MODERN MANNED, UNMANNED AND TELEOPERATED EXCAVATOR SYSTEM

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ABSTRACT

This paper presents a re-evaluation on the modern development and practical use of manned, unmanned and teleoperated construction vehicles in universities around the world, which focuses on the use of robotized excavators. Unmanned operation is becoming synonymous in the extreme environment operation. The operation is also becoming important in order to increase working efficiency and situational awareness. The review includes the theoretical, experimental and practical applications of such technology in the present days, particularly for excavators. Various innovation and control methods have been studied over the years by various entities, which provide the significant contribution by the scientific community to the progressing world.

***KEYWORDS**: Teleoperation, Construction robot, Excavator, Backhoe*

1.0 INTRODUCTION

An excavator is a modern construction machine used for earthworks, which includes digging, leveling, grading and handling heavy loads. The hydraulically powered machine generally consists of a boom, stick, bucket and a cab on a rotating platform. A robotized excavator, which is specialized as rubble removal robot is highly recommended for dangerous post disaster recovery operation. Practical applications of such system in Japan have been brought up as case studies. The system can be operated by humans, using a remote control through tether and wireless control from a distance. Sheridan (1992) defined the various operational terms regarding human control of machines, such as supervisory control, automation and teleoperation system. Such definition will be used to relate operational control for various types of modern excavators.

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1.1 Practical Applications of Teleoperated Excavators

First practical disaster restoration using teleoperation has been tested in Japan for post volcanic and earthquake disaster applications, such as the teleoperated construction in recovery work after the disastrous eruption of Mount Unzen Fugen Dake in 1994, that rendered the island uninhabitable due to lava flows and toxic volcanic gas emission. The volcanic eruption caused a lot of damage to a large number of houses and amenities by pyroclastic and debris flows. The debris usually flows down from the volcano, typically along the river channel and was frequently spotted during the rainy season.

Therefore, the Japanese government has decided to implement a construction technique known as Sabo, which can dig and carry away safely the rubbles. Sabo work is a Japanese construction technique that involves constructions of barriers and dikes that ensures public safety from disasters debris flow. The works at the Mount Fugen was conducted using the unmanned construction system. It was remote-controlled by human operators. The operators received real-time video images, while the commands from the operators were transmitted through wireless links.

In 2000, another volcanic eruption took place at Mount Usuzan, Japan. About 400 houses destroyed or damaged after the eruption. For this reason, in order to minimize the damage, unmanned construction was introduced to prevent the mud from flowing into the city (Hiramatsu et al. 2002). It was conducted farther away from the previous experience, with challenging condition such as radio frequency interferences and bad visibility conditions, contributed by buildings, trees and harsh conditions. The restoration works due to volcanic eruptions at the Mount Unzen in 1994, and the eruption of the Mount Usu in 2000, had marked the first large-scale unmanned construction of post disaster recovery works.

Eleven years later, in March 2011, a tsunami caused by the Great East Japan Earthquake totally overpowered the operational capability of the Fukushima Daiichi nuclear power plant (Egawa et al. 2013). This leads to catastrophic blackout and nuclear meltdown. Again, it was decided that remote-controlled hydraulic excavators and dump trucks had to be called in for the crucial cleanup of debris around the site, as shown in Figure 1.

(a) (b)

Figure 1. Unmanned operation at disaster area

2.0 RESEARCH AND INNOVATION IN TELEOPERATED EXCAVATOR

Today's challenge in modern teleoperated excavator is to provide a suitable condition for human operators to operate the system efficiently and safely from a distance. Several researchers have undertaken the challenge, and more and more research results have been achieved by providing the best solutions for a better future. The review includes studies by researchers which have submitted various achievements in haptic, visual and auditory feedback and in autonomous application of teleoperated excavator application. The applications can be divided into manned excavators, unmanned excavator and teleoperated excavators.

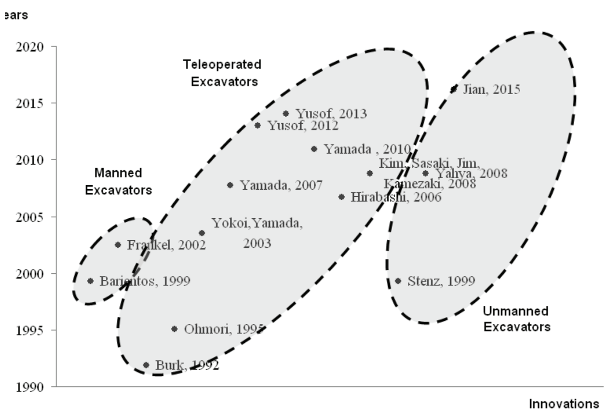
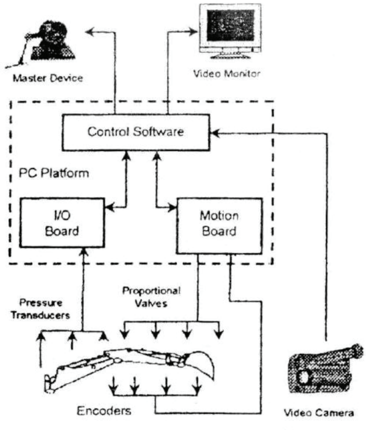


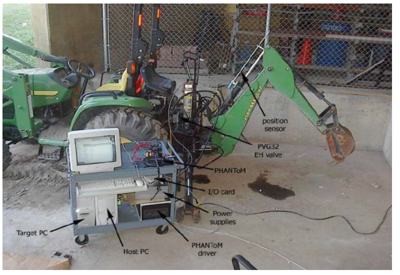
Figure 2. Three decades of innovations in modern excavators' applications

3.0 MANNED EXCAVATORS

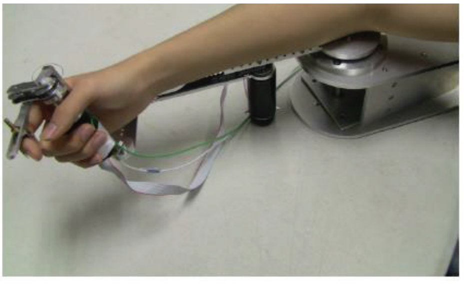
This segment introduces direct operated system, where human operator is always controlling the system on the machine itself, with extra haptic interfaces. Force feedback or haptic are always associated with improving teleoperation situational awareness. A research department of the Universidad Politecnica de Madrid had developed methods and algorithms to teleoperate a backhoe excavator with different bilateral control architectures with force feedback, as shown in Figure 3(a). (Barrientos et al. 1999). The purpose of the project is to provide to the operator an easy way to do the work. A simple, but repetitive task can provide a condition where the operator feels tired, which will reduce efficiency and safety awareness. In order to avoid this, artificial intelligence techniques have been used to provide some kind of supervisory control. Basically, it consists in the automation of some repetitive tasks such as digging holes and trenches. The automation is accomplished through the learning process on how the operator does the task. In order to achieve good results with the learning, fuzzy logic and neural networks have been used. Later, Frankel (2002) developed a test rig for haptic studies by using a small backhoe. Figure 3(b) shows a test rig with the use of haptic user interface as the master haptic input devices. It is capable of three degrees of freedom force feedback and six degrees of freedom positional sensing. Electro-hydraulic valves and magneto-restrictive position sensors are mounted to the backhoe. The control system is conducted by using Matlab. The arm is attached to valves that is mounted with position sensors and controlled by the haptic interface to accomplish the setup. The test rig is able to detect underground obstacles and avoid the damage. Although not equipped with remote-controlled ability, the system is able to reduce operator training time and enhance the digging accuracy. Other development involves the newly designed haptic device, (Dongnam et al. 2010) where it is used to control excavators, as shown in Figure 3(c). The system uses pressure transmitter to estimate the related forces in the system.



(a)



(b)



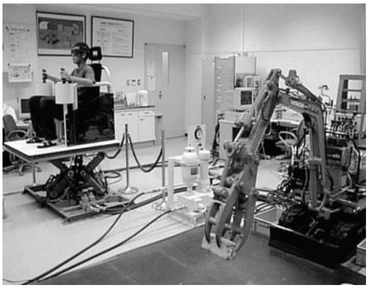
(c)

Figure 3. Haptic development for manned excavators (a) Backhoe excavator with different force feedback bilateral control architectures (b) Haptic small backhoe (c) Newly design haptic device for excavator

4.0 TELEOPERATED EXCAVATORS

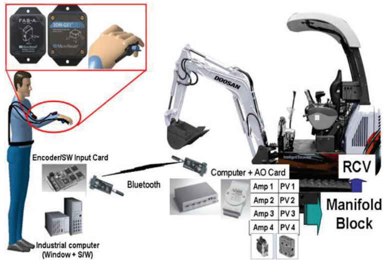
Teleoperated excavators involve a method to control excavators from some distance away. Burks et al. (1992) had focused on developing a teleoperated excavator for military applications as shown in Figure 4.

(a)



(b)

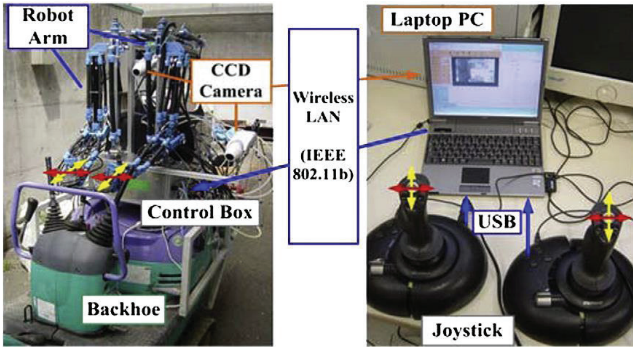
(c)



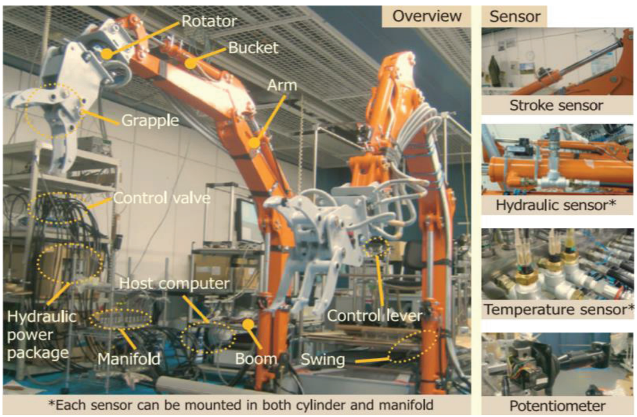
(d)

Figure 4. Teleoperated excavators (a) Teleoperated excavator for unexploded ordnance retrieval. (b) Teleoperated excavator with telegrasping performance (c) Underwater teleoperated excavator (d) Newly design arm controlled teleoperate excavator.

The study aims at using the excavator, in retrieving unexploded ordnance or radioactive waste. The result of the experiment provided both feasibility and human factors data that will be used to evaluate the design and potential applications of the teleoperation. The spontaneous hand controller coupled with the GUI reduces the difficult task and hours of training. The demonstration showed that the system is suitable for Explosive Ordnance Disposal (EOD) operations. The remote operation reduces productivity losses due to teleoperation. In 1994, Ohmori and Mano introduced the concept of master-subordinate-slave tele-earthwork system, which replace human operator by the use of a teleoperation system known as RoboQ. In 2003, Yokoi et al had developed a master-slave system which used humanoid robot to operate and control a backhoe. A field test had demonstrated the humanoid robot's ability to replace the human operator in excavation duties on a backhoe. The humanoid robots were capable of moving in the same manner as humans. Teleoperation involving telegrasping sensory perception, which is based on a master-slave teleoperation of a grapple-attached mini excavator, has been carried out by a group of researchers in Gifu University, Japan. (Yamada, et al. 2003). Test rig for a force feedback teleoperated robot has been set up, comprising of a joystick as the master and a mini excavator as the slave, as shown in Figure 4(b).



(a)



(b)

Figure 5. Specialized teleoperated excavator (a) Teleoperation using specialized robot arm on an excavator (b) Dual-arm excavator system

The operators use force feedback joystick to operate the grapple. The proposed control system significantly improved slow grasping of a soft object by improving the sense of grasping through force feedback application. (Yamada, et al. 2007). Such control requires the use of pressure and displacement sensors to be attached to the mini excavator. The research was verified by experiments and simulations, to confirm the validity of the control system. Yusof et al. (2012a) later conducted studies on operator sensitivity to various modalities, where the perception of the operator for each type of feedback was evaluated by using common 2D, 3D and virtual visual feedback. Precision grasping was also being tested by using auditory feedback, along with force feedback. (Yusof, et al. 2012b), (Yamada, et al. 2010).

In another development, Hirabayashi et al. (2006) from the University of Tsukuba had focused on developing a teleoperated excavator for underwater applications, as shown in Figure 4(c). The study also aims at visualizing 3-D images for leveling works. A land-based test rig of underwater teleoperated excavator has been developed by reconstructing a conventional excavator with a 0.09 cubic meter bucket. The operator is placed in a control room where the only visual information given to operate the excavator is the visualized haptic image on the computer screen. The result of the experiment was evaluated by the difference between ordered height and actual height. This was verified with the accuracy of leveling is sufficient for the practical leveling work. Kim et al. (2008) proposed an interesting study of controlling an excavator using the movement of the human arm, as shown in Figure 4(d). This research uses sensors mounted on the operator arm, which is used to control the movement and manipulation operation of the excavator. The proposed system enables the operator to control the excavator effectively, with respect to the conventional haptic devices. The developed system shows a good result and that efficient manipulation of the excavator is possible by using visual feedback from the operator. Sasaki and Kawashima, (2008) developed a remote-controlled pneumatic robotic system which can replace a human operator. Figure 5(a) shows the pneumatic robotic systems, which were actuated by pneumatic rubber muscles known as (PARM). The effectiveness of the remote-controlled operations conducted at local construction sites has been determined by the increase in working efficiency of more than 50% compared to the direct operation of the excavator. The same concept was studied by Yusof et al. (2014), by using a teleoperated electro-hydraulic actuator, equipped with 2.4GHz remote-control system.

In South Korea, Jin et al. (2008), from University of Ulsan developed a master-slave teleoperated excavator by using electro-proportional pressure valve as the slave, and advanced programming for controls. In another development, Kamezaki et al. (2008) from Waseda University had studied a concept of dual-arm double front construction machinery system, as shown in Figure 5(b). The test rig has two manipulators with a grasping mechanism, with 6 degrees of freedom, each including five single-rod hydraulic cylinders and one hydraulic motor. Two control levers are used to provide command to the valves. A hydraulic power unit containing an axial piston pump and oil tank and multiple closed-center pressure-compensated valves are used in providing power supply and control to the system. Skillful human action may require operators to obtain sophisticated operational skill. In the study, a simulator has been design in order to provide the necessary learning technique to control the dual-arm excavator system.

5.0 UNMANNED EXCAVATORS

Unmanned excavator refers to the operation of machine without direct human control operation. In this case, the system has been demonstrated by Stenz et. al (1999), as shown in Figure 6. The system is the first fully autonomous loading system for excavators which are capable of loading trucks with soft material at the speed of an expert human operator. The test rig setup involved two scanning laser rangefinders which recognizes the truck, measures the soil on the dig face and in the truck, and detects obstacles in the workspace. The sensors help the excavator to modify both its digging and dumping plans based on settlement of soil. In another study, Yahya (2008) proposed the concept of parameter identification, as a key requirement in the field of automated control of unmanned excavators. Three identification methods, the Newton-Raphson method, the generalized Newton method, and the least squares method are used and compared for prediction accuracy, robustness to noise and computational speed. Latest research includes a surfacing method by Jian et. al (2015), where the operation function is modeled through analysis of operation process and kinematics trajectory of the relieving tool. Modeling of the operation function will promote the application of the unmanned excavator and supply experience for advanced control of other unmanned construction machines.

Figure 6. Autonomous excavator with sensors mounted for unmanned operation

6.0 CONCLUSIONS

Classification of advanced manned, unmanned and teleoperated excavator has been evaluated. Each class requires attention to various feedback and control elements. Modern manned excavators explore the use of force feedback or haptic to increase situational awareness of the operator. A significant finding of the experiment shows that operators with no experience in manual operation of the vehicle were able to accomplish the assigned task easily with very little instruction. Studies also show that in modern teleoperated excavators, the use of haptic or force feedback, auditory feedback and visual feedback improve sensory perception. The use of 2D, 3D and even virtual reality display in visual feedback display also helps in improving human operator performance. This concept is already proven for tethered operation. Finally, the use of autonomous system for a fully automatic control during excavation processes reduces the burden of operation. A robust parameter identification scheme is required for field applications. The unmanned excavators also requires advanced modeling and control algorithm.

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