above observation, we decided to have joints equivalent to such joints as hip joints, knee joints and ankle joints but not finger joints.

In order to study the roles of hip and back bones, those areas were fixed and restrained from outside and we observed how these factors affect such walking patterns as S-curves, straight and turning. As a result, we found that the robot was able to walk at a speed of 8km/h even it was restrained.

Regarding the subject 2) of the locations of leg joint, we carefully observed human bone frames.
Regarding of the subject 3) of the movable extent of leg joints, we experimented the walking on flat surface and up and downs of staircase, measured the movement of joints and the extent of the movement of each joint of the robot.

Regarding the subject 4) of the center of gravity of each leg, we set our objective by referring to «the center of gravity of actual human body.»

Regarding the subject 5) of the torque placed on the joints, we the torque of joints by measuring the ground reaction force and the movement of leg joints of human walking.

And regarding the subject 6) of the sensor, we made a careful study on types of sensors to be required for the robot.

Human has three senses for sensing the equilibrium. One is the sensor to sense acceleration by ear drum, the second one is the sensor to sense the tipping rate by semicircular canals and the third one is the sensor to sense the angles of joints movement, angle acceleration, muscular strength, pressure feeling of foot sole and skin.

We also studied the visual sensor which complements and alternates the sense of equilibrium mentioned above and also manages the walking information. Basing on those informations, we concluded that a robot in its system needs a G-sensor, 6 axis force sensor and gyrometer to sense its own posture, and joint angle sensor in order to grasp the leg movement when walking.

Next subject discussed was the ground reaction force; that is, impact force imposed on the foot during the walking. Human body is so designed, as an example, to absorb the impact force with his soft skin tissues surrounding the foot, arch frame of bones forming the foot, and the roots of finger joints, and flexible movement of knee joint as the foot land the ground.

As the walking speed increases, the reaction force becomes larger even with the human's impact damper mechanism. We found that at the walking speed of 2 to 4 km/h, the load forced on the foot is about 1.2 to 1.4 times that of the body weight and at the walking speed of 8 km/h, it is about 1.8 times. Basing on these results, we made an initial specifications for our robot.

3. Development of Biped Walking Robot

Basing on a biped walking robot fabricated as a preliminary experimental robot, we then refined the specifications which meet the following functions.

1). To realize the walking speed of 3 km/h.
2). For attaching arms and hands of robot to the upper body.
3). Walking up and down a normal staircase.

For a research purpose, we began with static walk. However, since human walking is mainly of dynamic walking, we thought that the robot must also have dynamic walking feature and therefore our research effort have emphasized more on the dynamic walking. As a result, our walking program is a dynamic walking program based on the human walking data and we conducted our experiment.

Basing on our continuos research effort, we were able to consolidate those specifications mentioned above for a biped robot and complete a wireless robot movable with electric batteries mounted as shown in the figure 1.

4. Start of Flexible Walking Robot

Up to this point, the robot we developed was just able to walk on a straight line only. For the next stage, however, we began a research and development of a biped robot which can steadily move around in human life environment without tipover or falling down and is especially maneuverable on different road surfaces, undulation, slope and steps. As a preparation for further study, we developed a walking simulator taking the mechanical characteristics into account.

5. Technical Points for Realizing Stable Walking

When human is about to fall down while walking or standing straight, he pushes ground hard with a part of his foot sole to resist the falling. But when he is no longer able to resist, then he tries to recover his posture by changing his body movement or by taking an extra step. We have tried to achieve a high posture stability by adopting a similar recovery ability to the robot. The figure 2 explains the principle of the robot posture recovering.

Basically, a robot is controlled to follow the angles of leg joints of ideal walking pattern. A combined force of inertia force and gravity force of desired walking pattern is called «desired total inertia force.» As it is known, the point where the moment of the desired total inertia force becomes zero except the vertical element is called «Desired Zero Moment Point or Desired ZMP.»

The ground reaction force has an affect on each leg of an actual robot of which combined force is called «Actual Total Ground Reaction Force or ATGRF.» The point on the ground surface where the moment of ATGRF becomes zero except the vertical element is called «the Center of ATGRF or C-ATGRF.»

If the actual robot walks in ideal condition, ZMP and C-ATGRF will be at a same point. In actuality, however, even though the body posture is in accord with the desired posture and the joint angles are following the desired joint angles, C-ATGRF is off the desired ZMP as it is shown in the figure because of the irregular terrain. In this state, since the action lines of ATGRF and the desired total inertia force do not agree, a couple force produced by these forces acts upon the robot and the robot's entire posture tends to tipover. This couple force is called «Tipping Moment» which is calculated with the following equation.

Tipping moment = (Desired ZMP - C-ATGRF)
x Vertical element of desired total inertia force.

(Equation 1)

By observing this equation, we reached to an idea that if the distance between the desired ZMP and C-ATGRF were actively controlled, the tipover posture of a robot can be recovered by conversely utilizing the tipping moment. We believed that this is a basic principle for recovering the robot's tipover posture. The control to operate C-

ATGRF is called «Ground Reaction Force Control» and the control to operate the desire ZMP is called «Model ZMP Control.»

The ground reaction force control controls C-ATGRF by sensing with a 6 axis force sensor and by modifying the desired position and posture of feet.

The model ZMP control is to control the shifting of the desired ZMP to an appropriate position in order to recover the robot posture by changing the ideal body trajectory when the robot is about to tip over (that is, when the difference between the inclination of the body of actual robot and that of the desired body).

For an example, when the body of a robot tips forward, the model ZMP control system increases the acceleration of the desired body. As a result, the magnitude of the desired inertia force changes and the desired ZMP shifts its position to rearward of the original desired ZMP to recover the robot posture.

If the desired body position of the model changes, the spatial configuration of the desired body and feet will be off the ideal state. In order to bring this back to the ideal state gradually, the landing position of the feet is changed.

By having the controls described above to work simultaneously, we were able to achieve the robot to have a posture stabilizing control like human does.

6. Progress toward Humanizing

The next step is to realize a humanoid robot. We defined the functions of this humanoid robot as follows. The robot should be of such a type that he can automatically perform a certain type of works under the known environment and perform an uncertain type of works with assistance from a human operator under unknown environment. The first experimental humanoid robot had an overall length of 1,915mm and weight of 185 kgf.

We had first concentrated our study on how to realize the coordinated movement of legs and arms and therefore the computers for image processing and action plan, electric power supply, etc. were not installed on the first robot. Through the experiment with this robot, we studied a coordinated movement of the robot to perform such tasks as turning switch on and off, grasping and turning door knob and holding and carrying an object.

In the next stage, we developed a wireless humanoid robot as shown in the figure 3 which was publicly revealed by Honda as mentioned earlier. The overall length was 1,820mm with weight of 210 kgf. Computers, motor driver, batteries as a power source and transmitter were installed inside of the robot. The main functional specifications are listed below.

Mobility Performance:

1). Be able to move around on normal flat surfaces.
    Example: Plastic tiles, paved road, grazing, etc.

2). Be able to pass through a narrow opening:
    Width of the opening of 850 mm.

3) Be able to step over and cross over steps and mounds.
    Example: Step over steps with a height of about 200mm. Cross over steps of 150mm height and 150 mm length.

4). Be able to walk up and down the staircase of general buildings at a normal human speed.
    Example: Staircase with 200 mm height and 220 mm depth of each step.

5). Be able to walk on a known slope of about 10%.

Working Ability:

1). Be able to grasp and hold an object with weight of about 5kgf

2). Be able to perform a light work using such a tool as wrench by a remote control.

7. Future Plan

The future development will be divided into short term and long term plan.

For short term, emphasis will focused on the hardware improvement, which are;

1) Smaller, more compact robot
2) Mobility performance improvement
3) Operability performance improvement

For long term, we believe that increasing the physical versatility by way of mobility improvement and environmental adaptability, made possible by hardware and software technology advancement, as well as improving the autonomous mobility without detailed human instructions are important.

On the contrary, we also hope to develop technologies so that the humanoid robot can function not only as a machine, but blend in our social environment and interact with people, and play more important roles in our society.

Degree of Freedom (DOF)

Legs' DOF : 6 x 2 = 12

Actuators: DC servo motors
(+ Harmonic drives)

Sensors: Vision cameras
Gyrometers
G-sensors
Six axis force sensors

Weight: 150 kg

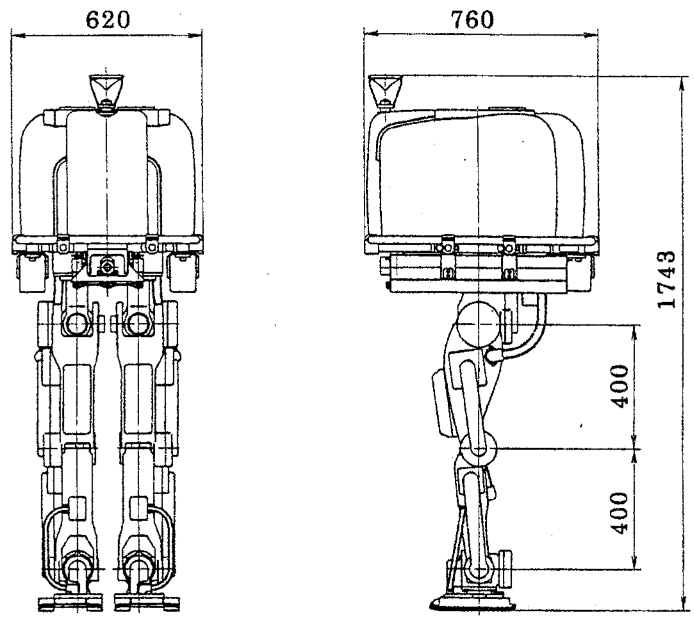

Figure 1: Biped Walking Robot.

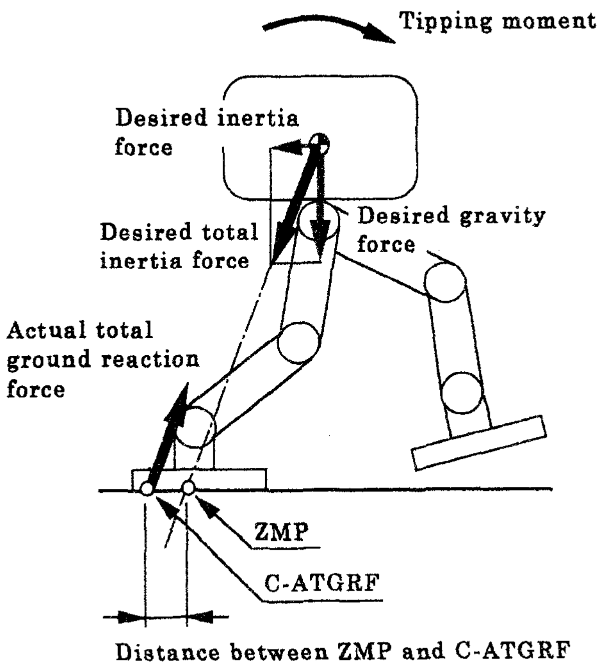

Figure 2: Dynamic Balance while Walking

Degree of Freedom (DOF)

Leg's DOF : 6 x 2 = 12
Arm's DOF : 7 x 2 = 14
Hand's DOF : 2 x 2 = 4

Actuators: DC servo motors
(+ Harmonic drives)

Sensors: Vision cameras
Gyrometers
G-sensors
Six axis force sensors
on wrists and feet

Weight: 210 kg

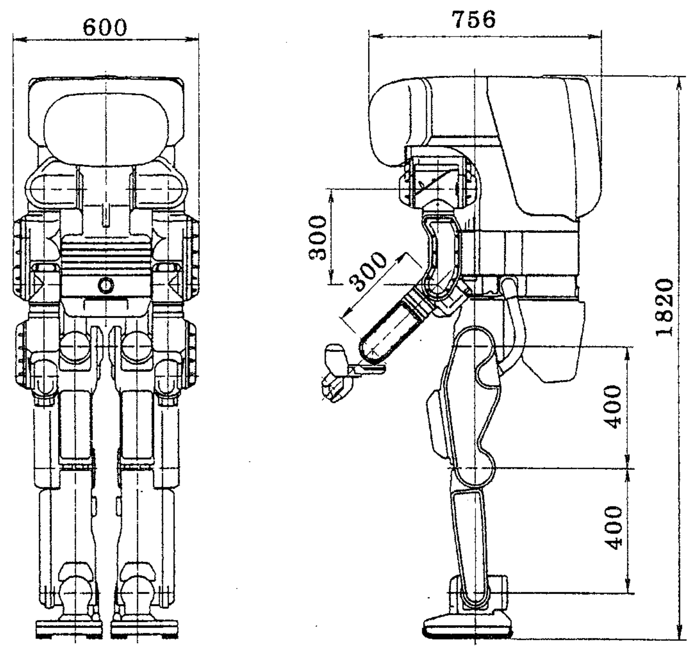

Figure 3: Humanoid Robot