Study on Performance of a Model Electric Off-road Vehicle

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Abstract

A model of a six-wheel electric off-road vehicle was developed from the environmental conservation and labor replacement points of view. All wheels of the vehicle can be moved up and down for crossing over an obstacle by sensing its shape from the front of the vehicle. Each of four wheels is independently driven by its own electric motor, which is attached to the wheel axle (i.e. wheel-in motor). The vehicle has a system for changing its center of gravity by shifting a weight longitudinally depending on the situation of the wheels' positions in order to maintain stability. A computer program automatically controls all of these movements. This paper presents the design concept, structure, vehicle control system and experimental results of crossing over the obstacles and turning.

Keywords. Electric off-road vehicle, Environmental conservation, Robotics

Introduction

Even in the research and development of agricultural machinery, environmental concerns prompt us to pursue the production of electric off-road vehicles that do not emit harmful gases. In Japan as well as in the U.S.A., automobile and electrical companies and various associations have been making extensive efforts to develop an electric car. These efforts in Japan are now at the stage where it is technically possible to make a very effective electric car with a maximum speed of 176 km/hr and a cruising distance per battery charge of 548 km at the speed of 40 km/hr and 270 km at 100km/hr. Furthermore, some electric cars are already being sold on a commercial basis in Japan.

Agriculture contributes 9 % to the global warming problems according to a report by the Intergovernmental Panel on Climate Change (IPCC). It was found that Japanese agriculture accounts for about 3% of total emitted carbon dioxide in Japan. In order to reduce the emission of carbon dioxide from agricultural vehicles and to help protect the global climate, it is essential that those in our research field to develop electric off-road vehicles. We have already investigated and showed the possibility of future electric tractors from the viewpoints of required power, battery performance, vehicle structure, improved low-energy cropping system, and so on (Oida et al., 1996). We are now designing and constructing a model of an electric off-road vehicle. We have been working a computerized control system to automatically accomplish the tasks of climbing

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over obstacles, keeping a main frame of the model electric vehicle horizontal, and turning with a certain turning radius.

Design Concept

The following points had to be addressed in designing the proposed model of an electric off-road vehicle:

1) Considering environmental conservation, no fossil fuel could be used for powering the vehicle,
2) The vehicle should be as light and simple as possible,
3) Its main frame should be kept nearly horizontal when crossing over irregular fields, supposing that the vehicle would be used as a running device for agricultural robots, and
4) The running device of the vehicle should not disturb the field surface so much in turning.

An outline of the design for our electric vehicle is as follows:

1) The vehicle has six wheels and three wheel axes (front, middle and rear), but no wheel axle,
2) Two front and two rear wheels are each independently driven by wheel-in type D.C. motors with supplied electricity from batteries,
3) The middle wheels are also each independently steered by a small D.C. motor but not driven,
4) All wheels are lifted up and down by pneumatic cylinders corresponding to the ground irregularity to keep the main frame horizontal, and the front wheels are lifted up only during steering,
5) The vehicle's center of gravity changes by longitudinally shifting the air compressor and batteries (i.e. heavy weights) in order to maintain stability,
6) To lighten the vehicle, a main frame is assembled with channel- or angle-shaped beams of aluminum alloy,
7) An ultrasonic distance meter is located at the front of the vehicle to sense field irregularity and control vertical movements of the wheels, and
8) There is no driver and the computer program controls all behaviors of the vehicle.

The first model was constructed 1997, and an obstacle climbing test was carried out (Yamazaki et al., 1998). The model was modified to improve the rigidity of the frame and to supply more pneumatic power, and the second model was used in turning tests conducted in 1998 and 1999.

Model Vehicle

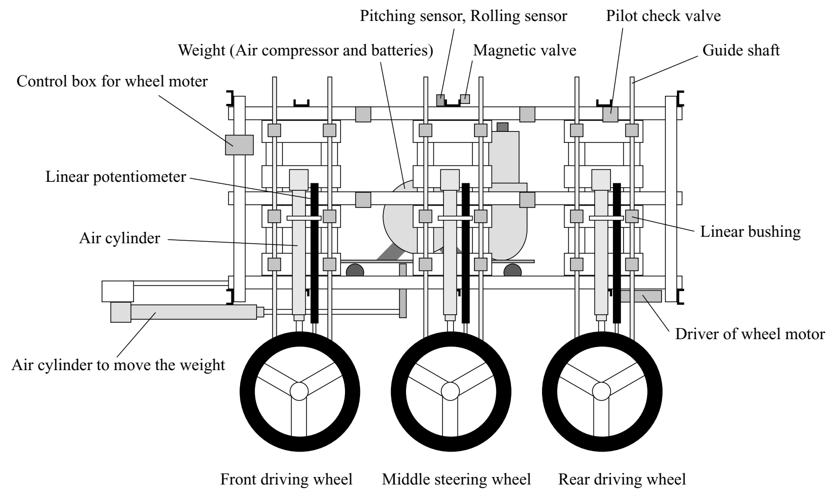

Figure 1- Experimental vehicle

Figure 1 schematically shows a side view of the constructed experimental electric vehicle (second model), of which the length is 1500 mm, width 1065 mm, and height adjustable in the range of 910 to 1160 mm. The mass of the vehicle is about 2220 kg. As mentioned in the previous section, the vehicle has six tires (2.50-10) taken from a wheel chair for handicapped persons. The front and rear wheels are each individually driven by a D.C. motor (150W, final output torque 24.5 Nm/71 rpm) of the wheel chair with a reduction gear of 1/35. The middle wheels are independently steered through a king-pin, knuckle arm, and tie rod by each small D.C. motor (9.8 Nm after speed reduction), which was used as a motor to move car windows. The top view of the steering mechanism is shown in **figure 2**.

Each wheel is vertically moved by a pneumatic cylinder (40 mm diameter for front and rear wheels and 50 mm diameter for middle wheels, stroke of 250 mm), to which air is supplied by an air compressor (capacity 76-92 liter/min, maximum pressure 0.69 MPa), guided by two shafts through linear bushings. The maximum vertical displacement of a wheel is 250 mm. The vertical position of each wheel is detected by a linear potentiometer to control the vertical movement of the wheel.

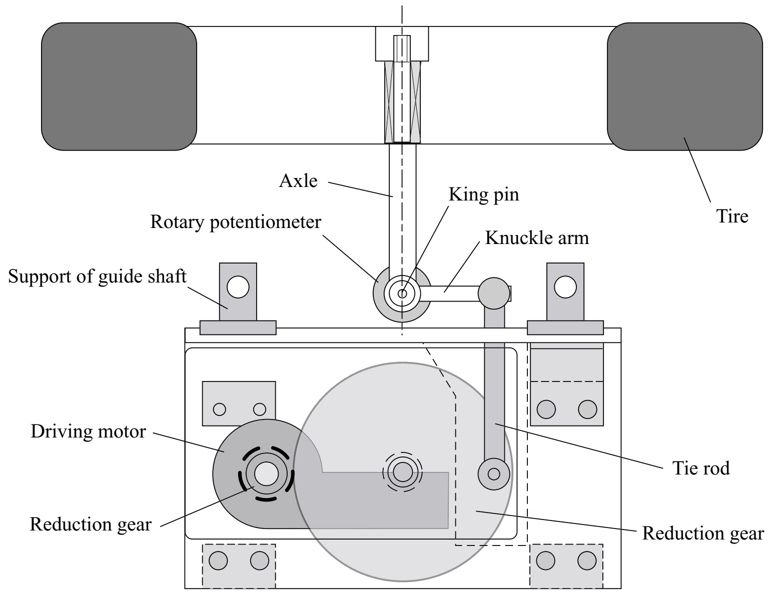

Figure 2 - Steering mechanism

When the vehicle crosses over a step obstacle, the front wheels are first lifted up and the middle and rear wheels carry the whole mass of the vehicle. Then the front wheels are put on the surface of the obstacle and the middle wheels are lifted up. After the middle wheels contact the obstacle, the rear wheels are lifted up. At this moment the front and middle wheels carry the vehicle mass. There might be a danger of the vehicle overturning when forward four wheels or back four wheels support the vehicle if the vehicle's center of gravity is fixed at a certain point. Therefore, it was necessary to longitudinally move the vehicle's center of gravity. This problem was addressed by sliding a plate, where the air compressor and two batteries (total weight 715 N) are located, 840 mm by a pneumatic cylinder with a stroke of 500 mm and a parallel link mechanism.

The vehicle is equipped with 11 sensors: the 6 linear potentiometers mentioned above to detect vertical positions of wheels, an ultrasonic sensor with good linearity in the measurement range of 0.1 to 3 meters to find the distance between the sensor and ground surface, 2 magnet-type inclinometers to detect the pitch and roll angles of the vehicle body, and 2 rotary potentiometers to sense the steer angles of the right and left steering wheels. Signals from these sensors are input into a notebook-type personal computer through an A/D conversion board of an I/O board. Running a control program, signals go to control units (solenoid valves of pneumatic circuit and power switches of the motor's speed control circuits) to start or stop the actuators (pneumatic cylinders and electric motors) through solid-state-relays.

Control for Crossing Over Obstacles

Control System of Crossing Over Obstacles

The behavior of the electric six-wheel vehicle was controlled for crossing over a step-type obstacle, of which had a length of 2500 mm and a width of 1500 mm. The height of the obstacle varied at 50, 100, and 180 mm. The entire control system is a combination of feed-forward and feed-back controls. In running operations the ultrasonic distance meter first detects the step variations in ground height. The computer finds the time and the step height from the signal of the ultrasonic sensor and then decides every time point of wheel vertical movement and of weight horizontal movement depending on the vehicle velocity and also decides the moving distance of the wheels by referring to the detected step height. The computer outputs signals at previously determined timing to move every actuator and sets the desired values of vertical wheel positions at the same time. This process is a feed-forward control. The position of each wheel is controlled at the desired value mentioned above by feed-backing the signal of the position detected by the linear potentiometer. This is a feed-back control. An algorithm to control the vehicle behavior is shown in **figure 3** as a flow chart.

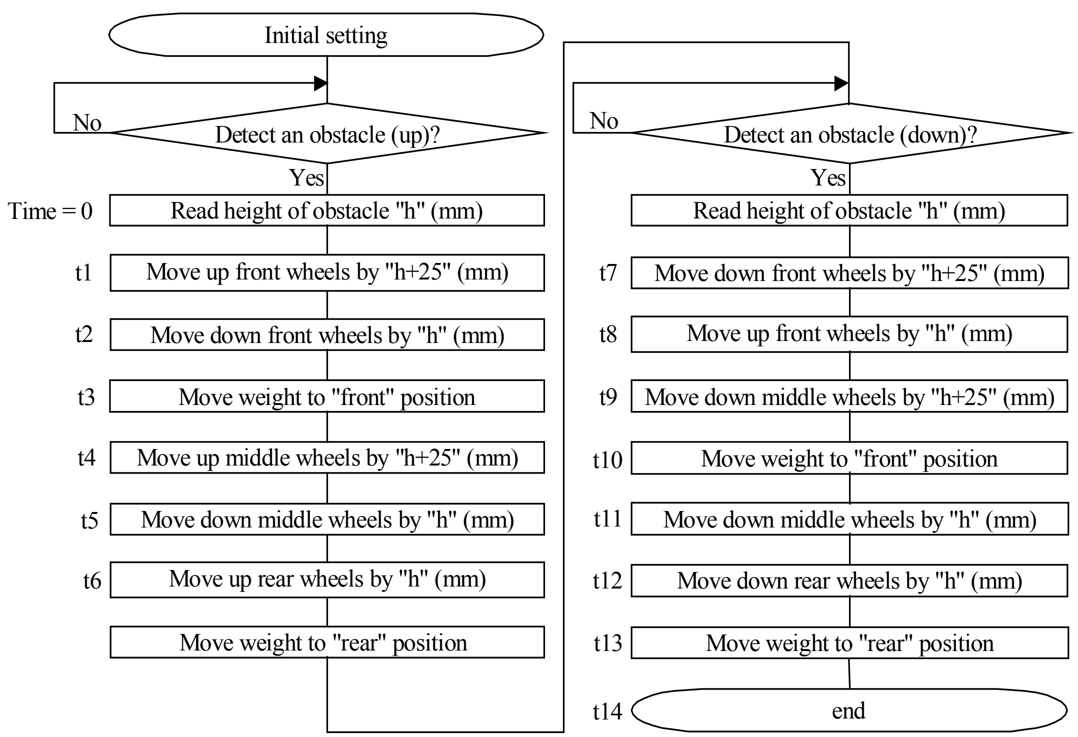

Figure 3 - Flow chart of crossing over obstacles

Experimental Results of Crossing Over Obstacles

Figure 4 shows photos of the vehicle behavior for crossing over obstacles. The times t6 and t9 correspond to the times listed in the control algorithm's flow chart in **figure 3**. Even though there were some unexpected behaviors, for instance a swing in pitch angle, the experimental vehicle could cross over obstacles without a driver by using the control program.

Time = t6

Time = t9

Figure 4 - Photographs of crossing over an obstacle

Turning Control

Control Algorithm

Turning of the model vehicle is controlled by the computer. After inputting the desired value of turning radius from the computer keyboard, the vehicle frame moves to a certain low position in order to increase the body stability during turning. The movable weight is shifted to the rear-most position and the front wheels are lifted up. The steer angles of left and right steering wheels are calculated by the computer in order to assure the Ackermann steering geometry, where there is no side force to wheels when the vehicle velocity is very low. At the same time, the difference in the peripheral velocities of rear left and right driving wheels is calculated and both peripheral velocities are determined according to the set velocity of the outer wheel of the turn. These signals are transmitted to the driving motors of the driving and steering wheels through the solid-state relays, and then the turning starts. The steer angles were controlled by a feed-back control circuit, and the peripheral velocities of the driving wheels were controlled by a PWM (pulse width modulation) control circuit. Both of these circuits were constructed by us. After a certain time elapsed, the turning was stopped.

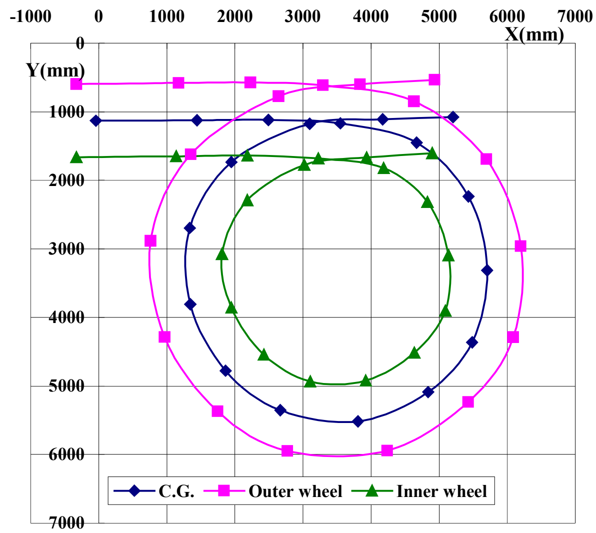

Figure 5 - Running path of outer and inner wheels and C.G. of test vehicle in turning

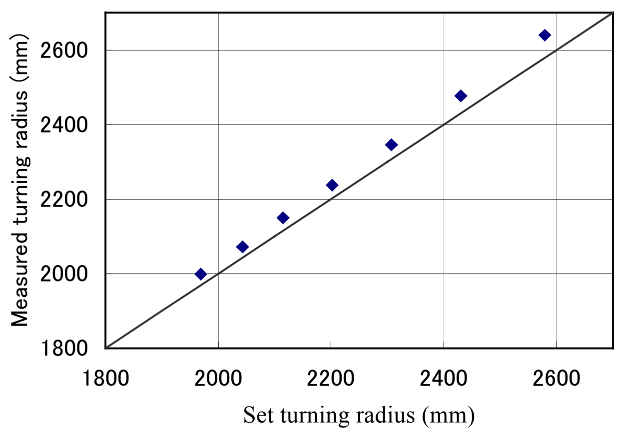

Figure 6 - Comparison of measured turning radius with set radius on concrete

Experimental Results of Turning

A steady-state complete circular turning was accomplished in the experiments where several set turning radii were given as the input. **Figure 5** shows experiment results of one running path in turning on a hard soil ground with the inner wheel at a steering angle of 15 degrees and a velocity of 1.2 km/h. Almost no lateral slip of tires was observed in all experiments. This means that the Ackermann steering geometry was always maintained for two independently steered wheels during the experiments.

The measured turning radius was compared with the set values in **figure 6**. The measured radius was about 50 mm larger than the set value, but the error was only about 2% on a concrete paved surface. The difference between measured and set turning radii was about 5% in turning on hard soil ground.

Conclusions

We proposed and developed a model of a six-wheel electric off-road vehicle with computerized control systems in order to contribute to environmental conservation and also to provide a running device for agricultural robots. Experiments of crossing over a step-type obstacle and turning control were successfully conducted without a driver. This is the first trial toward completing a promising electric off-road vehicle. Some problems, such as the necessity of air flow control and the necessity to have sensors to detect the position of wheels from ground, became clear through the experiment. Therefore, work on improvement measures will be continued. The method of supplying electricity to drive all of the vehicle's devices should also be investigated.

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