Automation and Robotics in Construction X
G.H. Watson, R.L. Tucker and J.K. Walters (Editors)

Autonomous Dump Trucks System for Transporting and Positioning Heavy-duty Materials in Heavy Construction Sites

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Abstract

This paper describes an autonomous dump trucks system being developed to overcome worker shortage problems and to prevent accidents in heavy construction sites (i.e., dam constructions, road constructions, etc.). The major distinctive functions of this system are:

(1) the autonomous driving function:
  - this system enables unmanned dump trucks to autonomously drive at 40 km/h as planned. The difference between the planned path and the trajectory is within ±90 cm;
  - the vehicle command system can recognize obstacles and prevent their being crashed or destroyed by, utilizing a color image processor;

(2) the advanced measurement function:
  - the laser navigation system provides measurement function (i.e., the measurement errors regarding the position and the direction are within ±50 cm and ±1 degree, respectively).

This system enables two operators to manage dump trucks without drivers. It is anticipated that this system could reduce approximate 30% of the workers required at heavy construction sites in the future.

1. INTRODUCTION

The Japanese construction industry has made research efforts to develop on-site automation in order to overcome declining productivity, increasing labor costs, hazards in job sites, and scarcity of skilled labor. Generally speaking, developing the modules of manufacturing, assembling and inspecting rather than transporting has received much attention and has been forced so far in the Japanese construction industry. Transportation of earth, sand and rocks in earthwork has frequently reconfigured operations and often severe environmental conditions. Dump trucks in earthwork do not depend on a fixed path such as railroad. Dump trucks operations are repetitive, tedious, boring, physically dangerous and critical to productivity in earth work.

Faced by a need to improve productivity and safety in earthwork, an autonomous dump trucks system in heavy construction sites is developed as shown in Figure 1. The dump trucks system should have adaptability for changing surroundings, such as long distance driving, high-speed driving, driving within road width, change of route, etc.. To secure the safety of driving, the dump trucks system must recognize specific workers or vehicles and take actions to avoid obstacles. The dump trucks system must at least have 3 driving modules, that is, remote control for loading and unloading, unmanned driving for transportation, and manned driving for movement to parking lot.

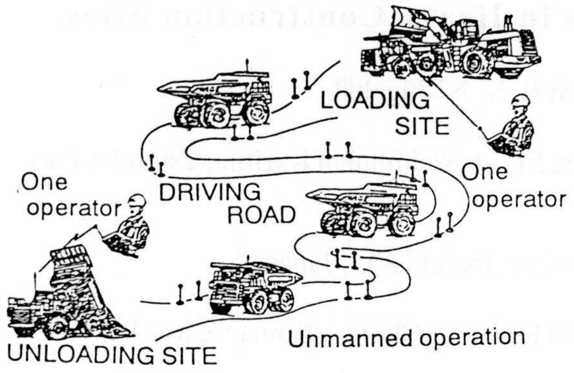

Figure 1. Image of an autonomous dump trucks system for transportation

The autonomous dump truck is equipped with a main unit and 3 sub units as show in Figure 2. These units work for the above 3 driving modules. The technologies required for the above 3 driving modules are developed by using the test vehicle shown in Photo 1.

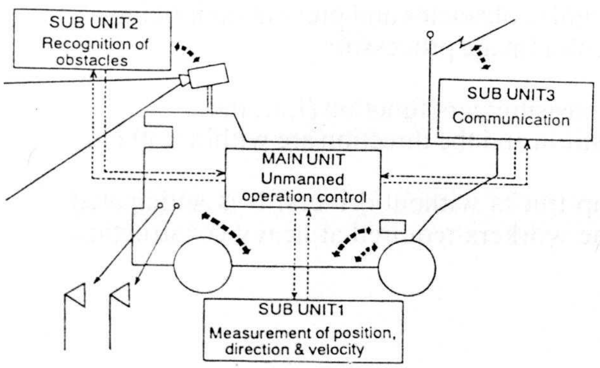

Figure 2. 4 units for an autonomous driving of dump trucks

Photo 1. Test vehicle for development of element technologies

First, this paper discusses the basic principles of the unmanned operation control of the test vehicle. Second, this paper shows the findings derived from the driving experiments of the test vehicle. Finally, we conclude with a summary of this study and discuss anticipated results and further research.

2. TECHNOLOGIES OF THE AUTONOMOUS DUMP TRUCK

It is indispensable for unmanned driving system of vehicle to have a real-time dead-reckoning function and obstacle avoidance function. This section discusses the dead-reckoning and obstacle avoidance functions of the test vehicle.

2.1 UNMANNED OPERATION CONTROL TECHNOLOGY (MAIN UNIT)

The unmanned operation control of the test vehicle is designed for 4-wheeled vehicles. The basic principles of the unmanned operation control consists of line and circle mode which were developed for "Yamabiko" robot. The "Yamabiko" robot is an independent 2-driving wheel steering type moving vehicle which is currently under study at University of Tsukuba.

As shown in Figure 3, a planned route on global coordinate system for unmanned driving is derived from combinations of local coordinates based on line mode and circle mode.

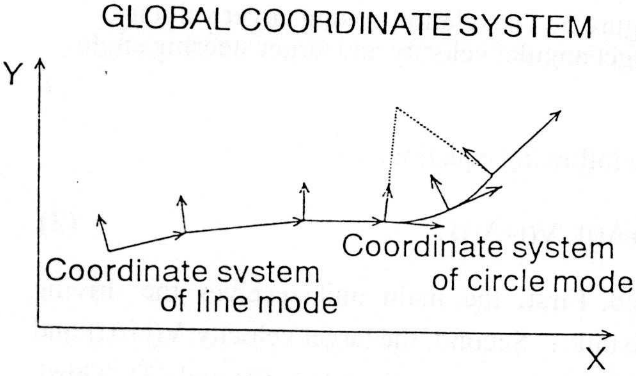

Figure 3. A planned route for unmanned driving

The unmanned control by line mode in Figure 4 requires target velocity $V(t+\Delta t)$ and target angular velocity $\omega(t+\Delta t)$. $V(t+\Delta t)$ and $\omega(t+\Delta t)$ are given by the following equations:

$$V(t+\Delta t)=V_d-K_4\,|\,\omega(t)\,|\,, \qquad (1)$$

$$\omega(t+\Delta t)=\Delta t\{-K_1\eta(t)-K_2\theta(t)-K_3\omega(t)\}+\omega(t), \qquad (2)$$

where V_d denotes set velocity; K_i for $i=1, 2, \cdots, 4$ denotes feedback coefficients; Δt denotes interval time between one sampling and the other. Feedback coefficients K_1 to K_4 in (1) and (2) were estimated by experiments so that the test vehicle can follow the planned route in a natural way.

The unmanned operation control by circle mode works for a curved driving along a small radius of curvature. Suppose that a 4-wheel vehicle is driving on a circle of a radius r. The relation among target velocity V(t+Δt), target angular velocity ω(t+Δt) and steering angle ϕ(t+Δt) of the vehicle is shown in Figure 5.

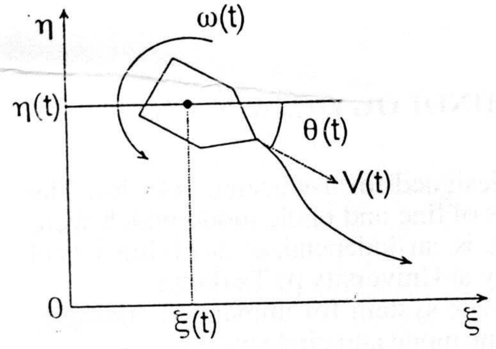

Figure 4. Local coordinate system of line mode

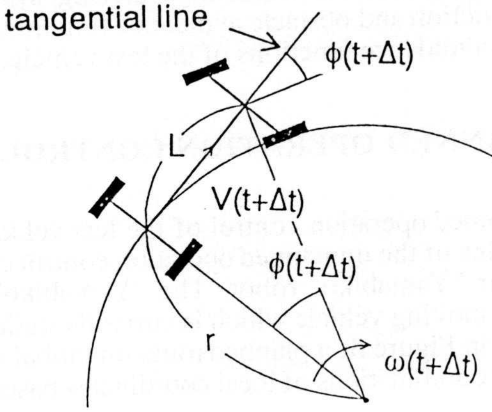

Figure 5. The relation among target velocity, target angular velocity and target steering angle

The target steering angle ϕ(t+Δt) is given by the following equation:

$$\phi(t+\Delta t)=\tan^{-1}\{\omega(t+\Delta t)L/V(t+\Delta t)\}. \tag{3}$$

Suppose that a unmanned driving is started. First, the main unit receives the driving information {η(t), θ(t), ω(t), V(t)} from the sub unit 1. Second, the target velocity V(t+Δt) and the target steering angle ϕ(t+Δt) are calculated based on the equations (1), (2) and (3). Third, the main unit performs a speed control (brake, accelerator) and a steering control according to those target values. This operation is repeated until the target point is reached.

2.2 POSITION, DIRECTION AND VELOCITY MEASURING TECHNOLOGY (SUB UNIT 1)

See Figure 6. Driving distance and velocity of the vehicle are detected by encoder sensors attached to rear tires. Direction of the vehicle is detected by a fiber optic gyroscope. Positions of the vehicle are calculated successively based on the driving distance and the direction.

A laser transmitter/receiver is equipped at the left side of the test vehicle as shown in Photo 2. Photo 3 shows that poles (2 poles/set) with laser reflectors (corner cubes) are installed along the driving route at an interval of approximately 50 m. Any accumulated positional errors in a long-distance driving are corrected based on the feedback data from the laser transmitter/receiver and the poles.

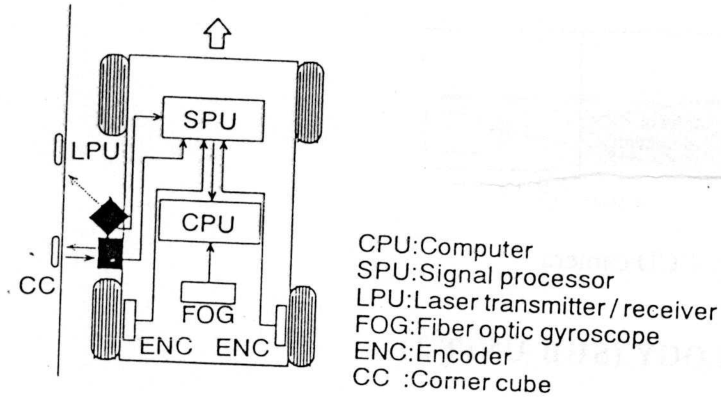

Figure 6. Position, direction and velocity measuring system

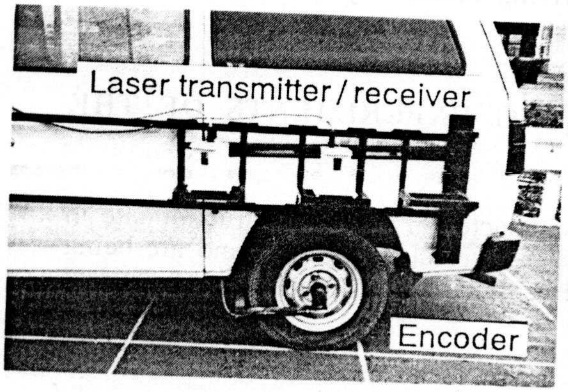

Photo 2. Encoder and laser transmitter/ receiver

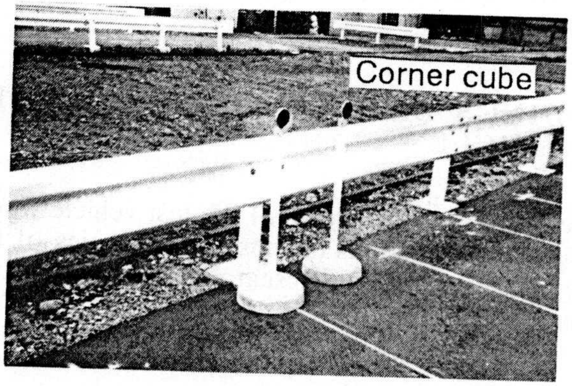

Photo 3. Laser reflector (corner cube)

2.3 TECHNOLOGY OF OBSTACLE AVOIDANCE (SUB UNIT 2)

To make an autonomous driving of a vehicle safer in outdoor environments, it is necessary to detect any obstacles in the front direction on the driving road and to take some safety measures for autonomous evasive action or stop of the vehicle.

This test vehicle has a front obstacle detecting system. This system uses a method of comparatively easy macro graphic detection. This system can fetch an image of the front view into a personal computer from a CCD camera equipped at the assistant's seat side. The image of the front view can be processed by a transputer loaded on this personal computer.

At the current stage, this system recognizes workers by extracting the helmet worn commonly by all workers. The color of the helmets is usually yellow in many construction sites. First, the processor searches portions of the same yellow color as that of helmets based on the brightness and the hue of the fetched image. Second, it discriminates between the presence and non-presence of helmets by searching their surface areas and shapes among the extracted portions. Thus, it is possible to detect workers within the range of 20 m ~ 60 m in the front direction (Fig. 7).

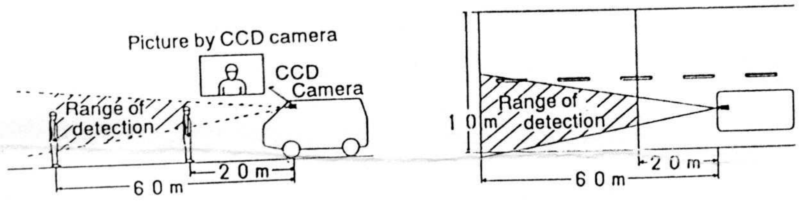

Figure 7. Range of detection of workers by CCD camera

2.4 COMMUNICATION TECHNOLOGY (SUB UNIT 3)

A simple remote-controlled operation by radio controller is available for communication system. By this communication system, it is expected that loading and unloading can be fully operable from remote locations as shown in Figure 1. Furthermore, it could perform to easily switch from unmanned driving module to manned driving module by this communication system.

3. FINDINGS DERIVED FROM THE DRIVING EXPERIMENTS OF THE TEST VEHICLE

The field driving experiment of the test vehicle was conducted in a dam construction site in 1991. Further refinements of those technologies of the test vehicle have been and are being evolved at the Technical Research Laboratory of Hazama. Table 1 shows the current performance of the test vehicle.

Table 1
Performance of the test vehicle

Function	Item	Target performance	Current performance
Driving mode	Manned driving	Free switching	Free switching
	Remote controlled driving	Free switching	Free switching
	Unmanned driving	Free switching	Free switching
Unmanned operation	Distance of continuous driving	2km	1.5km
	Maximum speed	40km/h	20km/h
	Width of meandering	±90cm	±130cm
	Radius of gyration	15m	40m
Measurement of position & direction	Position accuracy	±50cm	±50cm
	Directional accuracy	±0.5degree	±1.0degree
Recognition of obstacle	Worker(fine)	100%	80%
	Worker(Cloudy,Slightly rainy)	100%	100%
	Other vehicle	100%	Under development
Evasion of collision	Preceding vehicle at stop	100%	Under development
	Driving preceding vehicle	100%	Under development
Remote-controlled operation	Radius of operation	Within 50m	Within 50m

The continuous driving distance that the unmanned driving control could achieve is 1.5 km at the maximum speed of 20 km/h. The difference between the planned path and the trajectory was within ±1.3 m.

The unmanned driving experiments of the test vehicle of long-distance (2 km) and high-speed (20 to 40 km/h) are being conducted at the test course of the Public Works Research Institute of the Ministry of Construction.

4. CONCLUSION

This paper presents the major distinctive functions of the autonomous dump trucks system as follows:

(1) The autonomous driving function:
  - This system enables unmanned dump trucks to autonomously drive at 20 km/h as planned. The difference between the planned path and the trajectory is within ±130 cm;
  - The vehicle command system can recognize workers that worn a helmet by, utilizing a color image processor;

(2) The advanced measurement function:
  - The laser navigation system provides measurement function (i.e., the measurement errors regarding the position and the direction are within ±50 cm and ±1.0 degree, respectively).

Fig. 8 indicates an example of composition of workers at a certain dam construction site. Since this system enables two operators to manage dump trucks without drivers in heavy construction sites. It could reduce approximately 30 % of workers in the future. Likewise, the technologies in this study could, with some enhancements and modifications, perform useful functions for remote work vehicles in heavy construction sites.

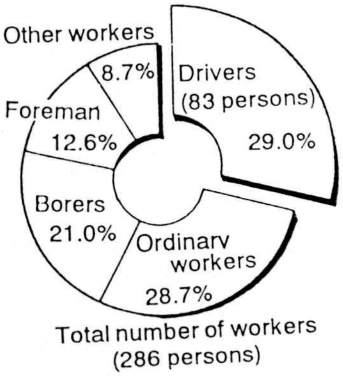

Figure 8. Example of composition of workers at a dam construction site

Further research problems are to develop technologies in respect of:

(1) making the directional accuracy being within ±0.5 degree by utilizing a fiber optic gyroscope;
(2) improving the ability to recognize workers by a laser radar;
(3) reciprocal communication technology among a plural number of vehicles;
(4) recognizing obstacles just before, behind, side of vehicle;
(5) recognizing other vehicles, rocks, holes, etc..

5. REFERENCES

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