Development of Leg-Wheeled Type Mobile Robot Prototype

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We propose a new type mobile robot, “IMR-Type 1” which is able to move around indoors efficiently. The prototype robot is a leg-wheeled type with 3 legs and 4 pairs of wheels on the tip of each leg. The robot can move using the wheels on a flat floor and walk using the legs to go up and down stairs or to move over a small groove or step. This paper describes the concept and mechanism of this robot, its developed distributed control system using CAN (Controller Area Network), and the results of practical tests to evaluate the use and reliability of this robot system, conducted at the Prototype Robot Exhibition set up at the 2005 World Exposition Aichi, Japan.

1. Introduction

In the future, with fewer children, aging of society continuing to develop and service industries advancing, much is expected from robots to widely support human activities in various fields including living, public applications, and medical welfare. For such robots working coexisting and cooperating with human beings, movility is one of the most important functions. In order to coexist and cooperate with human beings, bipedal walking robots have been the subject of vigorous research and developed as a moving mechanism to share space with people. The robitic bipedal walking should have the same moving function as that of a human and a high adaptability to the environment prepared for human beings. But the technology involves many problems to be solved before it is practically used, such as danger of falling and poor energy efficiency when walking.

Many robots utilizing wheels have been developed, but they are limited in movable area of mobility because they cannot adapt to steep slopes and steps. For such reasons, a leg-wheeled type combining wheels and legs has been developed as a more efficient moving mechanism. Since such a type adopts a mechanism to maintain stability with the center of gravity arranged between legs in contact with the ground when walking at a low speed, the degree of freedom is high and the composition is complicated. A moving mechanism having the upper part of body installed on a carted inverted pendulum model emphasizing high-speed movement has also been proposed, though the traversability is lower.

Aiming at constructing a system that can move fast and efficiently indoors, we have tried to develop a leg-wheeled type robot having 3 legs and wheels attached to the tip of legs. This robot has a hybrid moving function to walk with the wheels attached to the tip of legs in flat areas, which account for the majority of indoor space, while maintaining stability and using the legs to adapt to stairs, steps, and grooves that impede the moving with the wheels.

In this paper, we describe the concept and configuration of a prototype robot “IMR-Type 1” developed by participating in the Project for Supporting the Development of Prototypes, part of the Project for the Practical Application of Next-Generation Robots under the auspices of the New Energy and Industrial Technology Development Organization (NEDO), the configuration of a distributed control system using CAN (Controller Area Network) developed anew in this project, and results of evaluated tests conducted at the Prototype Robot Exhibition, Expo 2005 Aichi.

2. Concept of Prototype Robot

Representative operations assumed for the moving robot are watching and patrolling. Advantages of using the moving robot include the possibilities of monitoring places in blind spots for a fixed camera and obtaining detailed information (abnormal vibrations, abnormal sounds, etc.) difficult to be obtained without going to the site. **Figure 1** shows operating images during patrol

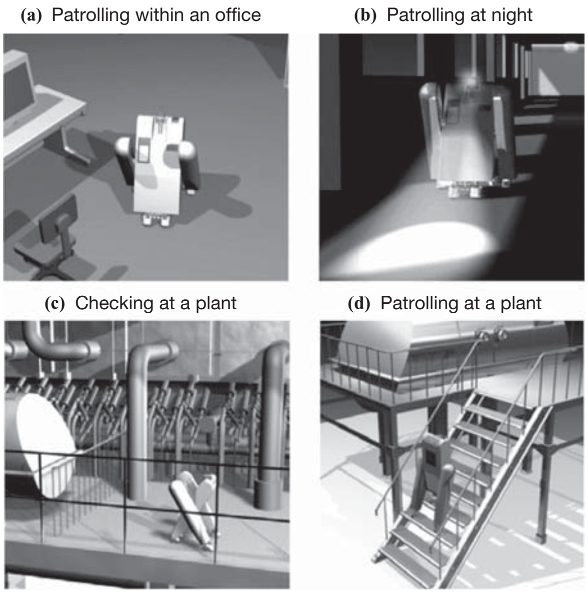


Fig. 1 Operating Images

within a factory and office. Most of passages used by humans are prepared flat, but in some cases, there are obstacles (piping, grooves, steps, etc.) and stairs, requiring a moving robot with high traversability.

In this development, we adopted a size to pass through passages used by humans and the concept of wheel-moving with high efficiency on flat surfaces and walking over obstacles. Assuming the passage width used by humans, we developed the prototype considering the possibilities as follows:

① moving through a passage of 900 mm in width
② securing the same line of sight as a human
③ walking stairs
④ simplifying the mechanism as much as possible

3. Outline of Leg-Wheeled Type Robot

Figure 2 shows the moving mechanism of the prototype robot. It is a 3-legged structure consisting of one leg attached to the central body and right and left legs to turn within a sagittal plane , which cut in the back/forth direction of walking referring to the leg. Each of the 3 legs has a degree of freedom to slide, and the central leg has two sets of ankles at the leg end. The right and left legs have one set of ankles each, totaling 4 sets of ankles, with wheels arranged in 2 rows. In flat areas, wheel-moving is done in a stable attitude with the central leg and right and left legs opened back and forth. The robot has no steering mechanism but turns by making in the velocity between wheels different.

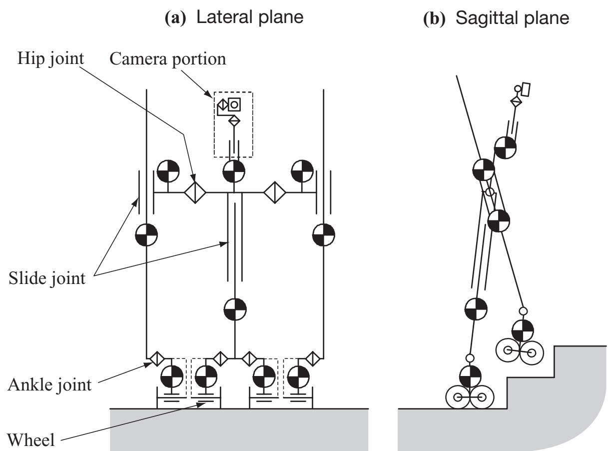


Fig. 2 Mechanical Configuration of the Robot

For passing over an obstacle such as a step, it can make the same form as for bipedal walking within the sagittal plane by synchronizing the right and left legs and alternately moving them and the central leg. When the robot stands on one leg in walking motion, the 2 pairs of wheels at the tip of leg can be taken as soles because they are brought into contact with the ground. The center of gravity in the lateral plane, which direction normal to the sagittal plane, is so designed as to be contained between the wheels in contact with the ground, thus providing structural stability. For this reason, stabilizing control in the sagittal plane is made only when walking.

It is also possible for the system to change the robot height by utilizing the sliding function of the legs. By using this function, the position of the monitoring camera attached to the upper part of the robot can be changed to the line of human sight (1 720 mm).

Figure 3 shows the overview of the developed prototype. It shows the robot positions changed

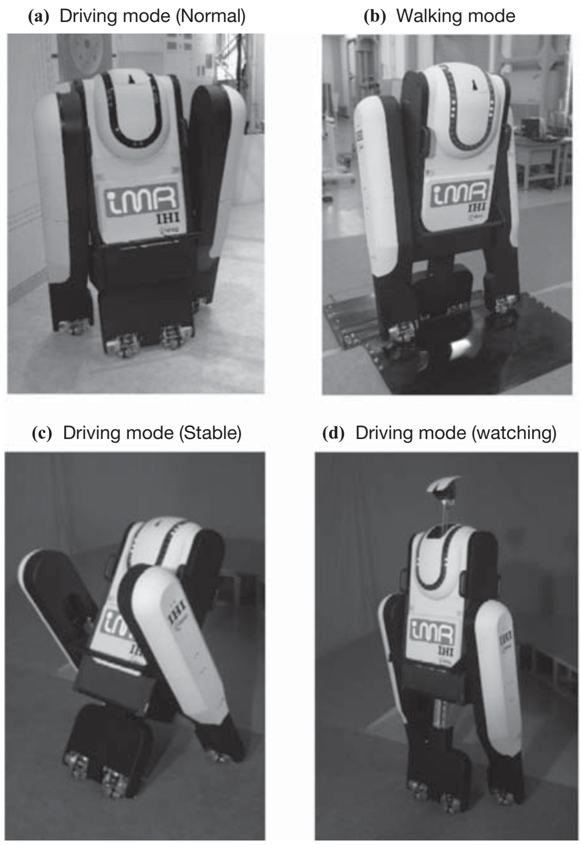


Fig. 3 Overview of Prototype Robot "IMR-Type 1"

in accordance with the operation situation. Main specifications of this robot are shown below.

Dimensions	700 (W) × 400 (D) × 1 150 to 1 720 (H) mm
Wheel	46 dia. × 8 pieces (4 pairs × 2 pieces)
Weight	60.0 kg
Movement mode & Maximum speed	
Driving mode	2.5 km/h
Walking mode	4.0 s/step
Movable size of walking stairs	
Maximum height	200 mm
Maximum depth	250 mm
Movable size of slope Maximum gradient	7 degrees (12%, continuous)
Degree of freedom arrangement	
Moving function (total)	13 degrees of freedom
Leg slide	3 degrees of freedom
Hip joint	2 degrees of freedom
Ankle joint	4 degrees of freedom
Wheel	4 degrees of freedom
Camera section	3 degrees of freedom
Movable range	
Moving function	
Leg slide	340 mm
Hip joint	± 80 degrees
Ankle joint	± 45 degrees
Camera section	
Slide	225 mm
Pan	±45 degrees
Tilt	±45 degrees
Power supply	
Battery type	nickel-hydrogen cell
Drive system (maximum value)	12 V × 4.5 Ah × 4 (48 V)
Control system (maximum value)	12 V × 3.6 Ah × 4 (24 V)
Operation time	about 75 min

4. Configuration of Distributed Control System

Future robot systems are desired to allow the easy addition of devices to the standard robot platform for additional functions. With the prototype robot developed this time, we developed a distributed control system in which the hardware of the internal system of the robot is modularized in functional units and the modules are connected in a network. For the network to connect the modules, we adopted the CAN proven with automobiles, etc. In consideration of the communications traffic and communication speed, the architecture of network consists of two parts. One is communicated massages of robot management and control commands. The other is a mobile motion control subsystem that is a real-time, high speed control system.

This robot motion is controlled by the movement commands from external devices. **Figure 4** shows the distributed control system architecture. For the method to send commands from external devices, we prepared a method via ORiN (Open Robot/Resource interface for the Network), a standard interface to connect multiple robots, using wireless LAN from the host computer for operating (host PC) and a method through radio-controlled communication from a handy controller.

The host system was composed of the following 5 basic modules for each function in the beginning.

① Robot management and control module
This module controls the entire robot by communicating with the host PC.

② Receiver module
This module processes signals from the handy controller (Radio-controlled).

③ Mobile motion control module
This module calculates and controls the motion of the moving mechanism.

④ Monitoring module
This module monitors the condition inside the robot.

⑤ Camera module
This module controls the camera position.

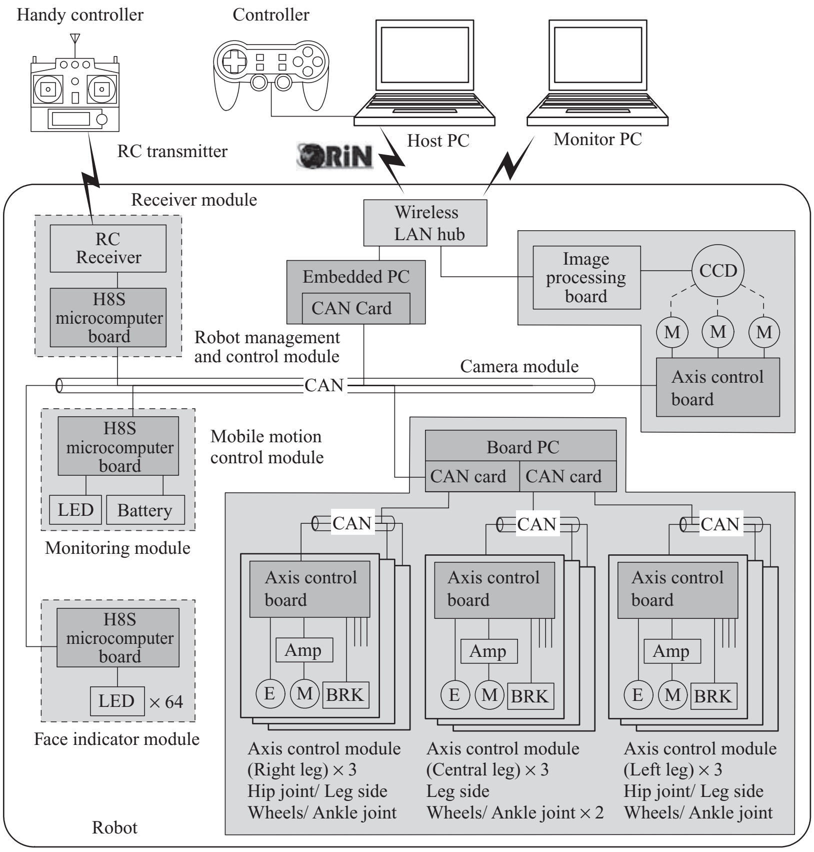
Conscious of the demonstration at Expo 2005 Aichi, we added a “face” by means of many LED displays. For this reason, we had to add the LED display module after the system construction, but we could easily add it without changing the system of other modules because we had adopted the distributed control system. This made it possible for us to confirm the ease of adding functions in the distributed control system.

The mobile motion control subsystem is composed of 9 axis control modules arranged for each drive axis of the moving mechanism and mobile motion control module. Since the communication rate of CAN, is 1 Mbps, is not enough to control 9 axes in real time, it was divided into the buses of 3 systems for each leg in consideration of the mechanism characteristics. With this configuration, we realized a real-time control subsystem at a cycle of 500 Hz for the robot motion control and calculation. The axis control module was made the axis control board equipped with interface for motor control, and it was developed anew by installing a microcomputer (H8S) having CAN communication function. **Figure 5** shows the overview of the axis control board.

By adopting these distributed control systems, we could promote wiring-saving and realized lighter weight with the harness mass almost halved.

5. Demonstration and Evaluated Tests

In the Project for Supporting the Development of Prototypes by NEDO, a demonstration assuming the year 2020 was positioned as evaluated test and implemented in the Prototype Robot Exhibition (June 9 to 19, 2005) at Expo 2005 Aichi. With this robot, we carried out the



(Note) ORiN : Open Robot/Resource interface for the Network
CAN : Controller Area Network
E : encoder
M : motor
BRK : brake
Amp : servomotor driver amplifier

Fig. 4 Distributed Control System Configuration

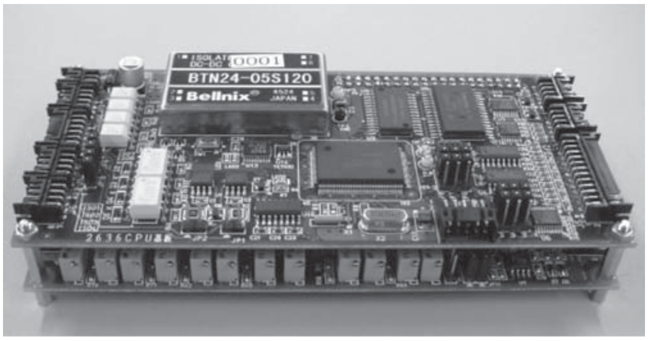


Fig. 5 Axis control board

demonstration to show the capability of the moving function with the patrolling and monitoring within a factory, etc. as the image of applied operations in accordance with the scenario shown in **Figure 6.**

We carried out the demonstration in the story form operated by the Host PC 32 times in 11 days and the demonstration continuously combining individual motion using the handy controller 44 times for 30 minutes each. During the period, the operation was performed without any trouble related to the circular movement of the demonstration course, and the following movement results were obtained.

Number of rounds	about 250 rounds (moving of about 6 km)
Walking stairs	3 steps (4 walks) × 250 times 750 steps 1 000 walks
Walking over obstacle	6 walks × 250 times, 1 500 walks

Through the aforementioned 11-day operation, we could verify the reliability of the developed system. **Figure 7** shows how the demonstrations were conducted.

Subsequently, we conducted the similar demonstration and evaluated tests without any major problems at Robo-Festa 2005 for young people (August 27 and 28), CEATEC JAPAN 2005 (October 4 to 8), and 2005 International Robot Exhibition (November 30 to December 3). Though these demonstrations, we confirmed that the robot it could adapt to different movement environments.

6. Conclusion

We developed a prototype robot “IMR-Type 1” to move in spaces where human beings move. For the moving mechanism of this robot, we adopted the leg-wheeled mechanism having both functions of wheel moving capable of moving fast, stably, and efficiently and the leg function to walk over obstacles. For the system of

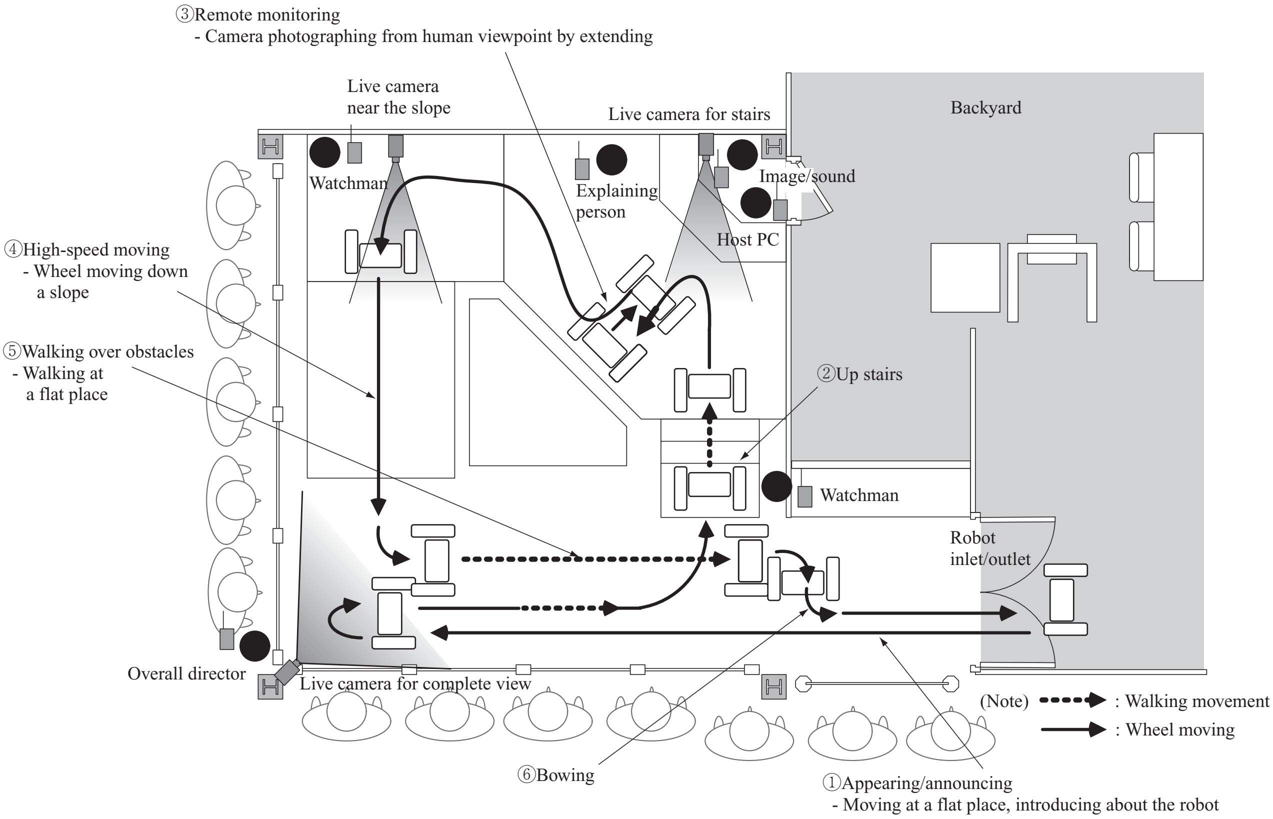


Fig. 6 Layout and Scenario of Demonstration

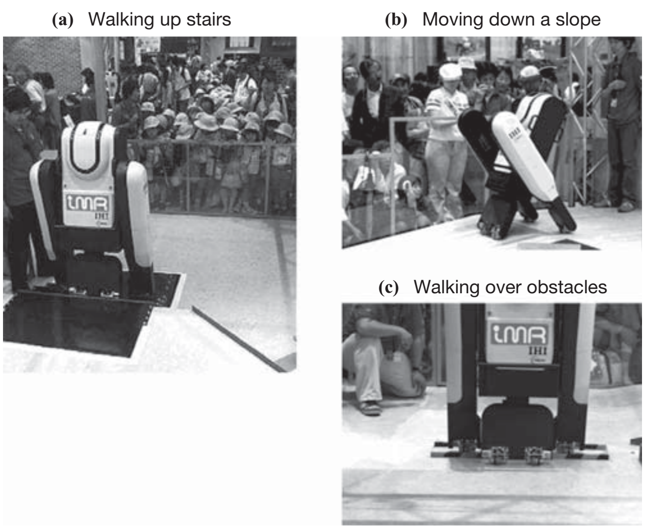


Fig. 7 Demonstration Scene

the robot, we constructed a distributed control system using CAN to facilitate adding or changing functions and realize wiring-saving. With the developed prototype robot, we confirmed the reliability of the robot system by conducting several demonstrations and evaluated tests at the Prototype Robot Exhibition of Expo 2005 Aichi and other places. In the future, we will develop such applications as factory patrolling and monitoring and reception/guidance. **Figure 8** shows the images of applications.

This research was conducted as part of the project for Supporting the Development of Prototypes, part of the Project for the Practical Application of Next-Generation Robots under the auspices of NEDO.

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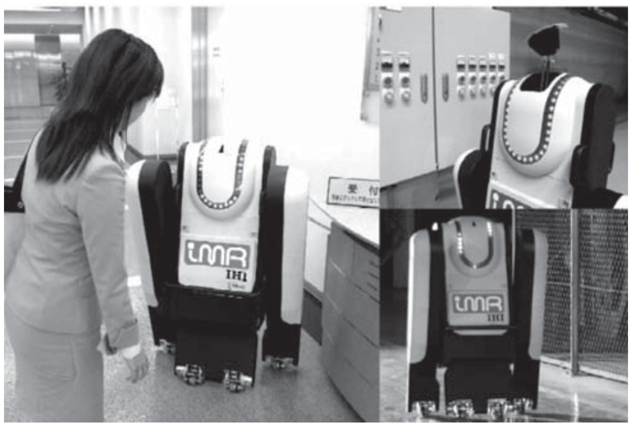

Fig. 8 Application image

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