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THE INTEGRATION OF A ELECTRO-HYDRAULIC MANIPULATOR ARM INTO A SELF-CONTAINED MOBILE DELIVERY SYSTEM

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ABSTRACT

The Portable Articulated Arm Deployment System (PAADS), pronounced “pads”, is a remotely controlled vehicle for delivering a tele-operated electro-hydraulic manipulator arm to a field deployable location. The self-contained system includes a boom vehicle with long reach capability, an electro-hydraulic manipulator arm, closed circuit television (CCTV) systems, and onboard tools. On board power systems consist of a self contained, propane fired 8 KW generator and an air compressor for pneumatic tools. The generator provides the power to run the air compressor as well as provide power to operate the 110 VAC auxiliary lighting system for the video cameras. The separate control console can be located up to 500 ft from the vehicle. PAADS is a fully integrated system, containing all equipment required to perform complex field operations.

The development of PAADS originated from a recognized need for a mobile delivery system with long reach capability. Compared to other existing equipment that has been developed in recent years, PAADS is more integrated and self contained. The only piece of equipment connecting PAADS to the control console is a cable, which is used to send control signals and to receive data transmissions and video signals. The entire PAADS design is based on commercially available components in order to minimize delivery and maintenance costs, and to maximize parts availability and reliability.

The project began with a Schilling Titan II manipulator which was available from a discontinued project. The development of PAADS was a phased approach, 1) selection of a vehicle delivery system, 2) integration of the manipulator hydraulics into the vehicle hydraulic drive system, 3) modifying the vehicle control system for remote operation, and 4) addition of on board power systems and tools for remote operations. The selection of the delivery vehicle was based on a hydraulic powered unit with articulating boom functions. The capacity of the boom was matched to the weight of the manipulator plus maximum handling capability. A multiple power source (battery and propane) for the hydraulic systems was selected for operations inside and outside of buildings.

Hydraulic integration of the manipulator arm into the vehicle hydraulic drive system was necessary to eliminate the tether management of hoses which extended vehicle operating range, minimized hydraulic pressure losses, and provided the opportunity to go to a radio frequency (RF) control system in the future eliminating the control cable. The hydraulic flow and pressure requirements for the manipulator arm were compatible with that of the mobile vehicle. However, the servo valves in the manipulator were more sensitive than the vehicle control valves and therefore an auxiliary hydraulic oil cooling system was required as part of the integration process. A number of interlocks had to be developed to prevent unintentional vehicle movement when the manipulator was being utilized.

Selection of the PLC (Programmable Logic Controller) control system emphasizes expandability and ease of adaptability during PAADS prototype development. The PLC approach provides real time control, digital communication between the control console and vehicle, and ease of adaptability in programing. The PLC approach also provided easy accommodation of the added diverse on board power systems consisting of a propane fueled auxiliary generator and an electrically powered air compressor. The diverse power systems are needed to support a suite of remotely deployable tools consisting of electric, hydraulic, and pneumatic types.

This paper presents the key decision points during system development. Emphasis is placed on ease of operator control and not on an intelligent machine approach. In addition, emphasis is placed on the philosophy of remote operation based on sound principals of integration.

1. Introduction

1.1 History behind the PAADS vehicle

The starting point for the PAADS vehicle goes back to the early 1990's when a Schilling Titan II manipulator arm with a control system was purchased at the Idaho National Engineering and Environmental Laboratory (INEEL) to assist in the retrieval of high level waste (calcine) from a storage facility. However, shortly after procuring the manipulator arm system, funding for the retrieval project was redirected to other programs and the project was halted. At this point, the property was transferred to the Remote Systems Applications Group for evaluation in determining uses on site involving remote handling requirements. During this evaluation phase, it became apparent that to make use of the manipulator arm's capability, a mobile delivery platform system would be required. At this point, the PAADS concept was not yet developed, however the need for a mobile delivery system was recognized as a necessity if productive use of this manipulator arm system was to be used for remote operations at different facilities at the INEEL Site.

1.2 Concept description

The PAADS concept was born in 1993 when a search in earnest was made for a mobile delivery vehicle that could accommodate the lifting capacity of the Schilling manipulator arm and power the arm hydraulics from the selected vehicle's hydraulic system. The search for the appropriate mobile delivery vehicle centered on those that were hydraulically powered with the energy to drive the hydraulic system from either battery power or engine driven. A secondary feature was the requirement that the engine driven hydraulic system, if so supplied, must have the ability to use propane as a fuel instead of gasoline due to the potential use indoors at facilities located at the INEEL Site. The mobile delivery system had to have 30+ feet vertical and 15+ feet horizontal reach to allow access to various elevations and provide maximum use of the manipulator arm for the various tasks. A wheeled delivery vehicle was preferable over a tracked type to minimize decontamination efforts and afford easy replacement of the traction devices. Above all, the mobile delivery vehicle had to be commercially available and easy to modify in order to accommodate the Schilling manipulator arm.

The result of this search was the purchase of a Genie tri-fuel model 45/22 Z-Boom articulated arm personnel lift as shown in Figure 1. The reasons for selecting this particular vehicle were several: 1) the vehicle had the reach capability and boom strength to accommodate the envisioned uses of the Schilling manipulator arm, 2) the vehicle had a hydraulic system with comparable operating characteristics and could be obtained with the same hydraulic fluid that the Schilling used, 3) the vehicle was wheeled driven and readily available via the procurement process at the INEEL, 4) while Genie Industries could not endorse the use of their product in this application, they were helpful in supplying technical information to make the evaluation and selection process favorable to this particular vehicle, and 5) the availability of a tri-fuel version allowed the use of propane instead of gasoline as a fuel for engine driven use of the vehicle. It should be noted that Schilling agreed with the basic approach to this selection process and provided technical assistance where applicable for vehicle selection.



Figure 1. PAADS vehicle in deployed position

1.3 Intended applications

The basic premise of the PAADS concept was to provide a remotely operated vehicle/manipulator arm system ready for mobile deployment, particularly in field areas lacking the infrastructure of power and services normally required for work operations. The unit was intended to perform in hazardous environments where personnel would not or should not be allowed to participate in various work-related tasks. The primary personnel hazard at the INEEL Site is high radiation fields and/or high radiologically contaminated areas where personnel entry contradicts with the ALARA (as low as reasonably achievable) goal for Department of Energy (DOE) Facilities. The impetus for PAADS was to minimize personnel radiological exposure when performing work activities in high radioactive fields or contaminated areas. Keeping with this philosophy, PAADS provides an integrated work platform that is remotely controlled by a console located some distance from the hazardous work area.

The intended uses of the PAADS vehicle are decontamination and dismantlement (D&D), environmental restoration, surveillance, and inspection tasks. Along with these applications, PAADS could be used in emergency situations requiring retrieval of equipment, hardware, or personnel in hazardous situations.

2. Overview of the Integration features

2.1 Hydraulic system

The integration of the Schilling manipulator arm into the Genie hydraulic systems was accomplished in four modifications. The first modification was to tie into the Genie drive circuit with a directional control valve that could, upon receiving a signal from the control console, divert hydraulic fluid either to the manipulator or to the drive circuit. The second modification consisted of installing an external convection cooled heat exchanger to accommodate elevated hydraulic oil temperatures. The third modification consisted of installing a circulation pump and lines to withdraw oil from the hydraulic reservoir and route it through the heat exchanger circuit and back again to the reservoir in order to help keep oil temperatures from reaching the 130 degree F limitation. The fourth and final modification was to supply a hydraulic power source for hydraulically operated tools that could be handled by the manipulator arm.

2.2 Control System

During the development of the control system for PAADS, modifications to the vehicle were implemented in three phases. Phase I was to remotely control the vehicle by duplicating the functions of the original operator control panel. Phase II of control system development was to integrate the manipulator to receive electrical and hydraulic power from the vehicle systems. Phase III was to control the auxiliary add-on systems and the high voltage (220/110 VAC) portions of the system.

Some fundamental goals were considered in the selection of a control system. These included:

- No power should be conducted through the tether cable between the remote control console and the vehicle.
- A very tight budget required minimal manpower expenditures for programming and development.
- Maintain the original capability of the vehicle controls for operating without the new control system.
- Emphasize simple operator controls. The operator interface should be as simple as the original vehicle controls.

In addition to these goals, mandatory requirements were defined due to the developmental nature of PAADS and due to the remote operation of a vehicle large enough to cause appreciable damage. These requirements included:

- At all times ensure safe operation, including "emergency stop" due to communication failure.
- Use off-the-shelf components for control system to ensure high reliability, availability and maintainability.
- Expandable and adaptable to address future capability and development of product.

2.3 Video System

Due to the size and reach of the PAADS vehicle, more cameras are implemented than on average remotely operated vehicles (ROVs). The video system consists of five color cameras having pan, tilt, and zoom capability located on the Genie vehicle and a sixth camera mounted on the wrist section of the Schilling manipulator arm. The five pan and tilt (P&T) cameras are all needed for safe navigation of the vehicle through openings and around obstacles. Three of these P&T cameras also assist with deployment of the boom. The other two P&T cameras are mounted near the manipulator and work in conjunction with the sixth camera during manipulator operations. This sixth unit is aligned for viewing the parallel jaws and work activities of tooling. Two lights are mounted near the manipulator arm for illuminating the work area. These lights can be controlled to vary the intensity to provide high contrast shadowing at the work location and can be dimmed to reduce glare.

In keeping with the intent of PAADS being a field deployable system, the control console is mobile and completely self-contained controlling all subsystems of the vehicle. Three subsystems are contained within the control console, the vehicle controls, the manipulator controls and the video controls. All equipment is contained within a 19" roll around rack. Fig 2 shows a schematic representation of the control console layout and tether to the vehicle.

2.4 Auxiliary Equipment Power Systems

In order to provide the necessary flexibility for PAADS to perform various work related D&D activities, a suite of power sources was necessary for use by the manipulator arm. The approach was to provide: 1) electric power, 2) pneumatic power, and 3) hydraulic power.

The PAADS equipment power systems consists of three main units plus additional electronic hardware to make this whole system function properly. These three units are the

original vehicle hydraulic power, the 8 KW propane fueled generator, and the 3.5 HP air compressor. All of these units reside on board the Genie vehicle and are part of the total self-contained PAADS concept.

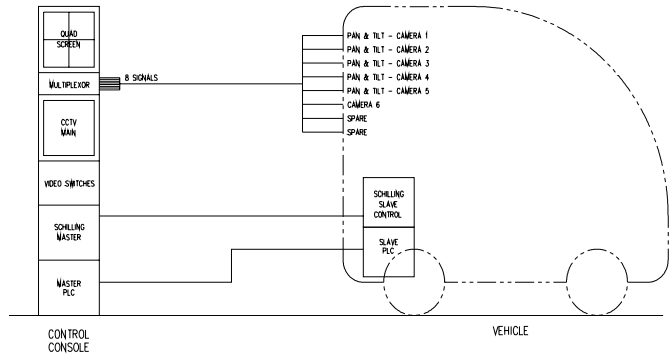


Figure 2. Control console layout and tether signal content

3. Hydraulic System

3.1 Basis of Approach

The basis of approach was to find a delivery vehicle for the Schilling manipulator arm that could adequately support the manipulator and that had the right hydraulic pressure characteristics along with flow to support this integration. The final decision to go with the Genie 45/22 Z-Boom personnel lift vehicle was based on several factors: 1) The vehicle had a hydraulic system (drive circuit) that was compatible to support the Schilling manipulator arm hydraulic requirements, 2) the vehicle was available in several versions, one of which was a tri-fuel, so that electric and propane power sources were available in the same unit, 3) the vehicle personnel basket platform height and reach capability more than meet the basic requirements, 4) Genie technical service representatives and a local distributor were helpful in answering questions during bid evaluations, and finally last but not least, 5) the quote for the vehicle was within the budget allotment for procuring a delivery vehicle. It should be noted that there are several other manufacturers producing vehicles comparable to the Genie unit that could have been utilized, but for the above reasons, the Genie was selected.

3.2 System Modifications

In order to understand the hydraulic system and how the integration of the manipulator arm was accomplished a block flow diagram has been included on the following page as Figure 4. (The bold sections of the schematic reflect modifications from the original equipment.) The integration of the Schilling manipulator arm into the Genie hydraulic systems was accomplished in four modifications.

The first modification was to supply the manipulator with hydraulic power from the main vehicle hydraulic system. The Genie vehicle has two basic hydraulic circuits, one for operating the articulated boom system/steering system and the second for providing the driving force for the vehicle. The boom circuit of the Genie vehicle operates of pressures up to 1500-psi while the driving circuit can operate up to the 3000-psi range. Therefore, the driving circuit was selected as the preferred source of hydraulic power for the Schilling manipulator arm. The first modification involved tying into the Genie drive circuit with a directional control valve that could divert hydraulic fluid either to the manipulator or to the drive circuit. In parallel with the manipulator arm is an adjustable relief valve so the pressure to the arm can be set.

The second modification consisted of installing an external convection cooled heat exchanger to accommodate elevated hydraulic oil temperatures. This unit is pictured in Figure 3. The reason for the heat exchanger is to keep oil temperatures below 130 degrees F for the Schilling arm. The servo valves located within the arm are



Figure 3. Heat exchanger mounted on PAADS vehicle.

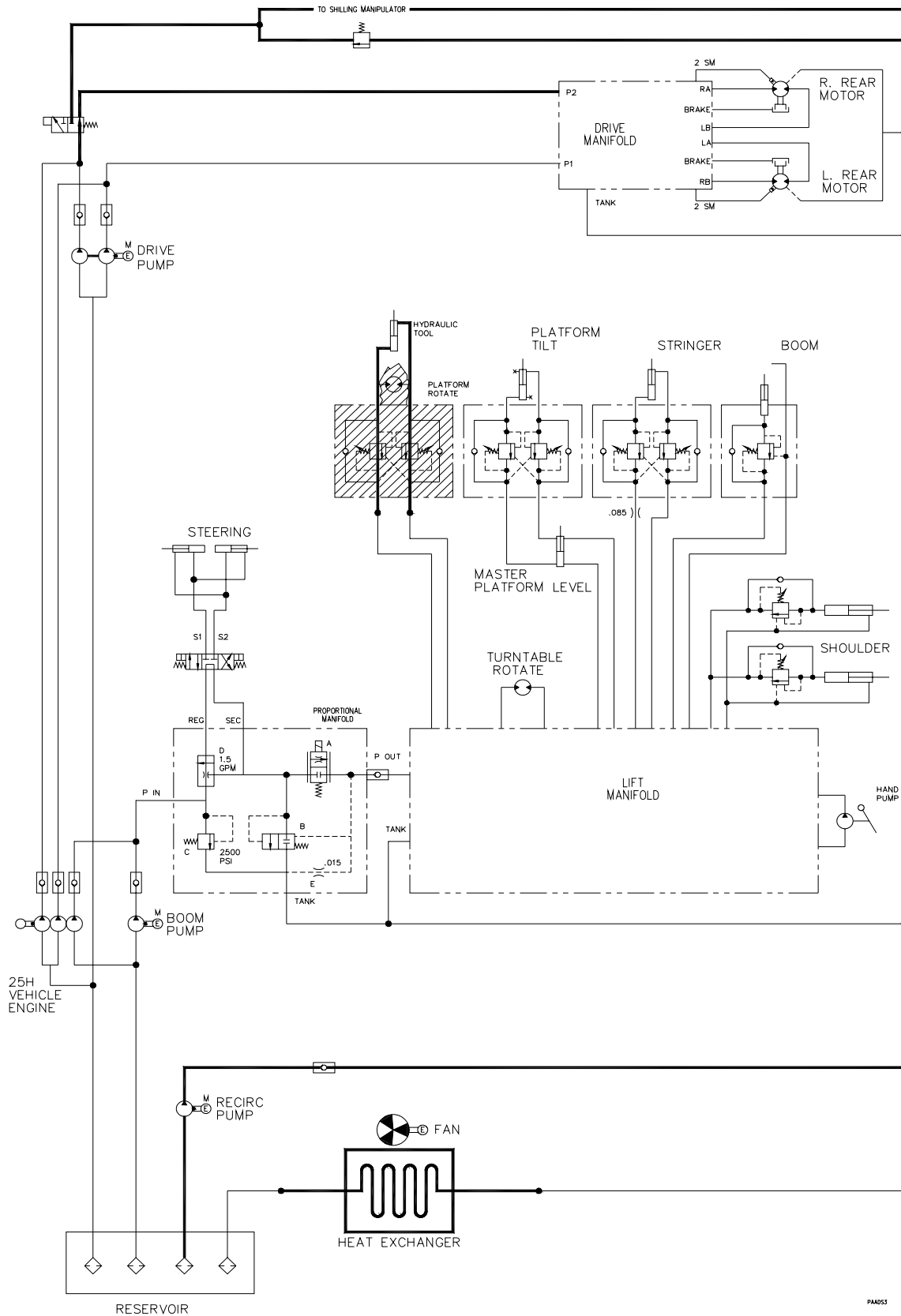


Figure 4. Block flow diagram of PAADS hydraulic system showing modifications from original equipment.

sensitive to temperatures above this point and can start to act erratically and possibly become damaged. This situation is not a problem for the Genie vehicle itself since the driving mode is usually for short durations and heat build up is not significant. However, the manipulator arm can be in use for much longer periods of time and therefore heat generation can be a significant factor for the hydraulic fluid. The heat exchanger cooling is augmented by an auxiliary external 12 VDC powered cooling fan that is activated by a temperature sensor in the hydraulic fluid and is programmed to come on whenever the manipulator arm is operating or when the reservoir circulation pump is running. A reservoir heater was installed to allow the hydraulic fluid to be warmed in cold weather conditions before use in the Schilling arm. Once again, this is because of the sensitivity of the servo valves.

The third modification consisted of installing a circulation pump and lines to withdraw oil from the hydraulic reservoir and route it through the heat exchanger circuit and back again to the reservoir in order to dissipate heat from the hydraulic fluid after the manipulator is shutdown. The pump is a 12 VDC unit that is programmed to operate when the reservoir temperature is greater than 110 degrees F and no other hydraulic pump is running.

The fourth and final modification was to supply a power source for hydraulically operated tools that could be used by the manipulator arm. The power was obtained from the Genie vehicle hydraulic system by eliminating the platform rotation feature on the vehicle boom and using this circuit for tool power. The modification involved disconnecting the supply and return lines to the rotary actuator on the platform and tying these lines into a spring loaded take up reel which connected to the tools. The platform rotate feature was no longer required since the Schilling manipulator arm has an azimuth (shoulder rotate function) that provided the same axis of motion as the platform rotation.

4. Power Systems and Remotely Operated Tooling

4.1 Power Systems

The PAADS tooling power systems consists of three main units plus additional electronic hardware to make this whole system function properly. The three units are the hydraulic tool power mentioned above, an 8 KW generator and the 3.5 HP air compressor as shown in figure 5. The generator and compressor reside on board the Genie vehicle and are part of the self-contained concept of PAADS.

The generator is tri-fuel model that can run on gasoline, propane, or natural gas. The unit was chosen because of the compact size relative to the output performance and because of the propane fuel usage, which is much preferred for indoor use. The generator as now configured on the Genie vehicle has been extensively modified to make it even more compact and usable on this chassis. The propane tank for the generator is carried in an easily releasable bracket next to the generator and is part of the generator complex located on the front of the vehicle. The generator produces both 110 VAC and 220 VAC (single phase) that is routed through the "high voltage relay" cabinet on the back of the Genie Z-Boom turret. The 110 VAC controlled by the operator console, powers the quartz halogen lights, on board battery charger, hydraulic reservoir heater, and 110 VAC tools. The tool circuit provides capability for reversing motors. This feature allows the use of reversible tools such as an electric impact wrench for loosening or tightening nuts and bolts. The 220 VAC circuit supplies power to operate the on board air compressor and 220 VAC tools if required. This tool circuit is not reversible.

The air compressor is a standard Campbell Hausfeld unit with a 20-gallon ASME-rated receiver tank. The operation of this unit is also controlled from the control console. The compressor is adequate for most of the smaller pneumatic tools such as one-half inch impact wrench, grinders, chipping hammers, etc. The Genie vehicle was purchased with the optional air hose already through the articulated boom structure, therefore termination of this line at the air compressor was a straight forward approach.



Figure 5. Generator and air compressor mounted onto PAADS vehicle.

4.2 Selection of Tools

A suite of tools supported by a tool rack is shown in figure 6. These tools were selected to demonstrate the various power sources available on PAADS, the versatility of the manipulator and the potential diversity of tooling that could be deployed. The tools initially selected consist of; 1) a 110 VAC reversible electric drill, 2) a one-half inch drive pneumatic impact wrench, and 3) a hydraulic shear system similar to the “jaws of life” equipment used to cut through metallic components to free victims in accidents.



Figure 7. “T” handle on tooling.

These initial tools were modified for remote use by providing each with a grip suitable for the Schilling manipulator with a parallel jaw. Because the parallel jaws have a circular hole both length wise and cross wise when closed to assist in holding onto equipment, this feature was taken advantage of in designing the grip for each tool as shown in figure 7. The tool grip for each tool was basically a “T” shape from bar stock that fit the parallel jaw grip with a custom mounting for each specific tool. The “T” shape allows the manipulator hand to align and hold onto the tool rigidly when closed.



Figure 6. Tool rack mounted on manipulator platform with remote tools.

5. Control System

5.1 Basis of Approach

To control the PAADS vehicle an Allen-Bradley Programmable Logic Controller (PLC) was chosen. This decision was based on the PLC meeting the design requirements for this remotely operated vehicle and fulfilling many of the design goals. The PLC approach was compatible with the original vehicle control scheme. Using the PLC greatly simplified the programming task for the entire project and provided all the needed communication capability built into the hardware. PLC's in general are industrial hardened, therefore very reliable (both hardware and software). They are vendor backed (for repair and troubleshooting) and replacement components are readily available. The PLC is easily expanded with virtually no modification to existing software by simply adding additional Input/Output cards. Probably the most important feature to this project is that the PLC is designed for safe shutdown and recovery from faults and communication failures.

The PAADS system controller was configured in a master/slave arrangement using Allen-Bradley's data highway for communication. The master PLC was mounted in the control console. This unit received inputs from operator actions such as throwing switches or moving joysticks. Any outputs from the Master PLC would illuminate status lights or control gauges on the console. All vehicle functions were wired into the slave PLC. The slave PLC was mounted on the vehicle on the back of the vehicle turret. This unit had no on board intelligence. All actions were initiated by communication from the Master PLC. In the event of a system fault or communication failure the slave PLC default mode was to open all circuits which would stop all motion and de-energize all circuits.

5.2 Implementation of Controls on PAADS

In order to understand the control system and how the PLC was integrated, a block schematic diagram has been included as Figure 8. (The bold sections of the schematic reflect modifications from the original equipment.) The integration of the control system into the PAADS vehicle was accomplished in three phases.

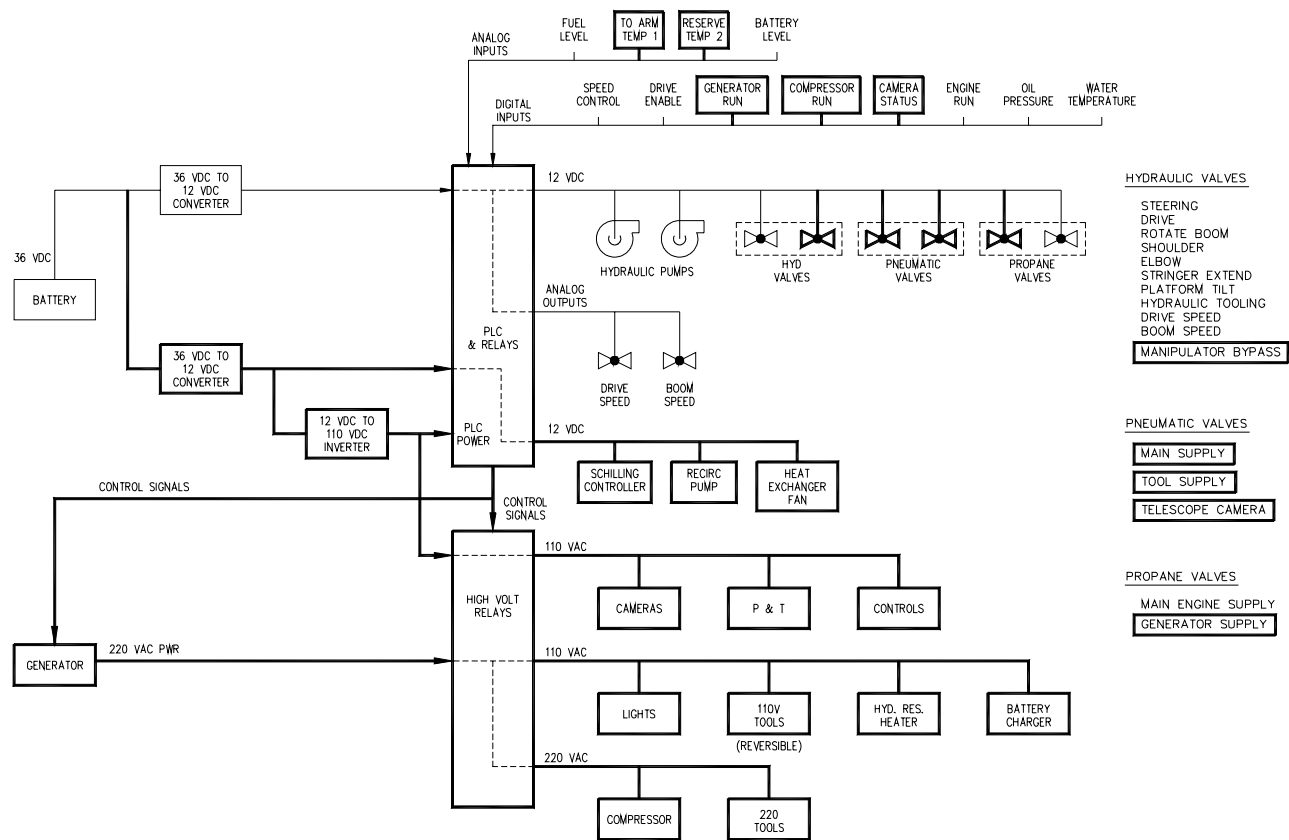


Figure 8. Schematic of PLC control system showing modifications from original vehicle.

Phase I of the control system development was to remotely control the vehicle. The original Genie vehicle had two control locations; one on the boom platform shown here in Figure 9, which provided full functionality including engine, boom and drive controls and a second control panel located on the side of the turret which just allows engine and boom controls. This second panel is intended for emergency recovery of the boom platform and routine maintenance operations. The PLC was tied into the original control wiring, shown here in Figure 10, and programmed to reproduce the signals originated at the platform. Duplication of control signals was relatively straightforward. The original platform console was hardwired with switches for energizing hydraulic pumps and valves. Each platform switch was replaced with a relay and controlled by digital output from the PLC duplicating the original signals.



Figure 9. Original platform control console

This approach to controlling the vehicle created two modes of operation: 1) local (with the platform console) or 2) remote (under PLC control). The benefit of this approach was maintaining the capability to operate the vehicle with the original platform control panel. The original console is used regularly around the shop for local maneuvering such as loading and unloading from a shipping trailer, performing maintenance, etc., without the need to power up the entire remote console. All original engine, boom and drive functions are still operational. A second benefit of this approach is that the backup control panel on the vehicle chassis is still operational.



Figure 10. PLC control cabinet

Phase II of the control system development was to support the Titan manipulator integration onto the vehicle. This included providing power to the Schilling slave controller, the re-circulation pump and the fan on the heat exchanger. For consistency with the Genie vehicle hardware, Schilling support components were selected for 12VDC operation. Insufficient power was available from the on-board 36VDC-12VDC converter that powered all vehicle valves, solenoids and relays. Therefore a second 36VDC-12VDC converter was installed to power the Schilling appurtenances.

The Schilling controller remained as a stand alone control system consisting of a master arm mounted on a remote (master) controller which communicates to the slave controller mounted near the manipulator arm. There was no intent to integrate control of the manipulator motion through the PLC. Control of the manipulator and communication between the master controller and the slave controller were run independent of the PLC.

Phase III added the auxiliary systems including high voltage (110VAC/220VAC) circuits, pneumatic circuits and video capability. First the generator was integrated. For isolation of high voltage from the PLC control cabinet (which is all 12VDC) a second cabinet was installed on the back of the vehicle turret to house all relays and circuits with 220/110VAC as shown in Figure 11. The pneumatic system and electric tooling are powered from the generator. Pneumatic valves were added on the low voltage side of the PLC to control the compressor airflow.

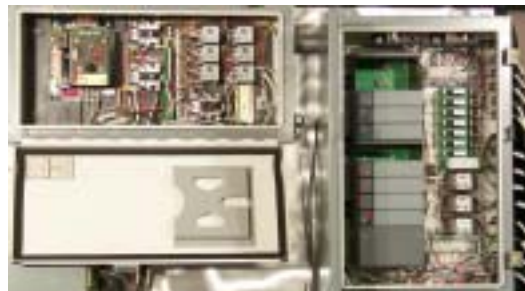


Figure 11. High voltage cabinet installed next to PLC cabinet.

Power and controls of the video system were handled differently then the rest of the equipment discussed above. Power for the video hardware including cameras, pan and tilt units and controllers was supplied from the vehicle's 36VDC battery through a 36VDC-12VDC converter and then a 12VDC-110VAC inverter. This approach allows the vehicle to be remotely operated on battery power without the generator running to power the video hardware.

6. Video System

6.1 Basis of approach

The video hardware used on PAADS includes; Panasonic CCTV cameras, Rainbow 8x zoom lenses, and Pelco P&T units. Each camera/P&T assembly requires 14 conductors for video feed and controls. Rather than routing all conductors needed to control each camera assembly back to the PLC for control, an alternate control strategy was selected. The control system for the video systems is based on Coaxitron hardware. In this system, a main coaxitron controller is located in the PAADS control console. The coaxitron controller has controls for all camera functions. The controller overlays these control signals for all camera functions into dead space of the video feed. A decoder box is mounted at each camera location that detects the control signals and drives the appropriate function. This approach saves excessive cable routing by only requiring a coax cable and power routed to each camera location.

Selection of these camera components and this control method was based on the emphasis for a simple system. The camera position is open loop controlled based on visual observation and relatively slow panning speeds. More advanced camera assemblies are available to provide enhanced capability such as serial communication and true position control however these units introduce more complexity, lower reliability and higher cost. Currently, this simple approach is adequate to meet the visual needs for operation of PAADS

6.2 Implementation of video on PAADS

Figure 12 shows approximate locations of each camera assembly on PAADS. Camera 1 is located on top of the elbow joint of the boom. This camera is the primary camera for driving the vehicle. Cameras 2 and 3 furnish left and right views of the chassis. These views are important for navigating obstacles. These cameras also give oblique views of the boom necessary during navigation, rotating the turret, and also when



Figure 12. PAADS vehicle showing camera mounts.

deploying the boom. Cameras 4 and 5 are mounted on the azimuth of the manipulator arm and are offset approximately 18 inches to the left and right. By mounting on the azimuth, these cameras pivot with the manipulator rotation reducing the amount of camera panning required to keep the manipulator in view. The left and right positions of the cameras give oblique views of the manipulator similar to the oblique views that the chassis cameras 2 and 3 give of the vehicle boom. The oblique views have also proven very beneficial for tool exchange.

Camera 6, the wrist mounted camera is most important during tool operation. This camera provides line of sight of the tooling similar to looking down a gun barrel. This view is invaluable for lining up tools onto bolt heads, performing drilling operations and during cutting. The camera is a Toshiba 6mm diameter fixed focus color camera. The wiring for the camera was fished back through the cable paths of the manipulator arm so no outside penetrations were required. A custom bracket was designed to replace one of the Schilling wire way covers. The camera and bracket are shown in Figure 13.



Figure 13. Camera mounting bracket

6.3 Control Console

The control console actually contains three separate control systems: the vehicle controls, the manipulator controls and the video controls. Vehicle controls are clustered into functional groups including drive controls, boom controls, tooling controls and auxiliary controls as shown in Figure 14. A separate panel houses all the status gauges and lights. Each switch correlates to a single axis of motion. No coordinated joint control is provided with this approach.



Figure 14. Vehicle portion of control console

Two emergency stops are integrated into the controls. One E-stop is interlocked with all power sources for tooling. This one switch will shutdown all tooling. The second E-stop is for the entire vehicle. This E-stop shuts down all systems on the vehicle including hydraulics, manipulator, generator and Genie engine. The subsystems are designed to lock all motions in their current position in the event of an emergency stop.

The manipulator controls include the remote (Master) controller and the master arm. The controller is simply mounted into the control console. No modifications were made to this unit. The master arm was dismantled from the master controller. The arm is mounted on a separate base plate to allow an adequate range of motion and so that the arm can be packaged for shipping.

The video controls include a Coaxitron camera controller, an 8 channel video switcher, and a quad-view multiplexor. In addition, two monitors are mounted in the console as shown in Figure 15. The primary monitor displays the currently selected camera view. The second monitor displays four cameras and typically shows the left and right views of the chassis (Cameras 2 and 3) and the left and right views of the manipulator (Camera 4 and 5). The video switcher lets the operator select any camera to be displayed on the main viewing monitor. The coaxitron unit will control whichever camera is currently selected including P&T, focus, and zoom.



Figure 15. Video portion of control console

7. Conclusions

7.1 Testing and Operating Experience

Extensive testing has been performed on the PAADS vehicle. The reach capability of the boom has given the vehicle flexibility to handle a wide variety of tasks. The combination of systems, vehicle, manipulator and PLC has proven to be reliable. The manipulator has been the least reliable component of the system requiring minor maintenance. The PAADS vehicle

has received testing involving continuous operation of the arm for up to two hours at a time. This amount of time pushed the extent of operator comfort for using the Schilling master arm. Also under battery power, the manipulator is operational for 35-45 minutes on a full charge.

Only minimal testing has been performed to date on the tooling. Testing to date has shown that all of these tools are usable, however the skill of the operator remains the biggest factor in the effectiveness of the equipment. Better orthogonal view angles than are currently provided by the on-board CCTV equipment would improve alignment and depth control and should alleviate some of the problems encountered. Boom sway due to play in the joints has not shown to be a problem for the initial tool set. Boom sway does prevent use of tooling like grinders, which require constant pressure.

7.2 Applications for deployment of PAADS

To date, PAADS has not been required for a field deployment. Two response teams have considered using PAADS. One operation was to replace HEPA filters, which were contaminated with Europium, and were generating a high radiation field. PAADS was considered for this job because the filter housings were located on the roof of a two-story building providing little access for other remote controlled vehicles. The other operation considered was to perform recovery actions from a burst drum at another DOE facility. A method was needed to inspect remaining drums in the contamination area for more bulging drums, relieve pressure if any bulging drums were found and the assist with cleanup activities. PAADS was suited for this task because the drums were stored in a stacked configuration meaning most drums were unreachable by standard remote operated vehicles. PAADS offered the reach and tooling capability required for this task. In both instances, alternate schemes were chosen for recovery primarily due to transportation costs and because PAADS was not completely operational at the time.

Besides these two accidents, PAADS was developed for use in D&D operations in large facilities, environmental cleanup and restoration, particularly in remote areas where facility services such as power are not available, as well as for use in hazardous operations unacceptable for human exposure. PAADS is available for deployment under contract with Lockheed-Martin Idaho Technologies Company (LMITCO).

7.3 Demonstrations

Two on-site (INEEL) demonstrations have been conducted using the PAADS vehicle. The first was performing maintenance work on a plasma hearth mockup. The operation was to reline the plasma hearth with new firebricks. This demonstration was only performed with a mockup in a radiologically clean environment. The actual task would be performed on a radiologically contaminated hearth posing sufficient hazards that remote operation would be required. The second demonstration was segregating waste in a waste handling mockup. This demonstration was used for determining feasibility of using the Schilling manipulator for performing waste sorting and packaging.

PAADS has also been transported to Pasco, Washington for an off-site demonstration near the Hanford DOE complex. The unit was demonstrated at the TRICEPE V trade show in Aug 1997. The vehicle was shipped on a lowboy trailer and transported approximately 600 miles each way. Unpacking and setup took less than two hours.

7.4 Conclusions

Integration of a hydraulic manipulator into the hydraulic power system of a mobile vehicle has definitely proven to be feasible. The single most important issue to be addressed beyond compatibility of vehicle and manipulator performance requirements is heat dissipation. A hydraulic powered manipulator is a significant heat generator and is normally operated for extended periods. Whereas the vehicles tend not to generate much heat and their use is more sporadic allowing ample time to dissipate any heat that is generated.

Other vehicle configurations (and vendors) could be used as a deployment platform substantially increasing the manipulator's versatility for applications. Other control systems could also be employed depending on the level of complexity required by the tasks to be performed. In the development of PAADS, the authors have found the simple open loop control system adequate for most tasks.

8. Recommendations

8.1 Areas for further study and evaluation

PAADS was initially developed as a tethered remotely controlled tele-operated vehicle for the deployment of the Schilling manipulator arm. One logical extension of communication systems is the removal of the tethered control cable between the control console and the vehicle itself and conversion to RF controls. Added to the overall complexity of integrating RF controls is the fact that PAADS is intended to perform inside buildings and facilities that have substantially thick concrete walls that have been used for shielding purposes. This can lead to using repeaters or depending on high power and frequencies thereby requiring special FCC licenses for the use and possibly some restrictions on where PAADS could be used within the INEEL Site or other DOE Facilities.

Another area that should be evaluated is that of a camera tracking system for those cameras that are used with the manipulator arm. Some investigative work has already been done to determine that there are systems available that would allow cameras 4 and 5 to automatically track the manipulator arm anywhere in its operating envelop. Initial information on one such system indicated that this approach could be installed relatively easily and at reasonable cost. This would certainly benefit the operator at the control console who would not have to make frequent adjustments to these two cameras in order to keep the manipulator hand in view.

The possibility of using 3D vision systems for control and operation of the manipulator arm should also be evaluated. A 3D vision system for cameras 4 and 5 would allow the operator to have depth of field and a better perspective on the work task that may provide easier maneuvering of the manipulator arm for tool control and task completion. This would certainly provide for better productivity and less frustration for the operator at the control console.

8.2 Suggested areas for upgrades (Near term and Long term)

Two near term improvements which are ongoing is the addition of a powered take-up reel for tether management and mounting manipulator viewing cameras on telescoping cylinders to provide improved viewing angles of the manipulator while in operation.

Several longer term projects being considered include adding a anti-sway bar which could rest against the work surface to stabilize the boom during operation. As discussed above, converting the communication systems from hardwire to radio control, and installing camera tracking capability on the manipulator viewing cameras are considered feasible and funding is being sought to implement these features.

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J. Rivera, engineer at the INEEL, consulted on the design and implementation of the video system

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REFERENCES

None