Advances in Robotics for Construction Machinery

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OVERVIEW: With robotics being increasingly adopted in a variety of products, such as cars and home appliances, Hitachi Construction Machinery Co., Ltd. is proceeding with greater use of robotics in construction machinery, its major objectives being to expand the scope of its application and to enhance the underlying competitiveness of the company's products. Hitachi Construction Machinery is developing robotics for construction machinery with a focus on three technologies: (1) operator assistance whereby the intelligence and control functions of a construction machine are used to assist its operator, (2) H/Is that provide smooth interaction between human and machine, and (3) improvements to the body functions of construction machines, including the front and crawler mechanisms. Hitachi Construction Machinery is also working on the fusion with external information networks, this being another important factor in introducing robotics to construction machinery.

INTRODUCTION

AS computers have become more widely used and more sophisticated in recent years, progress has also been made on applying robotics in common products such as cars and home appliances. Recognizing this trend, Hitachi Construction Machinery Co., Ltd. is proceeding with greater use of robotics in construction machinery, its major objectives being to expand the scope of application of these machines and to enhance the underlying competitiveness of its products. Robotics is an "integration technology" with a wide range of applications. Three key concepts for the use of robotics in construction machinery are intelligence and control, human interface (H/I), and body functions. Hitachi Construction Machinery is developing technology in each of these fields.

This article gives an overview of intelligence and control, H/I, and body functions for robotics in construction machinery, describes the technologies under development, and uses information integrated construction as an example of integration with external networks.

INTELLIGENCE AND CONTROL

Operator Assistance

Intelligence and control refers to the part of a machine that is analogous to a brain. Reference to intelligence in the context of robotics brings to mind images of automation and autonomous operation, and machines that function without human intervention. However, because construction machines are frequently used for work in unstructured environments where the materials change shape from moment to moment depending on the conditions, moving directly to automatic and autonomous operation is impractical. Instead, Hitachi Construction Machinery is undertaking research and development of intelligence functions that can be used for operator assistance, which means having a construction machine being driven by an operator provide support for itself. In particular, current research topics focus on support for non-operational factors, such as safety and ride comfort, so as to free up the operator to concentrate on the actual work to be done.

Dynamic Center of Gravity Measurement

To improve the safety of construction machines and make them easier to use, Hitachi Construction Machinery is developing a system for measuring dynamic stability in realtime in a way that takes account of the inertial forces that occur during operation. Conventionally, the stability of construction machines has been assessed for static tasks such as operating as a crane. However, construction machines are used for a wide range of tasks and large inertial forces can affect their stability, such as when a machine is required to perform a large movement quickly. Japanese Industrial Standards (JIS) only specify rudimentary methods for assessing dynamic stability and no development has previously been done on quantitative assessment techniques.

The system being developed has adopted zero moment point (ZMP) as an indicator for assessing stability that can take account of the dynamic aspects of machine operation. The system calculates ZMP in realtime. The same indicator has been used for walking robots in the past, and it can be interpreted as a point projection of the center of gravity that considers the dynamics of the machine.

Using ZMP as an indicator for assessing stability has the following two advantages.

(1) It allows the assessment to take account of the dynamics of the machine (inertial forces).

(2) Instability corresponds to machine lift, demonstrating that the indicator has a direct correlation with machine behavior.

The system calculates the ZMP from sensor measurements that detect the orientation of the construction machine, the acceleration of the center of gravity of major components, and the load on the attachment. Use of the system provides an accurate indication of changes in stability that would not be caught by a static stability assessment (see Fig. 1).

H/I

Smooth Interaction

As described above, the field of H/I technology is specific to construction machinery, which is characterized by the presence of an on-board operator. The interfaces can be broadly divided into information input systems that the operator uses to specify instructions to the machine, and information output systems used to present information about the machine and its surroundings to the operator. In particular, the amount of data handled by operating machines is increasing in step with the improving performance of the computers installed in the machines, so the ability to present this information to operators clearly is a major issue.

Similarly, making machine operation as simple as possible is important for more complex machine systems such as the double-arm working machines. That is, achieving a smooth interaction between human and machine is critical, and Hitachi Construction Machinery is working on research and development aimed at achieving this.

Periphery Monitoring

With the aim of enhancing the systems that output information to the operator, Hitachi Construction Machinery is developing an overhead view monitor that provides visibility over a large area and minimizes blind spots around the machine. Images from a number of cameras mounted on the machine are converted (shifted in viewpoint) and combined to generate an overhead (bird's-eye) view centered on the machine that is displayed on a screen in the cab as a periphery monitoring image. This system has the following features (see Fig. 2).

(1) The machine is fitted with a number of wide-angle cameras (160° horizontal field of view). Images from each of the cameras are converted (shifted in viewpoint) and then combined to produce images that cover a wide area (up to 360°). This allows the operator to see the situation around the machine at a single glance (the distance and direction of people or other obstacles).

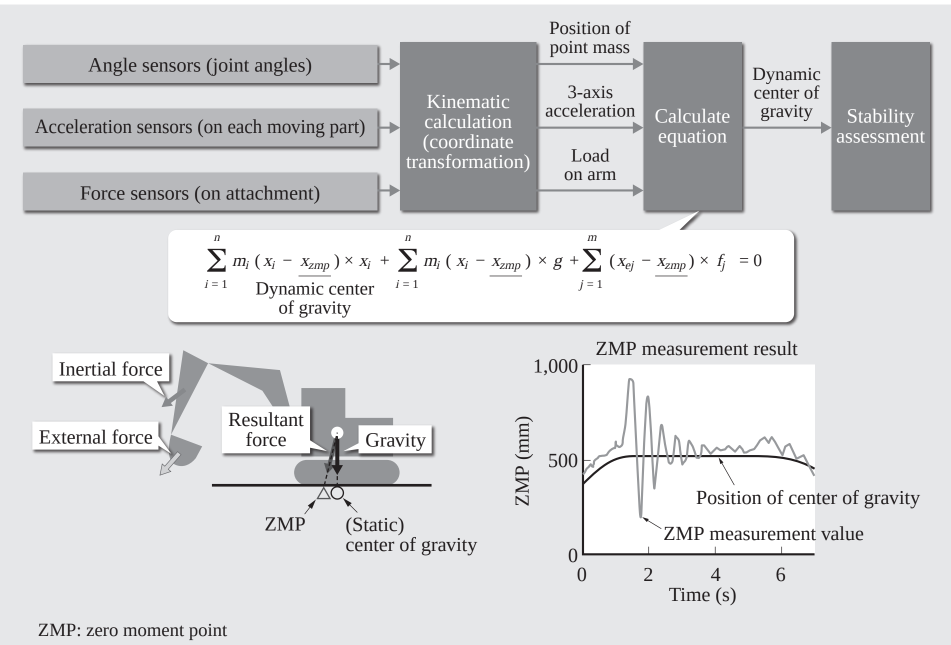


Fig. 1—System for Dynamic Measurement of Construction Machinery Center of Gravity.
The system calculates the ZMP from sensor measurements that detect the orientation of the construction machine, the acceleration of the center of gravity of major components, and the load on the attachment.

(2) The system allows the operator to select from a number of display options that show different areas or have different screen formats. Displaying the overhead image and rear-view camera image at the same time is one of the options.

BODY FUNCTIONS

Improvements to Body Functions of Construction Machines

As indicated by the name, body functions relate to the body of a construction machine. Of the two main objectives, body functions involve, in particular, technology that aims to expand the scope of application of construction machinery by increasing the range of tasks and activities they can be used for through research aimed at improving the functions of the arm (front) and undercarriage (crawler). Also, the concept of "embodiment" includes sensors and other sensing functions. Rather than developing the sensors themselves, the research is primarily concerned with how to make use of sensor information and how to utilize information from multiple sensors (sensor fusion).

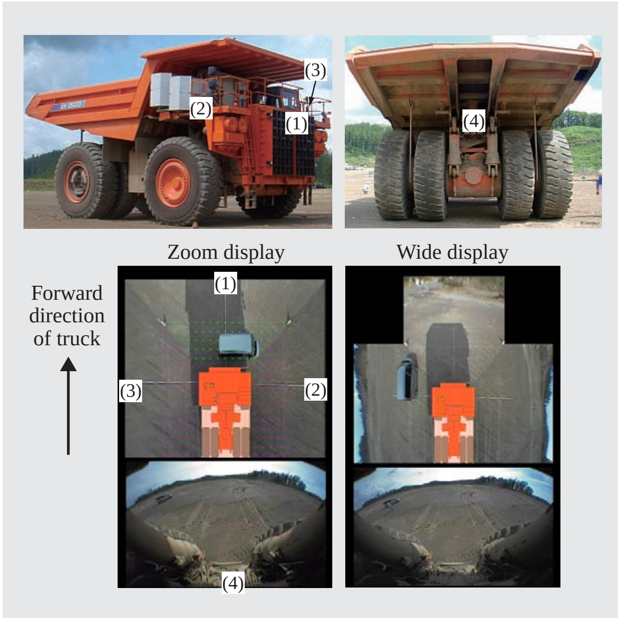


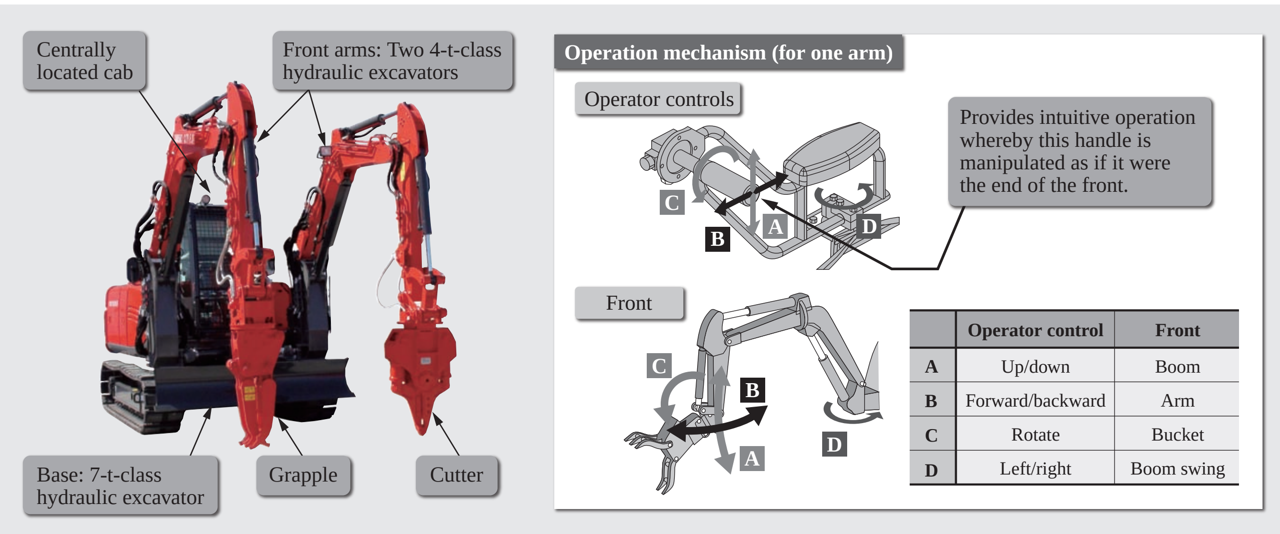
Fig. 2—Overhead View Monitor System.
An overhead (bird's-eye) view of the region around the machine (periphery monitoring image) is generated by converting and combining images from multiple cameras.

Double-arm Working Machine

To provide more advanced arm functions, Hitachi Construction Machinery has developed a double-arm working machine with an enhanced capability for performing complex operations. Because it is equipped with two arms at the front like a human being, the machine can perform complex tasks such as holding and cutting at the same time. The features of the machine are listed below (see Fig. 3).

(1) The ability to perform complex tasks such as holding and cutting at the same time or folding a long piece of material

(2) A hydraulic system capable of driving multiple actuators from a single pump that allows both arms to operate simultaneously



	Operator control	Front
A	Up/down	Boom
B	Forward/backward	Arm
C	Rotate	Bucket
D	Left/right	Boom swing

Fig. 3—Double-arm Working Machine (Left) and Operation Mechanisms (Right).
The photograph shows one of the custom-built 7-t-class double-arm working machines supplied to the fire department for routine use. The operation mechanisms use the velocity directive one lever method for intuitive control of both arms at the same time.

(3) A design that allows the operator to control both arms at the same time, with the right arm controlled by the operator's right hand and the left arm controlled by the operator's left hand
(4) The use of the velocity directive one lever method for the operator controls to provide intuitive operation and reduce operator fatigue
(5) A three-dimensional arm position calculation that prevents arms from colliding

A 7-t-class prototype model was supplied to a fire department in October 2008 so that its use for rescue work at disaster sites could be trialed. Based on their evaluation, two new custom-built machines fitted with special-purpose equipment were supplied for routine use in March 2011.

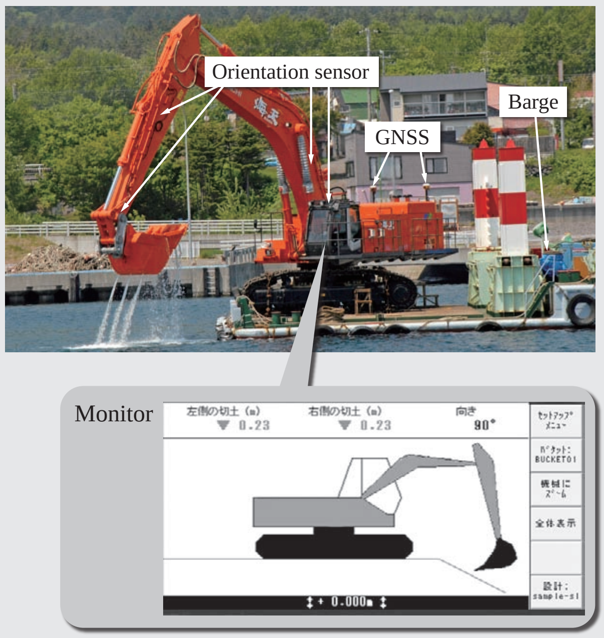
INTEGRATION WITH EXTERNAL NETWORKS

Rather than just considering the machine in isolation, an important part of the integration of robotics into construction machines is their fusion with external information networks. This section describes one example of integration with external networks, namely, information integrated construction.

Business of construction and fabrication can be thought of as consisting of surveying, design, construction, maintenance, and refurbishment processes. Information integrated construction focuses on the construction process in particular, and is a way of ensuring that this work is done efficiently and accurately based on electronic information collected from each process using information and communication technology (ICT). It is also a system for improving productivity and maintaining quality across all construction and fabrication processes by taking electronic information collected from the construction process and using it in other processes. Construction machinery is used in the actual fabrication of the facility being constructed. Accordingly, construction machines can both use information to perform their work and be a source of information about the progress of construction work.

The functions provided by information integrated construction can be divided into two categories. The first are the functions that use ICT to automate construction machines or to assist operators to perform work. A guidance system for hydraulic excavators is one example (see Fig. 4). The system uses a global navigation satellite system (GNSS) and total stations (TS) to determine the position of a machine and simplifies the job of its operator by displaying design drawings or work movement patterns. With Japan's aging population contributing to a shortage of experienced operators, examples of this sort of operator assistance technology being adopted are slowly starting to increase. Currently, design drawings are input into the cab computer manually via a memory card. In the future, it is anticipated that it will be necessary to provide construction machines with the ability to connect to the Internet and access the latest drawings remotely from the site office, both to improve work efficiency and to ensure that any changes to the drawings are passed on promptly to the machine.

The second category functions are those that use information collected during machine operation to help engineers working at the site to make better decisions. A fleet management system for dump trucks used at mining sites is one example (see Fig. 5). To ensure appropriate assignment of dump trucks across a mine site that might extend over several square kilometers, each dump truck is fitted with a GNSS that transmits its position to the mine site office in realtime. The mine site office tracks the location of each truck and formulates dump truck assignment plans based on the target production volume and the operational status of the dump trucks, loaders, and other plants. Based



GNSS: global navigation satellite system

Fig. 4—Guidance System for Hydraulic Excavator.
The system supports the operator by measuring the position and orientation of the machine and presenting information on work drawings and movement patterns.

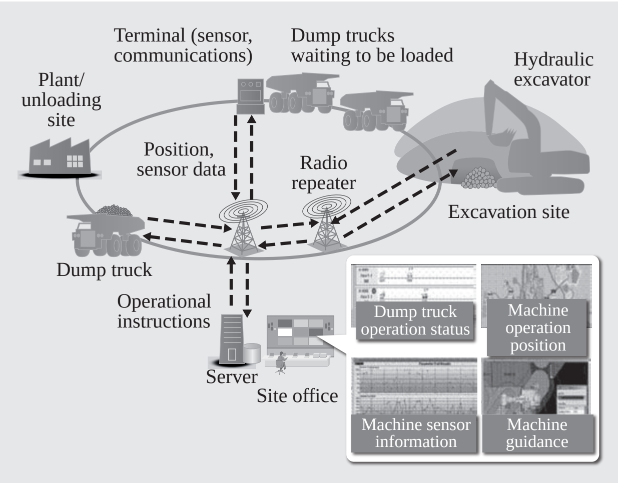


Fig. 5—Fleet Management System for Mining Dump Trucks.
Located at the mine site office, the system formulates dump truck assignment plans based on position information sent from each dump truck, and then sends instructions to the computer in each dump truck instructing it where to go next.

on this plan, the mine site office transmits information to the computer in each dump truck instructing it where to go next. Use of this fleet management system requires the installation of a wireless network at the site. Currently, a 2.4-GHz-band wireless local area network (LAN) with mesh topography is used. In addition to communications between machines and the site office, it is anticipated that the transmission of information between machines will also be required in the future to provide accurate, realtime updates about mechanical status, work volume, and other machine information.

CONCLUSIONS

This article has given an overview of intelligence and control, H/I, and body functions for robotics in construction machinery, described the technologies under development, and used information integrated construction as an example of integration with external networks.

In addition to reducing fuel consumption as a response to environmental problems, the growing market for construction machinery also has an increasing need for the use of robotics to provide more advanced functions for demolition and other work. In the future, Hitachi Construction Machinery intends to continue actively developing new construction machinery by bringing together its strengths in fields such as electrification and control technologies.

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