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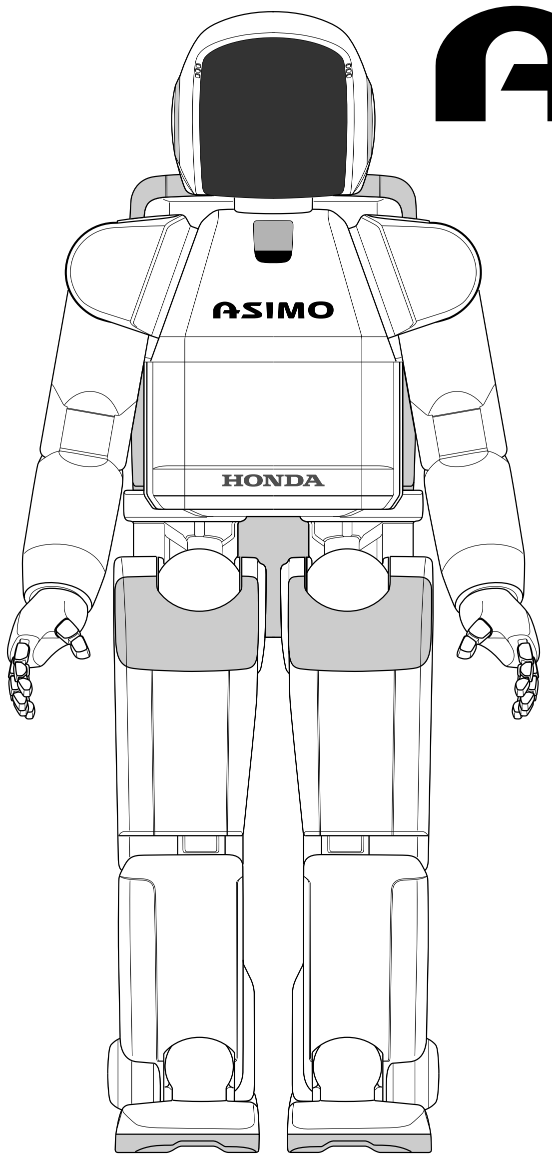


Technical Information

January 2003

American Honda Motor Co., Inc.
Corporate Affairs & Communications

The Honda HUMANOID ROBOT

Contents

ASIMO

By helping people,

and becoming their partners,

Honda robots are opening the door

to the 21st Century.

Prologue - Robot Development

Creating New Mobility

Following in the steps of Honda motorcycles, cars and power products, Honda has taken up a new challenge in mobility----the development of a two-legged humanoid robot that can walk.

Aiming for Function in the Human Living Space

Honda wants to create a partner for people, a new kind of robot that functions in society.

The Concepts Behind Honda's Robot R&D

The main concept behind Honda's robot R&D was to create a more viable mobility that allows robots to help and live in harmony with people.

Research began by envisioning the ideal robot form for use in human society.

The robot would need to be able to maneuver 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 two-legged walking technology could be established, the robot would need to be able to walk on 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 revolutionary new technology to create a two-legged walking robot.

Robot Development Process

*The "E" in Models E0~E6 stands for “Experimental Model."
*The "P" in Models P1~P3 stands for "Prototype Model."

Start of R&D

1986

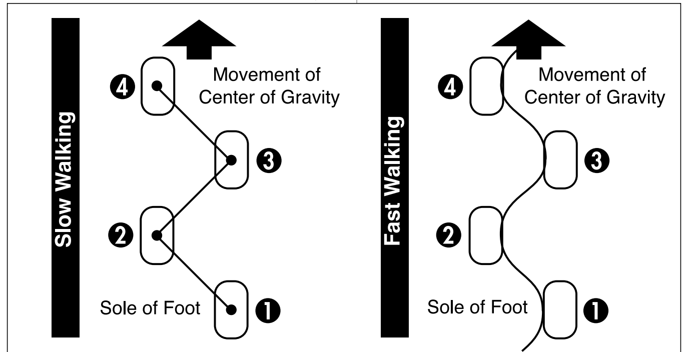
Examining the Principles of Two-Legged Locomotion

E0

First, a two-legged robot was made to walk.

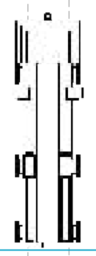
Walking by putting one leg before the other was successfully achieved. However, taking nearly five seconds between steps, it walked very slowly in a straight line.

Slow Walking & Fast Walking



- ● During slow walking, the body's center of gravity remains always centered on the soles of the feet.
- ● When body movement is used for smooth, fast walking, the center of gravity is not always on the soles of the feet.

To increase walking speed, or to allow walking on uneven surfaces or slopes, fast walking must be realized.



E0

1987 - 1991

Realizing Rapid Two-Legged Walking

E1-E2-E3

To achieve a fast walking pace, it was necessary to study how human beings walk.

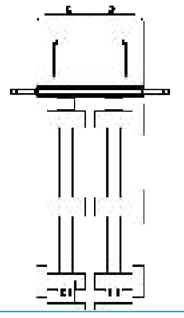
Human walking was thoroughly researched and analyzed. In addition to human walking, animal walking and other forms of walking were also studied, and the movement and location of the joints needed for walking were also researched.
Based on data derived from human walking, a fast walking program was created, input into the robot and experiments were begun.

The E2 robot achieved fast walking at a speed of 1.2 km/h on flat surfaces.

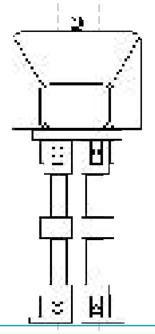
The next step was to realize fast, stable walking in the human living environment, especially on uneven surfaces, slopes and steps, without falling down.

TECHNOLOGY 1

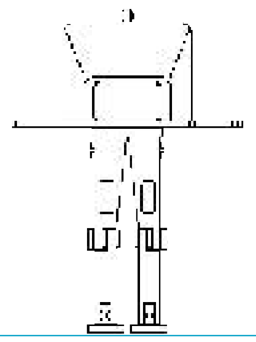
Research On Human Walking



E1



E2



E3

1991 - 1993

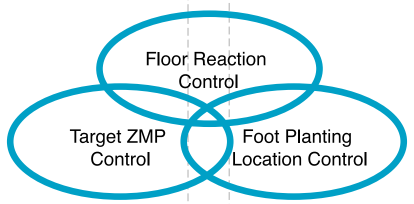
Completing the Basic Functions of Two-Legged Walking

E4-E5-E6

Establishing Technology for Stable Walking

Honda investigated techniques for stabilizing walking, and developed three control techniques.

The 3 Posture Controls Needed for Stable Walking

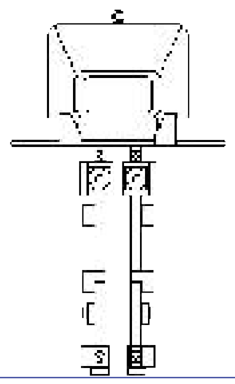


The walking mechanism was established with the E5. Honda's E5 robot achieved stable, two-legged walking, even on steps or sloping surfaces.

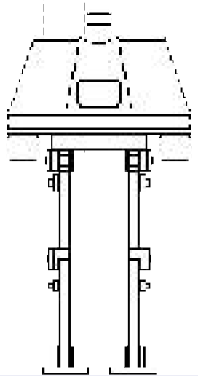
The next step was to attach the legs to a body and create a humanoid robot.

TECHNOLOGY 2

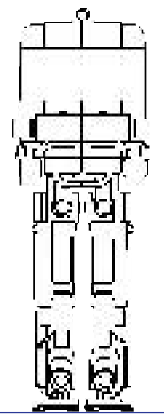
Achieving Stable Walking



E4



E5



E6

1993 - 1997

Research on Completely Independent Humanoid Robots

P1-P2-P3

Advances in Humanoid Robots

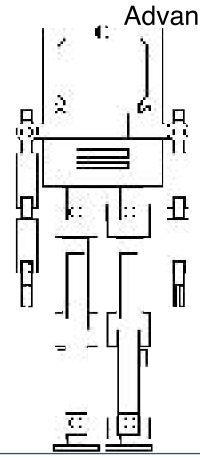
P1 Humanoid Robot Model #1
Height: 1,915mm Weight 175kg
The robot can turn external electrical and computer switches on and off, grab doorknobs, and pick up and carry things. Research was also carried out on coordination between arm and leg movements.

P2 The world's first self-regulating, two-legged humanoid walking robot debuted in December, 1996.
Height: 1,820mm Weight: 210kg
Using wireless techniques, the torso contained a computer, motor drives, battery, wireless radio and other necessary devices, all of which were built in. Independent walking, walking up and down stairs, cart pushing and other operations were achieved without wires, allowing independent operation.

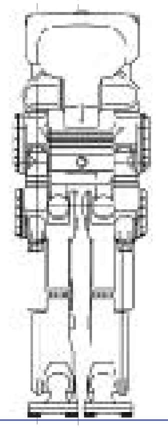
P3 The first completely independent, two-legged humanoid walking robot was completed in September, 1997.
Height: 1,600mm Weight: 130kg
Size and weight were reduced by changing component materials and by decentralizing the control system. Its smaller size is better suited for use in the human environment.

TECHNOLOGY 3

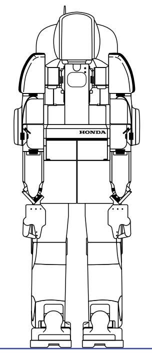
Advances in Humanoid Robots



P1



P2



P3

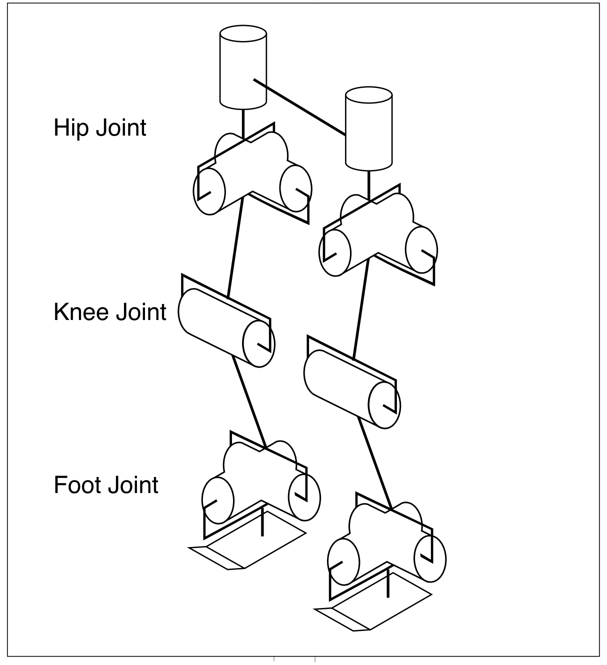
TECHNOLOGY 1 Research On Human Walking

The robot's walk is modeled on a human being's

In studying the fundamental principles of two-legged walking, Honda researched both human and other forms of walking, performed numerous experiments and collected an immense amount of data. Based on this research, Honda established fast-walking technology just like a human's.

1 Leg Joint Placement

The human skeleton was used for reference when locating the leg joints.
Regarding the toes' influence on the walking function, it became clear that the location where the toes were attached and the where the heel joint was positioned were very important in determining how the robot's weight was supported.
Contact sensations from the surface come from the foot joints. Because the foot joints turn from front to back, and left to right, there is stability in the longitudinal direction during normal walking, and feel for surface variations in the lateral direction is enhanced when traversing a slope at an angle.
The knee joint and hip joint are needed for climbing and descending stairs, as well as for straddling.
The robot system was given many joint functions such as hip joints, knee joints and foot joints.



2 Range of Joint Movement

Regarding the range of joint movement during walking, research was carried out on human walking on flat ground and on stairs. Joint movements were measured, and this determined the range of movement for each joint.

3 Leg Dimensions, Weight & Center of Gravity Location

To determine the location of each leg's center of gravity, the human body's center of gravity was used for reference.

4 Torque Exerted on Leg Joints While Walking

To determine the ideal torque exerted on the joints while walking, the vectors at the joints during human walking and during occasional floor reaction were measured.

5 Sensors For Walking

Human beings have the following three senses of balance:

- Speed sensed by the otolith of the inner ear
- Angular speed sensed by the semicircular canals
- Deep sensations from the muscles and skin, which sense the operating angle of the joints, angular speed, muscle power, pressure on the soles of the feet, and skin sensations

To "comprehend" the foot's movement during walking, the robot system is equipped with a joint angle sensor, a 6-axis force sensor, and a speed sensor and gyroscope to determine position.

6 Impact Force During Walking

Human beings have structural elements such as soft skin and heels, as well as arch structures consisting of toe joints. These combine with moveable parts which absorb bending impacts to the joints when the foot contacts the ground, softening the impact force.
Experiments and analyses of human walking have shown that when walking speed increases, floor reaction increases even when the impact reduction functions are at work. At walking speeds of 2~4km/h, the impact is 1.2~1.4 times body weight; at 8km/h, the load increases to 1.8 times body weight.
With the robot, impact-absorbing material on the soles of the feet and compliance controls are used to reduce the impact.

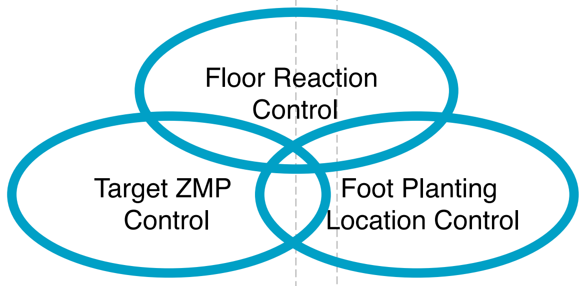
TECHNOLOGY 2 Achieving Stable Walking

To achieve stable walking...

Issues to be address in order to achieve stable walking...

•Not falling down even when the floor is uneven. •Not falling down even when pushed.
•Being able to walk stable on stairs or slopes.

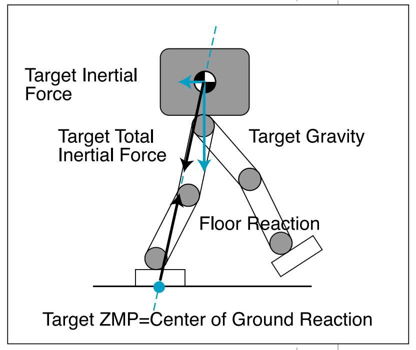
A Posture Controls to Achieve Stable Walking

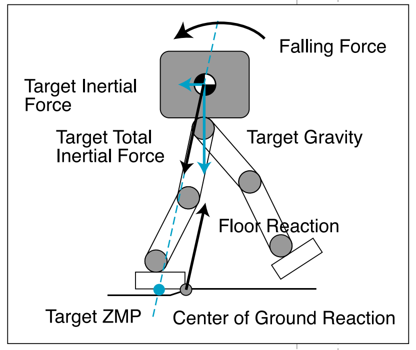


Floor Reaction Control	Firm standing control of the soles of the feet while absorbing floor unevenness.
Target ZMP Control	Control to maintain position by accelerating the upper torso in the direction in which it threatens to fall when the soles of the feet cannot stand firmly.
Foot Planting Location Control	Control using side steps to adjust for irregularities in the upper torso caused by target ZMP control.

* ZMP = Zero Moment Point: The point when total inertial force is 0.

B 3 Position-Control Arrangements

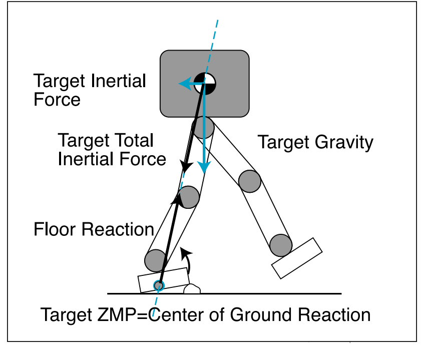




When the robot is walking, it is influenced by inertial forces caused by the earth's gravity and the acceleration and deceleration of walking.These combined forces are called the total inertial force. When the robot's foot contacts the ground it is influenced by a reaction from the ground called the floor reaction force.

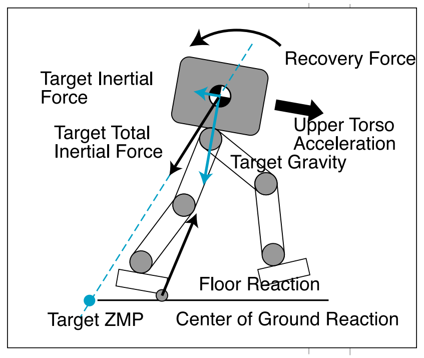
The intersection of the floor and the axis of the total inertial force has a total inertial force moment of 0, so it is called the Zero Moment Point.The point where the floor reaction force operates is called the floor reaction point.
Basically, an ideal walking pattern is created by the computer and the robot's joints are moved accordingly. The total inertial force of the ideal walking pattern is called the target total inertial force, and the ZMP of the ideal walking pattern is called the target ZMP.
When the robot is maintaining perfect balance while walking, the axes of the target total inertial force and the actual floor reaction are the same. Accordingly, the target ZMP and the center of ground reaction are the same.
When the robot walks across uneven ground, the axes of the target total inertial force and the actual floor reaction force are out of alignment, balance is lost and falling force is generated.
This falling force is comparable to the misalignment of the target ZMP and the center of ground reaction. In short, the misalignment between the target ZMP and the center of ground reaction is the main cause of loss of balance.

When the Honda robot loses its balance and threatens to fall, the following three control systems operate to prevent the fall and allow continued walking.



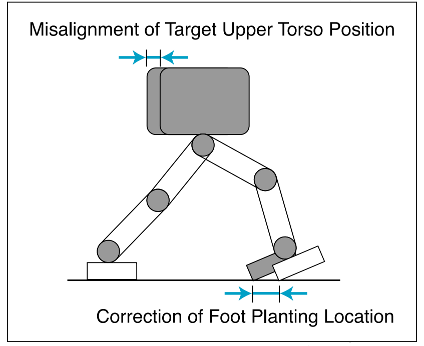
Floor Reaction Control

The floor reaction control absorbs irregularities in the floor and controls the placement of the soles of the feet when falling is imminent. For example, if the tip of the robot's toe steps on a rock, the actual center of ground reaction shifts to the tip of the toe. The floor reaction control then causes the toe to rise slightly, returning the center of ground reaction to the target ZMP.
Another example would be if something caused the robot to lean forward, the tips of the toes would be lowered, placing more pressure on them and the actual floor reaction action point would be shifted forward, generating a position recovery force. However, because the center of ground reaction cannot exceed the scope of the foot sole contact patch there is a limit to the position recovery force, and if the robot leans too far forward it will fall. forward it will fall.



Target ZMP Control

If the robot leans too far over, the target ZMP control operates to prevent it from falling.As stated above, misalignment of the target ZMP and the actual floor reaction action point generates a falling force. However, the target ZMP control maintains the robot's stability.For example, in the diagram to the left, if the robot starts to fall forward, its walking speed is accelerated forward from the ideal walking pattern. As a result, the target ZMP is shifted rearward from the actual floor reaction action point and a rearward falling force is created which corrects the robot's position.



Foot Planting Location Control

When the target ZMP control operates, the target position of the upper torso shifts in the direction of acceleration. When the next step is taken in the ideal step length, the feet will fall behind the torso. The stepping placement control idealizes the stride to ensure the ideal relationship between torso speed and length of stride is maintained.

TECHNOLOGY 3 Advances in Humanoid Robots

Creating a Humanoid Robot

After establishing the two-legged walking technology, work was begun on combining an upper torso with the legs and developing humanoid robot technology.
Studies were carried out to determine what a humanoid robot should be like to function in society and in a human living environment, and a prototype model of almost human size was completed.

A Basic Structure

Movement by Two-Legged Walking Mechanism

+

Work by Two-Armed Mechanism

To work in harmony with people and for ease of operation, it was decided that the robot should have two arms.

B Basic Functions

Target Point Movement

From the erect position, a camera is used to recognize two markers placed on the floor or other spots. After the robot estimates its present location and direction, it designates a target point. It then calculates the method giving the minimum amount of walking required to move from its present location to the target point. The gyroscope is used for inertial navigation as it moves to the target point, correcting for irregularities caused by slippage, etc.

Climbing/Descending Stairs

A 6-axis force sensor is used to measure steps, so the robot can negotiate even long stairways continuously without missteps.

Cart Pushing

The robot can push carts at a set speed, but if the cart encounters some kind of resistance the robot shortens its stride in response to avoid excessive pushing.

Passing Through Doorways

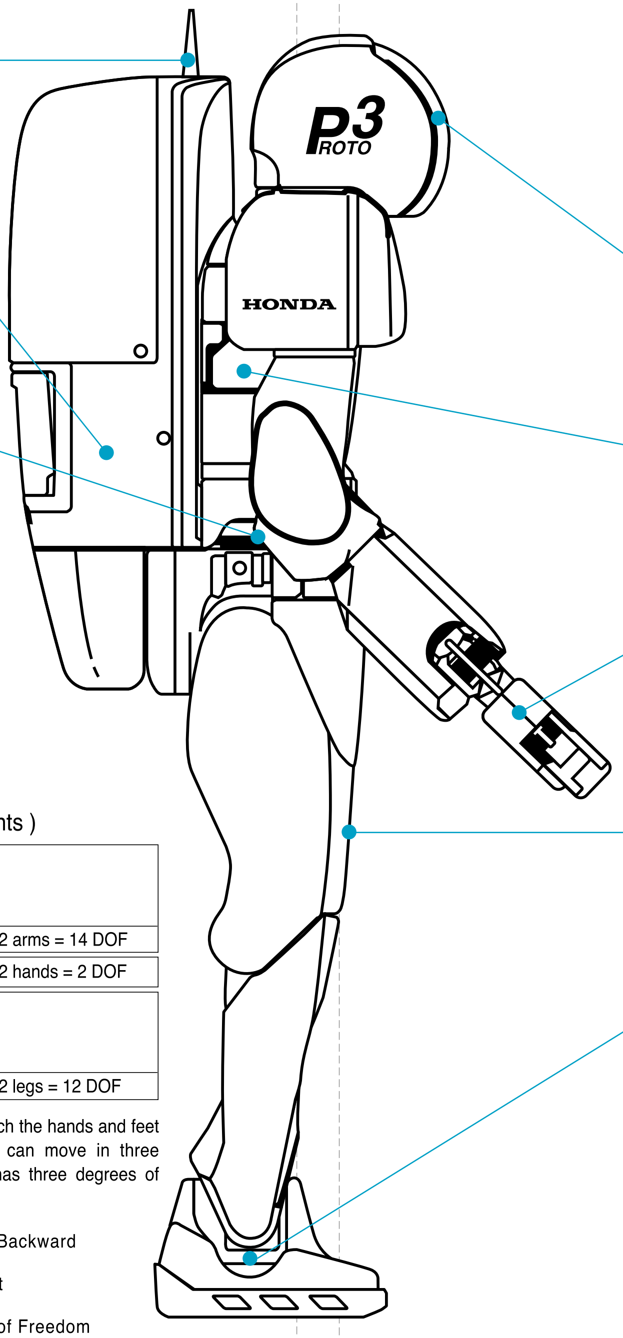
The robot can open and close doors while passing through doorways. As in cart pushing, its steps are regulated in response to the door's opening/closing condition.

Carrying Things

Each arm can carry up to 2kg while walking.

Working Via Remote Operation

The robot can tighten bolts and perform other tasks with the master arm while sensing hand operating pressure.



Antenna

Data is transmitted between the robot and the operating computer via wireless communication.

Battery

The nickel-zinc battery allows approximately 25 minutes of operation.

Gyroscope & Acceleration Sensor

These sense body lean and acceleration.

Height	160cm
Weight	130kg
Walking Speed	2km/h(Max.)

Camera

Images from the camera show the operator how to direct the robot and detect the target location.

Body

The body is made of a very lightweight and tough magnesium alloy.

6-Axis Force Sensor

This senses the direction and amount of force on the hand.

Actuator

A brushless DC servomotor and harmonic drive speed reducer perform the functions of human muscles.

6-Axis Force Sensor

Images from the camera show the operator how to direct the robot and detect the target location.

Compact & Lightweight

Light weight and compactness were achieved using lightweight materials and decentralizing the controls.

Degrees of Freedom (For Human Joints)

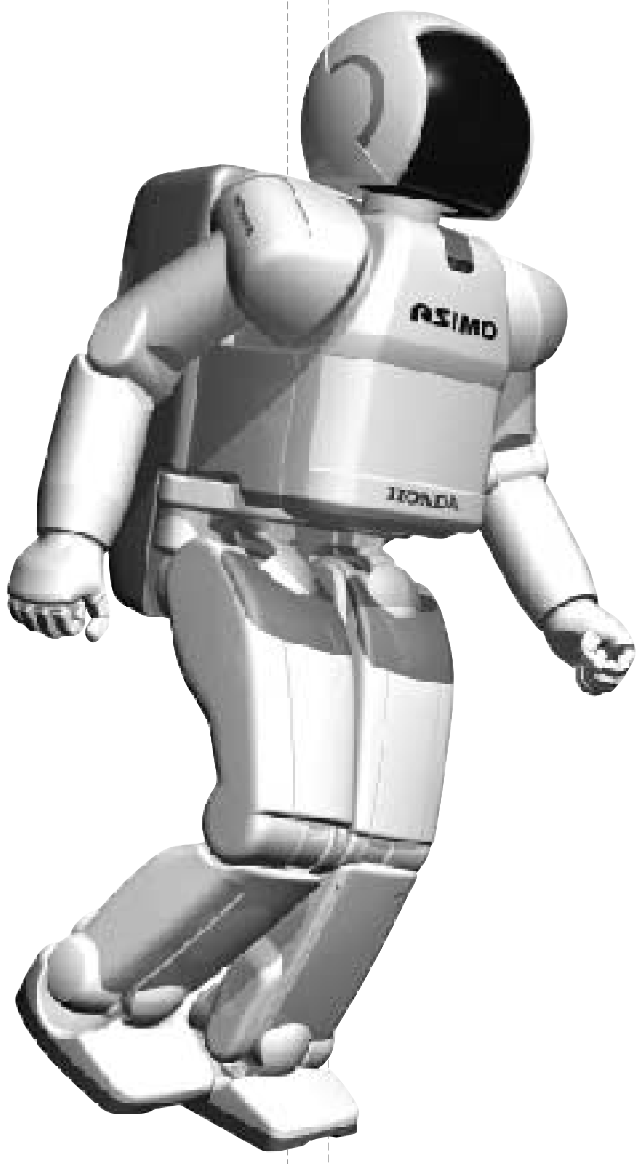
Arm	Shoulder Joint (F/B,U/D,RT)*1	3 DOF
	Elbow joint (F/B)	1 DOF
	Wrist joint (F/B,L/R,RT)	3 DOF
		7 DOF x 2 arms = 14 DOF
Hand	Grasping movement	1 DOF x 2 hands = 2 DOF
Foot	Pelvis joint (F/B,L/R,RT)	3 DOF
	Knee joint: (F/B)	1 DOF
	Ankle joint: (F/B,L/R)	2 DOF
		6 DOF x 2 legs = 12 DOF

Degrees of freedom (DOF) are the directions in which the hands and feet can move. For example, the human wrist joint can move in three directions: up, down, left, right, and twist, so it has three degrees of freedom.

*1
F/B : Forward/Backward
U/D : Up/Down
L/R : Left/Right
RT : Rotation
DOF : Degrees of Freedom

ASIMO Is Born!

As exemplified by P2 and P3, the two-legged walking technology developed by Honda represents a unique approach to the challenge of autonomous locomotion. Using the know-how gained from these prototypes, research and development began on new technology for actual use. **ASIMO** represents the fruition of this pursuit.



Naming ASIMO

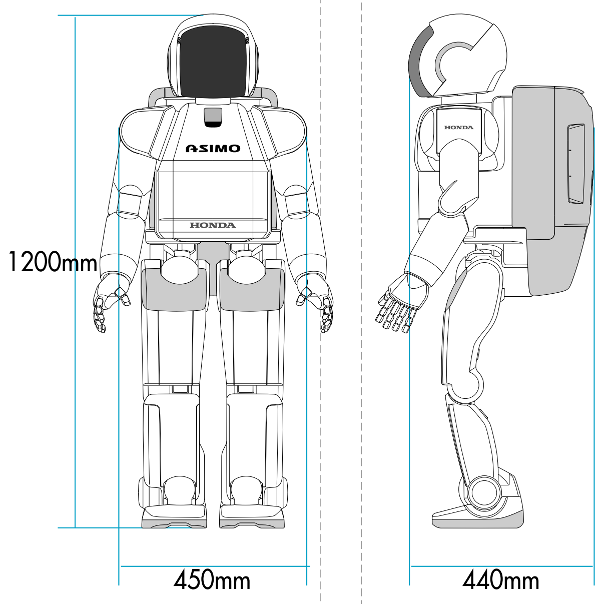
Advanced --- New Era
Step in --- Stepping
Innovative --- Innovation
Mobility --- Mobility

ASIMO stands for Advanced Step in Innovative Mobility.
It means advanced innovative mobility for a new era.

ASIMO Features

- Compact & Lightweight
- More Advanced Walking Technology
- Wider Arm Operating Parameters
- Easy to Operate
- Friendly Design

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.



Weight		52kg
Walking Speed		0 ~ 1.6km/h
Walking Cycle		Cycle Adjustable,Stride Adjustable
Grasping Force		0.5kg/hand (5-finger hand)
Actuator		Servomotor + Harmonic Speed Reducer + Drive Unit
Control Unit		Walk/Operating Control Unit, Wireless Transmission Unit
Sensors	Foot	6-Axis Foot Area Sensor
	Torso	Gyroscope & Acceleration Sensor
Power Section		38.4V/10AH (Ni-MH)
Operating Section		Workstation and Portable Controller

Degrees of Freedom (For Human Joints)

Head	Neck Joint (U/D,RT)*1	2 DOF
Arm	Shoulder Joint (F/B,U/D,RT)	3 DOF
	Elbow joint (F/B)	1 DOF
	Wrist joint (RT)	1 DOF
		5 DOF x 2 arms = 10 DOF
Hand	5 fingers (Grasping)	1 DOF
		1 DOF x 2 hands = 2 DOF
Leg	Hip joint (F/B,L/R,RT)	3 DOF
	Knee joint: (F/B)	1 DOF
	Ankle joint: (F/B,L/R)	2 DOF
		6 DOF x 2 legs = 12 DOF

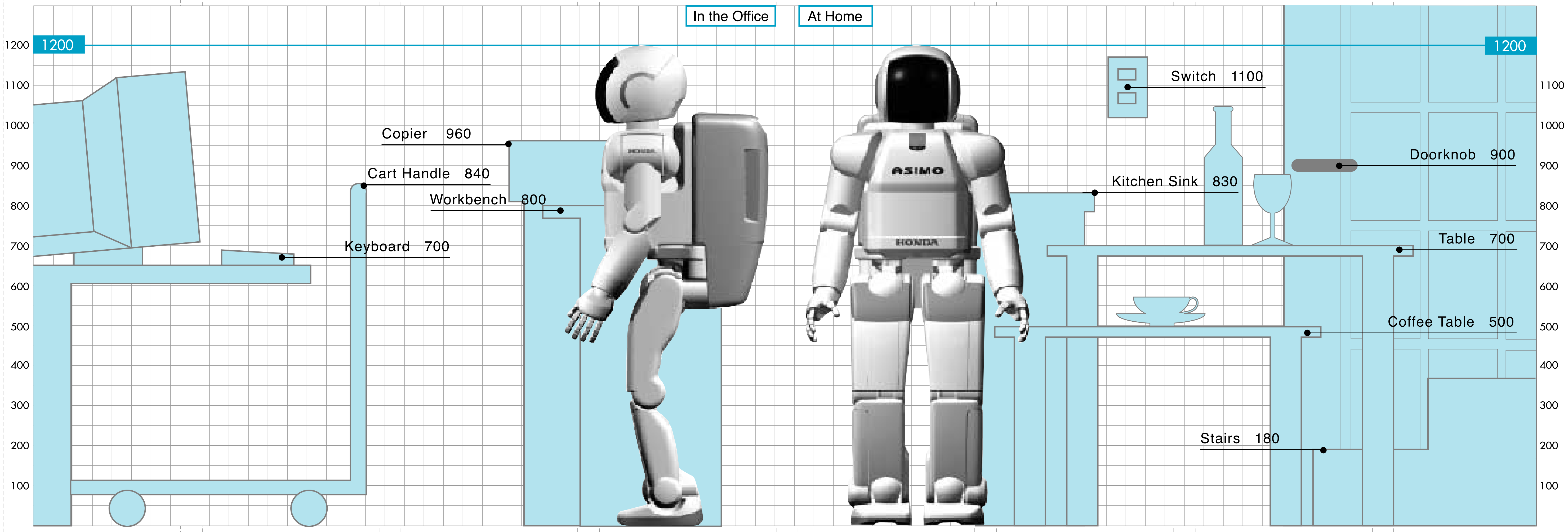
[1] F/B : Forward/Backward
U/D : Up/Down
L/R : Left/Right
RT : Rotation
DOF: Degrees of Freedom

The People-Friendly Robot

Small, Useful Size

The robot's size was chosen to allow it to operate freely in the human living space and to make it people-friendly. This size allows the robot to operate light switches and door knobs, and work at tables and work benches. Its eyes are located at the level of an adult's eyes when the adult is sitting in a chair. A height of 120cm makes it easy to communicate with.

Honda feels that a robot height between 120cm and that of an adult is ideal for operating in the human living space.



* The above heights are examples to serve as a reference (mm).

Smoother and More Stable Walking

The introduction of intelligent, real-time, flexible-walking technology allowed **ASIMO** to walk continuously while changing directions, and gave the robot even greater stability in response to sudden movements.

Earlier Ways of Walking

1 In the past, different patterns were used for straight walking and for turning, and a slight pause was required during the transition.

For Robots up to P3

Straight (A) ➡ Temporary Pause ➡ Turn (B) ➡ Temporary Pause ➡ Straight (C)

For example, when the P3 robot turned sharply when walking straight, its movement was awkward because it had to stop to make the turn.

2 Walking strides (time per step) were limited to only a few variations.

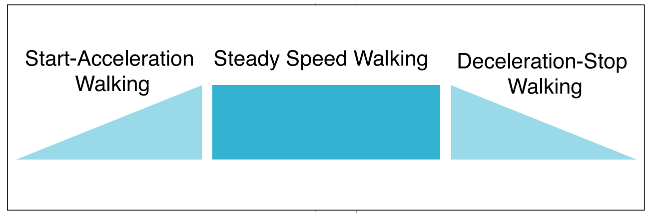
Because each walking pattern has a different stride(time per step), the robot could not change its stride(time per step) flexibly.

Creating Earlier Walking Patterns

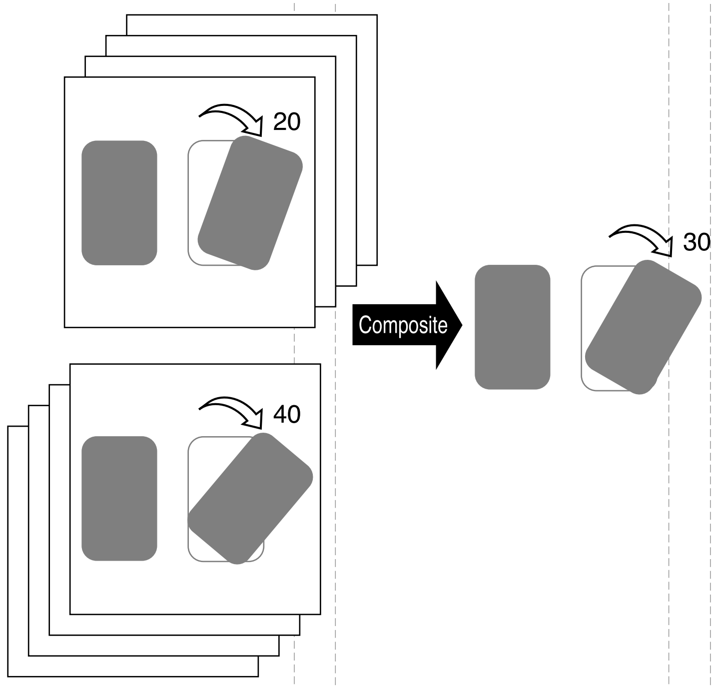
Earlier walking technology allowed roughly two different walking patterns.

A Straight (foot lifting with toes upward and landing on heel)

When walking in a straight line, the robot followed an ordered pattern of start-acceleration walking, steady speed walking and deceleration-stop walking, all of which was stored as time series data.



B Turning (Direction-Changing Walking)



Turning was accomplished by initiating multiple, different, turn-walking patterns based on strides (time per step) stored as time series data.

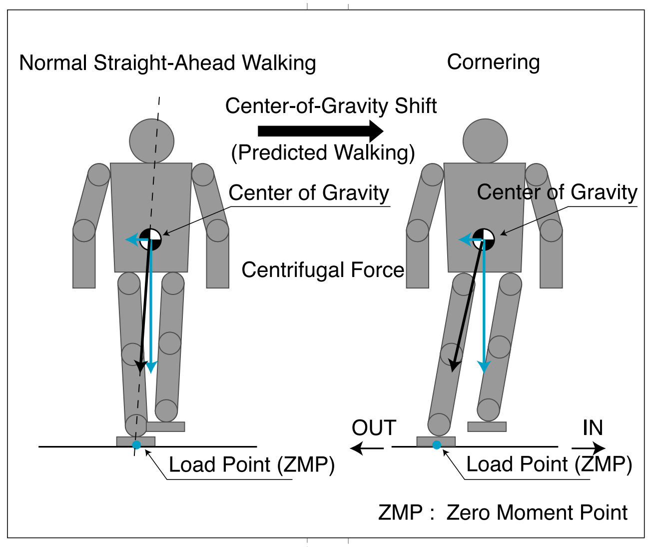
For example, the P3 robot combined 20° and 40° walking patterns to turn at 30°.

Intelligent Walking Technology

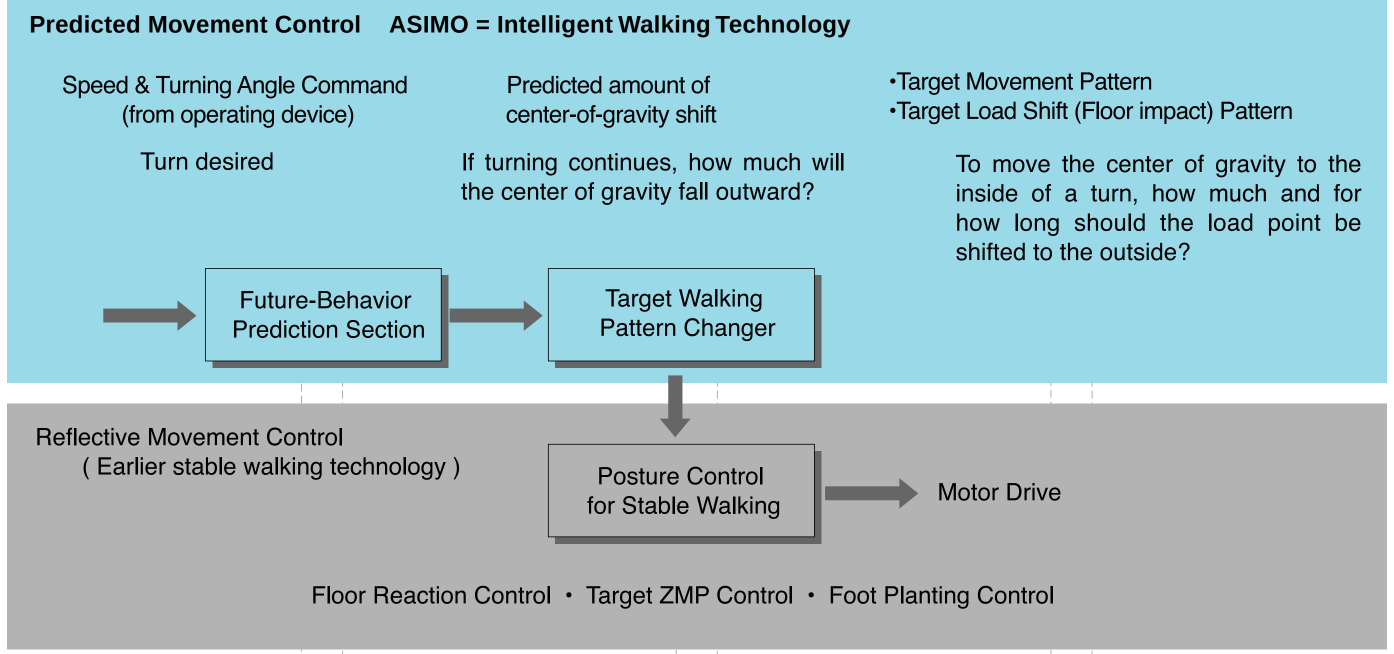
Intelligent Walking Technology features a predicted movement control added to the earlier walking control technology. This new two-legged walking technology permits more flexible walking. As a result, ASIMO now walks more smoothly and more naturally.

Creating Prediction Movement Control

When human beings walk straight ahead and start to turn a corner, before commencing the turn they shift their center of gravity toward the inside of the turn. Thanks to Intelligent Walking Technology, ASIMO can predict its next movement in real time and shift its center of gravity in anticipation.



Control Block Map



Predicted Movement Control **ASIMO = Intelligent Walking Technology**

Speed & Turning Angle Command (from operating device)

Turn desired

Predicted amount of center-of-gravity shift

If turning continues, how much will the center of gravity fall outward?

•Target Movement Pattern
•Target Load Shift (Floor impact) Pattern

To move the center of gravity to the inside of a turn, how much and for how long should the load point be shifted to the outside?

Future-Behavior Prediction Section → Target Walking Pattern Changer

Reflective Movement Control (Earlier stable walking technology)

Posture Control for Stable Walking → Motor Drive

Floor Reaction Control • Target ZMP Control • Foot Planting Control

Intelligent, Real-Time, Flexible Walking Achieved!

1 Continuous movement is possible without pauses.

Straight Ahead → Turning → Straight Ahead

Because continuous flexible walking is possible, ASIMO can move and walk rapidly and smoothly at all times.

2 In addition to changes in foot placement and turning, the stride (time per step) can be freely changed.

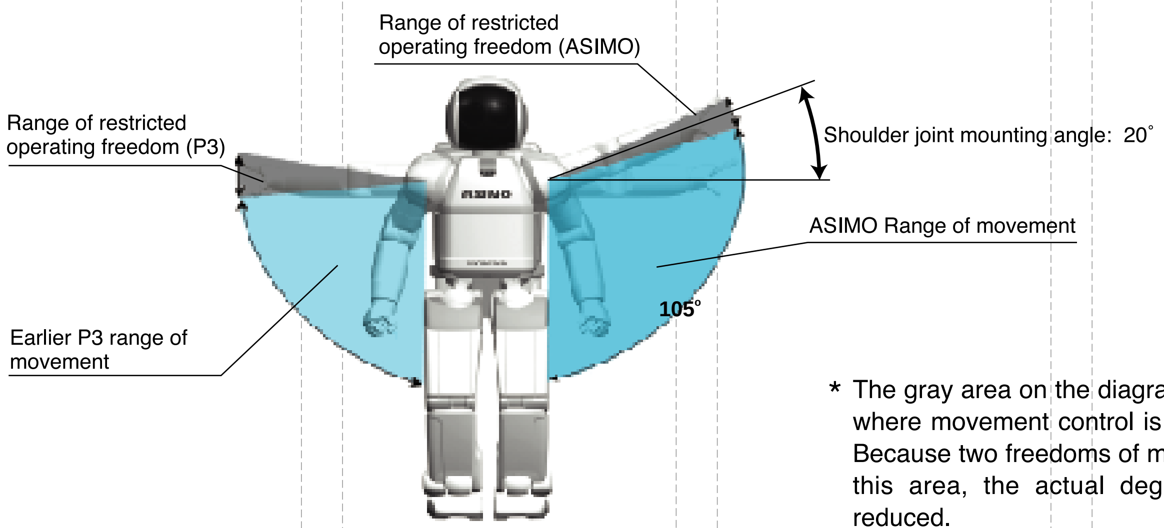
Robots up to the P3 turned according to combinations of stored walking patterns.
ASIMO creates walking patterns in real time and can change foot placement and turning angle at will. As a result, it can walk smoothly in many directions. In addition, because stride (time per step) can also be freely changed, ASIMO's movements are much more natural.

The Future of Intelligent Walking Technology

Thanks to Intelligent Walking Technology, ASIMO can change its walking smoothly and continuously at any time. Intelligent Walking Technology allows robots to coexist more easily in the human living environment. This technological development will allow robots of the future to work in harmony with people while avoiding obstructions on their own.

Expanding the Arm's Operating Range

By raising **ASIMO**'s shoulder joint mounting angle by 20˚, the elbow can now be raised up to 105˚ to better perform work.

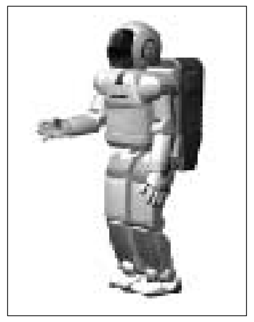


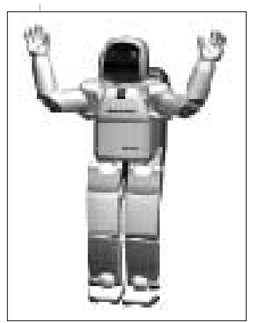
* The gray area on the diagram shows the areas where movement control is structurally limited. Because two freedoms of movement overlap in this area, the actual degree of freedom is reduced.

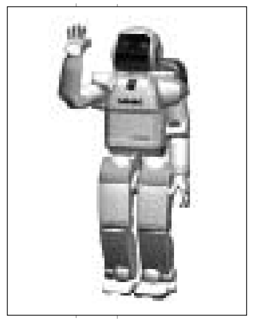
Improvements in Operability

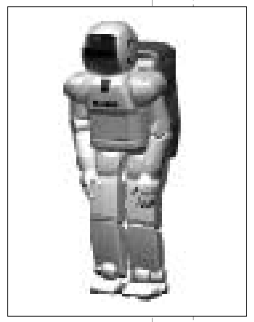
P3 was only controlled from a workstation, but **ASIMO** can also be operated from a portable controller to allow flexible walking control and motions from button operations (gesticulations). This permits more direct operation of **ASIMO**.

- Workstation
  - Start-up
  - Preprogramming Steps
- Portable Controller
  - Flexible Walking Operation — Forward & Reverse/Sideways Walking/ Angular Walking/Turning in Place/Cornering
  - Movements from button operation (gesticulations) — Recorded Movements Selected Using Buttons


Grasping


Waving Both Hands


Waving Goodbye


Responding

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Aiming for Even More Progress

ASIMO will truly

be able to help people

in the 21st century.

Honda's dream is that

ASIMO will help improve life

in human society.

Staying true to our

'Challenging Spirit,'

Honda's research & development

will continue with **ASIMO**,

to realize our dreams

for the future.