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RESEARCH ON AUTONOMOUS LAND VEHICLE FOR AGRICULTURE

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ABSTRACT

An autonomous land vehicle for agriculture (ALVA-Ⅱ) was developed. A prototype vehicle was made by modifying a commercial tractor. A Navigation sensor system with a geo-magnetic sensor performed the autonomous operations of ALVA-Ⅱ, such as rotary tilling with headland turnings. A navigation sensor system with a machine vision system was also investigated to control ALVA-Ⅱ following a work boundary.

Key Word:Farm vehicle, Robotization, Autonomous operation, Navigation, Geo-magnetic sensor, Machine vision, Image processing

I INTRODUCTION

The development of ALVA-Ⅱ is required from labor savings, the improvement of machine efficiency, the promotion of machine safety and comfortability, and so on. This research aims at the robotization of farm vehicles for such operations as tilling, cultivating and harvesting. A remote control system is not applied to this research, because it cannot release an operator from machine operations completely.

Subjects for the realization of ALVA-Ⅱ are as follows;

- to develop a computer controllable vehicle,
- to develop navigation sensor systems,
- to develop controlling programs for autonomous operations,
- and to ensure the safety for unexpected operations and obstacles.

II METHODS

Under the above mentioned subjects, the following studies have been carried out.

1. A prototype vehicle is made by modifying a commercial tractor to be controlled by electric signals, and navigation sensor systems and a computer system are installed on it.
2. To control a vehicle along target directions autonomously, a geo-magnetic sensor (TMS) is utilized to detect the heading direction of the vehicle. ("TMS system")

To control a vehicle following work boundaries such as a boundary between tilled and un-tilled areas, a machine vision system (VSX) is utilized to detect these work boundaries. ("VSX system")

3. Autonomous operation programs with these navigation sensor systems are developed, and the autonomous operation tests with ALVA-Ⅱ are conducted.
4. A navigation sensor system to detect the absolute position of a vehicle is studied for the navigation of wide uses.

III RESULTS AND DISCUSSION

1. Prototype Vehicle and Control System

The prototype vehicle is shown in Fig.1. The control system is shown in Fig.2.

The base tractor is a "KUBOTA GL-25", which is equipped with the latest systems and controls such as a shuttle shifting system for forward/neutral/reverse operation, the electric up/down switch of a hydraulic system, a bi-speed turning mechamism (a tight turning mechanism by increasing the front wheel speed) and the automatic leveling and depth control systems of implements.

Controlled objects and these actuators are shown in Table 1. The steering system, which needs an accurate control, and the shuttle system, which needs an reliable control, are controlled comparing with the actual position of these objects detected by potentiometers.

The control computer system consists of a master computer and a slave computer. The slave computer, equipped with a CPU board and a analog to digital board, detects the sensor signals and controls the steering system and so on. The master computer communicates with the image processing device described below by a serial interface (RS232C). The electric power requirements of AC100V and DC5V for the computer system and the sensors are supplied from the tractor battery of DC12V through a DC-AC inverter and a DC-DC converter.

The examined data on the relation between the steering control value from the computer and the actual steering angle of the front wheel is shown in Fig.3. It may be considered that this relation has a sufficient linearity for the purpose of this research. The time required for the steeing control is about 1 sec. at the steering angle of 20°.

2. Navigation Sensor Systems

2-1. TMS System

A geo-magnetic sensor (TMS, Watson FGM-200A) is used as the heading direction sensor for navigation. The measuring principle of TMS is illustrated in Fig.4. TMS is a 3-dimensional fluxgate type sensor, its power source is DC12V, and its sensitivity is $1V=25\mu T$(250mGAUSS). TMS is installed on the uppper and the center part of the vehicle.

The detecting errors with the surrounding magnetism and the vehicle (TMS) inclinations should be corrected to improve the detecting accuracy of TMS. As to the errors with the surrounding magnetism, the influence with the vehicle on TMS outputs is measured occasionally, and the measured influence is removed mathematically from TMS outputs. As to the errors with the vehicle (TMS) inclinations by the rocal roughness of ground, the inclinations (rolling and pitching) are detected by clinometers (Scheavitz Accu Star0238-01), and TMS outputs including the errors are corrected geometrically.

By means of these corrections, the repeatable accuracy of TMS system to the same direction is less than $\pm 0.5^{\circ}$ at the vehicle oparating.

2-2. VSX System

The principle of the autonomous operation following work boundaries is shown in Fig.5. Two monochrome TV-cameras are mounted on the right and the left side of the vehicle to perform the operation of back and forth passes. In case a work boundary is on the left side of the vehicle, the left TV-camera is used to detect the work boundary, the right TV-camera is used in the reverse case.

The location of two TV-cameras, their fields of vision and the vehicle is shown in Fig.6. The visual angle of the TV-camera is about 28° vertically and horizontally, and the field of vision of 1m in length and 0.8m in width is taken on the ground level under the conditions of Fig.6.

VSX was developed by Crops Engineering Systems Laboratory Inc.. A work boundary is obtained as the straight line on the border between the light and the dark by the image processings (the differentiation, the binarization and the Hough transformation) of the image signal from the monochrome TV-camera. The processing rate of VSX is above 30 times per second, which is a sufficient performance to be applied to the real-time control.

When the vehicle inclines, the attitude of TV-camera toward the ground changes and the field of vision on the ground deforms. Therefore, VSX data on the position of a work boundary includes errors in case of the vehicle inclining. To improve the detecting accuracy of VSX, the inclinations of the vehicle are detected by the clinometers, and VSX data is corrected geometrically.

3. Autonomous Operations with Navigation Sensor Systems

3-1. Autonomous Operation with TMS System

3-1-1. Autonomous Operating Program "ASRB"

"ASRB" is the autonomous operating program of ALVA-II with TMS system. "ASRB" executes the following tasks ①~④ repeatedly.

①The straight operation keeping the target direction of the forth pass for the target time

②The headland turning of 180° at the end of the forth pass

③The straight operation keeping the target direction of the back pass for the target time

④The headland turning of 180° at the end of the back pass

These target directions of the forth and back passes and the target pass time are taught in the manual operations of the first forth and back passes (teaching passes).

The flow of "ASRB" is shown as the flow of the solid line in Fig.7. The "Seering with Vehicle Direction" is executed according to the algorithm of the steering control shown in Fig.8.

3-1-2. Autonomous Operation Test

The autonomous operation test with rotary tilling was conducted at the test field in IAM-BRAIN. The operating velocity was 0.47m/s. The data input of TMS and the steering control were executed at intervals of about 1.2 sec..

The trace of rotary tilling is shown in Fig.9. The first forth and back passes were the teaching passes, and the subsequent 6 passes were the autonomous operation passes with "ASRB". The autonomous operation was generally performed, all traces of the autonomous operation were nearly parallel to the teaching passes, and the untilled area did not remain.

In such autonomous operations as to control the vehicle by the information of its heading direction, there remains the following problems.

- It is difficult to keep the turning radius and the pitch of the operating passes constant.
- The longer the operating distance is, the larger the positioning errors occured by the detecting errors of direction are.

• When such structures or vehicles as to disturb geo-magnetism exist near, TMS system cannot be applied to an accurate direction sensor.

3-2. Autonomous Operation with VSX System

3-2-1. Autonomous Operating Program "WBT- I "

"WBT- I " is the autonomous operating program of ALVA- II with VSX system only. "WBT- I " executes the autonomous operation following a work boundary by the steering control according to VSX data. The steering angle is determined by the deflection and the angle of the detected boundary line from the center line of VSX image (Fig.10).

A white line was set up with the white tape of 5cm width on the concrete pavement, and the autonomous operation test with "WBT- I " was conducted by using the white line as a boundary for tilling. The operating velocity was 0.5m/s. The data input of VSX and the steering control were executed at intervals of 1 sec.. Fig.11 is an example of the test results. The autonomous operation following the white line of a sine curve was performed without the white line being lost to view throughout.

3-2-2. Autonomous Operating Program "WBT- II "

In actual operations such as rotary tilling, it must be considered that the work boundary on real fields cannot always be detected, and a work boundary does not exist at the headland. The autonomous operation program "WBT- II " was developed for actual operations. "WBT- II " executes the autonomous operation following a work boundary in case of the work boundary being detected clearly, and in case of the work boundary being undetected or in case of the turning at the headland the autonomous operation with TMS system is executed.

The flow of "WBT- II " is shown as the flow of the solid line and the dotted line in Fig.7. For the execution of "WBT- II ", the same teaching data with the case of "ASRB" are requied to teach, and the initail work boundary is required to form in the teaching passes. The turning is primarily controlled corresponding to the vehicle heading direction detected by TMS system. When the work boundary of the previous pass is detected during the turning, ALVA- II stops turning and moves to the operation of the next pass.

The autonomous operation test with "WBT- II " of 4 passes was conducted by using the white lines as boundaries for tilling. The white lines were set up on the concrete pavement as the dotted lines in Fig.12. The white line was not set up on a part of the 3rd pass and through the 4th pass to make the situation of a work boundary being undetected. The operating velocity was 0.5m/s. The data input of VSX and TMS and the steering control in the operating pass were executed at intervals of 1 sec..

The solid line in Fig.12 is the trajectory of the center point of front axle. The autonomous operation following the white line was performed satisfactorily. At the places where the white line do not exist, including near the pass ends, the autonomous operation with TMS system was executed generally. The headland turning and the move to the next pass were performed successfully, exclusive of the turning from the 3rd pass to the 4th pass.

The autonomous operation with VSX system have just finished the stage of the test with the white line. In the stage of actual fields test, hard-ware considerations and soft-ware considerationsions will be required for the reproducible and stable detection of work boundaries.

4. Navigation Sensor System to Detect the Absolute Position

For more accurate and applicable navigation, the absolute position of a vehicle is needed to detect. The sensor system using photo–electric sensors (equipped on a vehicle) and reflecter poles (set at the each corner of a field) has been studying. The detection of the absolute position by this system is illustrated in Fig.13, and the photo–electric sensor unit is shown in Fig.14. The detecting errors of the position at a vehicle operating are now about 10cm. The stable detection of the position at a vehicle inclining and the extension of the field size to be applied are the subjects to be studied for the time being.

IV CONCLUSIONS

ALVA–Ⅱ with the navigation sensor systems and the computer system for the autonomous operation was developed.

(1) The prototype vehicle was made by modifying a commercial tractor.

(2) As the navigation sensor systems, TMS system to detct the heading direction of the vehicle and VSX system to detect the work boundaries were designed.

(3) The autonomous operations of ALVA–Ⅱ, such as rotary tilling with headland turnings, were performed with TMS system.

(4) The autonomous operation of ALVA–Ⅱ with VSX system and TMS system was examined by using the white lines as a work boundaies.

(5) The navigation sensor system to detect the absolute position of a vehicle was studied for the navigation of wide uses.

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Table 1. Controlled objects and actuators

Controlled Objects	Actuators
Steering System	Induction Motor, DC12V
Shuttle System	Hydraulic Cylinder, ϕ32mm
Brakes (Left and Right)	Hydraulic Cylinders, ϕ20mm×2
Up/Down Switch of Hydraulic System	Solid-state Relay
Engine Stop (Fuel Cut) Circuit	Electromagnetic Relay

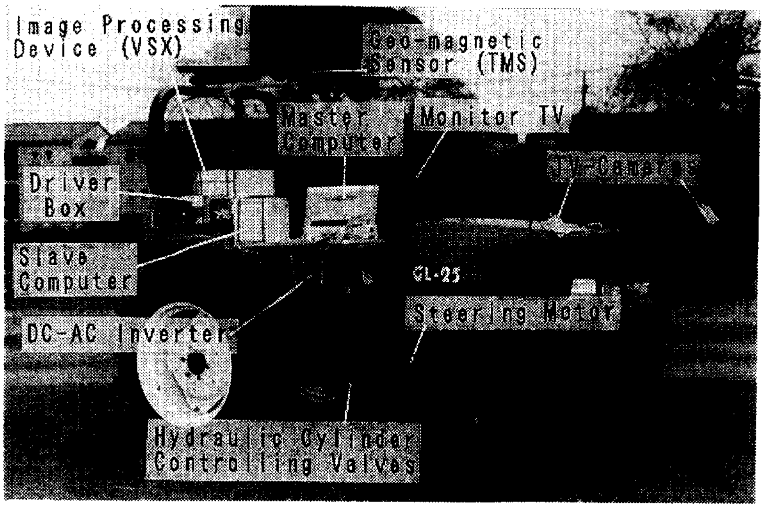


Fig.1. Prototype vehicle

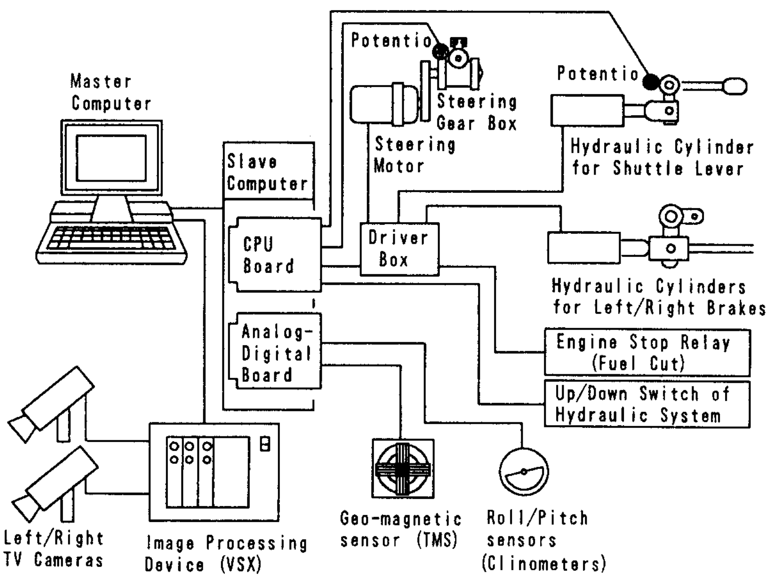


Fig.2. The control system of vehicle and navigation sensor

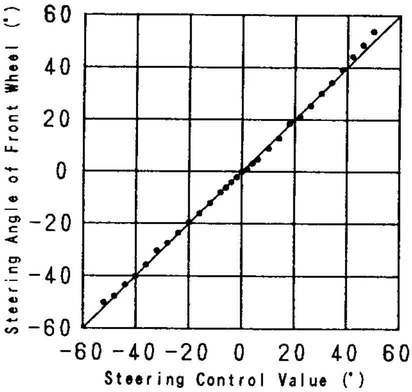


Fig.3. The examined data on steering control

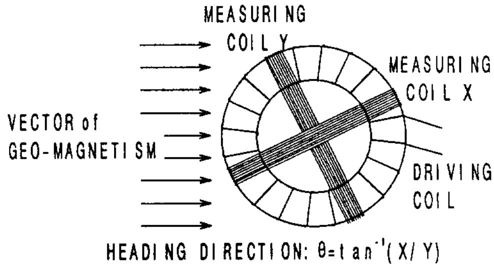


Fig.4. The measuring principle of geo-magnetic sensor

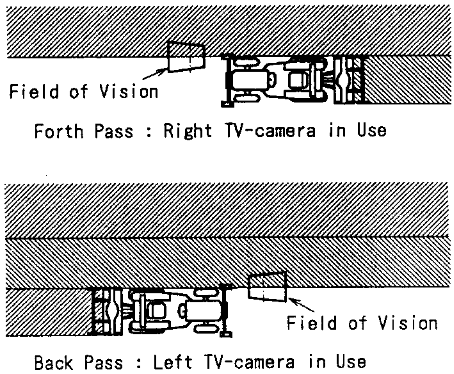


Fig.5. The autonomous operation following work boundaries

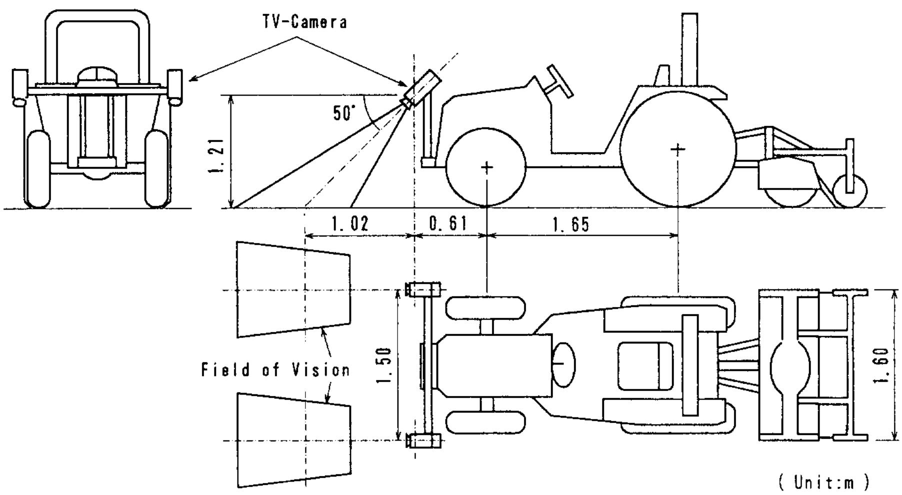


Fig.6. The location of two TV-cameras, fields of vision and vehicle

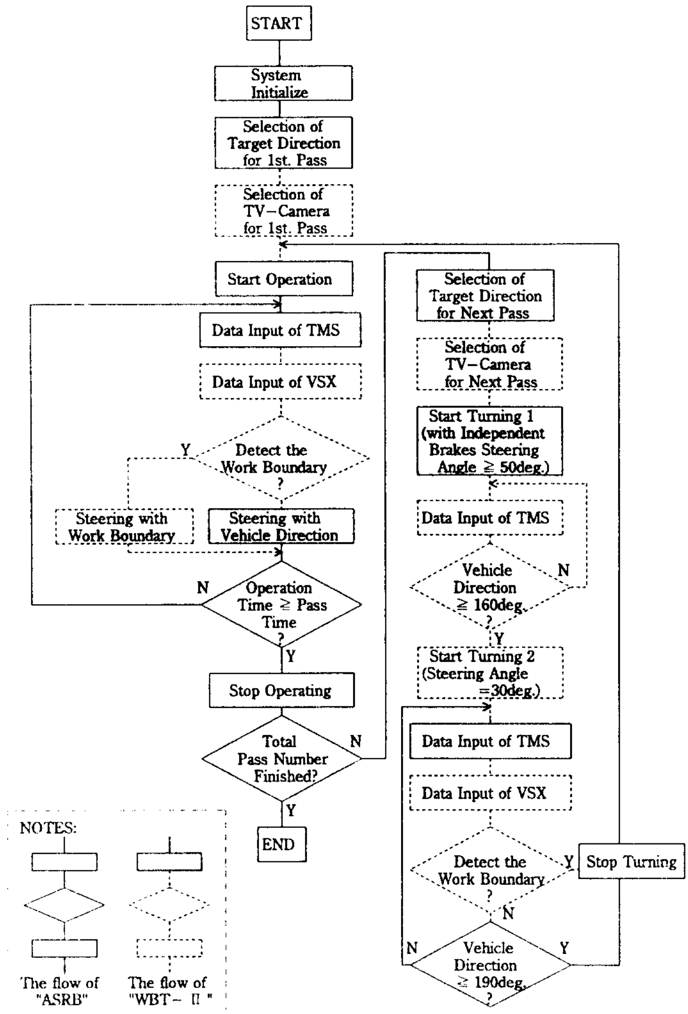
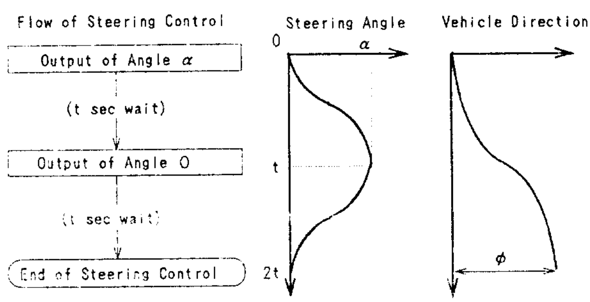


Fig.7. Flow charts for autonomous operations



Angle α is calculated by the following formulas.

$\phi = \frac{Vt}{L}\alpha$ = (Difference from Target Direction) $t=0.6s$ $(\alpha \leq 9^\circ)$

$=(0.6+(\alpha-9)\times 0.03)s$ $(\alpha > 9^\circ)$

V : Operating Velocity (m/s)

L : Wheel Base (m)

Fig.8. The algorithm of steering control in "ASRB"

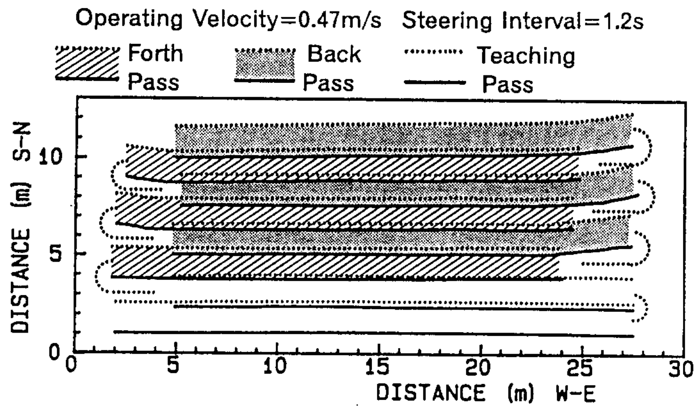


Fig.9. The trace of rotary tilling with "ASRB"

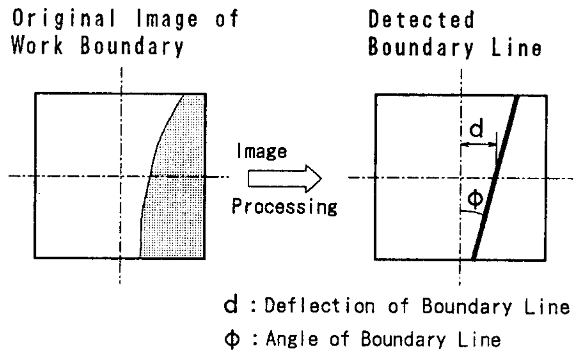


Fig.10. VSX data for steering control

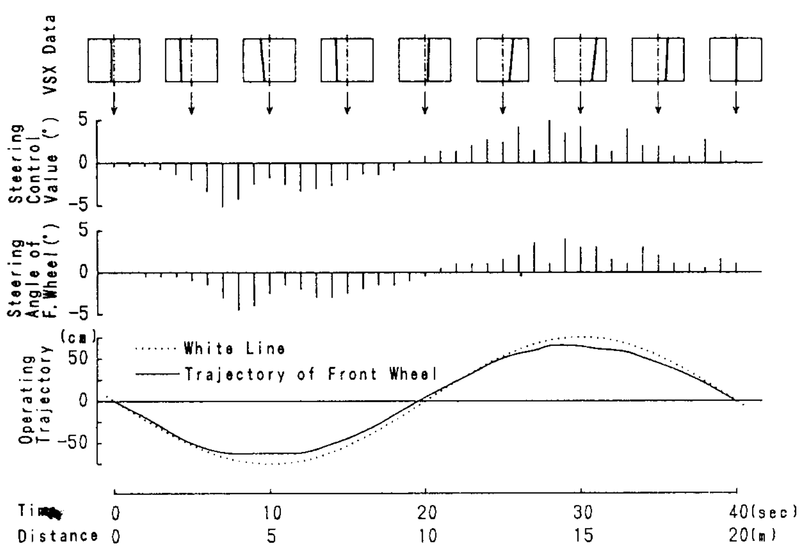


Fig.11. An example of test results with "WBT- I "

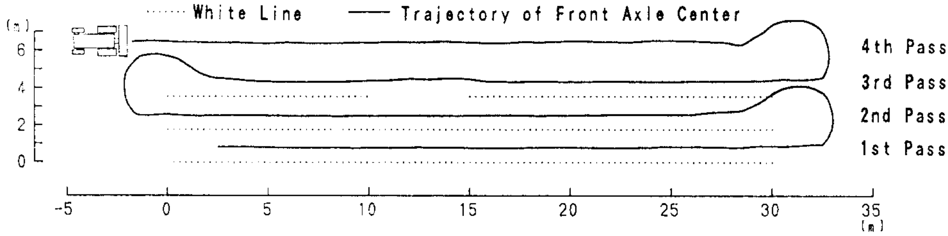


Fig.12. An example of test results with "WBT− II "

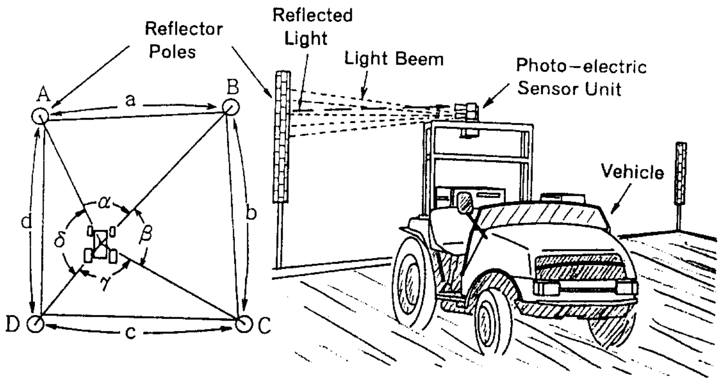


Fig.13. The detection of absolute position

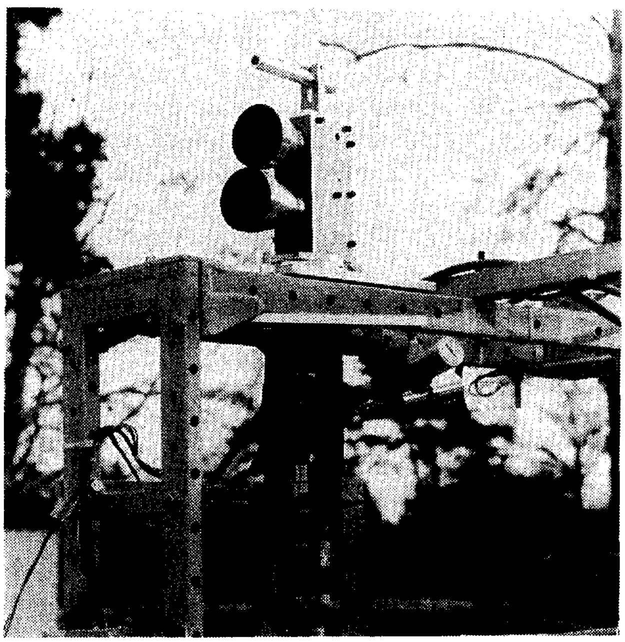


Fig.14. Photo−electric sensor unit