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Local communication-based navigation in a multirobot environment

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To realize cooperative tasks in a multirobot environment, individual robots must be able to move around the working environment smoothly with certain positional accuracy because the surrounding robots are obstacles and a mutual alignment of their positions becomes more important. It is, therefore, extremely important for a robot to have a reliable and adaptive navigation system. We have focused on the collision avoidance and the self-localization problems based on local communication to realize such navigation systems for a multirobot environment.

In a multirobot environment, every robot must avoid moving objects such as other robots. It is, however, difficult to recognize moving objects using conventional sensors. For this problem, we have developed the LOcally Communicable Infrared Sensory System (LOCISS). The LOCISS is a sensing device based on local communication with other robots using infrared rays as transmitting media. By transmitting/receiving the motion information, i.e. the moving direction and speed, each robot can recognize an other robot's motion easily, as shown in Fig. 1. Moreover, by transmitting/receiving a unique ID number, each robot can discriminate between other robots and obstacles. Robots can select adaptive behaviors to avoid surrounding obstacles based on a reinforcement learning on a situation which is recognized by LOCISS. To reduce the size of the state space for the learning, learning curriculum are divided into multiple layers.

Landmark-based self-localization usually requires environment maps which indicate positions of landmarks. However, management of such positional information needs large costs in a multirobot environment mainly due to stagnation of communication.

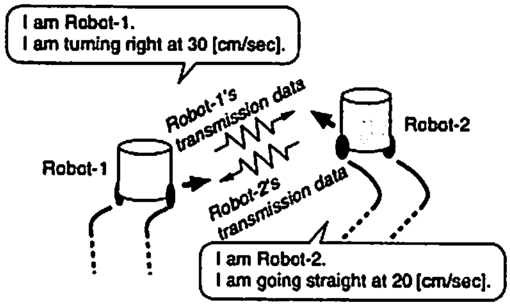

Figure 1. Concept of situation recognition.

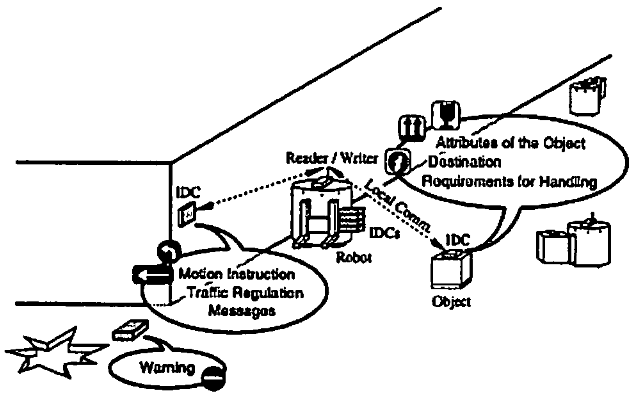

Figure 2. Concept of the IDC system.

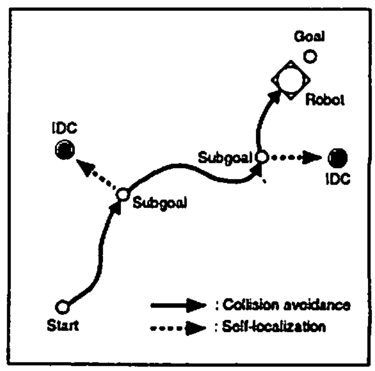

Figure 3. Strategy of navigation.

For this problem, we have introduced the Intelligent Data Carrier (IDC) as a landmark as shown in Fig. 2. The IDC is a portable device in which local information can be stored. Robots can acquire some information from IDCs using the Reader/Writer based on local RF communication. By putting IDCs on an environment as landmarks and writing their positional information into them, the robot can acquire such information only in a communicable area of an IDC. Additionally, the robot acquires other information which is needed to calculate its position by passive sensing devices. Consequently, landmark-based self-localization can be realized in a distributed manner without any global environment maps and large data management costs.

An autonomous navigation is realized by integrating these elemental methods based on local communication. Some subgoals are set between a start and a final goal for each robot as shown in Fig. 3. Some IDCs are also put on the ground to indicate each subgoal and the final goal. A robot usually moves toward its goal executing the collision avoidance procedure while it tries to communicate with an IDC. When communication with an IDC is established, the robot recognizes that it arrives at a subgoal and executes the self-localization procedure. The next subgoal is then given to the robot. If the subgoal is the final goal, the procedure of navigation is finished. By implementing the navigation system on real robots, an experiment was conducted among three robots.

The proposed navigation system is scalable to a number of robots in the system because the methods mainly utilize local communication. It is expected that complicated tasks which require robust and reliable navigation can be accomplished by applying the proposed navigation system.

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Biped-type leg–wheeled robot

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There are many types of locomotion such as by wheels, legs, crawlers, etc. Recently, by combining the mechanisms of two or more types of locomotion, mobile robots with the merits of those types have been developed. Among these robots, a typical class is leg–wheeled robots that can negotiate obstacles using legged locomotion and can travel fast on flat surfaces using wheeled locomotion. Many studies of leg–wheeled robots have been carried out. However, most of them use mechanisms that keep the center of gravity low to ensure stability when negotiating rough surfaces (steps, stairs, etc.). Such mechanisms suffer from low energy efficiency and slow negotiating speed because of being a complex system with many degrees of freedom.

Therefore, to allow a leg–wheeled robot to efficiently and speedily negotiate stairs that are typical indoor obstacles, we have proposed a new mechanism and its control scheme. The proposed new leg–wheeled robot will travel by driving the wheels with static stability on a flat surface and can negotiate stairs with dynamic stability by balancing its body on those actively controlled wheels that contact the ground. This type of robot with dynamic stability has a simple structure, because its mechanism does not necessitate static stability. Moreover, the high center of gravity is no disadvantage because the dynamic movement of the center of gravity can be controlled easily, and the energy-efficient wheeled mechanism will be useful for self-contained robots.

The 'biped-type leg-wheeled robot', which we developed as a new prototype of a leg–wheeled robot, is made of two legs connected by an actuated joint. Each leg has two wheels on the same axle. The axle is enough long so that the robot can be statically stable with one leg in the roll direction. A DC servomotor (23 W) is attached to the lower part of each leg for driving the wheels and one to the upper part of each leg for lengthening and shortening the leg. A DC servomotor (11 W) is attached to the middle part of one leg for changing the angle relative to the other leg in the pitch direction. A rotary encoder is

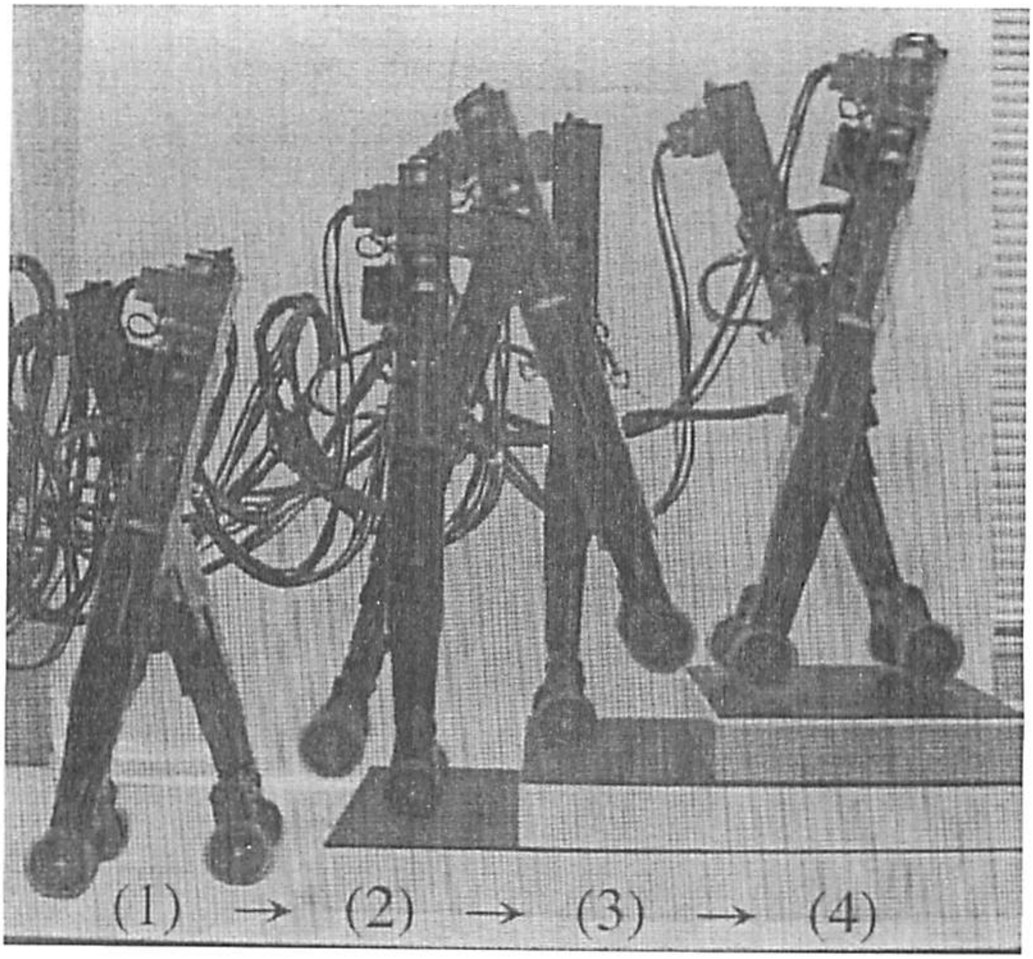

Figure 1. Going up stairs by the 'biped-type leg-wheeled robot'.

attached to each motor for sensing the rotation angle of the motor. A rate gyroscope is attached to each leg for sensing its angular velocity in the pitch direction.

In our control scheme, in order to enable fast negotiation of stairs, a dynamic trajectory planning and control method is adopted taking into account the dynamic interference that is inherent to the designed leg–wheeled robot. We also propose a method to connect the dynamic trajectory control motion in the statically unstable state and the structure changing motion in the statically stable state. Using the proposed methods, fast climbing up and down stairs (3 s [per step]) by this robot has been realized successfully (Fig. 1). As the result, the effectiveness of our proposed new mechanism and dynamic control methods for leg–wheeled robots have been confirmed by the successful negotiation control experiment.