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Investigation of Teleoperation Support System Using Environmental Recognition Sensors for Three-Parallel-Crawler-Type Mobile Robot

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Abstract

In this paper, we propose a simple method for the safe teleoperation of a three-parallel-crawler-type mobile robot with distance range sensors and a wireless camera having a fisheye lens. The method enables the robot to avoid collision when a distant operator manipulates the robot by viewing a streaming video. In addition, notifications of danger are shown on the control interface screen and an audible alarm informs of the risk of collision by using information obtained from distance-measuring sensors. The validity of this system was evaluated during on the basis of experimental results for the effectiveness the sensors during operation.

1. Introduction

In recent decades, various types of mobile robot have been introduced for use in complex and unstable environments such as homes or places where robots and humans coexist, outdoor environments, and so forth. To achieve a given task with certainty in such environments, mobile robots are required to have an excellent mobile mechanism, an environment recognition function, and an advanced motion control algorithm. As a mobile mechanism that can smoothly move on irregular terrain, it is well known that a crawler-type mechanism is superior to other types of mobile mechanism [1].

In our previous research, we developed a three-parallel-crawler-type (TPC-type) mobile robot with a teleoperation system that uses internal sensor data to generate the actual robot posture in a 3D image. The obtained robot posture helps the operator to decide the robot movement on irregular terrain. However, obstacle collision may occur since the operator cannot recognize objects surrounding the robot.Therefore, the use of a wireless imaging device and a distance range sensor is important.

In this paper, to improve the operationality or controllability of the TPC-type mobile robot's teleoperation system, we consider the use of external environmental sensors on the basis of the concept of the automation level.

2. Teleoperation System of TPC-type Mobile Robot

2.1 Experimental setup

The configuration of the teleoperation system for the TPC-type mobile robot is shown in Fig. 1. An operator can control the robot by manipulating a joypad connected to the control PC. The robot and the control PC are mutually connected by XBee wireless communication units. Moreover, a Raspberry Pi distributes a camera image via a Wi-Fi network.

Some sensor values and the camera image are presented on the PC monitor to support the teleoperation. The sensor values are collected by a microcontroller mounted on the robot and the camera image is captured by a camera module with a fisheye lens connected to the Raspberry Pi.

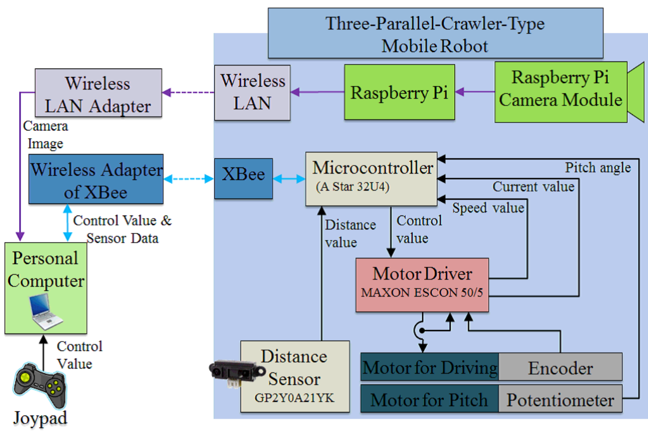


Figure 1: Experimental setup of teleoperation

2.2 Mobile robot

The appearance of the developed TPC-type mobile robot (total length 75cm, total width 62cm, height 64cm, camera unit height 21cm, total weight 28.3kg) is shown in Fig. 2. Each crawler unit is independently driven by a geared dc servo motor and linked with a main shaft in parallel. Therefore, the TPC-type mobile robot can move on the irregular terrain by changing relative angle between each crawler according to the road surface condition. In addition, the Wi-Fi module and the camera module with the fisheye lens are mounted on the robot as shown in Fig. 2. Infrared distance range sensors are also mounted on both sides of the robot.

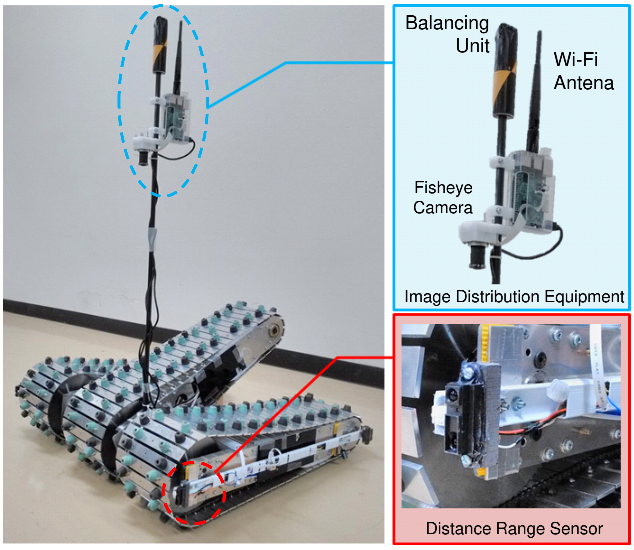


Figure 2: Developed TPC-type mobile robot

The robot is directly controlled by a microcontroller (A-Star32U4). Control signals of the three driving motors and the motor for the pitch are calculated by the microcontroller and sent to the motor drivers (Maxon ESCON 50/5). The motor driver controls the motor speed by using the actual rotation speed and a current sensor value so that the actual speed follows the speed command. Here, the motor driver feeds back the armature current and rotation speed of each motor to the microcontroller as an analog voltage.

The microcontroller collects some information on the robot such as the rotation speed of the motors, the armature current, the pitch angle of the center crawler, and the distances from obstacles measured by the infrared sensors. This information is fed back to the control PC via the wireless communication units.

3. Collision Prevention and Notification System

3.1 Concept of collision prevention control

In our previous research, we proposed a remote control system for a mobile robot with semi-autonomous control based on the collision danger degree [2]. This system is useful and effective as a human-oriented remote control system to avoid erroneous manipulation by the operator and successfully realize obstacle avoidance [3]. On the other hand, as an environmental recognition system using a camera, we investigated and compared several systems such as the use of a fixed-point camera in the workspace, a fisheye camera mounted on the robot, and direct observation by the operator. As a result, the most useful environment recognition system for teleoperation was found to be the fisheye camera mounted on the robot [3]. On the basis of these research results, in this paper we propose a simple human-oriented teleoperation system by which the TPC-type mobile robot can move safely without collision against obstacles even if the operator performs an erroneous operation.

3.2 System setup

We implement four infrared distance sensors (GP2Y0-A21YK) in the robot as shown in Fig. 2. The mounted positions and detection ranges of the sensors are shown in Fig. 3. The distance-voltage characteristics of the infrared distance sensors are not linear. Therefore, the output voltage of each sensor V[V] is converted to the distance L[cm] by the following formula.

$$L = \frac{26.159}{V - 0.07647} - 1.7647 \qquad (1)$$

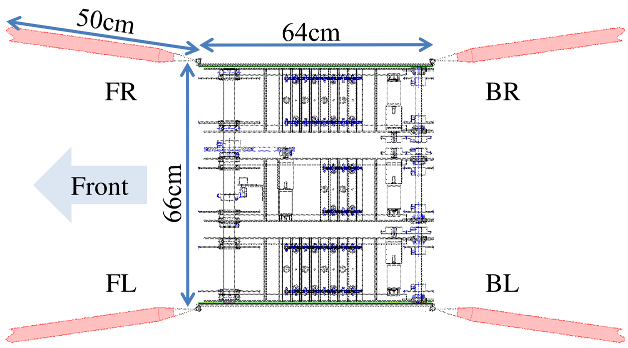


Figure 3: Detection ranges as above of infrared distance sensors

3.3 Collision prevention control algorithm

Collisions are prevented by limiting the motor rotational direction based on the sensor value. Table 1 shows the limitation method of the rotation for each sensor shown in Fig. 3. As shown in the table, the controller limits the forward (↑) and backward (↓) motion of each crawler individually depending on which sensors exceed the threshold voltage. Therefore, the robot can prevent the collision with an obstacle automatically independently of the operator's manipulation. If two or more sensors detect an obstacle at the same time, the limitation of the motor rotation also occurs.

The threshold distance is set to 17cm in consideration of the stopping distance on flat terrain. Figure 4 shows the result of controlling the motor speed using the proposed method.

Table 1: Limitation of rotation

Sensor	Left		Center		Right	
	↑	↓	↑	↓	↑	↓
FL	L		L			
FR		L		L		
BL			L		L	
BR				L		L

L : Motor rotation is limited

When the output of the distance sensor exceeds the threshold voltage (1.47V = 17cm) during the forward motion of the robot, the controller sets the speed command to zero. As a result, the motor is stopped.

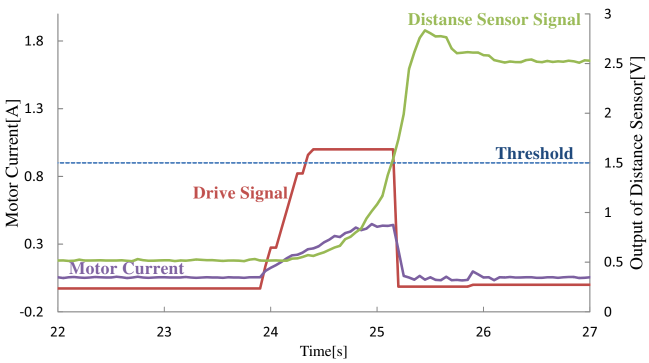
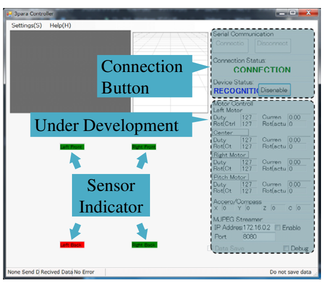
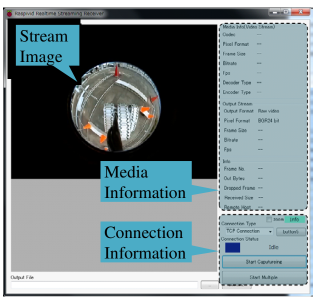


Figure 4: Result of motor control with sensors

Figures 5(a) and 5(b) show respectively window images of the crawler controller and camera viewer, which are presented to the operator. The crawler controller sends the control signal and displays some information on the robot, as typified by the distances output by the four distance sensors. If the obstacle is close than the threshold distance, the distance value is highlighted in red, as shown in the bottom left of Fig. 5(a) and a beep is produced. Here, the frequency of the beep depends on the position of the obstacle: 880Hz (front) and 440Hz (rear).



(a) Crawler control viewer



(b) Camera image viewer

Figure 5: Teleoperation windows

4. Experimental Results

4.1 Experimental field

Figure 6 shows an image and the size of the experimental field. In this field, the robot must travel from the start position to the goal while avoiding three obstacle blocks. It must also negotiate the step at the goal by deploying the center crawler.

The experimental field is observed by a fixed-point camera to evaluate the controllability the proposed teleoperation system. Here, the intervals between of the obstacle blocks are set to be narrow relative to the size of the robot.

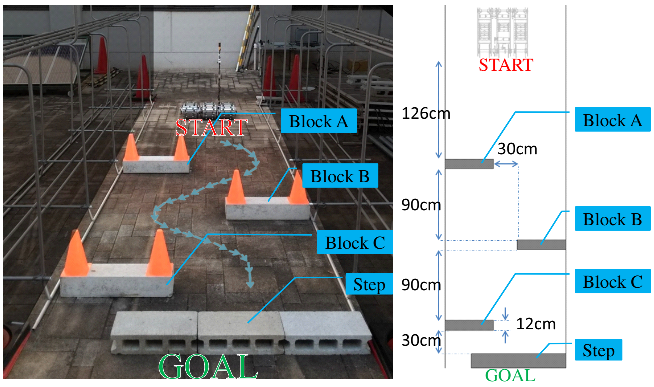


Figure 6: Experimental field

4.2 Experimental results of teleoperation

We evaluated the validity of the proposed system from the experimental results based on the sensor values, the control input by the operator, and the conflict between the control input and collision prevention control. Figure 7 shows an experimental result without sensors, and Fig. 8 shows an experimental result obtained using the proposed system. In Fig. 7, the distance sensors FR and BL continuously show high values shortly before the goal. On the other hand, in Fig. 8, the distance sensors show high values, but the values are reduced immediately. Additionally, by observation of the conflict flag, it can be seen that the result with the sensors has a long conflict time compared with the result without the sensors. We assumed that the reason for the difference is that the operator may focus on passing through the experimental field because of the collision prevention system. In fact, an experienced operator manipulates on the premise of automatic collision prevention control.

At the time of camera image (I) in Figs.7 and 8, the value of sensor BR increases rapidly. This is caused by block A entering the measurement range of sensor BR as the robot turns since the proposed control method prevents collision by forward and backward motion. Therefore, a future task is to detect and prevent obstacles that are approached by the rotation of the robot.

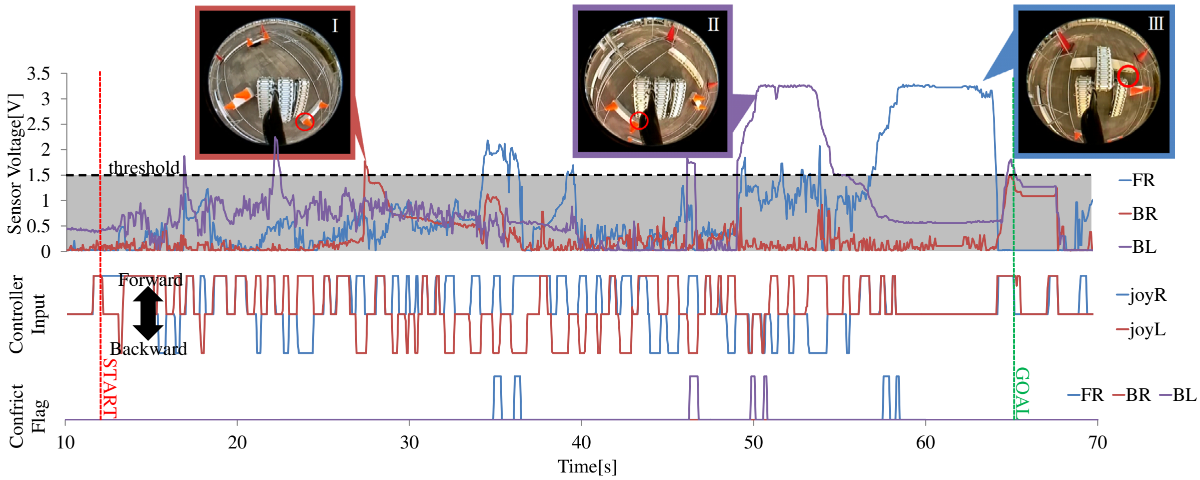


Figure 7: Experimental results of teleoperation without infrared distance sensors

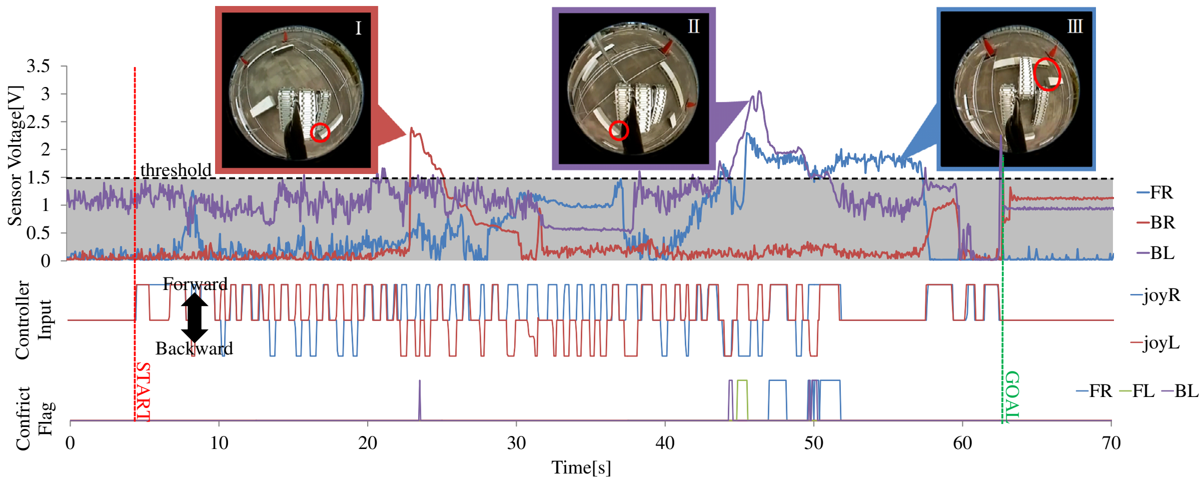


Figure 8: Experimental results of teleoperation with infrared distance sensors (proposed system)

Moreover, at the time of camera image (II) in Fig. 8, the values of sensors FL and BL both exceed the threshold voltage. Therefore, the left and center crawlers of the robot do not rotate forward or backward. In this case, the robot continues to undergo pivotal motion using the right crawler. However, sometimes the robot is unable to progress depending on the experimental environment. To solve this problem, it is necessary to improve the collision prevention control algorithm.

5. Conclusion

In this paper, we proposed a collision prevention control method for a TPC-type mobile robot. To detect obstacles, we mounted four infrared distance sensors on both sides of the robot. The rotation of the driving motor is limited, depending on the proximity of obstacles, for collision prevention. The experimental result using the proposed system demonstrates the effectiveness of the system compared with the system without sensors. A future task is to improve the system to avoid the problem of the robot not being able to progress.

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