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TECHNOLOGICAL INTERVENTION TO ELIMINATE DEATHS DURING PIPE-INSTALLATION

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ABSTRACT

Even though diverse support systems such as shoring, shielding, and sloping are to be applied to protect workers from cave-ins in trench excavating and pipe laying operations, accidents still happen. Tele-operation, which enables the control of a mechanical device from a safe distance provides a technical alternative making OSHA regulations non-applicable. This paper will present two remotely controlled manipulators able to install large and small pipes. Because of the need to be competitive on every project-bid, contractors have to be assured that new technologies not only work in the rugged environment of a construction site but that they also reduce cost. Not having to observe OSHA regulation results in many cost savings such as a reduction in excavation volume, less material to be backfilled and compacted, and a reduction in man-hours. The paper will discuss not only the technologies that were integrated into the system but also show the use of the system in the construction environment.

KEYWORDS

tele-robotics, construction safety, confined space, excavation, pipe-laying, innovation, technology, tele-operation, cave-ins

INTRODUCTION AND BACKGROUND

The traditional ways to prevent trench cave-ins are: 1) providing physical supports for each side of the trench, or 2) sloping the sides to a safe angle. Even though diverse support systems such as shoring, shielding, and sloping are to be applied during trench excavating and pipe laying operations, accidents still occur resulting in deaths or serious injuries to workers. Table 1 compares the trenching cave-in fatalities in different construction industry sectors showing that overall the construction industry has a staggering number of 54 deaths per year.

Table 1: *Excavation and Trenching Fatalities, by Industry – US, 1992-2001 (CDC, 2004)*

INDUSTRY	No.	%
Excavation Work	141	26.0
Water, sewer, pipeline, communication and power-line construction	131	24.2
Plumbing, heating, and air conditioning	59	10.9
Heavy construction	27	5.0
General contractors, single family homes	19	3.5
Heavy Highway	16	2.9

General Construction – nonresidential, other than industrial buildings	14	2.6
All other industries	135	24.9
TOTAL	**542**	**100.0**

Not accounted for, of course, are the injuries or near-fatalities that account to approximately 1,000 work-related injuries each year and an average of 140 permanent disabilities.

OSHA (Occupational Safety and Hazard Administration) observes regularly that some common causes of trench accidents include non-compliance with existing regulations because employers are either (1) unaware of the existence of the OSHA standards or (2) misinterpreting the requirements of the standards as regards exemptions based on characteristics of the soil. The following three pictures demonstrate that the dangers are many and come from many different "directions".

a) No Protection Installed **b) Slope Collapse After Pipe Bursts** **c) Trenchbox Stays Unused**

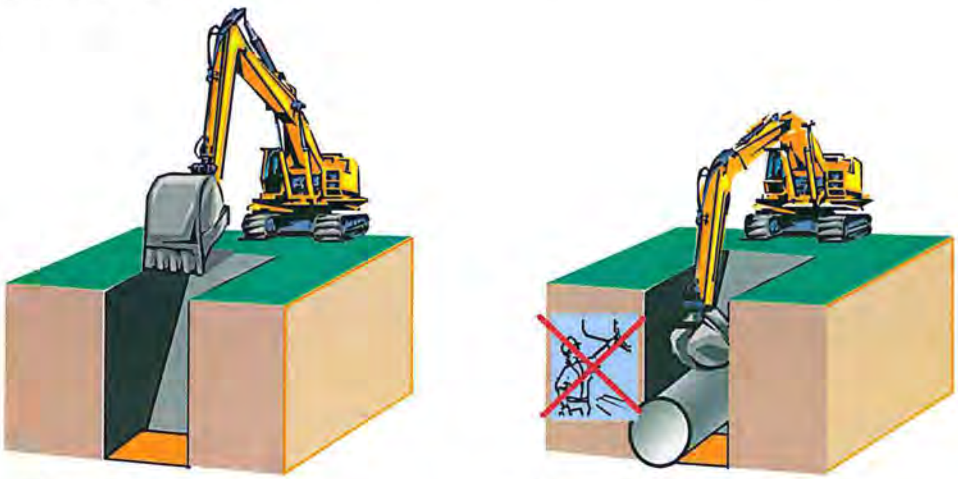
Figure 1: *Omnipresent Dangers Having Deadly Consequences when Overlooked*

Figure 1 a) shows that committed laborers are willing to work in situations that makes the trained engineer shudder. Figure 1 b) depicts the moment when the slope above the trenchbox, previously weakened by a pipe burst, fell into the trench killing one worker who stayed a second too long. Figure 1 c) represents a case in which a backhoe operator did not use the trenchbox, although it was available, to install a short pipe connection. One young worker was killed by a cave-in.

It is apparent that as long as humans have to enter the confined space of a trench they will be exposed to many different hazards. As the tally of accidents shows, even the various protective measures, including training, are able to reduce, but not eliminate the number of accidents. One approach, albeit drastic, is to find a way to eliminate the need for humans to be inside the trench at any time of the process. The technological intervention that could accomplish this change is a system that is able to install a pipe element according to accepted standards.

Figure 2 displays an approach in which a backhoe excavator not only digs a trench but, without needing an assistant, also transports and joints a pipe element to the previously installed pipe.

The presented scenario would require that the backhoe, one of the most commonly found pieces of equipment on a construction site, has to be turned into a device that allows the operator to perform the difficult tasks remotely. A technological concept that encompasses the necessary tools is called tele-robotics.



a) Trenching b) Remote Pipe-Installation

Figure 2: *A Tele-Robotic Approach to Pipe-Installation*

Tele-Robotic Manipulation

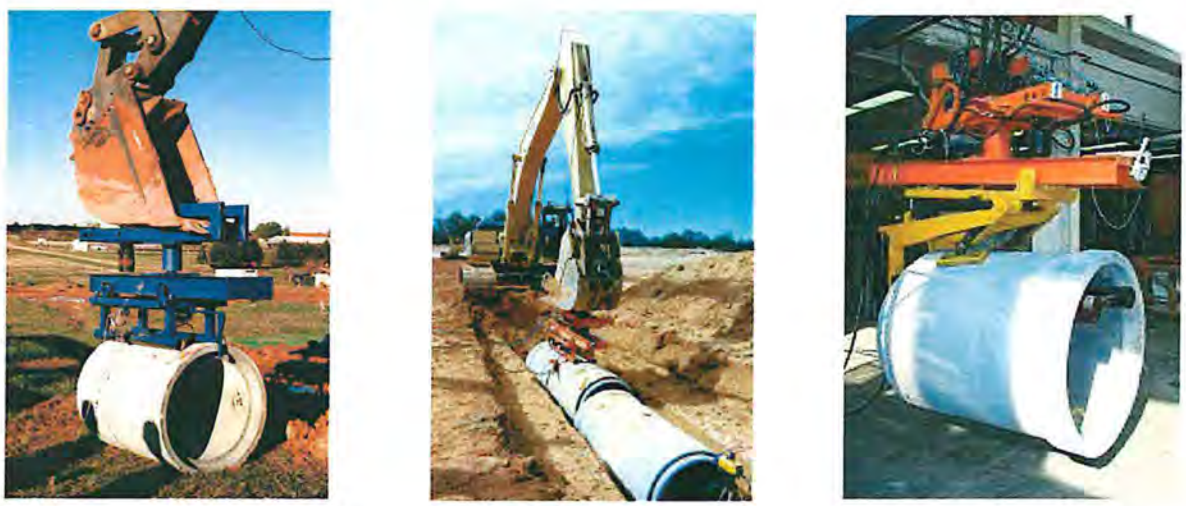
Tele-robotic systems, an advanced form of tele-operators, are mechanical devices that combine human and machine intelligence to perform tasks remotely with the assistance of various sensors, computers, man-machine interface devices, and electronic controls. A tele-robotic task may be passive (e.g., remote controlled by a human) or active (e.g., controlled by its own intelligence). The applications of tele-robots in industry can be classified according to environment, size, and task. Applications of this technology can be found: a) doing dangerous jobs (e.g., mine detection and clearing, handling toxic waste, and surveillance), b) work underwater (e.g., seafloor mapping and searching), c) airborne flight (e.g., reconnaissance), d) in space (e.g., space station or satellite services). The size of such devices may vary from a micro scale (e.g., for intravenous operations) to a human scale (e.g., for fire fighting) or even a large "structure" (e.g., mining draglines).

PROTOTYPING SAFE PIPE-LAYING TECHNOLOGIES

Backhoe excavators use electro-hydraulic controls to activate hydraulic valves which in turn actuate linear cylinders and motors. The operator uses joysticks with small hand motions resulting in large forces that push the bucket through the soil or lift heavy objects, such as concrete pipes. Common extensions are quick-couplers to exchange buckets and an extra hydraulic line leading to the end of the arm that can be used to power an extra tool, such as a hydraulic hammer. The closed system design makes it difficult to integrate additional electronic systems required to operate tele-robotic devices. As a result, it was decided to find an attachment-based solution.

Tele-Robotic Installation of Large Concrete Pipes

One device that was able to handle large pipes was designed and fabricated in 1994. Figure 3 presents an overview of the major advancements of the PipeMan (short for Pipe Manipulator) that were made after intermittent field tests. Changes included modifications of hardware and the addition of wireless controls (Bernold and Li, 2004).



a) First Prototype PipeMan b) Second Generation in Field Test c) Third Generation

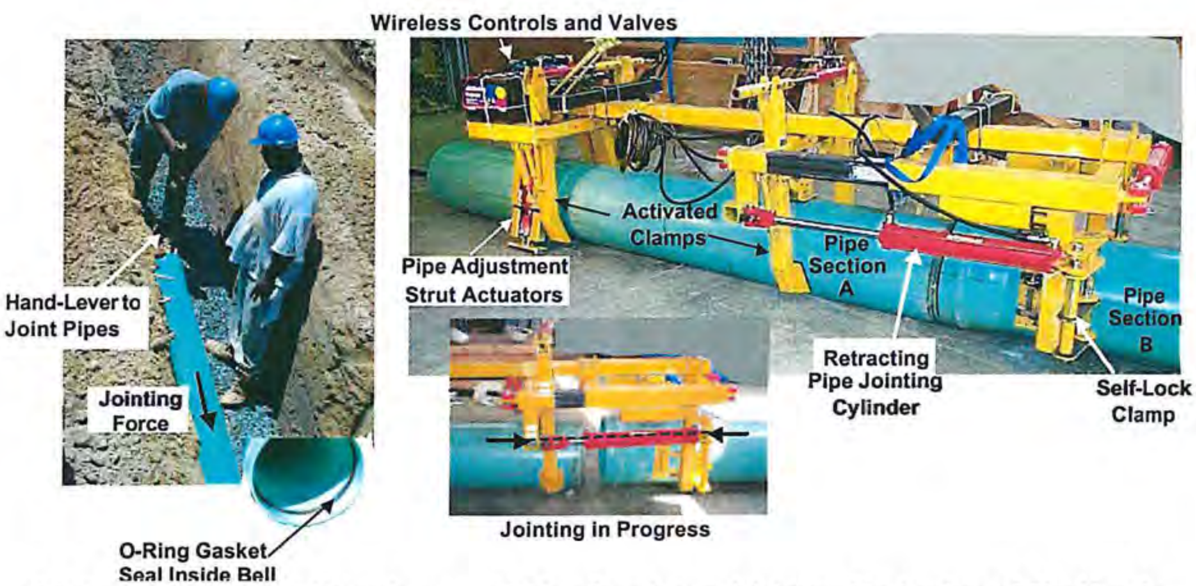
Figure 3: *Three Generations of PipeMan Prototypes*

As indicated in Figure 3 b), an extensive field-test was conducted in 1999 in which field personnel was laying 9 concrete pipes the traditional way during one day, and 9 concrete pipes using the PipeMan on the following day. The question "Will it work?" was quickly replaced with "How well does it work?" Fortunately, the operators, pipe-layers, and helpers accepted the new technology whole-heartedly even participating in brainstorming for substitutions for a broken winch, and took expert control of the hardware. They felt that the most important role of the manipulator was in protecting their lives by eliminating their hazardous stay in the trench.
The average cycle time spent for laying one piece of pipe with the PipeMan was 9 minute 6 second (576 seconds), whereas it took only 2.2 minutes with the conventional method. (Lee et

al., 2003) The use of a chain to replace the broken winch added approximately 5 minutes of time that was regarded as wasted time. For the third generation PipeMan, exhibited in Figure 3 c), the winch and cable approach to fastening the pipe to the carriage was substituted with a fork and clamp system. Moving to this mechanism reduced the cycle time to 3.6 min. Moreover, a crew of three is able to perform the installation instead of the conventional five, which drastically increases productivity. The productivity, measured in meters of installed pipe per man-hour, with a traditional five member crew is 1.9 m/man-hr and 4.2 m/man-hr for the Pipeman with three member crew. It is estimated that the daily production of the Pipeman would be approximately 70 pieces of 8 ft (2.4 m) pipes if laid consecutively into an open trench.

Tele-Robotic Installation of Small Pipes With O-Ring Seals

Creating tight joint seals is a priority for the installation of sewer pipes made of clay, cast iron, or PVC. One non-mechanical method of installation uses a single- or double O-ring type gasket and is referred to as the push-on-joint type seal. It has to provide an adequate compressive force against the sealing surfaces of the bell and spigot so as to effect a positive seal under all combinations of the joint tolerances. The gaskets are commonly installed inside the bell, as shown in Figure 4 a), into which the spigot end of the connecting pipe has to be pushed. To reduce the significant friction forces between the gasket and the spigot, both ends are covered with an appropriate compound just before joining or jointing the two pieces. Also depicted in Figure 4 a) is one method to produce the necessary normal force, a steel lever forced into the ground at one end and pressed against the end of the pipe

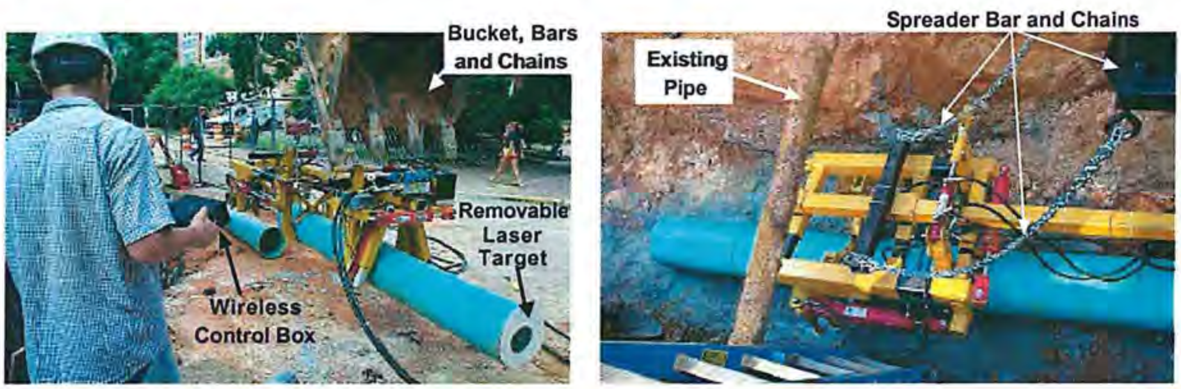


a) Laborer Joints Pipes Using Lever **b) Pipe Carrying and Jointing Mechanism of PipeMan Jr.**

Figure 4: Substitution of Human Jointing Operation with a Mechanical Approach

Because of the requirement to apply significant normal forces during jointing, the "push" approach of PipeMan was impractical. Furthermore, the pipes are much smaller and thus lighter while, at the same time, longer than concrete drainage pipes. For these reasons, a new device was developed and built, named PipeMan Jr. From the overview presented in Figure 4 b) one sees that the device consists of four main components: a) Two active clamps holding the pipe segment to be installed, b) wireless control interface, including live video, to operate the hydraulic valves, c) jointing mechanism with self-lock clamp, and d) struts that allow the operator to adjust the position of the pipe-end in the x and z directions. As will be discussed later the latter capability is critical in aligning the pipe to the laser beam used to achieve the necessary accuracy in line and grade.

Similar to PipeMan Sr. the tele-robotic system was brought into the field for testing, each time leading to new modifications. Figure 5 highlights two phases with increasingly more difficult test environments.



a) Weakness of the Wireless Video was Detected b) Line & Grade Laser was Poorly Integrated

Figure 5: *Field Tests of PipeMan Jr. Highlight Weaknesses*

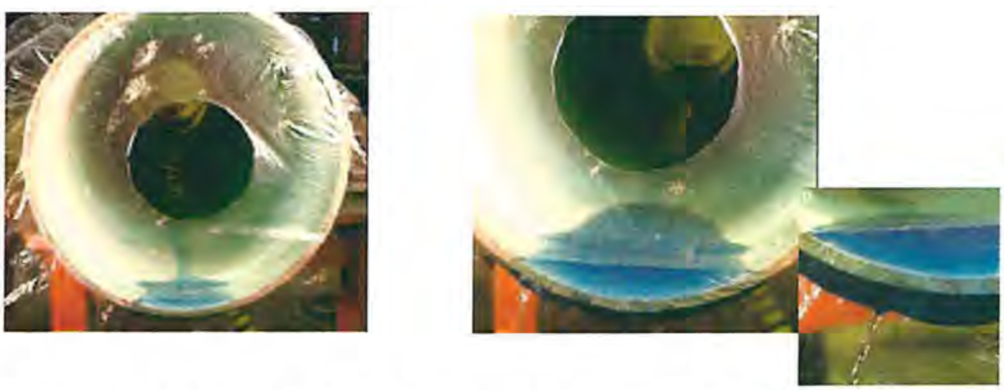
While the mechanical system can be tested in the laboratory, most other components have to face the real environment before the system can be considered ready for use. For example, Figure 5 a) confirmed that the wireless control interface, operated by Dr. Li, worked properly and that the concept of the removable laser target was sound. As the picture shows, PipeMan Jr., suspended from spreader bars on the backhoe bucket, was easily guided into place by the operator. On the other hand, the laser beam on the target was impossible to see, the wireless video was extremely unreliable (e.g., easily disturbed pictures), and the selected black and white monitor provided hard to recognize pictures (when the camera was working). While these weaknesses were immediately remedied with a new camera, wireless interface, flat-screen monitor, and a target prism, new problems showed up when the system was tested inside a real trench. Although it showed enough flexibility to maneuver around existing pipes, the gravel of the bedding and the installation of the laser created significant problems. The following will present how simple issues solved by hand are able to create "show-stoppers" for a remotely controlled system.

SUBSTITUTING HUMAN FACILITIES WITH TECHNOLOGY

A laborer (human) in the trench represents not only an extremely flexible tool but also a hands-on guide and a set of monitoring eyes close to where the "action" is. All these vital capabilities have to be either substituted or its need eliminated. Every tele-robotic application is unique and requires a systematic study of process needs to identify the many issues that have to be addressed. Two interesting problems will be discussed that had to be overcome in order to make PipeMan Jr. ready for its challenging environment.

Keeping It Clean

As mentioned earlier, the sand and gravel material constituting the bedding of the pipe created the risk that some of it would enter the bell end of the pipe. It was important to be able to remove debris before jointing or to disallow it from entering the bell end of the pipe. The solution was found in the use of water soluble plastic wrapped over the bell before being lowered into the trench. Figure 6 demonstrates how the plastic was applied and how it behaved after water was introduced from inside the pipe.



a) Thin Plastic Held in Place by Rubber Band **b) Blue Water Liquefies Plastic Quickly**

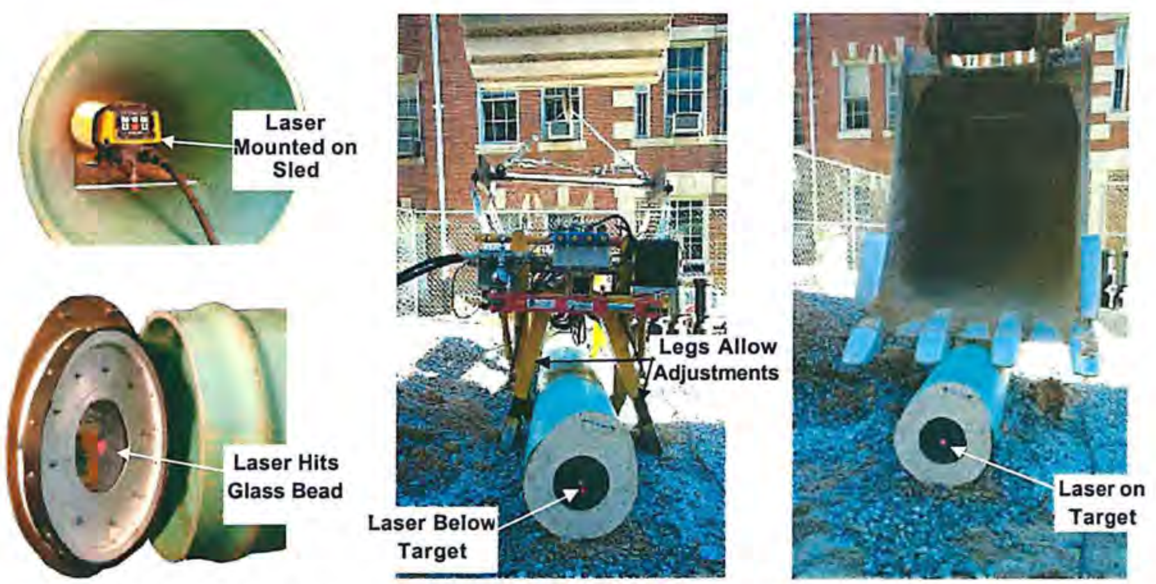
Figure 6: *Plastic Protects and Dissolves in Water*

Figure 6 a) and b) are self-explanatory in that they illustrate that, while sturdy when dry, water does not burst it but turns it into a liquid as well. The opening in the middle is necessary to allow the laser beam to pass uninhibited during installation. Only after one section is completed would water be allowed to remove the plastic.

Keeping Line and Grade

A major problem was to replace the laborers' capabilities to install a laser target, monitor the position of the laser beam on the target, and move the bell of the pipe so that it would be aligned to the laser beam inside the pipe. Two key questions were: where should the target be located and how could it be retrieved from the trench? Figure 7 portrays the answers to these questions.

The solution hinged on the decision to attach to each pipe a removable laser target that is visible to the operator during installation as shown in Figure 7. In order to increase the visibility of the laser beam when on target, a glass bead was mounted into the center of a see-through plastic held inside a frame that attaches to the bell of the pipe (this can be easily modified to fit other sizes). A handle on top offers an opportunity to insert a hook at the end of a retrieval rod thus allowing one person to remove the target from the surface. The laser itself is mounted on a platform that fits into the pipe in such a way that its laser beam is perfectly centered. Following a procedure already used by pipe crews, the installation is split into two phases. The first phase includes transporting, jointing, and aligning the new pipe segment with PipMan Jr. Alignment occurs by operating the two actuated legs, as shown in Figure 7 b), allowing the operator to move the end of the pipe up, down, and to each side. The goal of this maneuver is to either center the pipe or align the laser target vertically underneath the target which tells the operator that the end of pipe is in line but slightly above the desired grade. After the pipe is released and the PipeMan Jr. parked on the surface, the operator is now free to make the final small adjustment with the bucket as shown in Figure 7 c) a method commonly used. It is apparent that this only works when the grade differences are small and the bedding allows some compaction since pipes have to stay in the original round shape and not suddenly turn in ovals due to the applied force.



a) Laser and Removable Target b) Pipe In Line with Laser Beam c) Final Adjustment with Bucket

Figure 7: Retrievable Laser Target and Final Alignment with Backhoe Bucket

Keeping Control

As mentioned earlier, the operation had to be done wireless, only requiring hydraulic power available at the end of the backhoe arm (behind the bucket). To guide the jointing operation, the operator needs a close-up view of the bell and the spigot as a substitute for the eyes and hands that normally guide the end of the pipe. On the other hand, the hydraulic cylinders that actuate the different mechanism needed wireless control. Furthermore, the new installations needed to be non-obtrusive. Figure 8 presents the final human-machine interface.

The presented wireless communication system can be used for both pipe-manipulators and is, because of its modular design, easily expandable. In other words, more video cameras can be added or more control channels are available to add more motions. As shown, the small flat screen providing color images is protected by a sun-shade and clamped to the cabin frame. This simple solution allows easy removal in the evening to avoid theft. The same holds true with the small wireless camera mounted on the manipulator. The power for the screen comes from the battery of the excavator which provides 24 Volt which can be easily transformed. Both, the small control box and the camera have their own batteries. Pictures taken during the latest field test in November 2004, shown in Figure 8, indicate that the backhoe operator, felt immediately very comfortable with the system even though he had never used it before.

a) Clamp-On Flat Video Screen **b) Color Screen with Sun Shade** **c) Handy Wireless Control Box**

Figure 8: *Human-Machine Interface*

SUMMARY AND CONCLUSION

Traditional trenching and pipe laying requires workers to enter the trench, resulting in many fatalities and injuries due to the nature of the changing soil conditions and other work related circumstances. The tele-robotic concept promises to drastically reduce the risk to human life by keeping workers outside of the confined space of trenches. This paper presented the major components and functions of two tele-operated pipe manipulators that have been designed, fabricated, and tested in the field. Both prototype technologies were used to prove technical feasibility, and in one case, showed their economic viability by laying 8 pieces of concrete pipes without any workers in the trench. Each system went through several phases of tests and improvements, each time to be re-tested in the field.

Pipe-installation is a perfect candidate for a technological intervention to improve the safety of workers. This paper discussed two such technologies ready to be transferred into the industry. It is now up to construction to show its interest and willingness to protect its workers and at the same time reduce the cost of installing pipes.

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