JARQ 33, 275–282 (1999)

Development of an Automatic Steering System for Compact Tractor Used in Mulberry Fields

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Abstract

In order to promote sericultural labor-saving and to decrease costs, this study was carried out to develop an automatic steering system for a compact tractor used in mulberry fields. A new experimental vehicle for automatic steering was developed characterized by hydraulic transmission, front-wheel drive, and microcomputer control. A magnetic azimuth sensor and an ultrasonic sensor were selected as noncontact-type position sensors. Then, the sensor systems were developed to determine the positions automatically by using a microcomputer. Moreover, an automatic steering system that consisted of a microcomputer (8-bit CPU), the position sensor systems and the vehicle was developed and tested. As a result, the system enabled to control the travel of the vehicle in a mulberry field.

Discipline: Agricultural machinery
Additional keywords: microcomputer, control, sensor, automatic travel

Introduction

The mechanization of sericulture in Japan has proceeded only slowly, and silkworm rearing and mulberry cultivation are still mainly performed by human labor. Cocoon yield has been decreasing in recent years. Therefore, by expanding the scale of sericultural farming with multiple rearing of silkworms, it is important to save labor and reduce the cost of production in sericulture through the promotion of mechanization and automation.

Then, in order to increase sericultural productivity, this study was carried out to develop an automatic steering system for a compact tractor used in mulberry fields, based on the results of recent studies on agricultural machinery[1,4–6]. This report gives an outline of the system developed, which is characterized by travel controlled by a microcomputer with hydraulic transmission, use of noncontact-type position sensor systems to detect the tractor travel position in the system and automatic steering and turning in mulberry fields.

Experimental vehicle with automatic steering[3]

In order to improve the performance of the automatic steering system, based on the results of an experimental study on a previously developed automatic steering system using a contact-type position sensor[2], we developed an experimental vehicle for automatic steering. The vehicle is characterized by hydraulic transmission, front-wheel drive, and microcomputer-controlled steering.

The size of the vehicle was approximately that of a compact 4-wheel tractor. The dimensions of this vehicle were as follows: 140 cm in overall length, 80 cm in overall width and 110 cm in overall height. A gasoline engine (4.4 kW, 6 Ps) and hydraulic transmission driven by independent front wheels, were used for the driving system. Double pumps with double swash plates type ran 2 oil-hydraulic motors, then front wheels (driving wheels) were driven through 1/5 speed-reduction gears (Fig. 1). The vehicle was designed to move forward and backward at a continuously variable speed of 0 to 50 cm/s. The power-wheeled steering method, with a difference in speed between right and left driving wheels by the operation of each discharge regulation shaft of the double oil-hydraulic pump, was applied for the design of the system for vehicle steering. The steering apparatus of the vehicle consisted of a microcomputer, RS-232C interface, stepping motor drivers, 4-phase stepping motors, gears, cams, etc. (Fig. 2).

Since the microcomputer could approximately

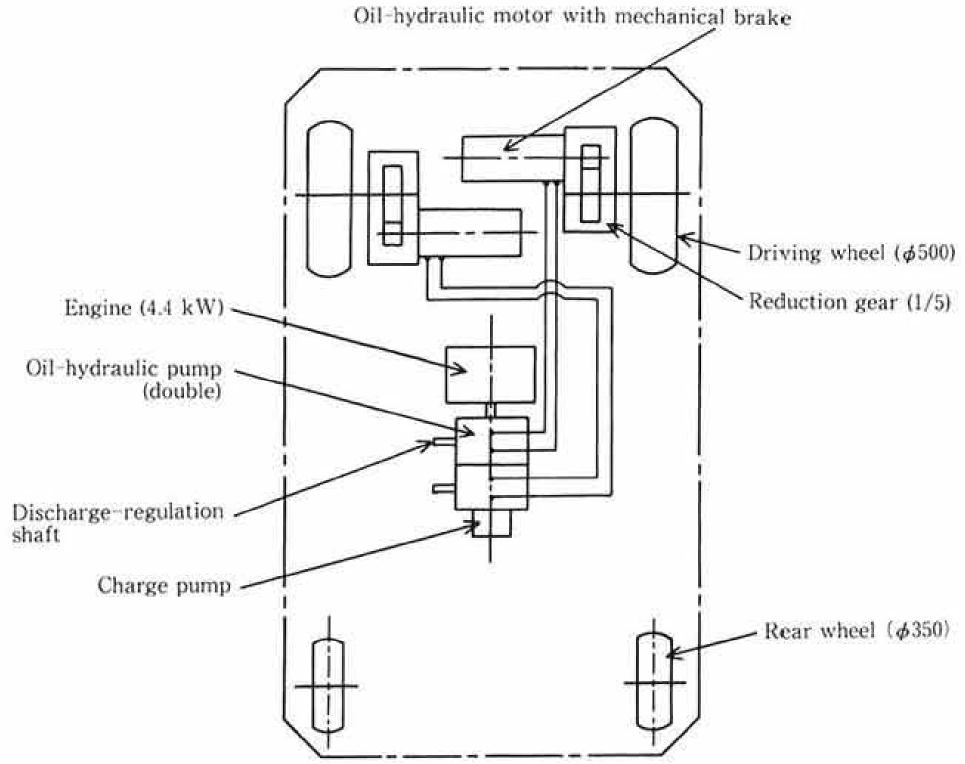

Fig. 1. Driving mechanism of experimental vehicle

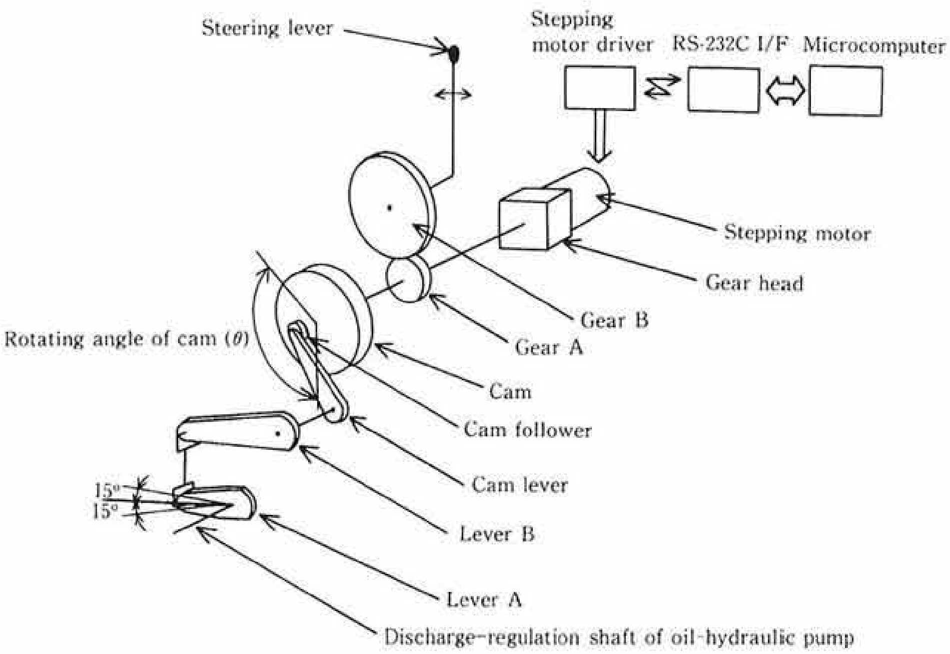

Fig. 2. Steering mechanism of experimental vehicle

control the revolution of each discharge regulation shaft of the oil-hydraulic pump, this vehicle could drive forward and backward at a continuously variable speed of 0 to 95 cm/s. As a result, the performance of the vehicle was similar to that outlined in the design specifications.

Noncontact-type position sensors for compact tractor[3)]

The traveling direction (heading) of the tractor and the distance from the tractor to mulberry stumps are the basic information required for the position for automatic travel of the small tractor in mulberry fields. Therefore, the noncontact-type position sensors that were readily connected to an 8-bit CPU microcomputer were studied and selected. A magnetic azimuth sensor was used to determine the direction of travel and an ultrasonic range sensor was used to detect the distance from the tractor to mulberry stumps.

Then, the sensor systems were developed to measure the positions automatically by the microcomputer. The magnetic and ultrasonic sensor systems were equipped with a microcomputer, interfaces, sensors (an ultrasonic range finder and a magnetic declinometer), power supply, detecting programs, etc. (Figs. 3, 4).

We studied the characteristics of the systems and the adaptation to automatic steering control.

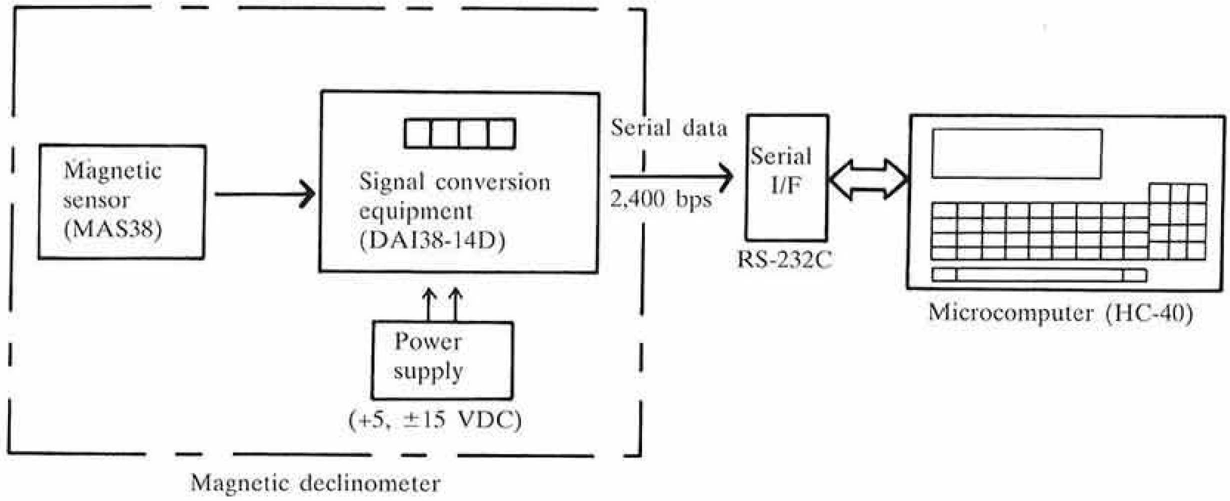

Fig. 3. Block diagram of magnetic sensor system

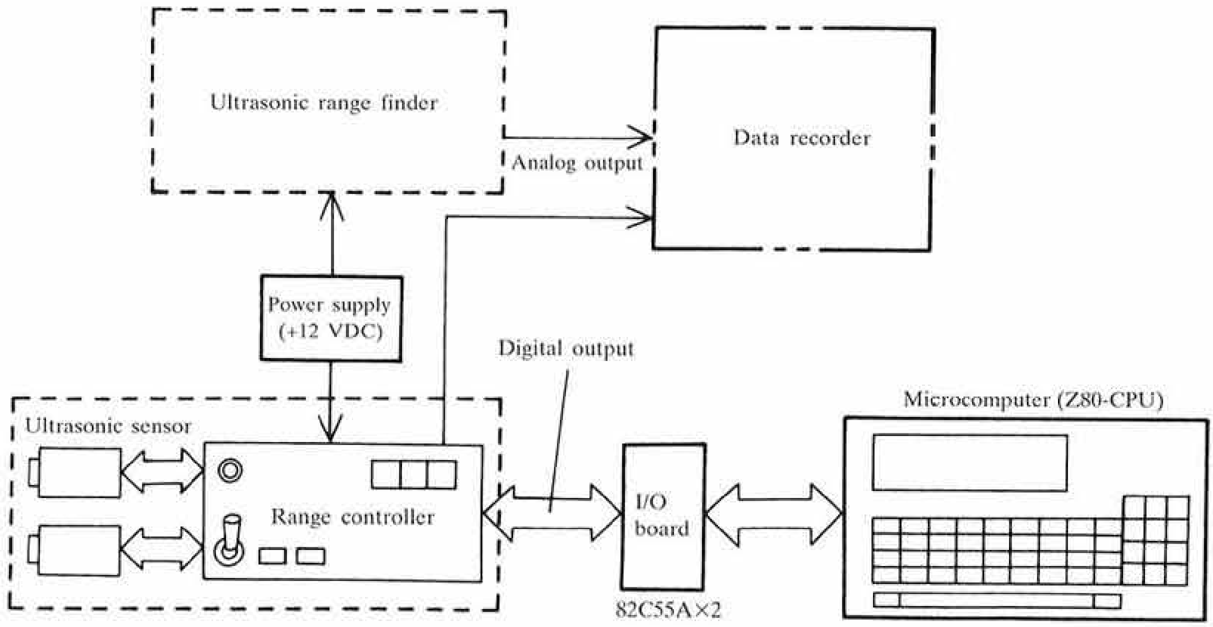

Fig. 4. Block diagram of ultrasonic system

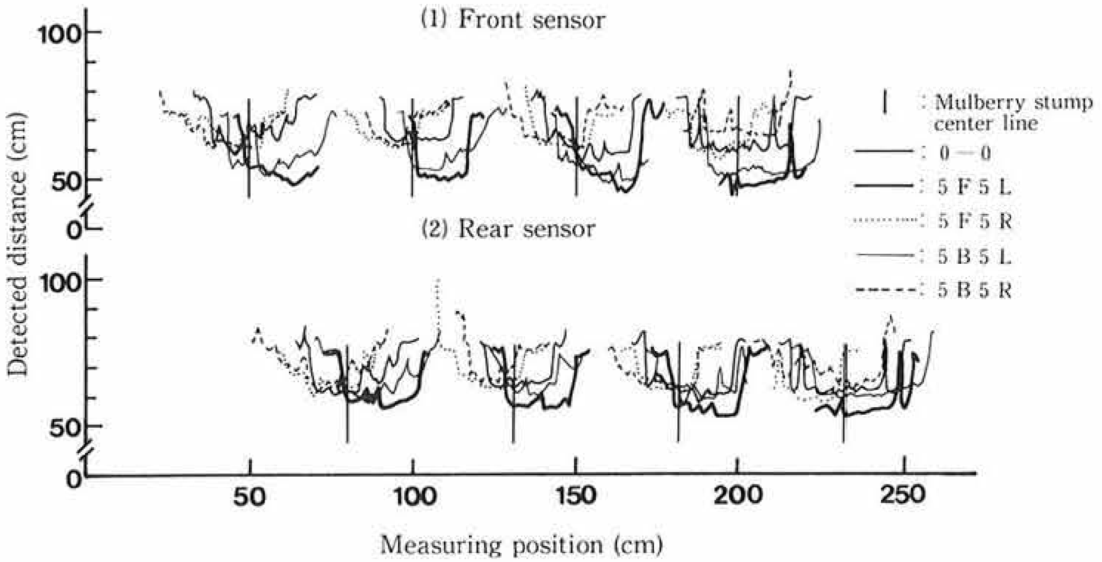

Fig. 5 Continuous range-finding of mulberry stumps (sensor tilted 5° and rotated 5°)

1) Magnetic azimuth sensor system

The magnetic azimuth sensor system enables to detect terrestrial magnetism and inputs azimuth data through an RS-232C interface every 50 milliseconds. The microcomputer can read the serial data whenever it is necessary by a program in BASIC language. This system was tested using the experimental vehicle equipped with the azimuth sensor. The measuring accuracy of this system ranged from 0.3 to 3.5° in the traveling direction of the vehicle.

2) Ultrasonic range system

A reflection-type ultrasonic range finder inputs 12 bits parallel data to an I/O board (82C55A) connected to a microcomputer. The microcomputer reads the range data through the I/O board. Resolution of the system is 4 mm and the ultrasonic frequency is 49.1 kHz. The measurement has a range of 0.29 to 10 m.

This system was tested within the distance from the sensor to model stumps made of polyvinyl chloride pipe and mulberry stumps were measured continuously. That is, the distance was measured by using the sensor, moving at a velocity of 3.7 cm/s in laboratory experiments (analogue data) and using the experimental vehicle equipped with the sensors, traveling at a velocity of 24 cm/s (digital data). Two ultrasonic sensors were installed outside of the left front wheel of the experimental vehicle at a height of 25 cm above the ground. When the distance to the stumps ranged between 60 and 70 cm, the target could be detected continuously by using 2 ultrasonic sensors, which were arranged, at a distance of 30 cm apart. To measure the range with accuracy within a distance of 15 cm, the position of the ultrasonic sensors

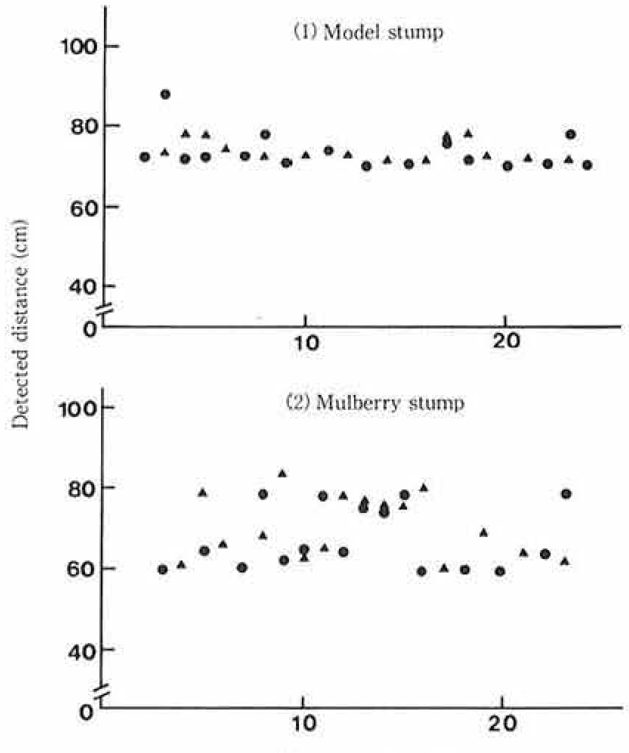

Fig. 6 Continuous range-finding in experimental vehicle travel (distance of 70 cm from stumps)
●: Front sensor, ▲: Rear sensor.

should be controlled by rotation and tilt of about 5°, respectively (Figs. 5, 6).

The results obtained suggested that the magnetic azimuth sensor system enabled to determine the traveling direction of the compact tractor and the ultrasonic range system enabled to detect a row of mulberry stumps for automatic steering of the experimental vehicle.

Automatic steering system and automatic steering control[3)]

Based on the results of the above experiments, a position sensor system combining the 2 sensor systems was installed on the experimental vehicle, and then an automatic steering system was constructed. The automatic traveling trial of the exper-

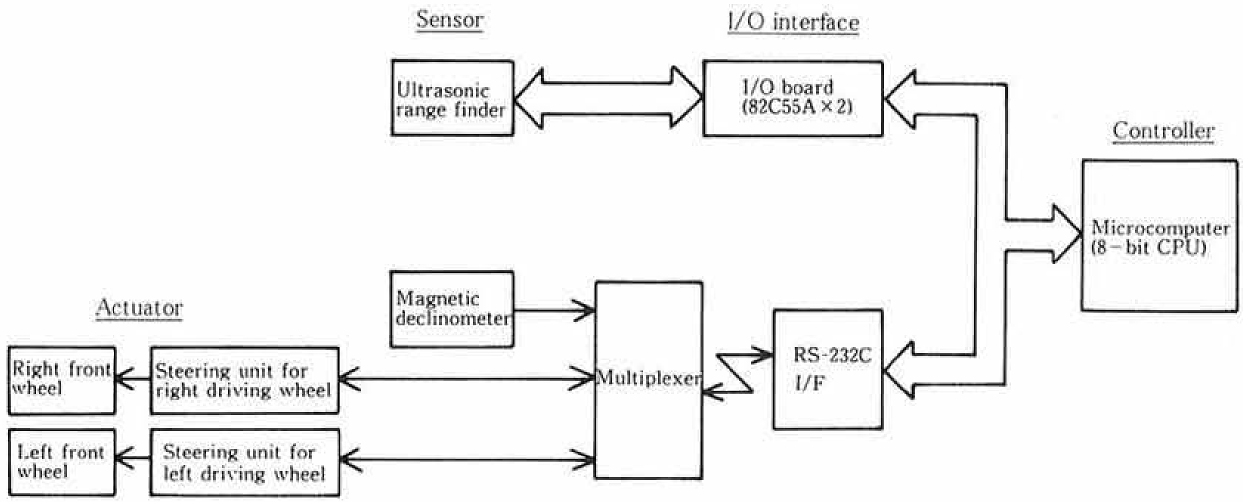

Fig. 7. Block diagram of steering control system

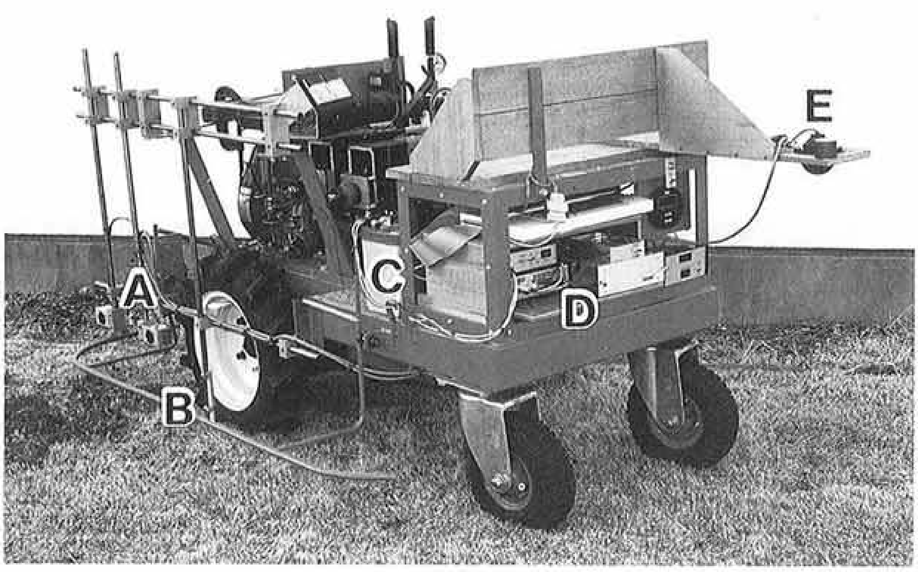

Fig. 8. Experimental vehicle equipped with steering control system
A: Ultrasonic sensors, B: Bumper, C: Auto-battery,
D: Control and instrumentation apparatus, E: Magnetic sensor.

imental vehicle was operated by using a program developed in BASIC language for automatic steering control in a mulberry field.

1) Automatic steering system

The automatic steering system was equipped with a hand-held microcomputer (8-bit CPU, 3.68 MHz) as controller, an ultrasonic range finder (ultrasonic sensor system), a magnetic declinometer (magnetic azimuth sensor system) as sensors, and a steering mechanism and front-wheel drive by hydraulic transmission, etc. as actuators for the method of automatic steering control (Figs. 7, 8).

Two ultrasonic sensors for the ultrasonic range finder system were located 30 cm apart outside of the left front wheel of the vehicle. The system measured ranges at a maximum rate of 0.2 s by using the microcomputer.

In order to avoid the influence of magnetic fields, the magnetic azimuth sensor was mounted on a plywood board on the right side of the rear of the vehicle because the magnetic declinometer was affected by the magnetic field of its iron body. The resolution of this azimuth was 0.1°.

Operation signals of the actuator were transferred through RS-232C, the multiplexer from the microcomputer in the automatic steering system. The actuator rotates the driving wheels of the vehicle at the same speed for starting the travel and traveling straight, and controls differentially rotational speeds between the right and left driving wheels in a steering, turning, and pivot turn.

Power was supplied by using +12 VDC automobile batteries and the voltage was transformed from +12 to +5, ±12 and ±15 VDC by DC-DC converters.

2) Method of automatic steering control

In a common mulberry field for automatic traveling, row spacing was assumed to be 2.0–2.5 m and intrarow spacing 0.5 m and left-hand sensing method was adopted. The vehicle traveled at a velocity of 24 cm/s along the mulberry stumps by automatic steering. Steering was applied continuously to move straight or trim (lateral movement with a proportional control action) to maintain a distance from the vehicle to mulberry stumps constant by using both the ultrasonic range finder and magnetic declinometer. The target value for the control of the distance was set at 10 cm. As shown in Fig. 9, after the vehicle turned 90° twice at a headland, it entered another inter-row space and only the magnetic declinometer was used to turn the vehicle.

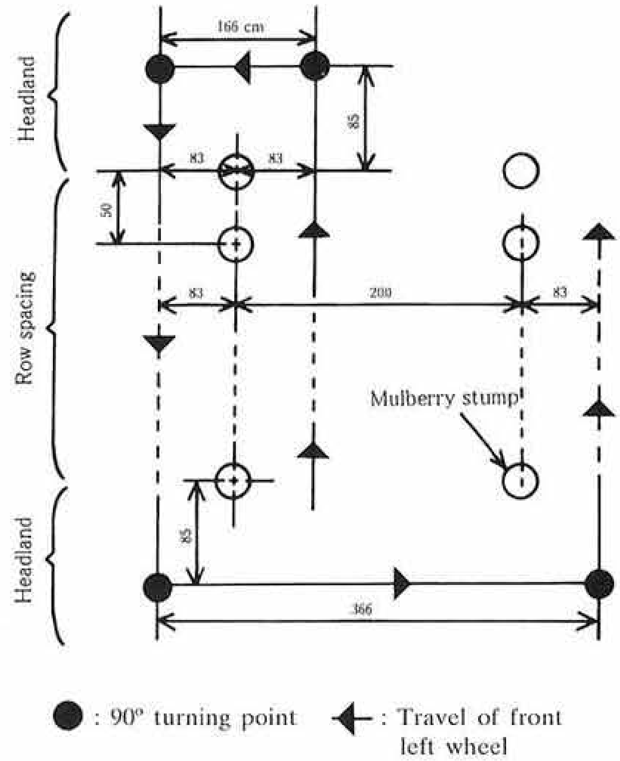

Fig. 9. Distance required to turn on asphalt road

3) Steering control program

The flowchart of an automatic steering control program is shown in Fig. 10. After the start of traveling, the automatic steering system detected a mulberry stump by using the range finding and measuring azimuth. If the controller of this system did not detect a mulberry stump for 3 times continuously, the vehicle stopped traveling. If the number of turns was not 0, the vehicle turned 90° twice and entered another inter-row space by the turning subroutine. On the other hand, when the controller continuously detected mulberry stumps, the traveling direction of the vehicle remained parallel to ridges with a turn of 5°. The controller also proceeded to trimming using the range finding and measuring azimuth 3 times. If trimming was needed, the controller trimmed the body by setting the value using the trimming subroutine and the vehicle traveled forward.

4) Test of automatic steering control

On a flat mulberry field with an inter-plant distance of 0.5 m immediately after shoot cut, which was used as test field, the vehicle traveled at a velocity of 24 cm/s using the control program over a distance of 70 cm along the row of mulberry stumps. The traveling trace in about the center of the vehicle's front body was drawn on the traveled path.

As a result, the traveling direction of the vehicle was almost parallel to the mulberry stumps and the system detected easily mulberry stumps using the ultrasonic range finder. Then the vehicle traveled automatically according to the row detected and turned at the headland (Fig. 11).

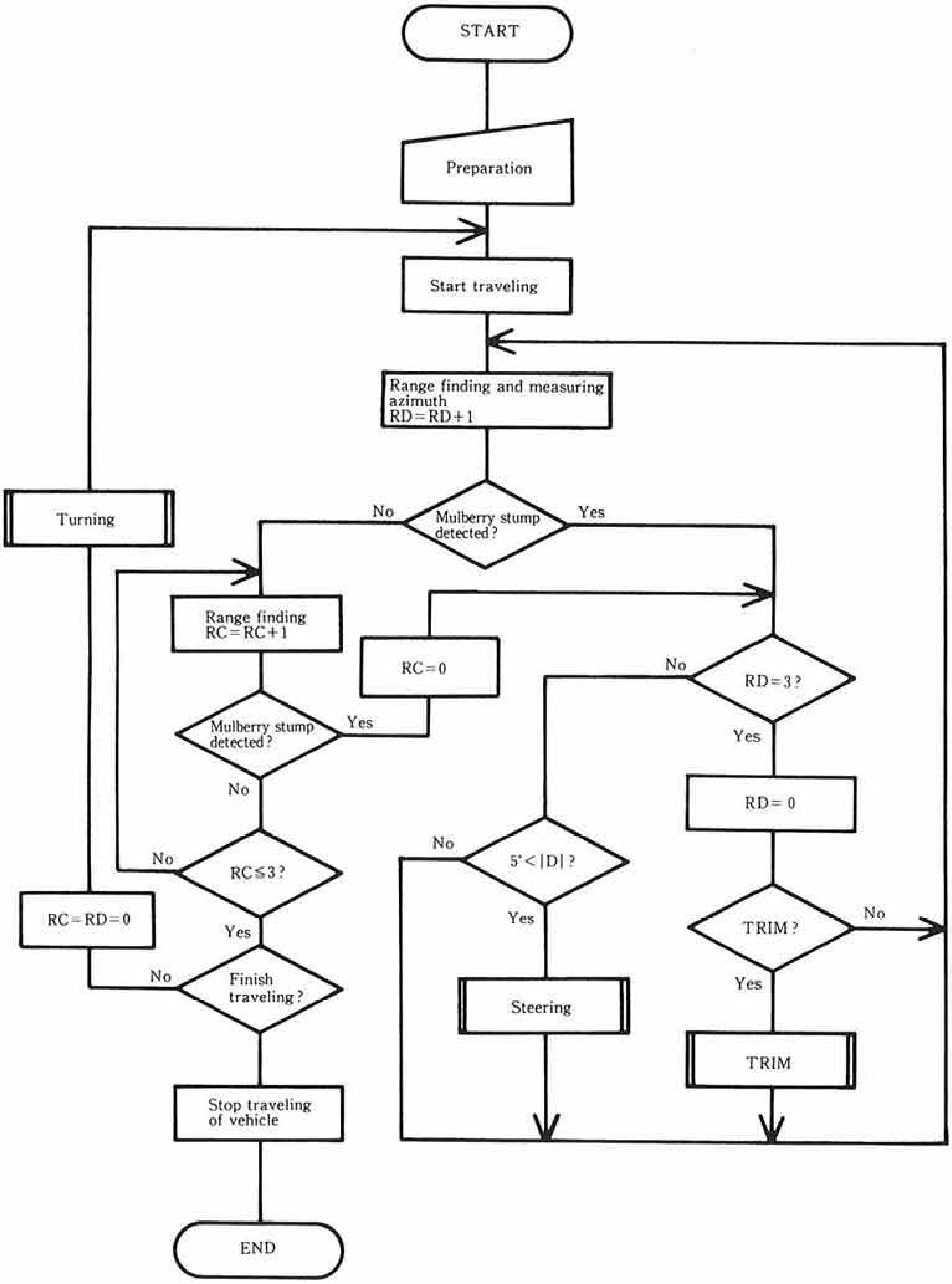

Fig. 10. Flowchart of automatic steering for compact tractor used in mulberry field

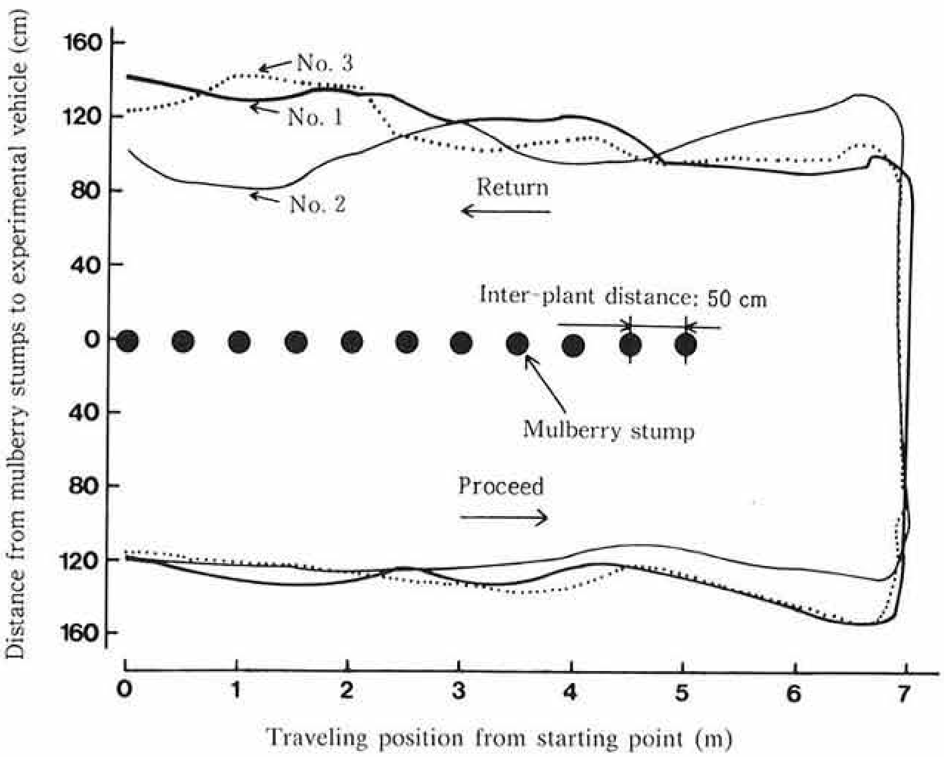

Fig. 11. Automatic steering in test field

However, the automatic steering control of the first turning at the headland was overrun at a distance of about twice 85 cm. The accuracy of turning at headlands was 90±5° by using the magnetic declinometer alone. Therefore, the results obtained suggested that for the most effective steering control, first the magnetic declinometer and second the ultrasonic range finder should be used, respectively, to maintain the traveling direction of the vehicle parallel to mulberry stumps (ridges) within 6°.

Conclusion

As stated above, by using noncontact-type position sensors, an automatic steering system was developed for a compact tractor used in mulberry fields. This system controls the steering, trimming, and turning of the experimental vehicle by the determination of the traveling positions of the vehicle using the range finder and the magnetic declinometer. Therefore, the vehicle was able to travel in the rows, along the mulberry stumps and turn at headlands on the mulberry field.

Moreover, the results suggest that pest control, herbicide spray and manuring could be automated by improving the performance of this system.

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(Received for publication, February 10, 1999)