# NEW CAPABILITY FOR REMOTE CONTROLLED EXCAVATION

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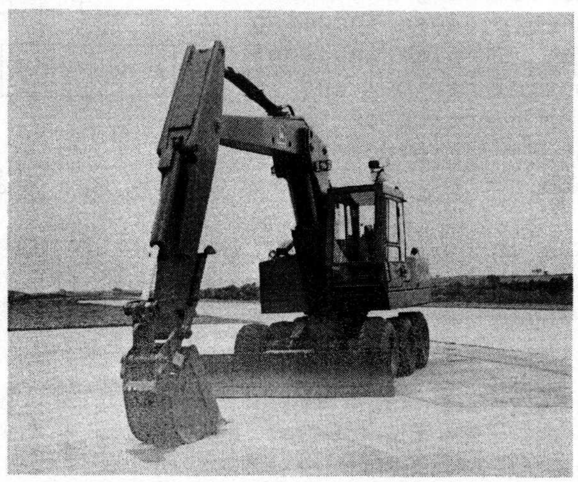
## ABSTRACT

Remote controlled operation of construction equipment has been state-of-the-art for some years. The availability of remote controls which have been designed and developed for general use on commercial machines is a recent development that is the subject of this paper. The John Deere teleoperated excavator represents a new capability that is now available to the construction industry for use on construction sites that preclude the on-site presence of human operators. This paper will describe the basic machine, the controls, vision system and integration of the remote control adjunct to the operational system. Much of the development of the initial capability was done with the cooperation of Vectran Corporation of Pittsburgh, Pennsylvania.

## 1.0 THE BASE MACHINE

The John Deere 690 Excavator is a commercially available production machine. The first teleoperated unit was fielded on this variant (Figure 1). The base machine is a 41,000 lb. excavator, modified for the Air Force to include a wheeled undercarriage, a dozer blade, stabilizers, a hardening package and variable boom geometry. The 690CR and now the 690DR are the mainstay of the Air Force rapid runway repair fleet. The machine has 125 net horsepower, 31 ft. reach and 20 ft. dig depth. It is supplied to the Air Force with a bucket, hydraulic breaker and tamper that enable it to perform the functions needed in repair of craters on damaged runways. The repair of runways is currently a manned operation. However, the Air Force needed an additional unmanned capability to deal



John Deere 690CR Excavator - Figure 1

with unexploded bombs at the Eglin AFB test range. This capability was provided by the Teleoperated Remote Controlled Excavator (TORCE).

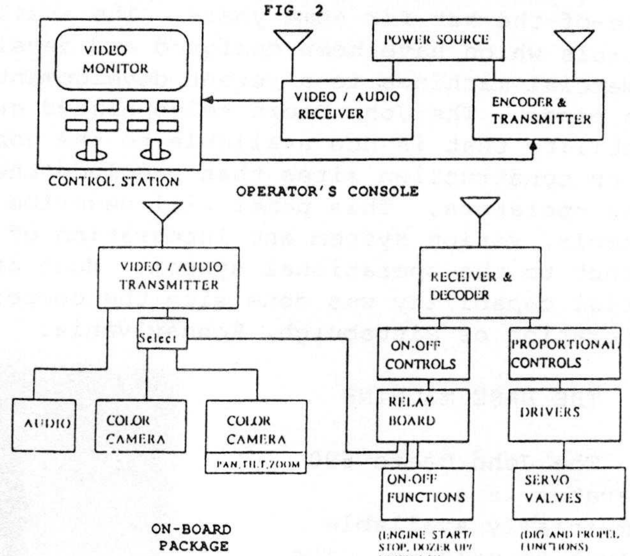
The TORCE excavator will transport and perform all work functions from a distance of 5,000 ft. on radio command and 1,000 ft. on coaxial cable. The Air Force has used this machine with success since its delivery in March 1987. The conversion of the base machine to remote controlled operation involved the integration of servo hydraulic controls, vision and audio feedback, remote operator's station, and data links.

## 2.0 ELECTRONICS

The remote adjunct has three basic subsystems. The simplified block diagram shows the operator's console, the on-board package and the data link (Figure 2). The console includes the video monitor and audio/video receivers and the decoding electronics needed to process incoming signals. It also includes the control devices and encoding electronics to generate and broadcast commands.

690 REMOTE CONTROL BLOCK DIAGRAM

FIG. 2

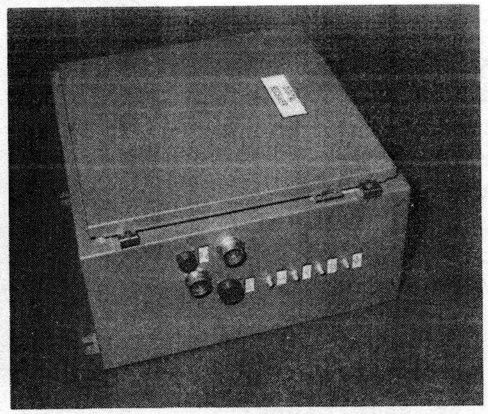



The on-board package receives incoming commands and converts them to electrical signals for valve and camera control. It also processes video and audio data and sends these out to the operator.

The remaining element is the link that joins the on-board electronics to the operator's console. This data link can be a coaxial cable, radio waves or optic fiber.

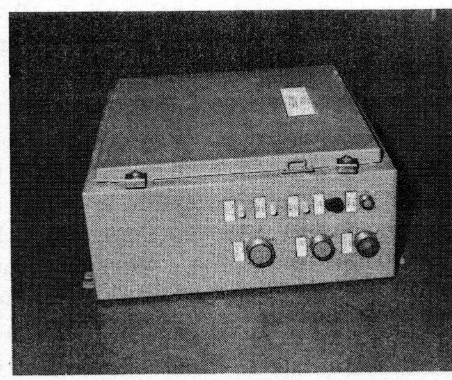
The 690C on-board package consists of two separate subsystems for the present version (Figures 3 and 4). The digital receiver package provides the functional interface with the machine while the video transmitter provides the sensory feedback data.

This environmentally sealed container (Figure 3) is mounted on the rotating house of the excavator. The system includes two receivers capable of 9600 baud. Its function is to receive a data string of digitally encoded commands on RS232, decode and interpret the command signals, then relay them to hydraulic servos and actuators. The relayed commands are analog signals that provide proportional control capability to the boom, arm, bucket, swing and transport hydraulics. This unit also generates signals that command discrete functions for engine stop/start, high/low speed select, blade up/down, engine speed, road speed, auxiliary tool, stabilizers, and bucket clamp. Fail-safe sensors in this unit will shut down the engine in the event that clear commands are not received.



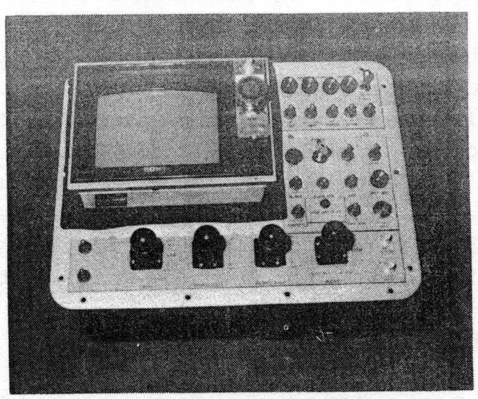
Digital Receiver - Figure 3

This second container is similar in size and shape to the first (Figure 4). Its function is to code and transmit video and audio data from the machine to the operator and to control the power pan/tilt/zoom functions of the roof mounted camera. This unit is also environmentally sealed and mounted on the rotating house.



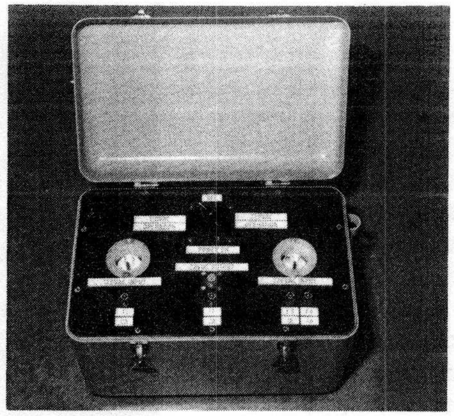
Video Transmitter - Figure 4

The operator's console is designed for adverse weather and handling (Figure 5). It weighs under 50 lbs. and can be accompanied by a



Operator's Console - Figure 5

battery pack (Figure 6) for 8 hours of isolated continuous operation. The 8 inch monitor provides viewing from either the fender mount or roof mount camera. A camera select switch, pan/tilt/zoom and manual iris override controls are mounted on the panel. The 4 joysticks are operated in the same manner as the cab mounted controls. This feature maintains the continuity of similarity with the cab and aids the operator in quick and errorless operation of all machine functions. The console can be operated from a 60Hz 110 volt source or the batteries can be charged from that source.



Battery Pack - Figure 6

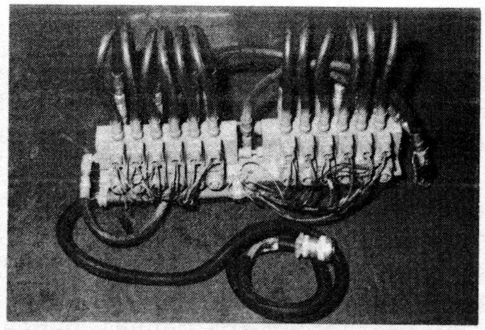
The RF data link has a 5,000 ft. range operating at 5 watts on the command link and 10 watts on the video. The Air Force system operates in the UHF frequency band with 12 Khz bandwidth on the command link and 6 Mhz on the video link. RF communications continue to be a problem in the United States and abroad due to the heavy demand for military and commercial use of the air waves. Video transmission, which is essential to remote operation, requires wide bandwidths which are increasingly difficult to obtain from the Federal Communications Commission (FCC). The ideal frequency range for teleoperation lies in the low end of the spectrum to achieve omni directional flexibility and maximum penetration of interposed ground features. The frequencies, however, tend to be preallocated or available only in narrow bands. One solution to the dilemma is to operate at higher frequencies and adapt to the limitations. Deere has addressed this issue as noted in the following paragraphs.

The heavy duty coaxial cable is provided for teleoperation with standoff distances up to 1,000 ft. This secondary data link enables fast response to areas where the RF link is not approved or appropriate. It may also be used on occasions where the suspect hazardous materials may be affected by RF energy or in locations where the RF transmission is blocked by geological features or metal structures. The cable was provided in coil form on the first unit for manual payout.

## 3.0 VALVES

John Deere 690 excavators are equipped with pilot operated hydraulic valves. The remote control system is superimposed on the pilot pressure system with this valve manifold assembly

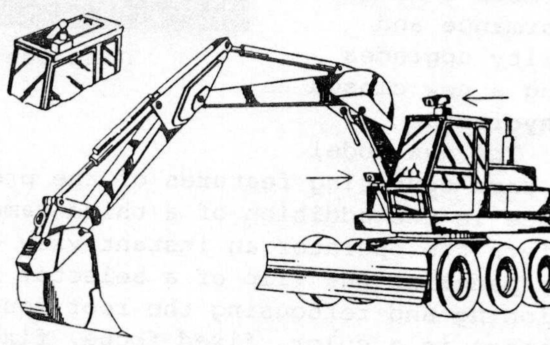
(Figure 7). Proportional functions are controlled through commercially available servo valves while the discrete functions apply solenoid valves. The remote control valve assembly is designed and integrated to be transparent to an operator seated in the cab who has the machine under manual control. Electro-mechanical actuators are mounted on engine fuel control and speed selector controls also in a way that does not interfere with manned operation.



Electrohydraulic Valves - Figure 7

4.0 VISION

Vision is provided to the remote operator with two cameras on the 690C model. The first camera is fixed focus auto iris, fixed but manually variable mount, located on the front right side. The camera has a wide angle lens directed to the area swept by the excavator linkage (Figure 8). Experience has shown this to be an essential view for remote operator inspection of details in the work area. The camera is color as is the roof mounted camera. This camera has power pan/tilt/zoom with auto iris. Additional manual iris override permits adjustment for improved vision in dark excavations. The roof mount with remote controlled aiming and zoom results in a narrower field of view with full operator discretion of the viewing target. It also provides visual operating feedback when manipulated to look through the cab roof at the instrument panel. This is a patented feature of the John Deere TORCE 690C. The sensory feedback includes an in-cab microphone which transmits operating system audible warnings and engine and hydraulic system operating sound levels. This audio feedback is a valuable link of operator to machine as he seeks to optimize performance by loading the engine and hydraulics to capacity without creating stall or relief valve opening. The antennae that are needed to receive command signals and transmit sensory data are mounted on the cab roof.



Cameras - Figure 8

5.0 MOUNTING

Modifications to the production excavator are needed to provide mounting points for the on-board hardware and electromechanical actuators. These brackets and components are designed to be mounted in less than 8 manhours using only simple tools. They also provide for on-board storage of the operator's console. The design for superposition of the teleoperation subsystems over the existing manual systems gives the user the option of removing the remote control components for storage during long-term manual operation or moving the remote control capability to any similar excavator equipped with an adaptor kit. We expect this feature to be particularly valuable to commercial users who may have multiple machines at widely separated sites.

6.0 THE PRODUCT IMPROVEMENT UPGRADE

John Deere 690D - Figure 9

John Deere has introduced the next evolution of the 690 excavator called the 690D (Figure 9). It incorporates a number of performance and reliability upgrades including a new closed center hydraulic system. The new model has the same operating features of the previous model. A major difference is the addition of a third camera inside the cab. This offers the operator an instant view of his machine instrument panel at the flip of a selector switch rather than repositioning and refocusing the roof mounted camera. The third camera is a color, fixed focus, fixed mount unit.

Another major change is the upgraded on-board electronics package which includes miniaturized relays and compact circuitry. This eliminates one of the sealed on-board containers. The reduction in package size and weight simplifies the mounting design and results in location which is more immune to the rigors of construction machine environment. The new operator's console will incorporate an 8 inch monitor and sufficient electrical power to complete 8 hours of operation.

Finally, the RF data link is being modified to operate partially in the microwave frequency regime. This change has the advantage that FCC approval is more easily obtained. The wide bandwidth is more readily available at microwave frequencies and therefore more appropriate for commercial uses.

The disadvantages of operating at these high frequencies is the requirement for line-of-sight communication between the sending and receiving antennae. Our present experience has shown this to be a nonproblem for the ordnance disposal and cleanup tasks that have been accomplished to the present time. Commercial uses, presently envisioned, should be equally insensitive to broadcast frequencies. The RF link that is now in development has the added feature of selected bands within the available frequency range. This enables control of up to 5 systems simultaneously at the same site. Control of multiple units from the same console is an option if only one machine is being worked at any given time. If multiple machines are in operation, then multiple consoles would be required.

The hardwire data link is also being upgraded with the addition of a cable reel that will simplify the payout/retrieve task for the coaxial cable. Fiber optic links have not been ordered up to this time, but they are also readily adapted to the system. The advantages of fiber optic links lies in their resistance to electromagnetic interference which particularly concerns the military.

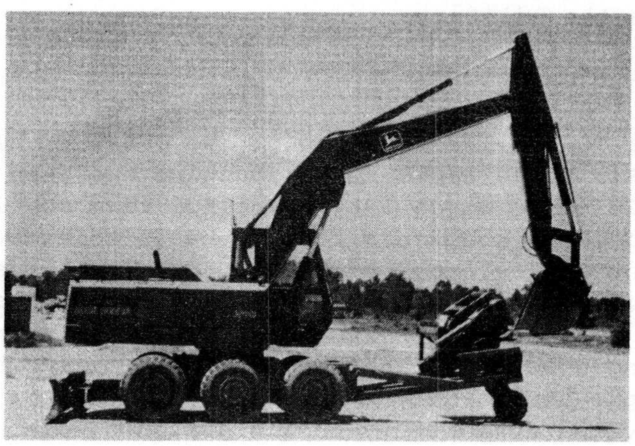
## 7.0 FIELD EXPERIENCE

The TORCE 1, adaptation of the JD690CR wheeled excavator to the Air Force rapid runway machine has been in operation at Eglin AFB since March 1987. The EOD team stationed at Eglin has used the system on a routine basis to excavate unexploded munitions and recover them for inspection. Their objective is to retrieve live pretriggered explosive devices intact for failure analysis while remaining safe from harm. The EOD team has changed personnel through the period, but has found that new people are readily trained. The excavator has functioned reliably and effectively in its assigned role.

The Eglin EOD team with its remote excavation capability was enlisted in the summer of 1987 to evaluate its use in cleanup activities at the Milan, Tennessee Army Ammunition Plant. Since its opening in 1941, the plant has buried a variety of explosives and obsolete munitions in trenches around the area. The exact location and contents of the burial sites were unknown, but the Corps of Engineers is concerned about ground water contamination and identification of the buried materials. The Corps of Engineers engaged the Eglin team to remotely excavate 55 sites. At the conclusion of the operation, the team had excavated 64 sites to an average depth of 18 ft. in 84 machine hours or about half of the time originally scheduled to complete the project. It had recovered over 300 items of ordnance and provided soil samples for analysis. The engineer in charge of the project estimated that 30 to 40% cost savings could be realized using remote controlled excavation as compared to using manned excavators. Onboard operators at hazardous sites could be required to wear fully encapsulated life support systems and then for only short working intervals. The reduced capacity, downtime and multiple crews needed to support a single excavation are all unnecessary with remote control. It was also noted that the Milan task was only a survey, that real cleanup work was yet to be done and that there are 12 other similar plants in the United States. Clearly, remote controlled excavation is here to stay.

## 8.0 THE FUTURE

Tyndall AFB is concerned with rapid runway repair and with the availability of trained personnel to operate repair machines as the time to repair becomes more critical. The Engineering and Services Laboratory initiated a program that was headed toward full automation of the runway repair process. The first task in the program was to provide automatic tool change. Deere, University of Florida and Westinghouse worked with the Air Force to produce the machine shown here (Figure 10). With the added expertise of BDM, the system can now change tools, dig trenches, dig pie-shaped or circular holes, level blade, tamp and break concrete all automatically by calling up the desired task on a computer menu. The operator need not be on board while the machine is working. This particular machine is a proof-of-concept system and normally prone to the reliability problems that engineers and laboratory technicians often find in prototypes. The manager of R&D systems at the AFESC has reported that the machine has logged 780 hours of operation with the sensors and computers on board.



Air Force Automatic Excavator - Figure 10

Where do we go from here? It is possible to remove operators from construction machinery cabs. It is certainly a necessary thing in operations like the Milan ammo plant and any job where hazardous materials or dangerous conditions are likely to exist. Whether or not it becomes commonplace in day to day construction work depends on its cost effectiveness. Can a contractor achieve a return on his investment by replacing manpower with computer power? Today, the answer is yes only when conditions exclude human beings. Tomorrow's answer will depend on the cost of labor and on the availability of low cost electronics.