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Modular Platform for a Bilateral Master/Slave Manipulator for Hydraulic Machines.

Eric Rohmer, Takayuki Takahashi, Eiji Nakano

Tohoku University

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連絡先 : 〒982 仙台市青葉区荒巻字青葉01 東北大学大学院 情報科学研究科 中野・高橋研究室
ROHMER Eric, Tel.: (022)217-7025 Fax.: (022)217-7023 E-mail: eric@robotics.is.tohoku.ac.jp

1. INTRODUCTION

Civil engineering machines like excavators, demolition machines and other special concrete injection machines are commonly used in construction sites because a lot of building tasks require large forces. All these machines have in common that they own a tool (bucket, grinding tool, concrete injection gun, etc.) linked to a n Degrees of Freedom (DOF) hydraulic arm driven by hydraulic cylinders. To learn how to use each kind of machines, the user must be well trained as he has to manipulate each link of the arm separately using a complex system of lever. In order to get coordination and to be able to work quickly and accurately, the worker needs several years of training. Moreover, in some cases like concrete injection or building destruction work, the user inside the machine is exposed to danger due to the risk of falling crumbles.

Regarding these problems, the design of a new architecture for civil engineering machines must take into account the following constraints:

- manoeuvrability of the machines: how to cope with the complex system of levers and the complexity of the tasks,
- interoperability: how to add remote control features to the machines, replace a real machine by a virtual one, etc.,
- diversity: how to deal with the different kind of civil engineering machines.

In this paper, we present a solution based on a new software architecture. This architecture is based on the integration of a computer system using a modular approach. In the first part, we show how we answer the problem of manoeuvrability using a master/slave force feedback control system. In the second part, we describe the communication process between the different parts of the system. Finally, we show advantages and applications of

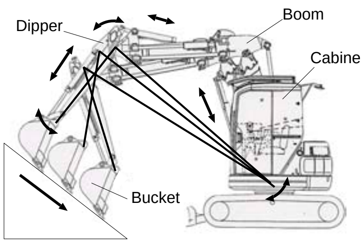

Fig. 1 Motion of the bucket in a straight path

the proposed platform, like the use of different kind of manipulators of virtual system simulators.

2. Manoeuvrability enhancement of the machines

2.1 The classical approach

At a first point, one should notice that conventional control device of hydraulic machines is corresponding to two (or more) levers directly connected to the valves that controls the pressure in each cylinders. The user controls each joints that means that each parts of the excavator separately. In other words, the user is controlling the position and orientation of the tool in joint mode. The tool control is then very difficult, because this control is not intuitive. Each lever can operate two types of command (for an excavator: right lever commands boom/bucket, and left lever commands cabin/dipper). In case of a backhoe, in order to build a slope (*Fig. 1*), the operator has to move the bucket, the dipper and the boom simultaneously. To keep the bucket in a special orientation to the ground, it is necessary to move both of the lever in a difficult gradually changing diagonal motion, in order to control the three gradually changing angles for a smooth motion. The second point is that the user have no feedback about the forces applied to his tool at the end of the arm. It has been proved that an assembly task, for instance, can usually be completed much faster when the operator has a feel for the forces and torques caused by contact [3]. And in case of a destruction of a house, in Japan, some new ecological rules constrain the civil engineering companies to separate concrete, iron, and wood from the heap of rubble. It becomes much easier to sort those materials while grinding the building than sorting them from the rubble. with a force feedback the user could know in which pile to drop what he just took out of the building.

State-of-art of solutions using robotics

This concept of using robotic field to solve the problem of the control system for hydraulic machines has been widely studied by Nakano *et al.*[1] and Lawrence *et al.*[2]. They suggest to :

- replace the system of levers by a more ergonomic and instinctive manipulator (*Fig. 2*),
- use a master/slave architecture to put intelligence between the manipulator (master) equipped by encoders on each articulations and the hydraulic arm (slave) equipped by linear encoders on each cylinders in order to control directly the tool (with different kind of control policies like position, speed,etc. in different mode like Cartesian, slope, etc.),
- make the system bilateral, in order to add a force feedback feature (need of ad-

ditional pressure sensors on the cylinders or torques sensors on the tool for the slave manipulator to have an endpoint sensing, and motors on the master to transmit force on the user's hand.

2.2 Integration of an intelligent module

In our research we introduce the concept of intelligent module between the manipulator (called master manipulator) and the hydraulic arm (called slave manipulator). This module is a computer system (with a variable complexity: one or many communicating computers), and has the following characteristics :

- It is an interface between master and slave manipulator. We need to abstract a communication layer (see section 2 Interoperability between the different components of the system)
- It owns a virtual image (geometry, specifications, current angular configuration etc.) of both master and slave manipulator, updated at each time step
- Computation capabilities as:
  - Forward, Inverse, Velocity Kinematics etc. are required to be computed for the management of the bilateral control of master and slave manipulators.
  - We need enhanced capabilities in order to let the user select different working mode to help him in his task (Cartesian, slope, pattern, etc. mode)
  - We want to display information from the master and slave manipulators
- A modular design in order to deal with several master and slave configurations and communication mediums (see section 3 advantages and applications of the proposed plate-form)

3. Interoperability between the different components of the system

The intelligent module concept allows to have different features like an easy master and slave replacement, a remote control feature, building site management, etc. . But we can see that for all of them, the intelligent module have to be able to manage communication (hardware and software) between the different parts : master manipulator/ computer system, slave manipulator / computer system, and computers inside the computer system. We need then to abstract a communication layer. In this research the idea is to :

- consider the master and the slave manipulators as two modules linked to the intelligent module. So the concept of slave module is a real (or a simulation of the) slave manipulator linked to an independent process called slave process. The master module is a real (or a simulation of the) master linked to a independent process master process. And the intelligent module is system of computers (or only one computer) where a control management process (brain process) and master and slave processes are running.

So each module have his own communication layer, that allows to have a remote control of the hydraulic machine.

- have an abstracted communication layer:
  - each components of each modules are communicating with each other using an IO manager, what ever the communication medium is: TCP/IP Ethernet based communication (can be WIFI), serial line, a bus connected to a FPGA card or a PCI card , etc.
  - the communication protocol is normalized (data packetization / unpacketization)

That allows an easy interchangeability of masters and slaves manipulators and modularity of the architecture(*Fig. 3*).

4. Advantages and applications of the proposed platform

4.1 Characteristics of the plate form

The platform characteristics are:

- Object Oriented Platform: coded in C++ language
- multi OS: the processes can be compiled to run on windows, Unix/Linux
- Modular system: the processes can be run on one or different computers

An architecture example is shown in (*Fig. 4*) The slave process is running in an embedded computer and the master and brain process are running on a remote computer. The intelligent module is then composed on two computers communicating through a wireless LAN.

4.2 Validation of the platform

Simulation system

We developed a simulation system:

- advantages: with the simulation system we can test different configuration and simulate the connection to any kind of slave or master manipulators. For example we can test the system on a hydraulic machine that does not exist like a two arms one, and plug two masters (virtual or real) to test the ergonomic of the system.
- specifications: for the dynamic calculation, the Open Dynamic Engine classes are used [4], and OpenGL for the 3D displaying [5].
- Tested master manipulators: we did successfully test a new kind of master manipulator called mono-lever, on a virtual 5 DOF Komatsu excavator, adding Cartesian, and slope mode with force reflecting.

Results

Thanks to the modular system we did test many different configurations, using a virtual master manipulator or a real one (plugged to a FPGA+sh4 connected to the intelligent module through a serial port), controlling a virtual slave. We used an intelligent module composed by one to three computers communicated with each other through the LAN. This modular system allowed us to test many characteristics like delay in the system,force feedback accuracies, ergonomic of some manipulators, etc.

5. Conclusion

This integration opens to civil engineering work, the way of teleoperation, task helping numerically control, possibility to train the worker on a simulator. It allows us to change the topology of the master/slave system by easily deports the brain in a powerful remote computer. The well known concept of Computer Integrated Manufactory can be translated to the management of building-sites.

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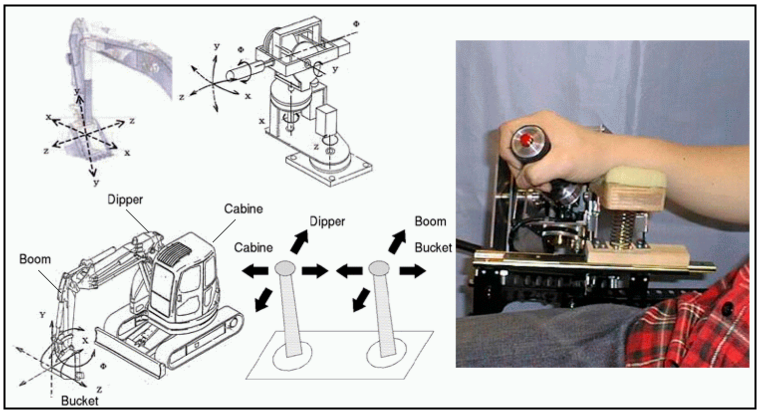

Fig. 2 Ergonomic master manipulator using Cartesian mode

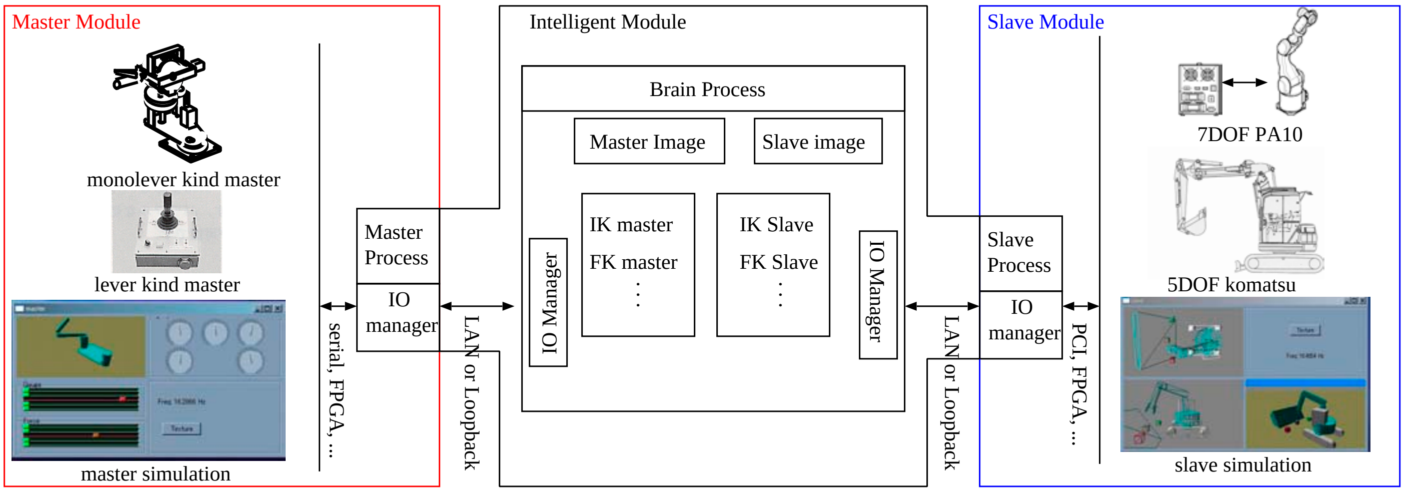

Fig. 3 Modularity of the architecture

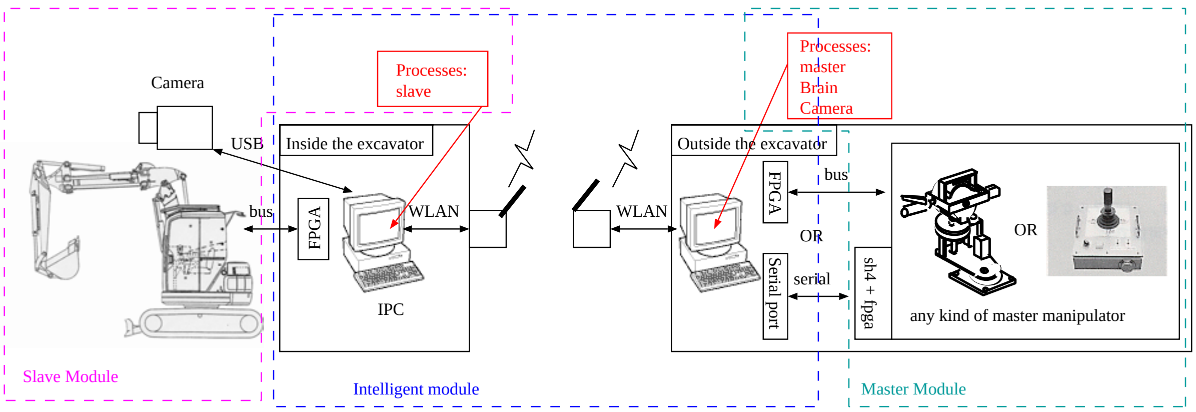

Fig. 4 Remotely controlled work