Automation and Robotics in Construction X
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DEVELOPMENT OF A ROBOT ASPHALT PAVER

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Abstract

Frequent changes in the paving conditions of general roads in Japan require considerable labor. This demands a heavy work load and a high level of skill to the asphalt paving operators and screedmen, and also affects the work load of subsequent manual operations, such as shoveling and raking.

In this project, five automation items to be developed were determined, after analyzing the present paving work by Industrial Engineer (IE) analysis and considering the paving work as a total system. The items are asphalt mix feeding, control of paving thickness, screed extension, steering operation, and operation of receiving the asphalt mix. The automation was achieved by using various sensors, an image processing system, and element technology using fuzzy control. The initial aim of labor savings and reduction in the level of skill could be achieved by developing this robot asphalt paver.

1. INTRODUCTION

Lack and aging of skilled workers, and dropping off of young workers from the construction industry have been continuing in Japan today. However, road paving work still depends on manual labor and adequate skill to a large extent. The reasons for this are:

(1) Land space is small and land acquisition for roads is difficult. Therefore, frequent changes in the paving widths are general in Japan.
(2) Ensuring the correct paving thickness, trimming the paving edges and finishing the surface, need manual labor.

To solve these problems, we have jointly developed a one-man robot asphalt paver with the aim of labor savings and reduction in the level of skill. The robot asphalt paver is a total system consisting of preprocesses (material transport), self processes (asphalt paving) and post processes (manual operations such as shoveling and raking).

2. ANALYSIS OF EXISTING WORK PROCESSES

We analyzed the following items to extract functions to be improved and developed:

(1) Analysis of current paving work processes
The functions of the conventional paver, operators, screedmen, and workers were analysed using IE techniques and video recording the paving conditions.

(2) Survey of the conventional asphalt paver and finished shape
Paving work was carried out only by operators and screedmen, and influences on the operations of the operators and screedmen and the finished shape were surveyed.

(3) Analysis of operational functions of the conventional paver
A questionnaire survey was performed on the operations for each work condition for the operators and screedmen, and the level of difficulty of machine operations was analyzed.

The problems confirmed quantitatively from the analysis are as given below.

(1) The steering and asphalt mix feeding operations, which are manual operations done by the operators, account for a large percentage of the work.
(2) The transverse movements of the screedman for screed control, checking and controlling the paving thickness is large.
(3) Raking work load is heavy while shoveling work load is light.
(4) While the conventional paver is docking with the dump truck, the overall work efficiency decreases.
(5) Irregular work (manual work) occurs at the beginning and the end of the paving work (Ex: the tapering to the existing road), resulting in peak work load of the workers.

As mentioned above, (5) cannot be avoided at the design stage. However, (1) to (4) are problems related to the conventional paver functions. These points were taken up as targets for development.

3. DEVELOPMENT POINTS

This development project was planned as a total system centering around the conventional paver from the transportation of materials to shoveling and raking works based on the results of analysis of the present operations. The five points which complied with development targets are given below.

(1) Asphalt mix feeding
Asphalt mix feeding to the front of the screed is an operation that needs maximum concentration of the operators. A uniform feeding over the entire width of the front of the screed lightens the heavy work load in the shoveling, raking and cleaning operations of the paving edges.
Also, it reduces variations in laying thickness and influences the next item.

(2) Controlling the paving thickness
Decreasing the level of skill in screed adjustment operations, which largely depends on experience, skill and intuition, helps one-man operations.
Also, if the laying thickness is uniform, quality of the finished pavement naturally improves and the work load in post processes also decreases.

(3) Extension of the screed
The adjusting work of the screed to match the paving width is an extremely heavy work for the screedmen, and this operation has a considerable influence on post processes.

(4) Steering operation
The steering operation bears considerable importance for the operators. Automation of steering operation plays an important role to develop one-man operations.
Also, the steering operation is closely related to screed width adjustments, which also influences post processes.

(5) Receiving the asphalt mix
The overall working efficiency decreases during the docking and undocking with the dump truck when receiving the materials. This was observed from the results of analysis of the present working processes. If the docking with the dump truck is smooth, there will be an improvement in the post processes. By semi automating docking indications (position, distance) of the conventional paver, and instructions for truck hitching and dump-up angles, uniform feeding of materials is possible.

If the above mentioned items are automated, the operator needs only to monitor the automatic operations and to do a part of the auxiliary operations by himself. Also, automation reduces the number of workers required in post processes and lightens the work load of the workers, surely resulting in overall labor savings and reduction in the level of skill in the total system.

4. DEVELOPMENT FUNCTIONS

Automation is necessary for achieving the development targets. The development items are described in detail below.

(1) Automatic feeding of asphalt mix
Four ultrasonic sensors were placed at the center and the both ends of the screed. The sensors at the center automatically control the asphalt mix feeding quantity of the bar feeder. The sensors at the both ends automatically control the asphalt mix feeding quantity of the screw conveyer.

(2) Automatic control of laying thickness
The paving thickness is measured and indicated with four ultrasonic sensors consisting of two sensors on each end, an inclination sensor and a travel distance sensor. The paving thickness is automatically controlled, based on the data measured by the sensors.

The fundamental technology used in (1) and (2) above, is the same as reported in "Development of Advanced Asphalt Finisher" in the 9th ISARC, and is applied to this project with several application developments. For details, refer to the paper of the 9th ISARC.

(3) Image processing system used for automatic extension of the screed and steering
The automatic extension of the screed and steering is mutually interrelated. The control systems are so made as to be interrelated and the points given below were taken into account.

· Existing structures are used as reference lines to eliminate new reference settings for control, thereby achieving labor savings
· The same sensor is used for sensing the whole objects usable for reference lines
· Common sensors are used for automatic screed extension control and automation of steering to reduce the number of sensors.

Based on the above prerequisites, we have developed a sensor (tentatively named 'road eye') using laser beams and a CCD camera. This sensor detects the edge if there is a level difference in the reference line. For flat reference lines such as white lines, only the CCD camera is used, which detects the reference line by binary values of bright and dark of the image.

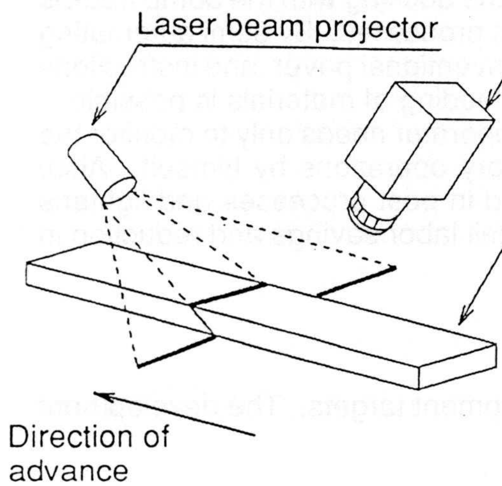

Figure 1.

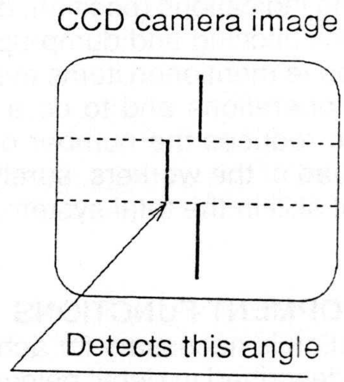

Figure 2.

The example of using a curb stone as the reference line is explained here. As shown in figure 1, a laser slit beam is projected from the front side on the curb stone and the CCD camera captures the image. In this image, the edge of the curb stone can be detected because the laser slit beam is at a different level. Figure 2 shows the monitor image (after converting to binary values) of the edged curb stone.

(4) Automatic screed extension control
Figure 3 shows the screed part of the robot asphalt paver and its movement with time. Sensors are installed at two locations - the front end (sensor A) and the rear end (sensor B) of the screed endplate. Both sensors, A and B are controlled so that they are always on the inside (paving side) the reference line. This is to keep the screed always inside the reference line to prevent collision when the reference line is a structure and to prevent overflowing the materials from the reference line when other lines are used as reference lines. Figure 4 shows the control system block diagram.

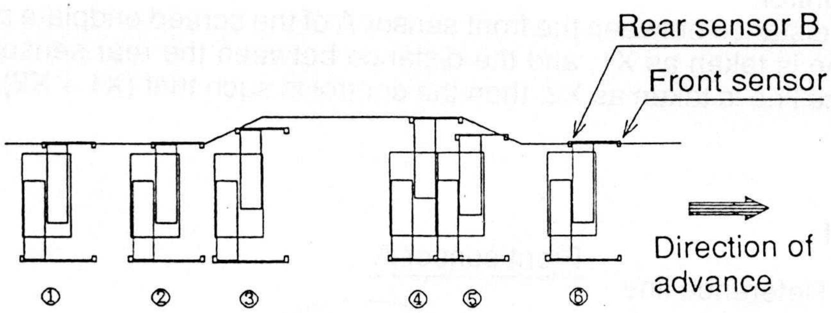

Figure 3. Indication of the screed movements only

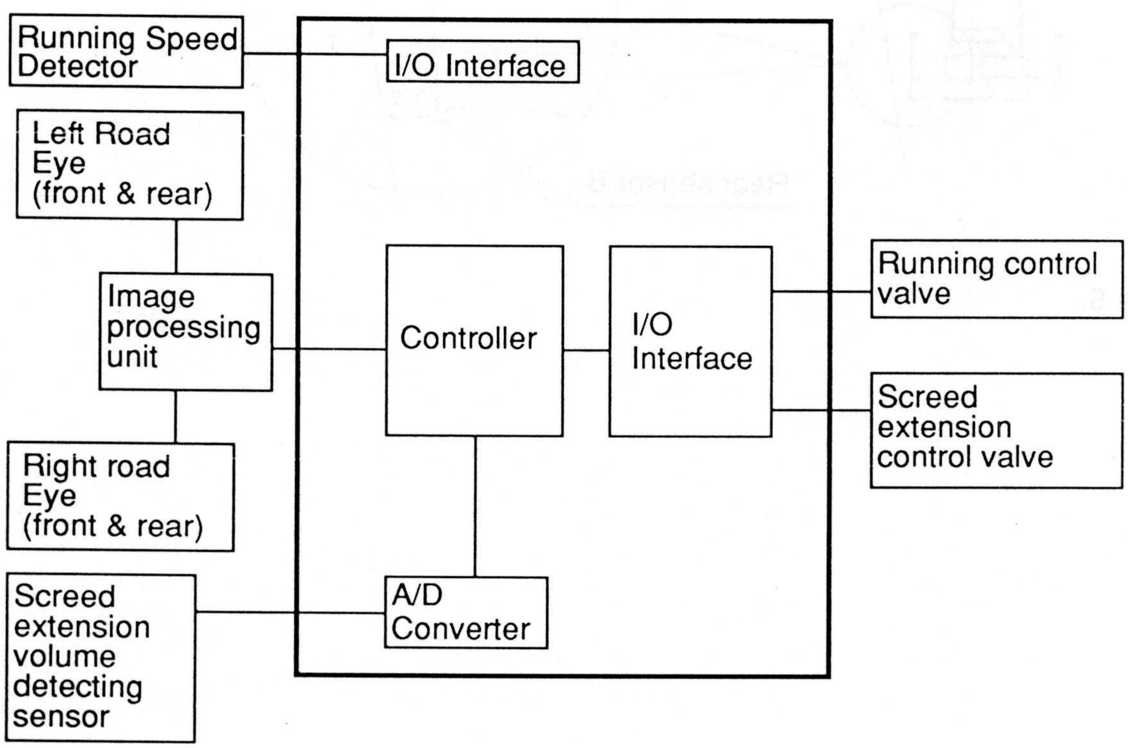

Figure 4. Control system block diagram

(5) Automatic steering device

The sensor used for measuring the azimuth angle deviation of the robot asphalt paver is the road eye, which is used also for the automatic screed extension control. Therefore, the sensing position is behind the swiveling shaft center of the vehicle body, and the road eye moves opposite to the steering direction at the start of the steering operation. Also, the steering angle must be changed according to the displacement of the line of travel from the reference line. Under these conditions, fuzzy control was used because we predicted that framing of control rules by numerical functions would be difficult.

The two fundamental rules for control are given below.

1) Vehicle travel control

In figure 5, if the distance between the front sensor A of the screed endplate and the reference line is taken as X1, and the distance between the rear sensor B and the reference line is taken as X2, then the control is such that (X1 + X2) / 2 = 0.

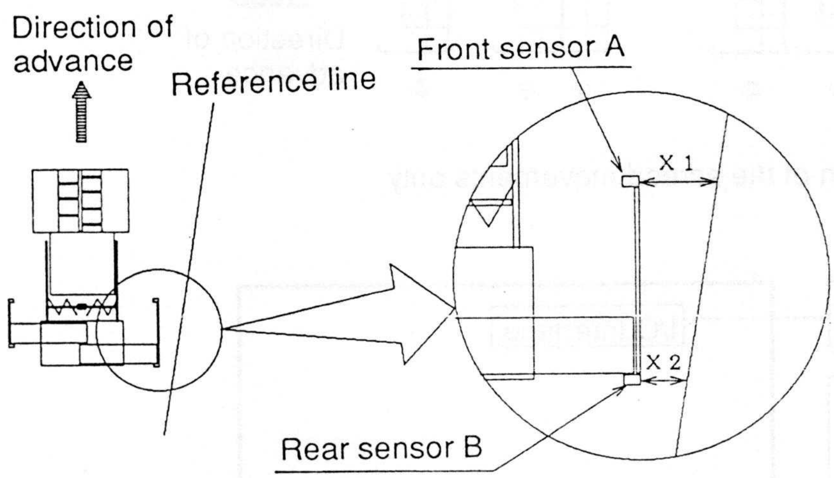

Figure 5.

2) Parallel travel control
The vehicle is always controlled to move parallel to the reference line such that $X1 - X2 = 0$. This control has the effect of restraining the overshoot control that is likely to occur in vehicle travel control.

To determine these control rules, computer simulation was carried out and the controls rules were applied to the actual machine, after verifying effective working of these rules.

The control block diagram is shown in figure 4.

(6) Semi-automation of asphalt mix receiving process
This development is divided into two parts.

1) Devices for guidance and operation instructions for the dump truck driver
A large indicating panel was installed by the side of the cabin of the robot asphalt paver. The indication of the panel has two modes, the docking mode with the dump truck and the material feeding mode, which are automatically switched each other. During the docking mode, the distance remaining to the stop position, is displayed on the indicating panel by the distance sensor. When the stop position is reached, STOP is indicated on the panel. The robot paver operator can make the lateral displacement displayed on the indicating panel by pressing the button. If a person or an object comes between the dump truck and the robot paver at this time, an alarm is generated. Also, during the material feeding mode, instructions for dump-up, dump-down, and release can be displayed by pressing the button.

2) Automatic truck hitching
The dimensions of the rear wheels of the dump truck and the rear end of the vessel vary depending on the type of the dump truck. The truck hitching device developed in this project starts the hitching operation automatically when the rear wheel touches the push roller. Then, the push roller retracts in the rear direction, and is locked automatically when the position of the vessel rear end becomes the same as the position of the hopper.

5. SPECIFICATIONS OF THE DEVELOPED ROBOT PAVER

Table 1 shows the main specifications of the robot paver developed in this project. Figure 6 shows the outline drawing of the paver.

Table 1. Specification

Total weight:	13000 Kg
Overall length:	6700 mm (Max)
Overall width:	2490 mm (in transportation)
Engine power:	66 Kw/2000 r.p.m.
Paving width:	2.5 - 4.5 m
Automatic system:	
Mix feeding:	Ultrasonic type automatic feeder
Laying thickness control:	Ultrasonic type automatic adjuster
Laying thickness measurement:	Ultrasonic type automatic measuring device
Screed extension:	Image-processing type automatic extension device
Steering:	Image-processing type steering device
Dump truck guiding:	Semi-automatic dump truck guiding device

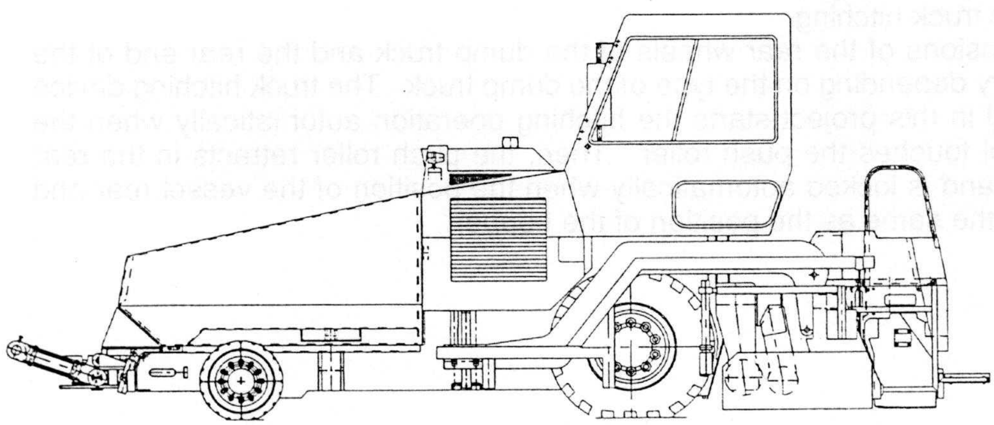

Figure 6.

6. CONCLUSION

Considerable labor savings and reduction in skill were achieved by the robot paver developed in this project. We will make further efforts to improve performance of the robot paver and popularize it to general paving projects in Japan. Also we are planning in future to apply this automation technology to other kinds of construction.