A mechanical intelligence in assisting the navigation by a force feedback steering wheel for a snake rescue robot

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Abstract

In this paper, we developed a snake rescue robot basing on the proposed mechanical intelligence. The mechanical intelligence is designed to avoid obstacles and to realize desired motions when the robot is navigated by a remote force feedback steering wheel interface. We use free joints to connect modules of the snake robot. Modules can freely turn according to their neighbors. An obstacle-avoiding wheel is mounted on the head of the snake robot. When the head encounters an obstacle, the wheel touches it first to transfer the sliding friction between the wheel and the obstacle into rolling friction, so that the head avoid the obstacle easily. A metal wire is used to link gears mounted on both sides of each module. When any part of the snake robot's body encounters an obstacle, the wire length of each side varies automatically to change the robot's body shape, so that the snake robot avoids the obstacle. The wire length of each side can also be adjusted by a motor. By adjusting the wire length of each side, the snake robot can move in the desired direction. The mechanical intelligence based snake rescue robot has light body, low cost and low computation cost. Experiment results show that the designed mechnical intelligence is effective in realizing desired robot motions together with the force feedback steering wheel interface.

Keywords : Human Interface, Mechancial Intelligence, Navigation, Force Feedback Steering Wheel, Rescue Robot, Snake Robot.

1. Introduction

In large-scale disaster sites, such as earthquakes, professional rescuers are often not enough to meet need. At the Kobe earthquake that happened in 1995, most victims were saved by civilians. The number of victims saved by firefighters, polices, and the Self Defense Force were not large. So we suggested that many non-professional volunteers, such as housewives, operate rescue robots to save victims in large-scale disaster sites [1].

Non-professional volunteers are characterized with little even no knowledge about robotics. The need of many non-professional volunteers to operate rescue robots brings the requirement of novice users oriented rescue robot system design. The designed rescue robot system should be easy to learn its operation without having much knowledge of robotics.

Under this consideration, we proposed a strategy of operating rescue robots through novice users oriented human interfaces and developed a force feedback steering wheel interface [1]. This interface provides an everyday operation for users to navigate rescue robots as that of driving cars. It has been used to navigate a tank rescue robot [2].

Disaster sites are characterized with collapsed structures. There are many narrow spaces and tough fields. In such constructions, rescue robots that have smart bodies and many freedoms are expected to be developed. Snake robot is a kind of such robots [3, 4]. It is suitable to explore narrow spaces because of its smart body and multiple freedoms.

To adopt redundant rescue robots brings another problem on how to operate them. In order to lighten users' workload on learning to operate the interfaces and to reduce cost, we propose a general human interface strategy for operating multiple kinds of rescue robots. With this consideration, the steering wheel interface is expected to have the ability for operating not only tank rescue robots, but also snake rescue robots.

There are some problems in realizing the navigation of a snake rescue robot by the force feedback steering wheel. The steering control has only two signal channels. One is for direction. The other is for speed. The tank rescue robot is like a vehicle. Its motion is obtained by the moving of two wheels. The two channels of signals are enough to realize the tank robot's desired motions. A snake rescue robot has many modules and joints. The steering wheel interface can only indicate the speed and the direction for the robot. It has no signal channels for making collaboration among the robot's modules and joints. Other problems lie at the requirements such as light weight, low cost, and low computation cost for rescue robots. Conventional researches about snake robots used actuators at every joint to obtain desired motions. This construction makes the robot very heavy. A heavy robot would destroy the structure of a disaster site to make things worse, since the structure of a disaster site is fragile. To use many actuators also increases the robot's cost. It is not advisable to deploy very expensive robots into the disaster sites, since they are easily destroyed in such dangerous environment. Furthermore, many mounted actuators would need high computation cost. Considering these problems, a new construction that has light weight, low cost, low computation cost and adapts to the force feedback steering wheel interface is expected for developing the snake rescue robot.

For a snake rescue robot, we think that it should have two important functions. One is to avoid obstacles passively. A snake robot is expected to explore structures with narrow spaces. Such structures have many close obstacles. A snake robot has long body. Although its head can successfully avoid an obstacle, its body is still possible to be barred by other obstacles. This case usually occurs when the robot changes its direction or when there are moving objects in the disaster site. In such case, the robot's body should avoid obstacles automatically. The other important function is to obtain desired robot motions. This means to let the robot move along a planned path or avoid an obstacle actively, while maintaining collaboration among all of its modules.

To realize these functions while avoiding the problems described above, the authors suggested a mechanical intelligence for constructing the snake rescue robot [1]. Modules are connected with free joints. There is a metal wire assembled on both sides of its body. When the robot encounters an obstacle, it will avoid the obstacle by the self-adjusting ability of joints and the metal wire. If we adjust the wire length of the two sides, we can also change the robot's direction to avoid the obstacle.

This paper developed a prototype of a snake rescue robot using the proposed mechanical intelligence. We also present the results of some experiments to evaluate the effectiveness of the mechanical intelligence in assisting the robot's navigation by the force feedback steering wheel interface. The following of the paper is organized as five sections. Section 2 describes the system outline. Section 3 presents the force feedback steering wheel interface. Section 4 introduces the mechanical intelligence based snake rescue robot. Section 5 presents the results of experiments and discusses them. Section 6 concludes this study.

2. System Outline

Figure 1 shows the outline of the developed system. A wide view camera is mounted on a snake rescue robot. The prototype of the snake robot is shown in Fig.2. The camera has a view angle of 180 degrees. Video signals and data of other sensors are transferred to the receiver and passed into the data processing computer. This computer processes video signals intelligently and displays them on the monitors.

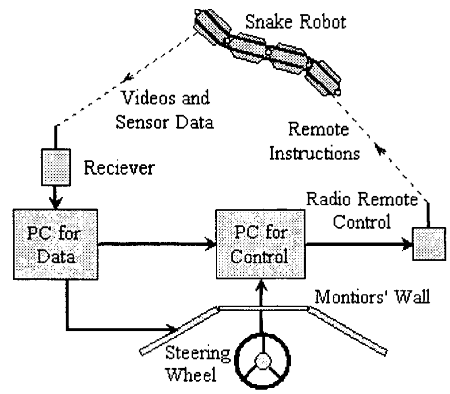

Fig.1 System outline

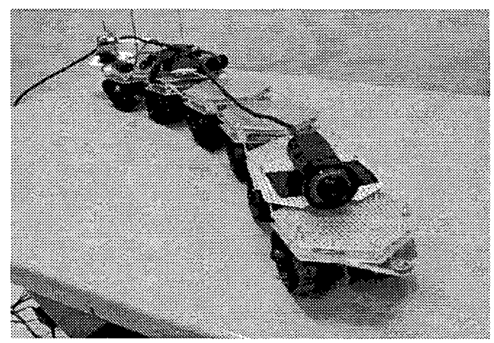
Fig.2 The developed snake robot

For useful information recognized by system intelligence, it automatically warns users with words such as "Victim Found" displayed on the monitors. While watching incoming videos of the local disaster site, the user can navigate the robot by operating the force feedback steering wheel. The instructions for the direction and the speed of robot movement are passed into the radio remote control and transmitted to the robot. When the robot gets them, it moves under the control of its mechanical intelligence to access the object area.

3. Steering Wheel Interface

A force feedback steering wheel interface is developed as a novice users oriented human remote operation method. It consists of a steering control and a six monitors' wall. Figure 3 shows the developed interface. The steering control has a wheel for the control of direction and two pedals for the control of speed and direction (forward and backward). Because the image of the wide view camera distorted optically, we divide the camera's view into six parts. Three computers are used to process each part of the camera's view and display them on six monitors with no distortion.

While watching local information displayed in the monitors' wall, a user can operate the steering wheel and the two pedals to navigate the snake rescue robot. The expanded

Fig.3 The steering wheel interface

non-distorted local videos support the user's vision strongly. The operation of the robot like driving cars in daily life is suitable to a novice user. Any user who has experiences of driving a car can operate the steering wheel interface easily. Even if he has no driving experience, he can learn to operate it quickly.

4. The Mechanical Intelligence Based Snake Rescue Robot

4.1 Necessity of Developing Mechnical Intelligence

The necessity of developing mechanical intelligence lies at three main points, to assist to realize the snake robot's navigation together with the steering wheel interface, to fulfill special requirements for a rescue robot, and to realize functions needed in structures with narrow spaces.

The first point is to assist to realize the snake robot's navigation together with the steering wheel interface. We expect the force feedback steering wheel interface to have the ability for navigating not only a tank rescue robot, but also a snake rescue robot, in order to lighten users' workload on learning the operation and to reduce cost. The force feedback steering control has two signal channels. It is suitable to navigate a tank rescue robot. Because navigating it needs only two parameters, speed and direction. For a snake rescue robot, its desired motion is acquired by speed, direction, and collaboration of all joints and modules. The steering control can indicate speed and direction for a robot, but it cannot make collaboration among modules and joints of the robot. To navigate a snake rescue robot by the steering wheel interface, we decide to use a remote operation and local semi-automation controlling strategy. Let the steering wheel interface indicate direction and speed for the snake robot. The desired motions are realized by the robot itself.

Moreover, a rescue robot has special requirements of light body, low cost, and low computation cost because of its dangerous working environment. A weighty robot would destroy the structure of a disaster site, since the structure of a disaster site is fragile. It is also not advisable to deploy very expensive robots into the disaster sites, because they are easily destroyed in such dangerous environment. Furthermore, the system should not have to use two much computation source for controlling the robot's modules and joints, since it must process many incoming data on real time. Conventional researches about snake rescue robots used actuators at their joints to obtain desired motions. Such constructions made the robots expensive and weighty. The computation cost also increased. To avoid these problems, new construction of a snake rescue robot is required.

Finally, it is expected to realize special abilities of a snake rescue robot through its body construction. Snake robots are used to explore structures with narrow spaces. There are many close obstacles in such environments. One of the most important abilities of a snake robot is to avoid obstacles. A snake robot should be able to avoid obstacles actively and passively. To avoid actively means to change the moving direction of the robot's head to avoid an obstacle. This function in fact means its ability of moving along a desired path while maintaining collaboration among all the modules. To avoid obstacles passively is also required for a snake rescue robot. A snake robot has long body. When its head turns, its body may be barred by lateral obstacles although the head avoided them. Moreover, at a disaster site, there may be moving objects. If these moving objects hit the robot's body, the robot should avoid them automatically. In a word, a snake rescue robot should be able to avoid obstacles passively and have the ability of moving along desired path, while maintaining its body balance.

4.2 Mechanical Intelligence Based Snake Rescue Robot

The developed snake robot has six modules. These modules are same in sizes and structures. Every module has a hexagon contour from the top view, like Fig.4 and Fig.5. The length of each side is 65 mm. Each module has a motor to drive its two pedrail wheels. The robot has a body length of 83 cm. Free joints connect modules. With these free joints, a module can turn a maximal angle of 60 degrees in one direction according to its neighboring module. In other words, it can turn in a range of 120 degrees according to its neighboring module. With the hexagon contour of each module and the free joints, the robot's head (the first module)

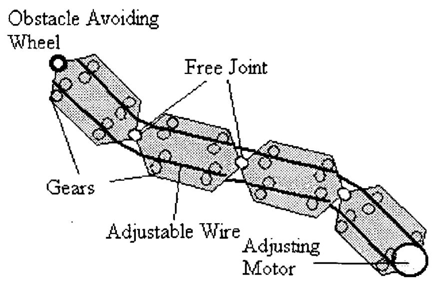

Fig.4 The mechanical intelligence

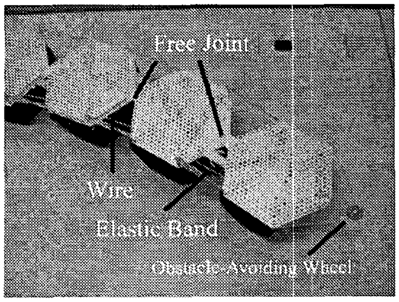

Fig.5 The developed mechanical intelligence

can turn a maximal angle of 300 degrees according to the last module (the sixth module).

A metal wire is assembled around the both sides of the snake robot's body. It connects all modules by gears mounted on them. The total length of the wire is fixed. When the snake robot changes its body shape, the wire lengths of each side will change. If the wire length of one side becomes long, that of the other side will becomes short, vice versa. If we adjust the wire lengths of both sides, we would obtain desired body shape of the snake robot. A motor mounted on the tail of the snake robot is used to realize this function. The wire and the motor have the ability to change the robot's head to turn a maximal angle of 35 degrees in one direction.

An obstacle-avoiding wheel is mounted on the head of the snake robot. When the robot's head encounters an obstacle, the wheel rotates to transfer the sliding friction between the robot and the obstacle into rolling friction, so that the robot avoids the obstacle easily, as shown in Fig.6.

The hexagon module shapes, the adjusting device (including the wire, the adjusting motor, and the gears), the free joints, and the obstacle-avoiding wheel construct the mechanical intelligence for the snake rescue robot.

4.3 The Function of the Mechanical Intelligence

The function of the developed mechanical intelligence can be summed up as three aspects, to avoid obstacles (passively and actively), to make collaboration among modules, and to meet special requirements for a rescue robot.

Figure 6 and 7 illustrate the passive obstacle-avoiding manner. Figure 6 shows the head of the snake robot encounters an obstacle while it is moving ahead. The obstacle-avoiding wheel first touches the obstacle. It rotates to avoid the obstacle. When the head deviates from its current direction, the wire length of each side changes automatically. So the robot's body shape changes. It facilitates the snake robot to avoid the obstacle.

Figure 7 shows the body of the robot encounters an obstacle. In this case, the wire length of each side changes. Some part of the wire mounted on the side near to the obstacle slides into the other side. The robot's body shape changes to avoid the obstacle.

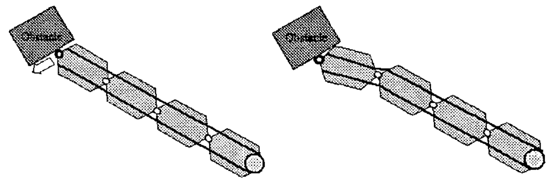

Fig.6 Passive obstacle avoiding at encountering a frontal obstacle

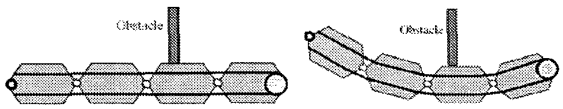

Fig.7 Passive obstacle avoiding at encountering a lateral obstacle

We can also actively adjust the wire lengths of each side by a motor to obtain desired turning angles or to avoid obstacles. Figure 8 shows this process. When the motor turns anticlockwise, like Fig.8 (1), the wire slides to the right side. The length of the left side wire becomes short. The length of wire in the other side becomes long. So the robot's head turns to the left. Figure 8 (3) shows the contrary process of turning right. By adjusting the difference of the wire length between the two sides, we can obtain different turning angles.

When the snake robot encounters an obstacle, or when we adjust the wire length of both sides by the motor, we can see that the free joints and the wire work together to make collaboration among every module automatically. Such a mechanical intelligence needs no additional PC computation. The adopted components are light and not expensive. They make the robot have a light body and a low cost.

5. Experiment Results and Discussion

We design experiments to evaluate the effectiveness of the developed mechanical intelligence in assisting to realize the snake robot's navigation together with the force feedback steering wheel interface.

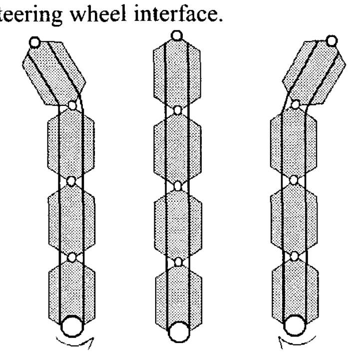

Fig.8 The motor adjusts the wire

Figure 9 demonstrates the effectiveness of the obstacle-avoiding wheel. There are many black wood blocks that simulate a disaster site. For short blocks, the snake robot can move over. There is a tall obstacle locating ahead of the snake robot. In Fig.9 (2), the robot's obstacle-avoiding wheel touches the obstacle. The wheel rotates and the head of the robot turns to the left. At last, the robot's head moves ahead and avoids the obstacle. In this experiments, we only give the instruction of moving forward through the force steering wheel. The robot avoids the obstacle automatically. The free joints and the wire adjust the robot's modules to collaborate each other automatically.

Figure 10 demonstrates the effectiveness of the free joints and the wire in automatically adjusting the snake robot's modules when a moving obstacle hits its body from a lateral side. In this experiment, we also only give the of moving forward to the robot through the steering wheel. A wood block hold by a person hits the robot's body from the right side. It is used to simulate a moving obstacle in a disaster site. We can see that the robot automatically changes its body shape to avoid the obstacle under the working of the free joints and the wire, although we don't give instructions for turning.

Figure 11 shows the effectiveness of the wire and the adjusting motor in changing the robot's moving direction to avoid an obstacle. We turn the steering wheel right to give the robot instruction of turning right. The snake robot turns right first, like Fig.11 (2). Then we send the instruction of moving forward by stepping on the pedal of the steering control. The robot avoids the obstacle and moves toward the right front direction of it. In this experiment, the wire slides to the left side of the robot under the driving of the adjusting motor. The wire of the right side becomes short. The robot turns right to avoid the obstacle.

Figure 12 shows the process of the snake robot running across a narrow space formed by four tall obstacles to access a red ball. In this experiment, we give instructions of moving speed and turning direction to the snake robot through the steering wheel interface. The robot moves under these instructions and its mechanical intelligence. In Fig.12 (2), the robot's obstacle-avoiding wheel touches a tall obstacle. It rotates and the robot's head slides to the right. Finally, the snake robot crossed the narrow space to access the red ball successfully, as shown in Fig.12 (9).

From these experiments, we can see that although the steering wheel interface can only give instructions of speed and direction, the robot's desired motion can be obtained by the combined controlling of the remote instructions and its mechanical intelligence.

Fig.9 The snake robot passively avoids a frontal obstacle by the mechanical intelligence

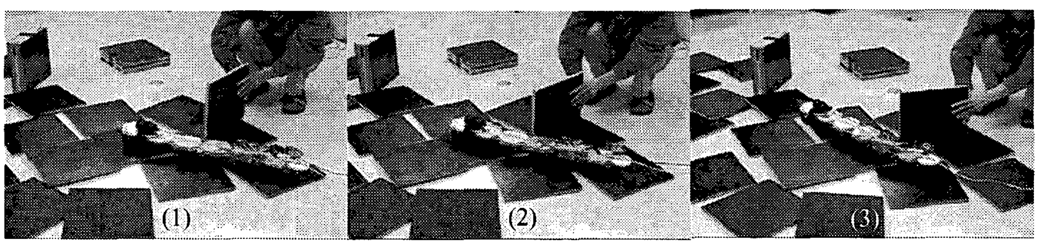

Fig.10 The snake robot passively avoids a lateral obstacle by the mechanical intelligence

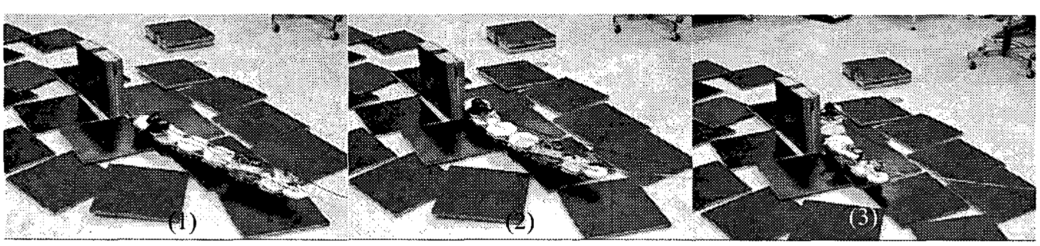

Fig.11 The snake robot avoids a frontal obstacle by actively adjusting the wire lengths of both sides

6. Conclusions

In this paper, we developed a mechanical intelligence based snake rescue robot and navigated it through a force feedback steering wheel interface.

The mechanical intelligence includes hexagon module shapes, an adjusting device (including a metal wire, a adjusting motor, and gears), free joints, and a frontal obstacle-avoiding wheel. When the snake robot encounters an obstacle during its moving, the obstacle-avoiding wheel first touches the obstacle. It rotates to transfer the sliding friction between the robot and the obstacle into rolling friction, so that the robot's head can avoid the obstacle easily. The free joints and the hexagon module contours make a module turn freely in a range of 120 degrees according to its neighboring module. The wire is used to make the collaboration among the modules of the snake robot for changing its shape. When any of the robot's modules turns, the wire length of each side changes to adapt automatically. By adjusting the wire lengths of each side through a motor, we can also actively change the robot's shape to obtain desired direction of robot movement. The mechanical intelligence construction has cheap cost and light weight. It needs no additional computation of a computer.

Experiment results show that the mechanical intelligence is effective in making the collaboration of different modules and avoiding obstacles when the snake robot is navigated by a steering wheel interface.

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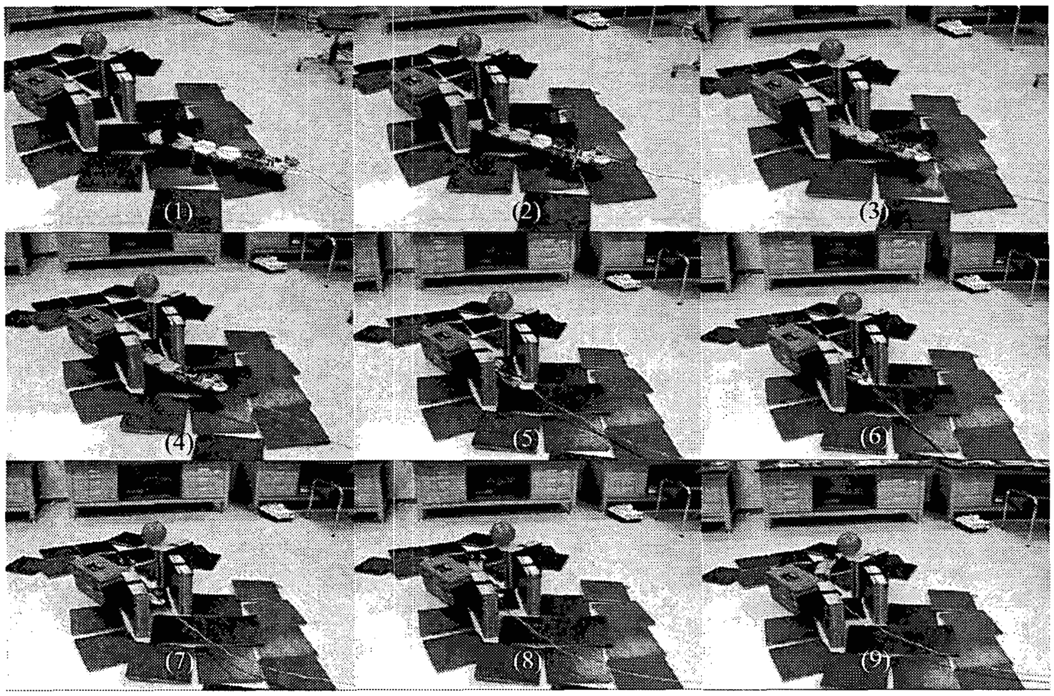

Fig.12 Motion of the snake robot crossing a narrow space navigated by the steering wheel and mechanical intelligence