Development of New ASIMO

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ABSTRACT

A New ASIMO humanoid robot with advanced physical capabilities that can work autonomously in a real-life environment, such as in an office, was developed in an effort to realize a robot that can coexist with and assist people in society. To attain these goals, by integrating more joints and additional sensors that help ASIMO recognize its surrounding environment, a new control system was developed. The following enhancements were achieved: Obstacle detection was enhanced and route guidance was added for greater mobility; ASIMO was equipped with the ability to run in both circular and straight directions; manipulative ability was enhanced by adding new functions that allow the robot to hand-carry light objects and to push other objects using a cart; and it was provided with the ability to better interact with people.

1. Introduction

Honda has for a long time been engaged in research on humanoid robots in its attempts to further innovative forms of mobility. Through their ability to coexist and cooperate with people, such robots are able to function usefully in society, which provides them with added value. In the course of this research, a variety of technologies were acquired, including findings from analyses of how humans walk, designs for actuator mechanisms for bipedal walking, and methods for controlling bipedal walking. These technologies were put to use in the world's first autonomous bipedal walking humanoid robot, the P2, the prototype of which was publicly announced in 1996(1). In November 2000, Honda introduced ASIMO, which was made the minimum size adaptable to the human living environment, with the aim of making it an actually useful robot that can function in close proximity to people(2). ASIMO became available for rent in 2001, and was exhibited in 30 or more countries around the world in 2002. Since then, Honda has continued to explore the interaction between people and robots in search of ways to make robots more useful. The Company has equipped them with human interactive functions that give them the capability of recognizing people's posture and actions, as well as distinguishing among individuals' faces so robots can interact more smoothly with humans(3). Through activities like these, Honda has sought to further its dream of a humanoid robot that functions together with human beings; to illuminate new frontiers for exploration, and to develop a wellspring of technological know-how.

This article presents an overview of the new model ASIMO (Fig. 1) that was presented in December 2005, with a focus on the evolution of its functions.

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Fig. 1 Humanoid robot “New ASIMO”

2. Development Goals

Figure 2 shows a roadmap that leads to the ultimate goal for ASIMO, which is to make it “a robot that coexists and cooperates with people and performs useful functions in society.” The development stage has been divided into three steps, assigned respectively to entertainment, public-use, and personal-use applications.

The new ASIMO is congruous to the second step. The goal in its development was to enhance its mobility and its ability to work autonomously in a real-world environment, such as an office. Practical jobs envisioned for ASIMO include reception and delivery. The objectives as shown below were defined in terms of movement, work, and human interaction; and technical development was conducted accordingly.

(1) Movement Functions
- It is able to move smoothly without running into people or walls.
- It is able to move with agility.

(2) Transport Functions
- It is capable of transporting and delivering lightweight objects such as trays.
- It is capable of transporting objects using a cart.

(3) Human Response Functions
- It is capable of quickly recognizing individual people and has the capacity to behave adaptively in interactive situations.
- It is capable of walking hand-in-hand with a person.

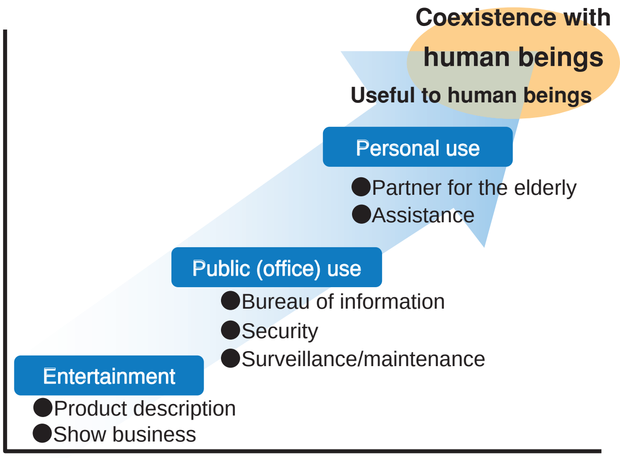


Fig. 2 Development of ASIMO

Table 1 Specifications for ASIMO

Height	1300mm (in self-standing)
Weight	54kg
Speed	0 - 2.7km/h (Walking) 6.0km/h (Running in straight line) 5.0km/h (Running in circular pattern)
Sensors	· Stereo camera (for human) · Slit laser sensor (for floor shape) · Ultra-sonic sensor (for obstacles) · IC tag with optical communication unit
Power section	51.8 V (typ) / 10Ah (Li-ion 14 cells)

3. Main Specifications

3.1. Basic Specifications

The main specifications of the new ASIMO are shown in Table 1. Its height is 1300 mm and its weight is 54 kg. It has been given the walking speed of 2.7 km/h so that it can walk at the speed used when guiding a person to a destination. The exterior design carries on the innovative-yet-familiar image of the previous ASIMO, while developing it further and allowing for the installation of various devices. The power supply system has been changed to use a lithium ion secondary battery for greater compactness. On-board recharging has also been newly adopted for this system, to enhance usability.

3.2. Structure of Joints

The new ASIMO has been given a total of 34 degrees of freedom with the addition of one axis in the waist, two axes in each arm, one axis in each hand, and one axis in the head. The turning axis in the waist was added to cancel out the spinning in the torso that occurs when the robot’s movement is speeded up. In the arms, the wrists were given two more axes, for a total of seven degrees of freedom. This increased the degrees of freedom for determining the appropriate position of the hands when working, thus greatly enhancing operability. The thumbs were given an additional degree of freedom to enable them to clasp lightweight objects. In the head area, one axis was added to the neck to enable it to tilt, thus increasing expressiveness when interacting with people. The legs have six degrees of freedom, as before. The structure of the joints and the degrees of freedom are shown in Fig. 3.

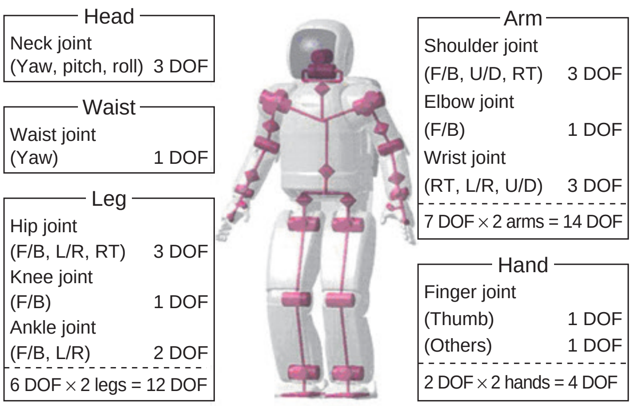


Fig. 3 Joint structure and DOF (Degree of Freedom)

3.3. Basic Control Systems

The new ASIMO systems have been revised in every respect to allow the robot to quickly recognize its surroundings and move with agility. Recognition of the surrounding environment is accomplished using a head-mounted stereo camera, as before, together with an added floor-surface sensor, ultrasonic sensor and an IC communication card combined with a photosensor. Integrated control systems were developed that are able to plan combined actions in response to greater amounts of sensor data. To enable agile movement, a higher-speed main CPU (10 times faster than the former CPU) was used; the speed of the internal communications system linking the main CPU with the sensors and motor drivers was increased (five times faster than before); and the motor driver response was stepped up (to four times faster than before). These measures significantly enhance the overall responsiveness of the system to situational changes.

4. Mobility Functions

It is necessary for a robot to move with agility in a real-world environment so that, for example, it does not bump into walls, desks or other structures, or run into people, and so that it will be able to move quickly to avoid hitting people. The new ASIMO has been given significantly enhanced navigational and obstacle-detection capabilities and new running control technology, which provides the basis for agile movement.

4.1. Route Guidance

ASIMO is guided along a route map that is set up in advance. It calculates its own position using a gyro sensor, checks it against its position according to landmarks placed on the floor surface, and makes corrections in real time to proceed on its course in the real-world environment (Fig. 4).

4.1.1. Landmark detection

As there are diverse lighting conditions in offices and other such real-world environments, it was necessary to make the robot more capable in that regard. Retro-reflective markers are employed as landmarks for this purpose, and an LED for infrared light irradiation installed at the robot's waist. Detection processing uses images captured through an infrared radiation pass filter (Fig. 5), and the shutter speed can also be adjusted automatically when images are being captured. This has enhanced the reliability of landmark detection even in locations that receive direct sunlight.

4.1.2. Self-position correction

The new ASIMO can correct its own position in real time while walking. When calculating its orientation using landmarks, it compensates for the yaw component that occurs during walking. This was done to increase the accuracy of its self-orientation. As it became possible to correct its landing position while walking, the robot became able to move without stopping along the way.

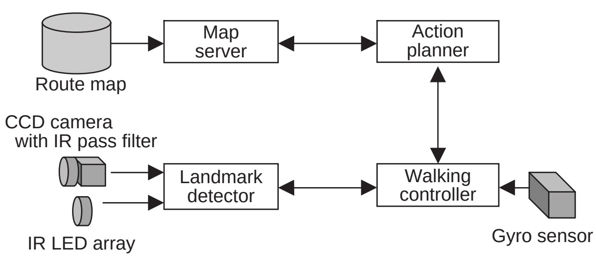


Fig. 4 Block diagram of navigation

4.2. Obstacle Detection

As shown in Fig. 6, the new ASIMO detects obstacles using three different sensors with different detection ranges. These are (1) the floor-surface sensor, (2) the ultrasonic sensor, and (3) the head-mounted stereo camera. Obstacle information output by the various sensors is used by the action planner to calculate obstacle positions relative to ASIMO. The robot has gained the ability to initiate deceleration or stopping behavior in response to distance, light and other such changes in the environment.

4.2.1. Obstacle detection by floor-surface sensor

The new ASIMO has been equipped with a floor-surface sensor so that it can detect objects that are on the floor in its path. It radiates several narrow beams of infrared light from its waist area onto the floor, and takes pictures of it using two CCD cameras also installed in the waist area. The images captured by the different cameras are measured by the light-section method; and for each measured point, the estimated height above the floor is calculated. Measurement points that are more than a certain height above the floor are considered to indicate the presence of an object on that part of the floor. These results are used to calculate the positions and shapes of objects within measurement range, which are then output as obstacle information. The robot is capable of automatically reducing its walking speed when the floor-surface sensor is unusable because it is receiving direct sunlight. At those times, it can use other sensors to decide whether or not to stop.

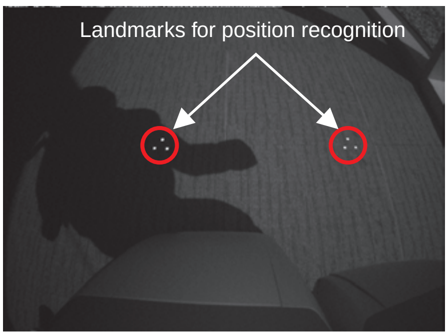


Fig. 5 Image of Landmark detection processing

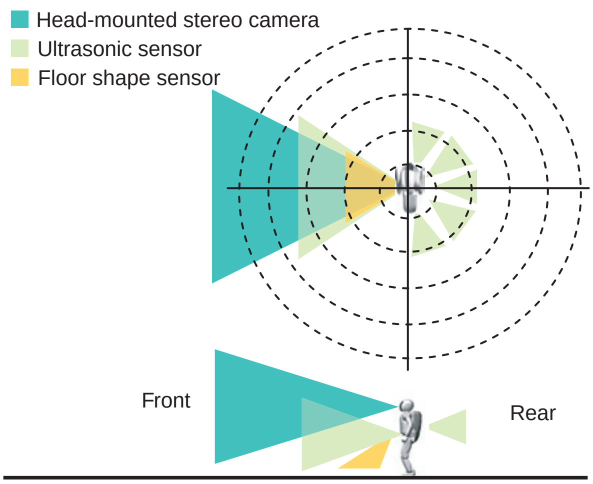


Fig. 6 Obstacle detection area

4.2.2. Obstacle detection by ultrasonic sensor

The new ASIMO is equipped with a total of six ultrasonic sensor units in the waist area, one aimed to the front and five to the rear. These detect transparent glass windows that cannot be detected by the floor-surface sensor or head-mounted stereo camera, as well as walls and other objects that are outside the range of the cameras.

4.3. Running Control Technology

The objective for the new ASIMO has been to achieve smooth, stable running as a basis for agile movement. Reduction of foot landing shock and alleviation of spinning in the torso or slipping of the feet were issues in this regard. Those issues were resolved, however, and the robot has achieved a speed of 6 km/h when running in a straight line and 5 km/h when running in a circular pattern (with a turning radius of 2.5 m). Figures 7(a) and (b) show the robot's running posture.

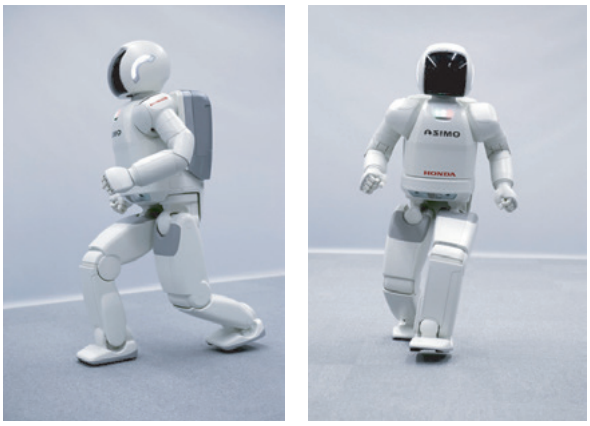
4.3.1. Reduction of foot landing shock

A stronger foot landing shock occurs when running than when walking. This can be effectively reduced by enhancing the responsiveness of compliance control. In this case, compliance control means that when force sensors (load sensors) attached to the foot soles detect the foot landing shock, the control system responds by adjusting the target angle for all of the motors in the legs to pull in the entire leg. This made it possible to limit the peak foot landing shock to 2 G when running, as shown in Fig. 8, at a speed of 6 km/h (flight duration 0.08 sec, length of stride 525 mm) (Fig. 9). These values may be said to be at levels on a par with human beings. Future areas of enhancement include increasing absorptive capacity during movement over an uneven floor.

4.3.2. Generation of target motion to avoid spinning or slipping

The movement of a robot causes acceleration and deceleration in all parts of its body, which generates inertial forces. The robot is also subject to the force of gravity. The cumulative effect of all these forces is termed the total inertial force. The opposing force from the floor to the soles of the feet is called the ground reaction force. The magnitudes and lines of action of the total inertial force and the ground reaction force are identical.

The method previously used to balance the total inertial force and the ground reaction force, as shown in Fig. 10, was to have the robot hold its upper body perpendicular to the floor while thrusting the feet against the floor, to accelerate the upper body forward parallel to the floor. If this method were also applied to running, then the ground load would diminish when the robot was in flight and just before and after. This would cause the force of the feet thrusting against the floor to exceed the limit of the static frictional force, causing the robot to slip.



(a) Running in straight line (6km/h)

(b) Running in circular pattern (5km/h)

Fig. 7 Running posture

Fig. 9 Flight duration while running (High speed camera)

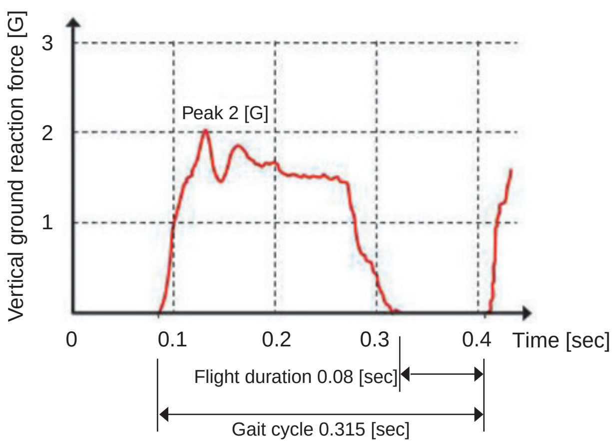


Fig. 8 Vertical ground reaction force at 6 km/h

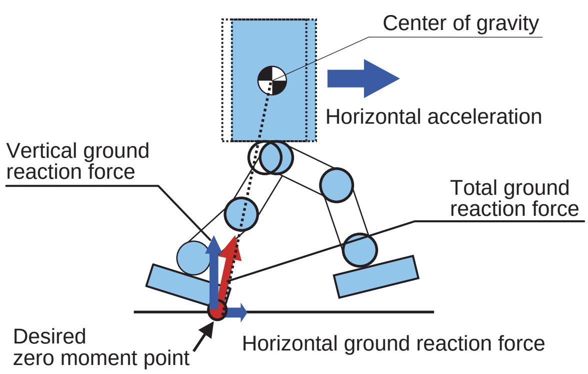


Fig. 10 Balancing motion via upper body horizontal acceleration

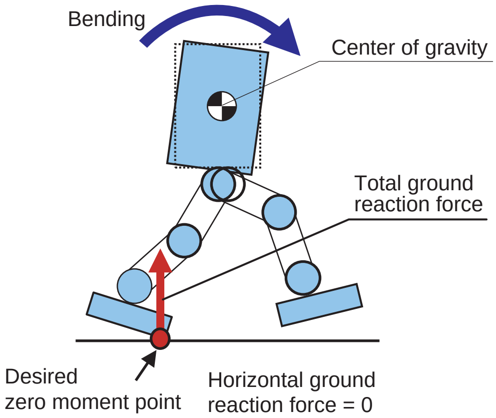


Fig. 11 Balancing motion via upper body rotation

When people sense that they might fall over, such as when standing or walking in a skating rink, they actively lean their upper bodies in the direction they are falling, as seen in Fig. 11. They use this reaction to try to balance themselves. This action does not depend on horizontal ground reaction force. When these two balancing actions are combined properly in accordance with the limit of the static frictional force, they can generate a target motion that prevents slipping.

Swinging the legs also generates spinning forces (the moment of force that tries to rotate around the vertical axis). The robot twists its upper body to cancel out these forces.

Both feed-forward and feedback controls use these actions, which prevents spinning and slipping while achieving highly stable walking (at a speed of 2.7 km/h) and running movement.

5. Work Functions

The new ASIMO has become capable of performing various services autonomously. These include transporting documents, beverages on a tray and other such lightweight objects (lightweight object transportation function), and guiding a cart along a route with some flexibility (cart guidance function).

5.1. Transporting Lightweight Objects

The new ASIMO uses force sensors to detect the load exerted on its hands when gripping a lightweight object. This has made it possible for the robot to independently judge the timing for opening and closing its hands. In addition to the detection of external forces using the force sensors, joint angle error information of the hands is also used to determine the grasping status of objects that it is transporting. Ranging information from its head-mounted stereo camera further detects whether it has documents or a tray; and it has been provided with the ability to judge the timing for lowering its arms after delivering something. The robot integrates this kind of visual and kinesthetic information with numerous other items of information to achieve a natural delivery style that adapts to the movements of the recipient.

One issue was how to limit the vibration in the robot's fingers caused by the foot landing shock when it is transporting a tray. This was solved by adopting vibration controls that feed back the acceleration component exerted on the fingers in a speed control loop, while also limiting vibration in the waist when the robot is walking while grasping something. As a result, the foot landing shock at the tray position was reduced by 20% and the peak angular velocity on the pitch circumference was reduced by 40%, thus realizing stable transportation of lightweight objects.

5.2. Cart Guidance Function

Research on the movement of robots pushing carts or other wheeled objects had been conducted in the past[4], but it was limited to linear movement. The new ASIMO was envisioned as being able to guide a cart that it pushes through offices or other such passages in a real-world environment. The aim, in other words, was to realize the capability for guidance along a path; for guidance on a route that involves right angles, such as turning sharp corners; and for dealing promptly with changes in paths and surface conditions of roadways, changes in transportation volume and other such factors, and adjusting speed accordingly. The following three technologies were developed for this purpose:

(1) Technology for predicting the future movement of a cart.
(2) Technology for determining movement of the robot's whole body in response to the predicted movement of a cart, taking into account the range where the robot cannot step, the full stretch of its arms and so on.
(3) Technology for guidance speed control to avoid the range noted above in response to changes in the floor surface or changes in weight.

These technologies provide a foundation for making continuous revisions to action plans in real time. This has made it possible for the robot to guide a cart autonomously and without imposed limitations, without exceeding its action boundaries, while adapting to changes in the external environment.

6. Human Response Functions

The new ASIMO has various added capabilities. It can quickly recognize an individual person, and is capable of adapting its behavior to others in a real-time manner (human detection). It is also capable of actions that involve holding people's hands (shaking hands and walking hand-in-hand).

6.1. Human Detection

Images from the pair of CCD cameras installed in the robot's head were formerly processed to isolate objects resembling the human form. The human object information (position, ID, speed) would then be provided as output. The system developed for the new ASIMO functions with the addition of an IC communication card. This combination is capable of detecting the positions of people in all directions around the robot, while also acquiring information about those people.

The IC communication card system uses existing radio communications in conjunction with optical communications that makes use of the directional characteristics of light and separates all the directions into eight. As shown in Fig. 12, the system is now capable of detecting the direction to any person within a 4-m radius of the robot.

ASIMO has further been given the capacity to behave adaptively in interactive situations, such as when it is acting as a receptionist, by applying these various functions (Fig. 13). When functioning as a guide, for example, the robot adjusts its actions according to the distance from and direction of the other party. It can turn in that person's direction and speak facing the person directly, with its head angled to meet the person's line of vision and so on.

6.2. Shaking Hands and Walking Hand-in-Hand with a Person

Force sensors have been installed in the robot's wrists and used with compliance control, to extrapolate the direction and speed of travel desired by the person with whom it is interacting. Thus it can respond flexibly, interact adaptively such as shaking hands and walking while holding a person's hand (Fig. 14).

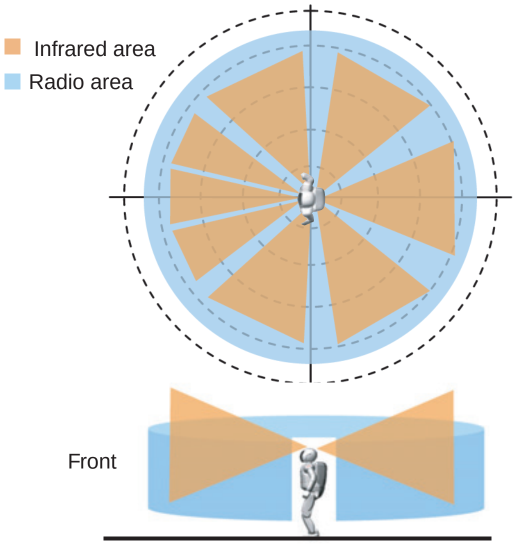
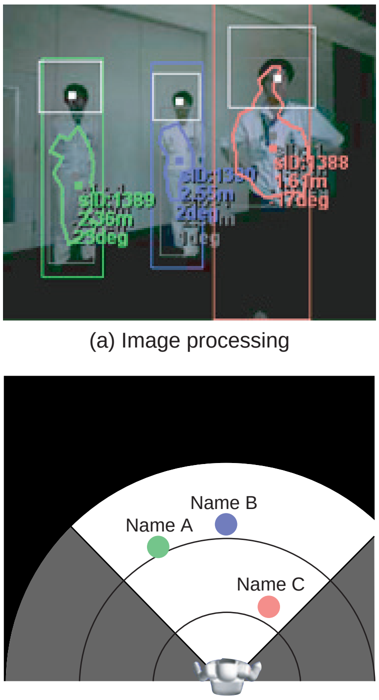


Fig. 12 Detection area of IC communication card



(a) Image processing

(b) Integration of IC communication card & Image processing

Fig. 13 Result of human detection

Fig. 14 Walking hand-in-hand

7. Conclusion

The development of the new ASIMO aimed at achieving a robot that could work autonomously in an office or other such real-world environment, and exhibit greater mobility. All this was intended as a step toward the goal of "a robot that coexists and cooperates with people and performs useful functions in society." The number of joint axes was increased; new control systems equipped with sensors for perceiving the surrounding environment were installed; and new running control technology was applied, enabling it to move with greater agility and to carry out real-time interactions with humans. As a result, the robot has evolved into an autonomous receptionist, a guide in an office, and a practical worker that can use transportation tools.

Our intention at Honda is to further refine the technologies developed for the present ASIMO so that its range of practical applications can be expanded in the future.

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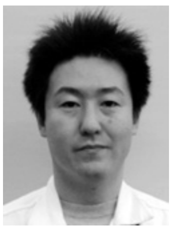

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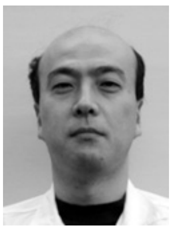

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