Intelligent Herbicide Application System For Reduced Herbicide Vegetation Control Phase II – Commercialization

Division of Research
& Innovation

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DISCLAIMER STATEMENT

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California Department of Transportation

Intelligent Herbicide Application System for Reduced Herbicide Vegetation Control
Phase II – Commercialization

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16. Abstract

This report describes the development of a commercial prototype intelligent herbicide application system (IHAS). The improved design incorporates a parallel "add-on" type fluid handling system to allow existing variable-rate herbicide injection systems currently used on Caltrans herbicide spray vehicles to be retrofitted with IHAS technology, and a dual camera system for weed recognition under partially shaded lighting conditions. The new IHAS is capable of targeting green plant material within a 3.66 m perpendicular distance to the direction of travel on either side of the herbicide spray vehicle for herbicide application.

The basic principal of an intelligent herbicide application system (IHAS) is that a real-time machine vision system can detect live (green) plant material growing along the roadside, and when coupled to a rapid-response spray control system, will permit the California Department of Transportation to selectively apply post-emergence herbicides exclusively to the unwanted plant material. The implementation of the IHAS technology will allow the California Department of Transportation to reduce the amount of resources required to maintain an effective weed control program using herbicides while at the same time reducing the amount of chemicals unnecessarily released into the environment.

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Introduction

The California Department of Transportation expends a considerable amount of human and financial resources in its highway maintenance program for the control of vegetation along the shoulders of highways. Effective weed control has multiple benefits including reduced fire hazard, increased visibility and safety for drivers, reduced loss of natural resources (e.g., water) to unwanted vegetation and a reduction in alternative hosts for insect pests and diseases. Application of herbicides is one of the more efficacious and economical methods of weed control.

A major issue in California is the current reliance on chemical methods of pest control. Helsel[1] estimated that in 1984 16 billion dollars were spent worldwide on pesticides. Further, Helsel reported the United States as the largest pesticide user in the world applying more than three times the quantity of pesticides as the second largest user (Japan). A total of 4.5 billion pounds (2 billion kg) of chemical pesticides were used in 1995 in the US[2]. Unfortunately, the continued reliance on chemically based pest control practices has potentially detrimental effects upon the environment and human health in the form of contamination of water supplies and soils. In addition, the effect of chemical residues is often cumulative and their continued use can be increasingly detrimental to the environment.

There is a need to develop improved means of weed control in a reduced herbicide environment. Slaughter et al.[3] and others have demonstrated that one possible solution is to reduce herbicide requirements by targeting post-emergence herbicide sprays only to plant vegetation and not the surrounding soil. If the California Department of Transportation applied herbicides only to targeted plant material, the energy and material costs involved in weed control could be reduced and, subsequently, the amount of herbicides released into the environment greatly reduced. Additionally, the productivity of the weed control operation could be increased, allowing more reliable control.

The concept of intermittent spray control for plant sprayers has been previously investigated. Reichard and Ladd[4] discussed work in which plant conductivity and a charged probe were used to detect the presence of target plants. They also developed intermittent spray control systems that detected vegetable plants through steel wires and systems based on photo-detectors. The detection systems were limited to targeted plants that could fit between the sensor system based on operational conditions of tripping a wire switch or interruption of a light beam. Field tests of the control systems (Ladd et al.[5] and Ladd and Reichard[6]) found reduction of applied spray

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1 Helsel, Z.R. 1987. Pesticide use in world agriculture. In: Z.R. Helsel (Ed.), Energy in plant nutrition and pest control. Elsevier, New York, p. 194.

2 Aspelin, A.L. 1997. Pesticides Industry Sales and Usage, 1994 and 1995 Market Estimates. Biological and Economic Analysis Division, Office of Pesticide Programs, Office of Prevention, Pesticides and Toxic Substances, US Environmental Protection Agency, Washington, DC.

3 Slaughter, D.C., D.K. Giles, and C. Tauzer. 1999. Precision offset spray system for roadway shoulder weed control. ASCE Journal of Transportation Engineering. 125(4):364-371.

4 Reichard, D.L. and T.L. Ladd. 1981. An automatic intermittent sprayer. Trans. of the ASAE. Vol. 24(4):893-896.

5 Ladd, T.L., D.L. Reichard, D.L. Collins and C.R. Buriff. 1978. An automatic intermittent sprayer: a new approach to the insecticidal control of horticultural pests. J. Econ. Entomology. Vol. 71:789-792.

material ranged from 24 to 51% with little or no reduction in pest control efficacy. Giles et al.[7,8] developed a spray application system that used ultrasonic sensors to trigger spray nozzles on or off based on tree presence or absence. The system was physically limited to large targets typically found in orchards.

Several researchers (e.g. Hollaender[9]) have documented distinct absorption characteristics of chlorophyll; detectable maximum peaks occur at 675 nm region of the visible spectrum. Other researchers have attempted to use this information to develop a non-contact sensor for detecting chlorophyll-containing materials (e.g., plants) versus non-chlorophyll containing materials (e.g., soils). Generally, in those studies, the difference in reflectance between plants and the soil background is based on foliage chlorophyll absorbing red radiation while soil reflects red radiation. Additionally, in other earlier studies the ratio of visible to near-infrared radiation[10] and the ratio of red to near-infrared radiation[11] were used to distinguish green vegetation from the soil background. Several of these studies have led to commercial plant detector-sprayers (e.g., Weed Seeker PhD 1620, Patchen California, Inc., Los Gatos, CA and Detectspray-S45, Concord Inc., Fargo, ND).

Systems based on discrete reflectance sensors, such as those described above, are limited to relatively short operating ranges due to averaging of the signals of all of the objects in the field of view, including the plant and the background levels. As sensor height is increased, the plant detection resolution decreases. Merritt et al[12] reported that plants greater than 20 cm^2 were detectable using a sensor height of 23 cm. While this sensor range is allowable for many boom spraying applications, it is not useful for detecting smaller plants from boomless systems where sensor to target distances can exceed 3 m. Alternatively, computer vision systems, having greater resolution, can provide the plant detection performance required for detecting smaller plants.

Slaughter et al. [3] developed a machine vision based a precision offset spray system (figure 1) for control of vegetation along roadsides. In this system spray material is delivered to the region adjacent to the vehicle in which the plant lies and not to surrounding soil. The system used a single camera, mounted approximately 2 m above the road and was capable of detecting weeds as small as 6.25 cm^2. The system substantially reduced the amount of herbicide applied to non-plant material (up to 97% reduction in applied pesticide compared to conventional continuous

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6 Ladd, T.L., and D.L. Reichard. 1980. Photoelectrically-operated intermittent sprayers for insecticidal control of horticultural pests. J. Econ. Entomology. Vol. 73:525-528.

7 Giles, D.K., M.J. Delwiche and R.B. Dodd. 1988. Electronic measurement of tree canopy volume. Trans. of the ASAE Vol. 31(1):264-272.

8 Giles, D.K., M.J. Delwiche and R.B. Dodd. 1987. Control of orchard spraying based on electronic sensing of target characteristics. . Trans. of the ASAE Vol. 30(6):1624-1630, 1636.

9 Hollaender, A. 1956. Radiation biology. Vol. III. McGraw-Hill. New York.

10 Hooper, A.W., G.O. Harries, and B. Ambler. 1976. A photoelectric sensor for distinguishing between plant material and soil. J. Agric. Engng. Res. Vol. 21.

11 Haggar, R.L. C.J. Stent, and S. Isaac. 1983. A prototype hand-held patch sprayer for killing weeds, activated by spectral differences in crop/weed canopies. J. Agric. Engng. Res. Vol. 28.

12 Merritt, S.J., G.E. Meyer, K. Von Bargen, D.A. Mortensen. 1994. Reflectance sensor and control system for spot spraying. ASAE Paper No. 94-1057. ASAE, 1950 Niles Rd., St. Joseph, MI, USA.

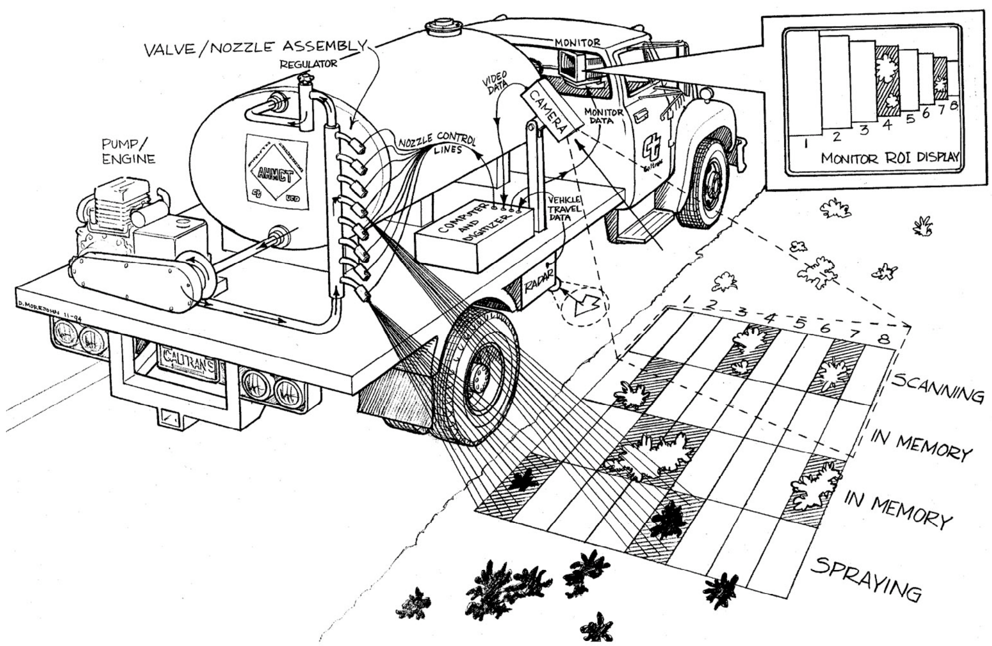


Figure 1. Illustration of the precision offset spray concept developed by Slaughter et al.[3]

spray applications). This study indicated the value of machine vision technology for reducing both environmental and economic costs of weed control. Additionally, the concept of “offset" or “boomless” spray applications (i.e., no spray boom extending beyond the vehicle boundary) was shown to be technically feasible.

The research prototype system developed by Slaughter et al.[3] did not address issues of uneven and unlevel terrain, or varying light conditions. Also, the influence of wind on spray accuracy was corrected by applying additional herbicide prior to and after the intended target to ensure herbicide hit the target when wind deflected the spray in flight.

The basic principal of an improved precision offset spray system is that a real-time machine vision system can detect live (green) plant material growing along the roadside and, when coupled to a rapid-response spray control system, will permit the California Department of Transportation to selectively apply post-emergence herbicides exclusively to the unwanted plant material. The implementation of this technology will allow the California Department of Transportation to reduce the amount of resources required to maintain an effective weed control program using herbicides while at the same time reducing the amount of chemicals unnecessarily released into the environment.

Objective

The technical objective of this research was to develop an intelligent herbicide application system (IHAS); that is, a spray application vehicle that uses machine vision system to detect plant material along a roadway shoulder and specifically target plant material with herbicide in real-time. Herbicide is delivered to the plant region, not adjacent soil, based on automated commands from the IHAS.

The improved IHAS was capable of:

1) Targeting green plant material within a 3.66 m perpendicular distance to the direction of travel on either side of the herbicide spray vehicle.

2) Working in parallel to the existing pre-emergence herbicide application system to allow Caltrans to operate the vehicle in either the non-IHAS mode (conventional spray applications) ***or*** in the IHAS mode (targeted herbicide application).

3) Improved detection of green plant material under non-uniform illumination conditions (e.g., shadows caused by roadside signs) typical of naturally illuminated roadsides in California.

4) Having the potential for commercial manufacture; the IHAS project involved the cooperative effort of researchers at the University of California, Davis and design engineers at Adaptive Equipment, Inc., with the ultimate objective of producing a commercial prototype IHAS.

5) Recording spray events and ambient conditions of wind speed and direction, air temperature, average slope of ground, and vehicle location in the form of a DGPS (Differential Global Positioning System) "as applied" spray map. The system has a "lock-out" capability, where spray valve actuation is disabled if any of the monitored ambient parameters are outside specified or defined limits. Additionally, the system can warn the vehicle operator if the vehicle is located inside a previously identified prohibited spray zone. The IHAS uses commercially available sensors, controllers and other components, with custom interfaces as needed, for robust spray control of roadside vegetation.

Intelligent Herbicide Application System (IHAS)

The IHAS (figure 2 shows the passenger side of the vehicle) consists of three subsystems:

1) Valve Control System (VCS)
2) Weed Mapping System (WMS)
3) DGPS Data Logging System (DLS)

Briefly, the VCS is responsible for setting the parameters used for spraying. That is, this portion of the IHAS accepts input and displays information to the vehicle operator. The WMS uses machine vision to develop a spray application map with concurrent one-to-one mapping to spray valves for targeted herbicide application. The DLS archives ambient conditions in addition to location application information for later retrieval and assessment. An in-depth discussion of these subsystems follows.

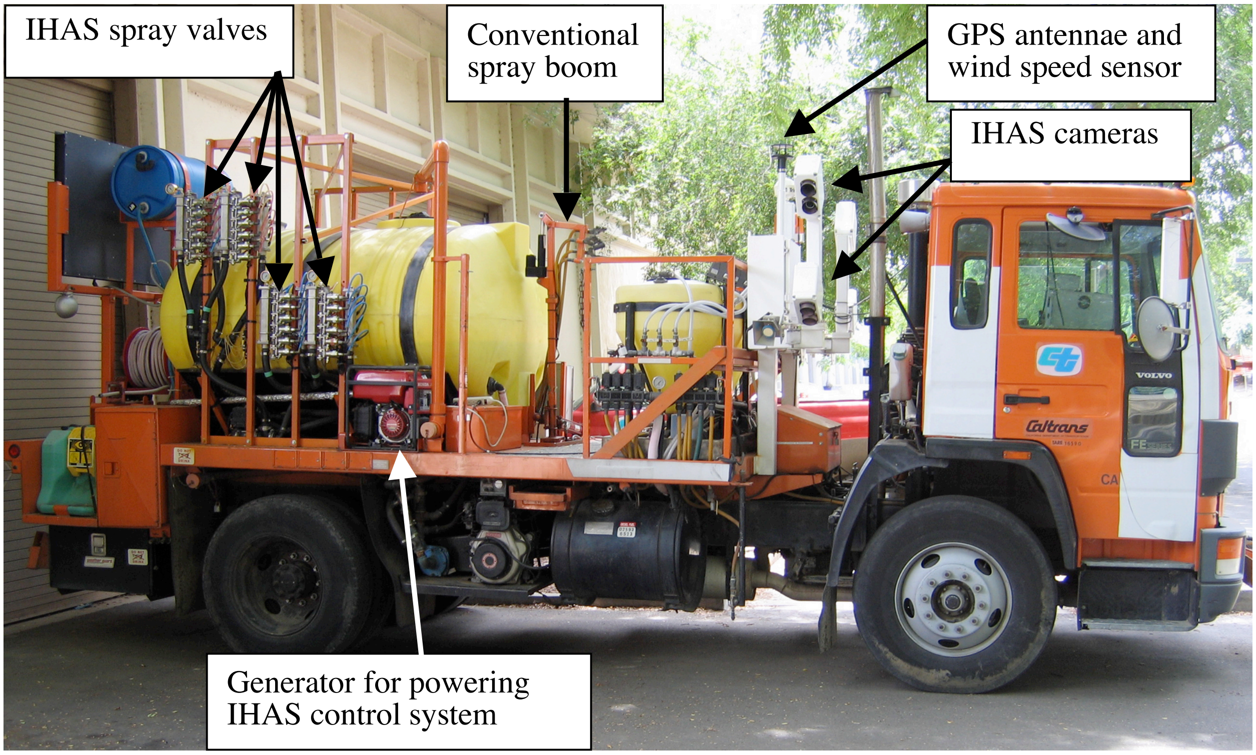


Figure 2. Passenger side of the IHAS vehicle showing locations of several subsystems for targeted herbicide applications.

Valve Control System

The VCS is the primary controller component of the IHAS. It is responsible for accepting operator input, displaying information to the operator, coordinating the image acquisition process and operating the spray valves based upon the digital video spray map information. The VCS was originally developed in an earlier phase of the project. Changes to the VCS in this phase of the project included an expanded spray coverage up to 3.66 m perpendicular to the truck foot print on both sides of the vehicle (i.e., PLC processing speed was increased and additional control hardware added for the additional spray valves). A general overview of the VCS is provided here; additional details on the VCS system can be found in Appendix A.

A programmable logic controller (PLC) acts as the central administrator of the VCS. The PLC monitors the ground speed radar sensor (which is shared between the existing Raven spray controller and the IHAS) to determine vehicle speed and displacement and uses this information to control valve actuation and timing signals for 24 valves specific to the side of the road being sprayed. Spray application, or weed map, data is transferred from the WMS to the PLC via an Ethernet connection and is stored until the vehicle has traveled to the appropriate location for valve actuation to spray the identified targets in the weed map. The PLC uses valve activation delay timing, spray time-of-flight, physical distance (in the direction of travel) between the camera and the nozzle, and vehicle speed to determine valve actuation times.

The commercial prototype VCS (Adaptive Equipment, Gainesville, FL) developed for IHAS is shown in Figure 3 and consists of the following hardware and software components:

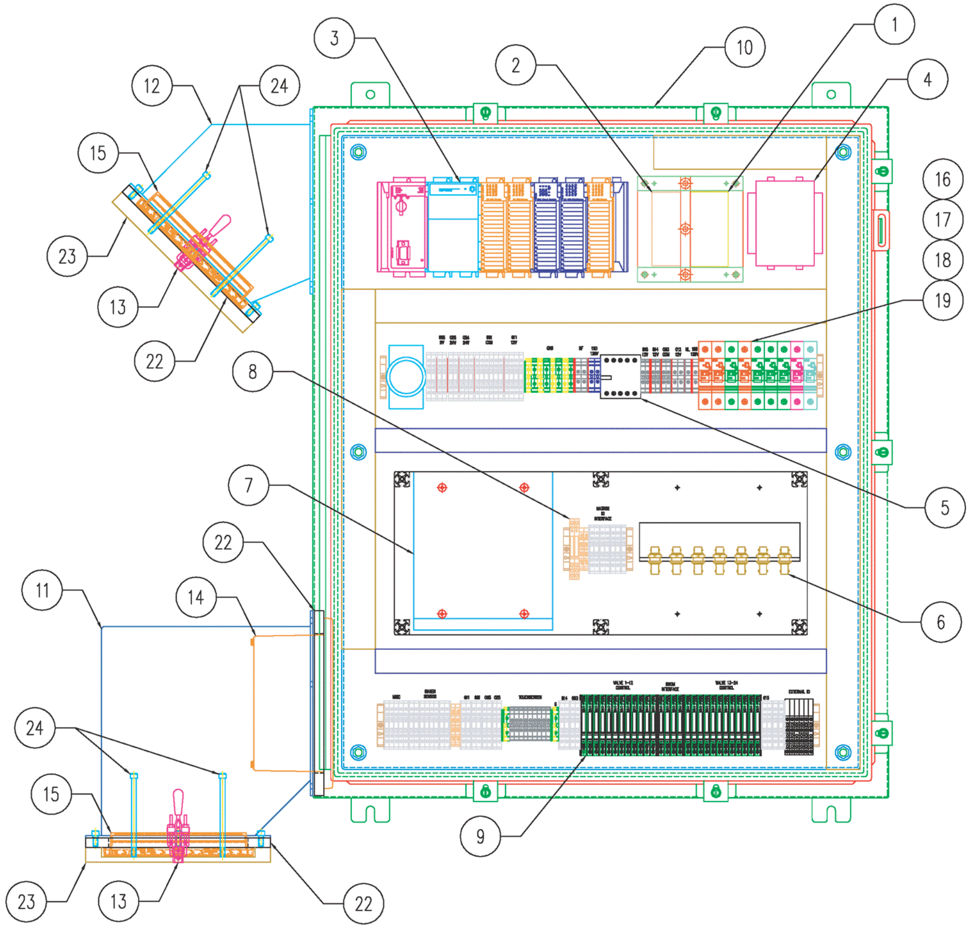
1) A NEMA 12 enclosure mounted to the bed of the Caltrans spray vehicle;
2) A gasoline powered generator mounted to the bed of the Caltrans spray vehicle to generate 120VAC for all IHAS components except IHAS spray valves;
3) A PLC with non-volatile memory;
4) An in-cab touch-screen operator interface to allow for initial pray parameter set-up, monitoring of system parameters and capable of tuning system parameters;
5) Wiring and connectors for the PLC-valve interface and other external components (e.g. radar, PC, power source monitor, operator interface, etc.); and
6) Software and hardware required for communication between the VCS, WMS, and DLS.

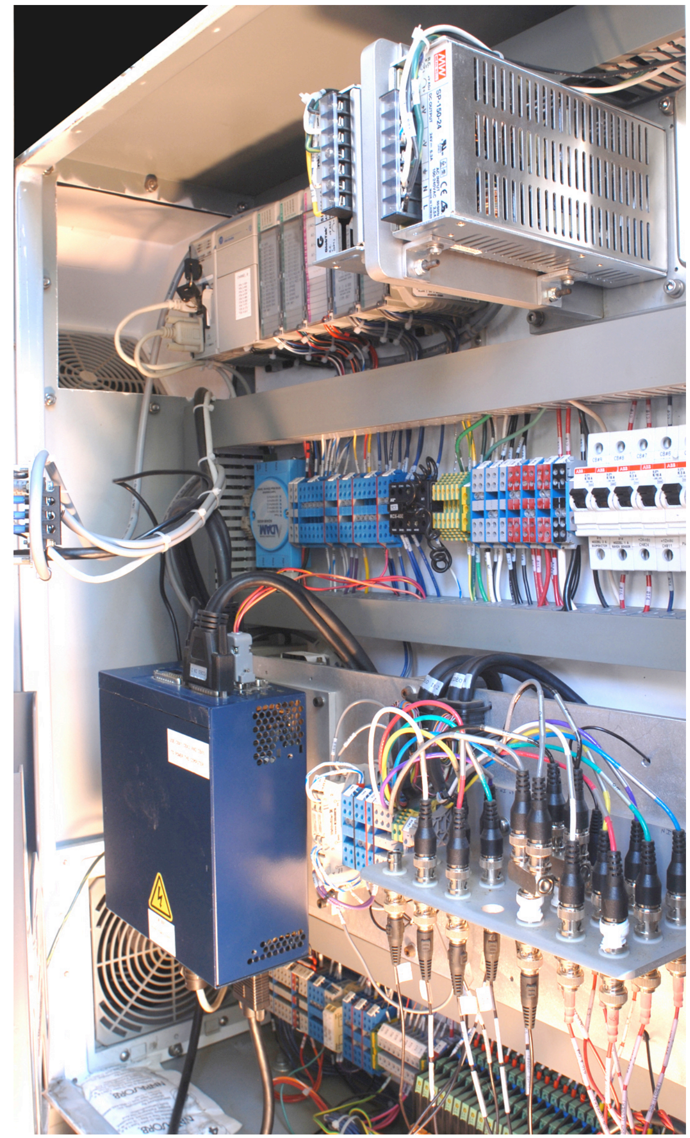
All wiring diagrams, component information, and layout diagrams associated with the VCS can be found in Appendix B.

Most of the electronic components associated with the VCS (e.g., PLC, DC power supplies, valve relays, etc.) were housed in the NEMA 12 rain-tight enclosure mounted on vibration resistant shocks at the rear of the vehicle deck on the driver's side of the vehicle. Additional NEMA 12 enclosures were used for various devices and connectivity. Valve relays were housed in an enclosure mounted at the base of the VCS main cabinet on the deck. An enclosure resides at the front of the vehicle deck to select the specific side of the vehicle for spray applications. A monitor and keyboard for communicating with the weed map computer (machine vision computer) were enclosed and mounted approximately mid-deck on driver's side of the vehicle. An additional enclosure was mounted near the monitor enclosure and contained an electrical input connection for a function generator used to simulate radar pulses of vehicle motion and allowed system diagnostic tests while the truck was stationary. Power for the VCS and additional components was provided by a gasoline-powered generator mounted on the passenger side of the vehicle.

<u>Operator Controls</u>. Communication with the VCS by the spray vehicle operator is through a touch panel interface located in the cab of the vehicle (figure 4). The interface includes an emergency stop switch above the touch panel display. Both are located in the cab and can be easily accessed by the operator.

The touch panel (PanelView Plus 1000) allows the vehicle operator to input specific conditions. Figure 5 shows several screen shots of the touch panel interface: system start-up menu, system status menu, system run-time menu and spray nozzle selection options. For example, the vehicle operator can select specific spray nozzles (or all spray nozzles) to continuously spray (manual mode) or automatically spray based on the WMS communication with the VCS. The vehicle operator can set time of flights for the spray valves based on their location and spacing configurations for the nozzle booms. Additionally there is a run-time menu that gives the vehicle operator immediate feedback on vehicle ground speed and spray flow rate through the system. Detailed information on instructions for the vehicle operator interfacing with touch panel and





Legend of selected components (see Appendix B for additional details)

1, 2 & 4: DC Power supplies & conditioning
3: Programmable logic controller (PLC) 5, 9: Relays
6: Video signal bulkhead 7: Machine Vision Computer
16 - 19: Power circuit breakers 11 & 12: Exhaust vent rain shields

Figure 3. IHAS main enclosure; general schematic showing component layout (left) and enclosure photograph (right).

Figure 4. Driver view inside cab of spray vehicle containing IHAS operator interface with touch-panel (left), emergency stop switch (above touch-panel) and global positioning system (right) installed adjacent to conventional spray control systems.

setting up initial operating conditions in addition to a pre-spray check list with start-up and shut down procedures are given in Appendix C.

Fluid Handling System

One goal of this project was to adapt the fluid handling system of the existing conventional direct injection spray system to work with the IHAS machine vision-activated spray system. The main design constraint was that the IHAS was to be an "add-on" system placed in parallel with the existing Caltrans pre-emergence herbicide application system. Specifically, this parallel design will allow Caltrans to operate the modified herbicide vehicle in either the normal conventional (non-IHAS) mode ***or*** in the IHAS mode. Note that both modes can not be operated simultaneously.

Unlike conventional spray systems, a fundamental principal of the IHAS is that a variable number of spray valves can be opened and closed every 15 cm (6 inches) of travel. This distance is a non-adjustable defined parameter for the IHAS system and is the basic spray dimension unit.

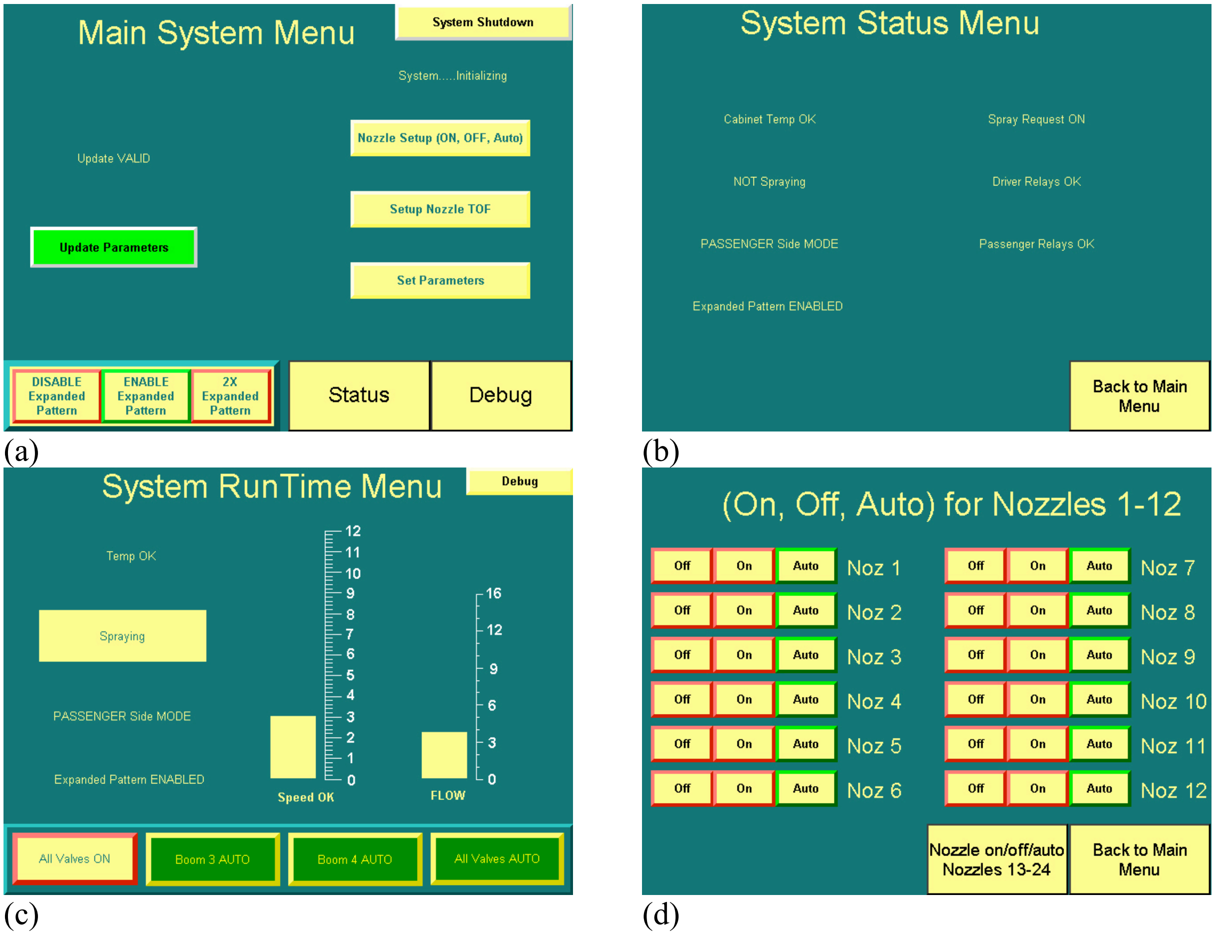


Figure 5. IHAS touch-screen interface as seen by vehicle operator with several options shown: a) default (main screen) display when vehicle is stationary, b) system status screen, c) spray operation screen, automatically displayed when vehicle is in motion and spraying, d) nozzle control screen.

For example, if the vehicle is traveling at 16 kph (10 mph), a variable number of valves (up to 24) may be opened and closed 15 times per second; and spray can be launched from the vehicle to targeted weeds within 15 cm square blocks (6 in square) up to 3.7 m (12 feet) away from the vehicle foot print.

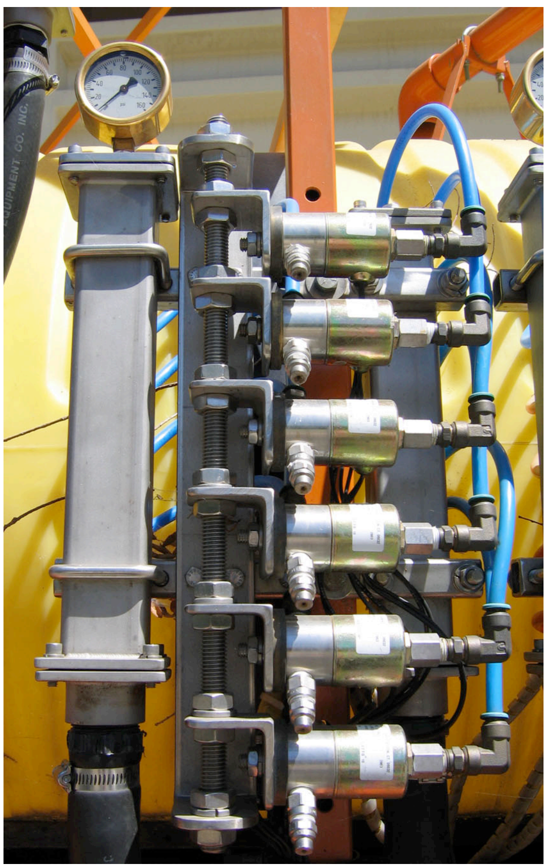
For accurate targeting of weeds, constant pressure at each nozzle is required independent of the number of valves firing (i.e., nozzles spraying). To accomplish this physical requirement, the IHAS uses three-way valve technology to resolve the variable valve/pressure issue.

The required fluid handling changes were:

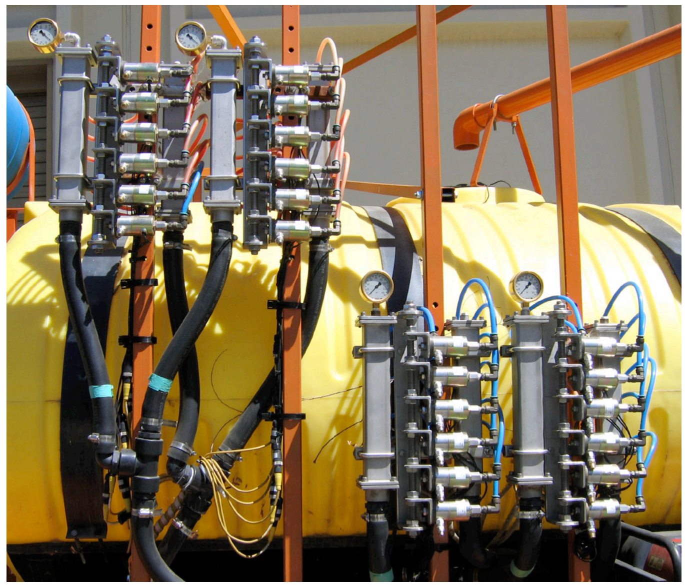
1) Addition of a fixed nozzle tower for each 0.9 m (3 foot) spray region consisting of six IHAS nozzles per tower with each nozzle targeting a 15 cm square area, perpendicular to the vehicle foot print, and parallel to the vehicle path (see figure 1).

2) Addition of electronically actuated 3-way valves (one per IHAS nozzle).
3) Implementation of a method of fluid buffering to minimize herbicide concentration variation.
4) Implementation of a method of communication between the IHAS and the Raven injection system.
5) Modification of truck plumbing to allow the IHAS to share system components with the existing spray system.

Figure 6 shows the nozzle towers on one side of the vehicle with spray valves, supply manifolds and return manifolds to maintain a constant pressure during variable spray applications.



(a)



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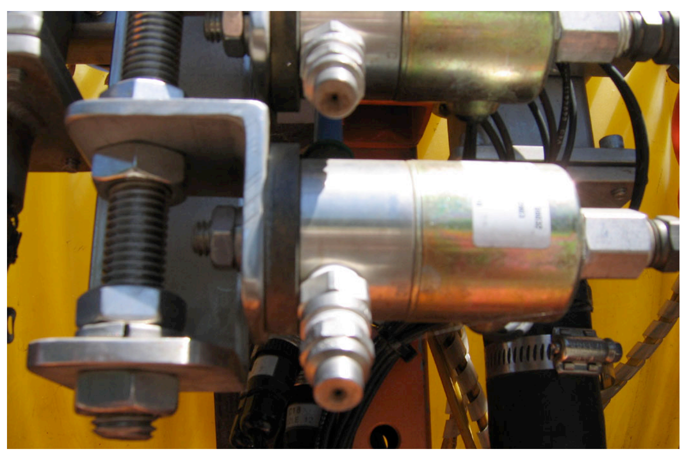


(c)

Figure 6. IHAS spray tower with supply and return manifolds. a) single nozzle tower showing six spray valves/nozzles with supply manifold on left and return manifold behind valves/nozzles. b) All four nozzle towers on one side of the vehicle. c) three-way valve with spray nozzle.

Plumbing Modifications. A schematic of the modified plumbing system is shown in figure 7. The only components added in-line with the existing system were a shut-off valve and flowmeter added to the outlet of the water tank. Nozzle towers were connected into the existing pressure line in place of the rear hand-gun, however they could simply be added to the existing system to maintain functionality of the rear handgun if desired. The bypass flow from the valve towers enters just below the chemical injection point and is mixed as it passes through the centrifugal pump. The motor and pump pulleys were changed to increase pump speed and the 517 kPa (75 psi) regulating valve was opened to increase flow pressure at the nozzle. The desired "at nozzle" pressure was 276 kPa (40 psi). Pressure gauges were installed on the nozzle/valve supply manifolds to allow visual monitoring that adequate pressure was available during spray events.

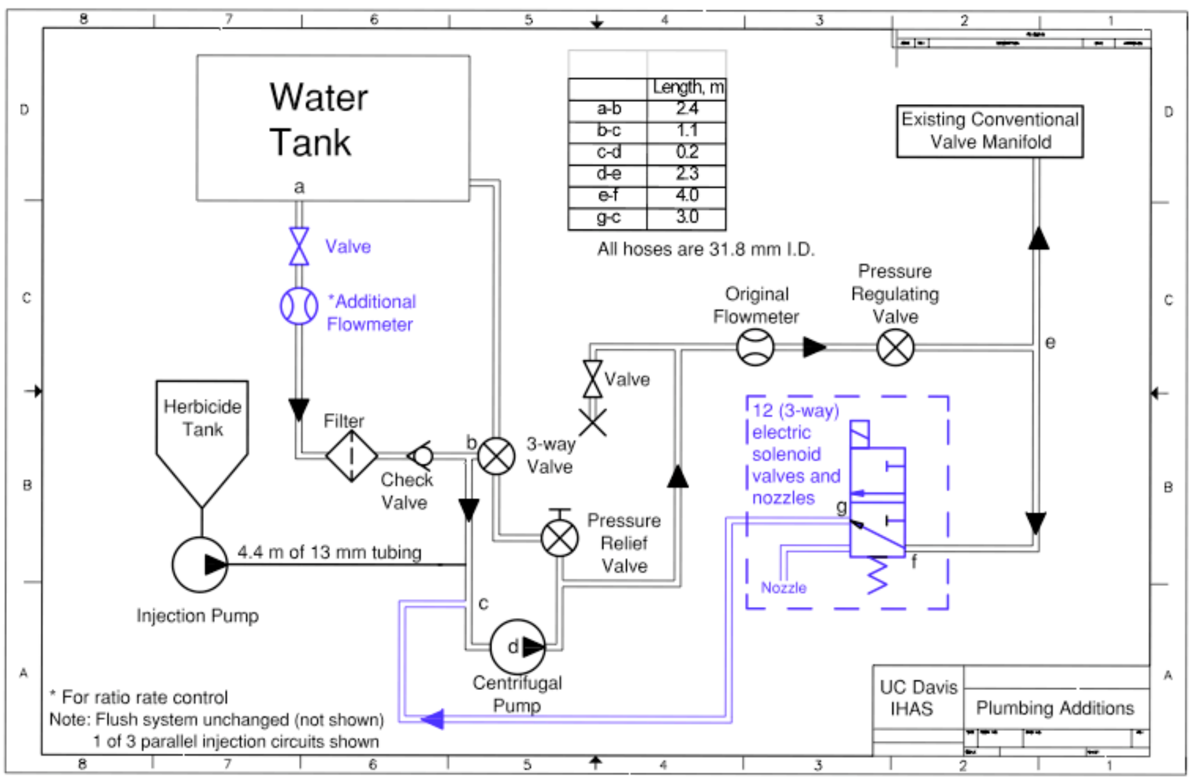


Figure 7. Schematic of the IHAS fluid bypass system used to minimize fluid pressure and herbicide concentration variations under variable spray demands (note IHAS additions in blue were added to the existing fluid handling system on the vehicle).

To maintain targeting accuracy and constant supply pressure at all valves, independent of the number of nozzles actively spraying, IHAS incorporated the use of a continuously circulating bypass system. The IHAS 3-way nozzle control valves allow fluid to flow either through the nozzle or, when the nozzle control valve is not activated, allows fluid flow bypass to the return line; flow re-enters the fluid system upstream of the main pump. This design maintains a constant flowrate through the valves and minimizes pressure fluctuations associated with a variable number of valve activations. The volume of fluid re-circulated in the loop, approximately 3.2 liters (0.85 gal), buffers and stabilizes herbicide concentrations at the nozzle. These concentrations would likely vary due to transport delays of newly injected chemicals due to rapid changes in flow demands. This artificial "fluid tank" is momentarily diluted under sudden heavy loads due to the increased flowrate of fresh water drawn in to replace the recent spray output. However, as the heavier weed load is sensed, a control signal is sent to the injection pump to increase chemical concentrate added to the solution in order to bring the concentration back to the desired level. One of the IHAS to Raven communication designs, "boom switch control," (described below) anticipates changes in demand by "looking ahead" into the spray map and communicating this information to the Raven with sufficient lead time to eliminate any concentration lags.

Two different control methods can be used by IHAS to control the rate of chemical injection with the Raven SLC750 controller (Raven Industries, Inc., Sioux Falls, SD): "boom switch control" and "ratio rate control." Since individual IHAS nozzles target the same ground area, it is possible to use the Raven boom switches to electronically adjust the injection rate in proportion to the number of IHAS valves open at any specific time ("boom switch control"). For "ratio rate control," usually intended for handgun operation, the chemical injection rate is set proportional to the flow of water leaving the system.

When IHAS uses "boom switch" control, the VCS continuously updates the Raven controller with the number of nozzle/valve configurations currently spraying. It is possible to represent the number of activated valves as a 4-bit binary value and set the boom width value of the least significant bit to the coverage width of one IHAS nozzle. Therefore, in the Raven SLC750 set-up, the boom width value for boom 1 is set to 15 cm (6 in.), boom 2 to 30 cm (12 in.), boom 3 to 61 cm (24 in.), and boom 4 to 122 cm (48 in.). In IHAS mode the VCS is connected to the Raven controller in place of the Raven boom switch box and if, for example, four valves are on (4 x 15.2 cm = 61 cm), the controller sends a signal on the boom 3 line, which corresponds to 61 cm (24 in.). In this way the Raven injection controller receives continuously up-to-date valve activation data from the VCS and adjusts the herbicide injected accordingly.

The other control method used by IHAS is the "ratio rate" mode. In this scenario, the system determines the chemical injection rate set point as a user-specified percentage of the flow of water leaving the system. This simplifies the VCS operation as no electrical communication is needed between the Raven injection controller and the VCS. However, the flowmeter on the conventional (non-IHAS configured) spray vehicle is located at the pump outlet. In this configuration, the combined flow leaving the system for spray application and return flow from the IHAS return manifolds are measured. This combined measurement was separated; the requirements for IHAS indicated that a flowmeter was required at the outlet of the water tank in order for an accurate measurement of fresh water entering the system and to ensure ratio rate applications were configured and injected with appropriate herbicide rates.

Weed Mapping System

The IHAS uses color machine vision to develop a spray map of the weeds growing along the roadway shoulder. From the machine vision image captured, objects with a "green" appearance, corresponding to the color of living plants, are classified as weeds and their location noted within the computer system for spray application. IHAS uses eight 3-CCD video cameras for weed mapping. Four cameras are mounted on each side of the vehicle: two are configured for capturing close images and two are configured for far images. Three-CCD sensor technology is traditionally used when high quality color images are desired without the additional computational cost required to anti-alias filter a single CCD image with a higher resolution sensor. For use in the IHAS configuration, 3-CCD technology was used to eliminate false "green spots" due to aliasing, that occur when imaging non-plant scenes such as black and white gravel or dark cracks in bare soil surfaces. Additionally, computation time required to analyze each image was a concern because spray vehicles typically travel at speeds up to 16 kph (10 mph) and the machine vision system must analyze the entire roadway shoulder area (up to 3.66 m or 12 ft) for weeds in real-time. In the future, as more powerful computers become available, it may be feasible to use less costly 1-CCD technology.

The cameras were mounted in rain-tight enclosures on a frame that was welded to the front deck of the spray vehicle (figure 8). Each enclosure contained two cameras (Hitachi models HV-D30, Hitachi Kokusai Electric America, Ltd, Woodbury, NY) where one camera was configured for operation under illumination with direct sunlight and the second camera was configured to acquire images in the shaded regions of a captured scene. The machine vision computer (Matrox model 4-SightII, 1.2 GHz, Matrox Electronics Systems, Ltd., Dorval, Quebec, Canada) was equipped with two real-time color video frame-grabbers (Matrox model Meteor-II). There is a video control switch mounted on front of the camera support frame that informs the Matrox computer and PLC which cameras and valve towers to use for spraying (that is, basically the switch engages the system for driver or passenger side spraying).

The lower camera enclosure ("near" cameras) on each side of the truck was positioned to capture roadside images along a 1.8 m (6 foot) perpendicular distance from the vehicle footprint. The upper camera ("far" cameras) enclosure captured images between 1.8 m and 3.6 m along the same transect as the near cameras. When the vehicle is in motion at speeds above 1.6 km/h (1 mph) the radar sensor outputs a pulse stream to a high-speed counter in the VCS. The number of pulses per time captured from the radar sensor is proportional to the distance traveled per time. The VCS monitors the radar pulse count to determine vehicle speed and distance traveled. During video capture and nozzle spraying, a region 0.76 m (30 in) wide (in the direction of travel) by 1.8 m (6 ft) long (perpendicular to travel direction) is analyzed for weeds in each image captured by the WMS. The near and far cameras are multiplexed (i.e. they share the same frame-grabbers) and images not acquired simultaneously, but sequentially in an alternating pattern (i.e. near, then far, then near, then far, etc.). Thus, the VCS outputs a trigger or synchronization signal to the WMS every 0.38 m (15 inches) of vehicle travel. At each trigger signal, a pair of images (both sun and shadow) from either the near or far camera set are acquired and analyzed to create the weed map for the corresponding region of shoulder being imaged. Once analyzed, the weed map is transferred to the VCS for spray application to weed specific regions.

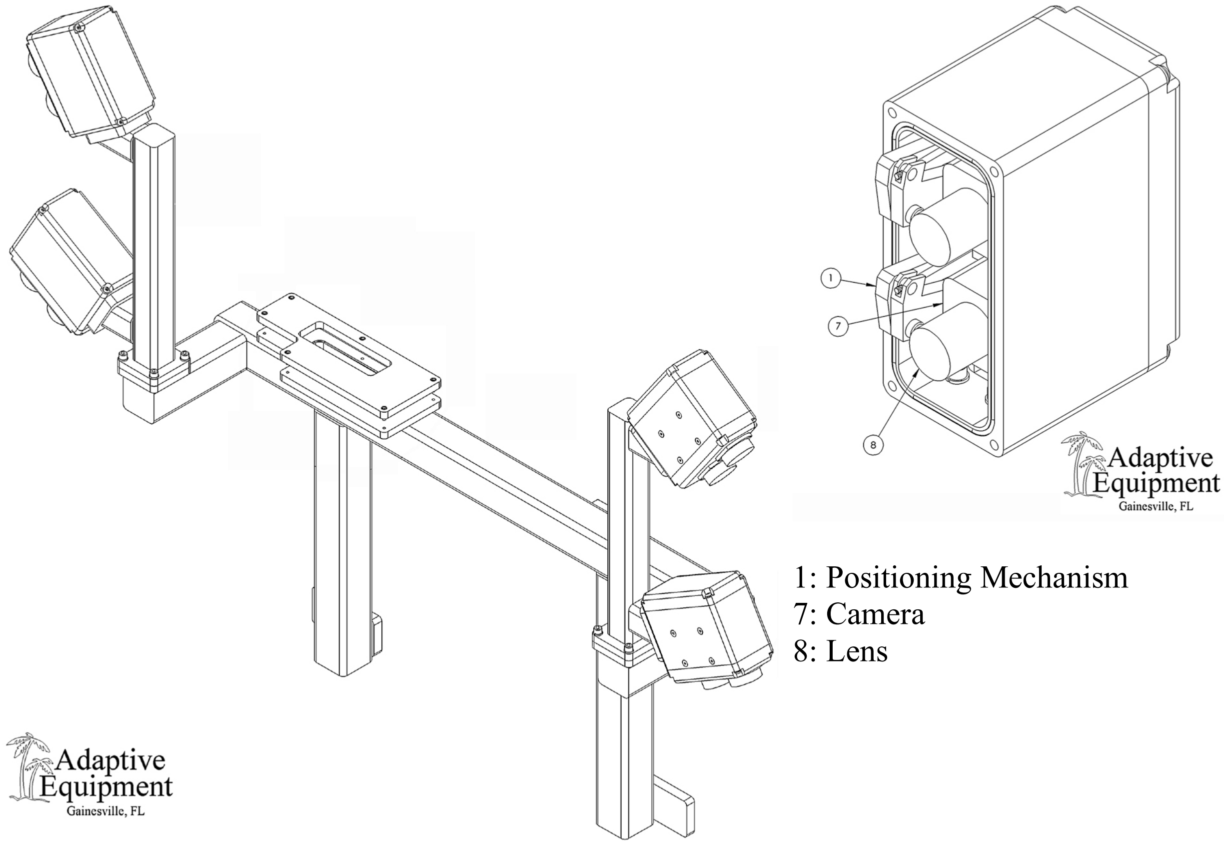


Figure 8. Camera mounting system for IHAS; the left image shows the camera mounting frame with four camera enclosures and the right image shows one camera enclosure with the front cover removed revealing the sun camera (top) and shadow camera (bottom).

Camera resolution tests. Camera resolution for the actual target size that can be detected and sprayed were determined for both near and far cameras on the passenger side of the vehicle (with the assumption that cameras on both sides of the vehicle would be similar). These tests were done on a flat, black-top surface on the UC Davis campus. All tests used 0.635 cm (¼ in) thick green scrubbers used for cleaning kitchen ware cut to several different square dimensions.

Based on the 24 nozzles, per side of vehicle, for spraying up to 3.66 m (12 ft), it should be noted that each nozzle is adjusted to spray over a 15.2 cm (6 in) square area. Hence, nozzle 1 is targeted within a square area beginning at a distance of 0.305 m (1 ft) and ending at a distance of 0.457 m (1.5 ft), which is the starting point for the 15.2 cm square target area for nozzle 2. The remaining nozzles are targeted in a similar fashion and distances are easily determined from the first nozzle setting.

For the resolution tests, scrubbers were centered within each 15.2 cm (6 in) square area corresponding to each nozzle along a perpendicular transect from the truck. The spray boundary for nozzle 1 begins at a perpendicular distance of 30.5 cm (1 ft) from the vehicle footprint. Table

1 gives the results from the resolution tests. Minimum target size for the near cameras, that is, up to a distance of 1.83 m (6 ft), was a 1.9 cm (0.75 in) square. Minimum target size for the far cameras was a 3.8 cm (1.5 in) square.

Table 1. Camera resolution tests; results are indicative of size of material recognized by cameras for spray application.

Size of scrubber cm (in)		Speed of vehicle kph (mph)	Near camera tests Percent of targets sprayed, %	Far camera tests Percent of targets sprayed, %
0.635 x 0.635	(0.25 x 0.25)	4.8 (3)	0	0
1.27 x 1.27	(0.5 x 0.5)	4.8 (3)	0.05	0
1.9 x 1.9	(0.75 x 0.75)	4.8 (3)	100	0
		12.8 (8)	50	0
2.54 x 2.54	(1 x 1)	4.8 (3)	100	50
		12.8 (8)	100	0
3.8 x 3.8	(1.5 x 1.5)	4.8 (3)	100	100
		12.8 (8)	100	100
7.62 x 7.62	(3 x 3)	4.8 (3)	100	100
		12.8 (8)	100	100

Spray deposition tests. Spray deposition assessments of the system were determined for a general broadcast scenario, with all nozzles spraying, and a random target analysis using 6 targets randomly placed within a predefined grid (figure 9). The test location was on the UC Davis campus with a flat black-top ground surface. Two vehicle speeds were evaluated for the broadcast and random target tests: 3 mph (idle speed) and 10 mph. The broadcast application entailed turning all valves on and driving by the targets at the test speed, with three replicates per test; random target tests were also replicated three times. All targets for all tests used 15.2 cm (6 in) square green scrubbers. Deposition, or spray recovery assessment on targets, was determined by using brilliant sulfaflavine (BSF). The carrier fluid was mixed and analyzed prior to all tests; average recovery of the carrier fluid tank was approximately 19.8 ppm (BSF). Weather conditions over the test duration are given in Table 2.

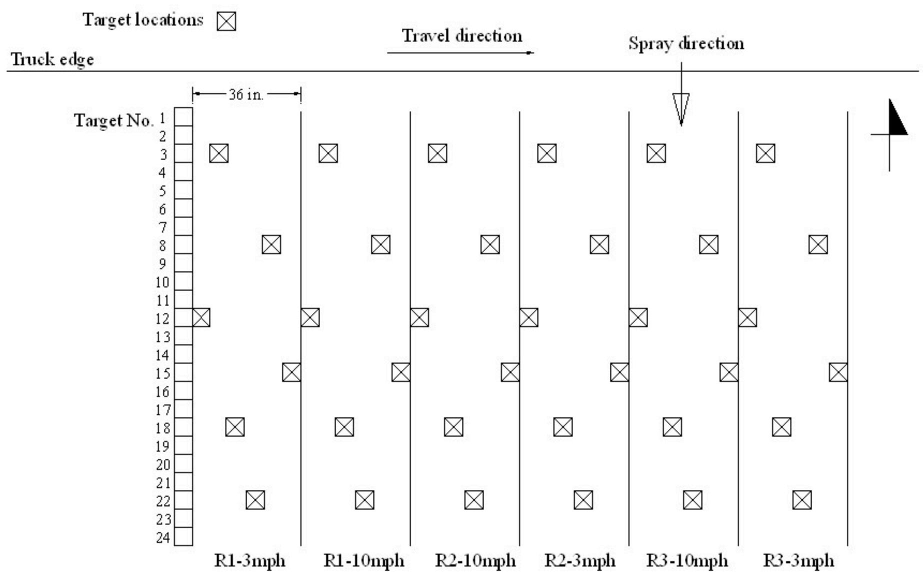


Figure 9. Grid set-up for spray deposition showing replicate and speed of vehicle for the tests.

Table 2. Weather conditions for spray deposition tests; data were obtained from the California irrigation management information system (CIMIS) website for the UC Davis campus.

Time	Air Temp C	Vapor Pressure kPa	Wind Speed m/s	Wind Direction 0-360	Relative Humidity %	Dew Point C
1100	11.2	0.8	4.2	348.5	59	3.6
1200	12.5	0.8	2.7	349.4	55	3.6
1300	13.8	0.7	1.3	298.0	47	2.8

Broadcast deposition results from the two test speeds are given in Table 3. The concentrations are given as a percentage of the spray tank mix concentration (19.8 ppm) along with average concentration, standard deviation and ranges of the actual concentrations (ppb).

Random target spray deposition results are given in Tables 4-6. Table 4 gives each deposition replicate as a percentage of the spray tank mix (19.8 ppm). Table 5 gives a comparison of the average of the replicated target depositions normalized to the average (all 24 targets) broadcast deposition for each test speed and the average of the replicated target depositions normalized to the spray tank mix (19.8 ppm).

Table 3. Broadcast depositions as a percentage of spray tank mix (19.8 ppm) for two test speeds and range of actual spray depositions concentrations (ppb) for all targets.

Target	3 mph, broadcast Percent of tank concentration	10 mph, broadcast Percent of tank concentration
1	1.5	0.9
2	1.6	1.0
3	1.9	1.1
4	2.4	1.3
5	3.7	1.6
6	4.6	1.6
7	5.7	2.1
8	7.9	2.5
9	9.3	1.9
10	6.9	3.6
11	5.4	3.0
12	6.3	4.5
13	3.9	3.3
14	3.4	3.7
15	4.9	2.8
16	4.9	2.1
17	3.9	1.8
18	3.7	2.2
19	4.6	2.4
20	4.2	1.8
21	3.7	1.9
22	1.2	1.8
23	0.7	1.3
24	0.1	0.6
	Concentration, ppb	Concentration, ppb
Average	796.5	419.0
St. Dev.	446.6	192.1
Minimum	26.0	115.1
Maximum	1836.6	886.8

Table 4. Random target deposition results as a percentage of tank concentration (19.8 ppm).

Target	3 mph			10 mph		
	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3
	Percent of tank mix			Percent of tank mix		
3	3.1	7.6	4.6	1.5	0.7	1.8
8	5.1	6.1	12.3	3.9	2.5	2.4
12	1.8	7.8	10.3	1.3	0.9	3.3
15	7.0	5.8	5.4	1.2	0.4	1.3
18	7.3	7.3	6.1	2.8	0.6	1.8
22	2.5	2.7	1.2	0.4	0.0	0.7

Table 5. Random target deposition averages for two test speeds; deposition for each replicate target location was averaged and normalized to average broadcast deposition (all 24 targets) and spray tank mix concentration (19.89 ppm).

	------- 3 mph ---------		-------- 10 mph ---------	
Target	Percent of broadcast	Percent of tank mix	Percent of broadcast	Percent of tank mix
3	100	5.1	63	1.3
8	100	7.8	100	2.9
12	100	6.6	87	1.8
15	100	6.1	46	1.0
18	100	6.9	82	1.7
22	53	2.1	18	0.4

Data Logging System

An environmental data and as-applied spray actuation location logging system was assembled from several manufacturers' standard components and a custom built communication gateway controller. The communication backbone of the data logging system (DLS) was a DGPS capable commercial spray rate controller (Model Legacy 6000, Midwest Technologies, Wheaton, IL) coupled with a Control Area Network (CAN) to allow a user interface console to communicate with and record data from four Product Control Modules, a Power Speed Module, and a Switch Sense Module. Analog inputs of the Product Control Modules were connected to sensors to detect wind speed, wind direction, ambient temperature, and roadside slope. In the instance that any of these measured conditions fell outside pre-defined minimum and maximum values, the communication gateway triggered the VCS to prevent ("lock-out") spray discharge. The measured environmental conditions and positions where valves were activated were recorded with GPS coordinates to produce maps of areas sprayed with corresponding environmental data at the time of spray. The user manual for the DLS is given in Appendix D.

The communication gateway was constructed to passively listen to the messages on the Control Area Network and to notify the VCS to disable the spray system if the environmental conditions exceeded preprogrammed threshold values. The gateway box also monitored inputs connected to solenoid valve drive lines in order to capture information on when valves were triggered and spray was being discharged from the vehicle. The gateway controller executed a sample and hold routine; valve pulses triggered the gateway controller to set an output line to the Switch Sense Module and hold the line high for 900 ms. In this way, the Legacy 6000, which logged 1 data point per second, could detect any valve triggered during the 1-second period without regard to the duration of the valve pulse.

A DGPS receiver (Model AgGPS 132, Trimble Navigation Ltd., Sunnyvale, CA) was connected to the Legacy 6000 console and was used to reference the environmental sensor data to current latitude and longitude coordinates. The geo-referenced data was written to a map file on a flash card for later retrieval and analysis. The GPS antenna was attached on the centerline of the vehicle between the CCD cameras (adjacent to the wind speed sensor). Since the antenna was a few meters in front of the spray valves actual locations of spray deposition were shifted backward from the referenced locations in software.

A directional wind speed sensor (Model Wind Sonic, Gill Instruments Ltd., Lymington, Hampshire, UK) was mounted above the cab of the truck and connected to two of the Product Control Modules. One output from the sensor indicated the relative wind speed (as measured from the moving vehicle). The second output from the sensor indicated the wind direction relative to the front of the truck (as measured from the moving vehicle). The Product Control Modules converted outputs into values that could be transferred over the CAN. The Legacy 6000 console recorded the measured wind speed with GPS coordinates to a map file on the flash card. The Raven radar-based speed and displacement sensor used to measure vehicle ground speed was interfaced to the VCS for spray timing purposes, and was also used by the communication gateway module to resolve absolute wind speed. That is, the gateway module subtracted the vehicle velocity vector from the relative wind velocity vector to calculate actual wind velocity. Actual wind velocity was compared with a pre-defined maximum wind threshold to ascertain if spray lock-out was needed.

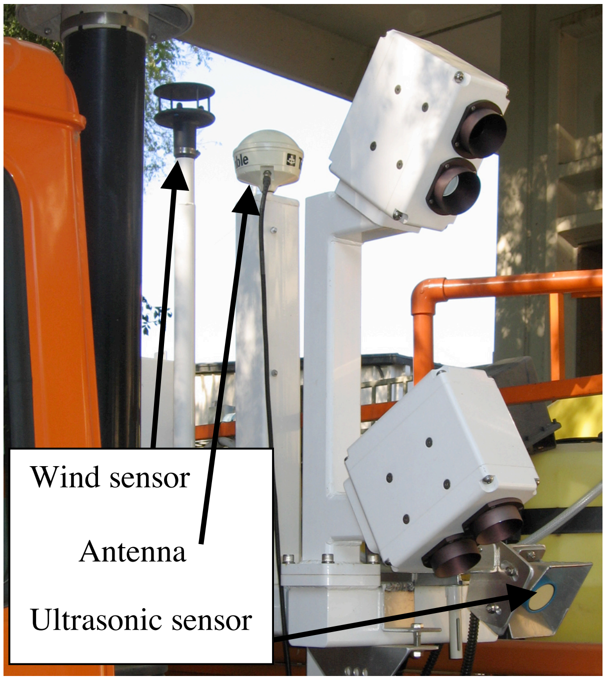
An RTD temperature sensor with radiation shield (Model TT-GPL-R-100, Enercorp Instruments Ltd., Toronto, ON) was also mounted beneath the camera frame and interfaced to the Product Control Module. Temperature values were transmitted on the CAN bus and recorded on a flash card. The communication gateway module compared temperature values with pre-defined minimum and maximum threshold values for control of the spray lock-out feature on the VCS.

Two ultrasonic distance sensors (Model UM30-15113, Sick AG, Waldkirch, Germany) were attached on the sides of the spray vehicle angled 40^{o} down from parallel to the ground as shown in Figure 10. The sensor outputs were routed through a SPDT relay switch to a single Product Control Module. The relay was controlled by a PLC signal indicating whether the sprayer was operating on the driver's side or the passenger's side. A description of the slope calculation is given in Appendix D. The DGPS antenna, wind speed sensor, ultrasonic sensor (and locations) and Legacy interface screen are shown in Figure 10.

Measurement Verification. Conversions from voltage to measured units were programmed into the Legacy Product Control Modules for each sensing instrument. Accuracy of sensor outputs and unit conversions were verified by comparing system measurements to those from other, independent, instruments. Because the DLS was designed to collect environmental conditions while moving, verification measurements were conducted on the moving vehicle. Included in the ambient condition tests were verifications of absolute wind speed, absolute wind direction, ambient temperature, roadside slope, and spray deposition geo-referencing.

All tests for the system interface and capturing of the environmental conditions were conducted on or near the UC Davis campus. For the wind velocity tests, conditions on the test day indicated wind direction from due north at an approximate speed of 4.5 m/s (10 mph). Ambient weather conditions included clear skies and a temperature of 11 C (52 ^{o}F). Environmental conditions and GPS latitude, longitude, and time stamp data were collected on the vehicle with the DLS. Wind conditions and time stamps were also recorded with a stationary weather station (Model Ultimeter 2000, Peet Bros., St. Cloud, FL). In order to validate the wind velocity correction algorithm, wind velocity minus vehicle velocity, the vehicle was driven east and west at varied speeds. Three repetitions of eastbound/westbound data were collected.

In post-process, GPS coordinates and time stamps were used to calculate the spray vehicle's velocity. Measured wind velocity was subtracted from vehicle velocity to calculate absolute wind velocity. Time-referenced wind speeds and wind directions were compared with those measured from the stationary weather station for accuracy verification. Table 6 shows the average measured wind speeds and average measured wind directions during a series of replicate test runs. Figure 11 displays an example test path with resulting wind vectors. Although the eastward and westward data points were nearly overlapping, the map shows that wind velocity was nearly the same for both travel directions. Data from Table 6 show that wind speed measured on the vehicle was consistently lower than the speed measured by the stationary instrument. However, two of the three averages were within one standard deviation of the stationary wind speed measurements.



(a)

(b)

Figure 10. DLS instrumentation: (a) DGPS antenna, wind sensor and ultrasonic sensor, (b) Legacy interface screen.

Table 6. Absolute wind speed and direction.

	Wind Speed (m/s)		Wind Direction (degrees)	
	On-board	Stationary	On-board	Stationary
Rep 1				
Average	4.582	5.167	339.7	346.8
Standard Deviation	1.138	1.071	18.7	15.6
Rep 2				
Average	4.184	6.083	321.8	320.9
Standard Deviation	1.243	0.891	18.9	15.0
Rep 3				
Average	4.499	5.328	325.9	351.6
Standard Deviation	1.627	0.889	18.6	16.7

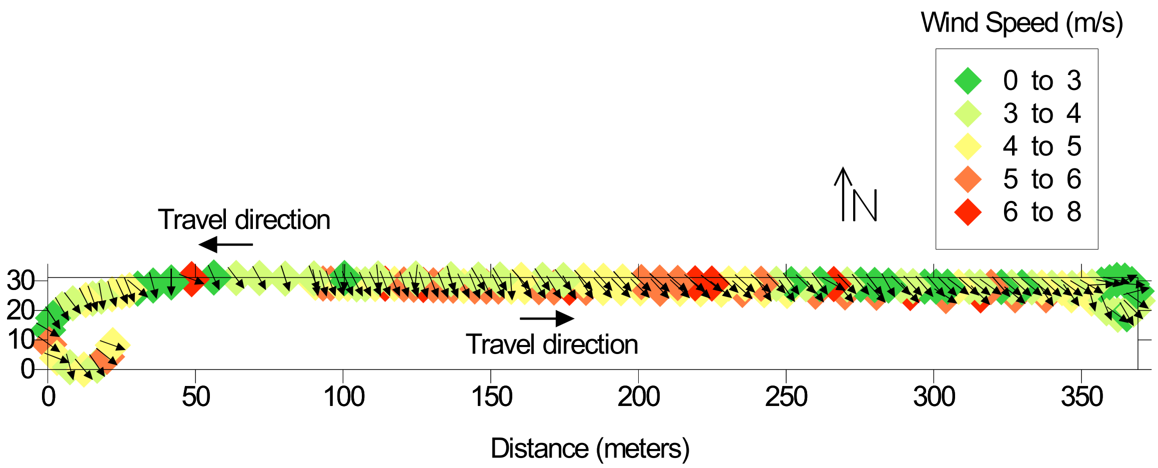


Figure 11. DGPS wind map from field verification tests

Ambient temperature measurements were recorded with the DLS and verified with a shaded stationary thermometer. Measurements on the vehicle were recorded while moving in order to prevent engine heat from increasing ambient temperature measurements; data are given in Table 7. Because ambient temperature changed slowly over time, visual representations of temperature data are not very revealing. In order to demonstrate the mapping capability of ambient temperature, data was collected on the spray vehicle in the morning, the vehicle was parked for a few hours, and collection was continued in mid-day. Figure 12 displays an ambient temperature map that indicates a temperature change between morning and afternoon hours. Results indicate that on-board temperature measurements were within 1 degree C of those obtained with the stationary thermometer. Because the efficacy of most agricultural chemicals changes over a large temperature range, the sensor accuracy was deemed sufficient for this application. Additionally, most maps revealed very little change in ambient temperature, but visual representations that were collected over large time intervals did indicate temperature fluctuation.

Table 7. Ambient temperature on spray vehicle vs. stationary thermometer.

Temperature (degrees C)	
On-board measurement	Actual
21.9	22
25.4	25
25.5	26
28.1	28
30.1	30

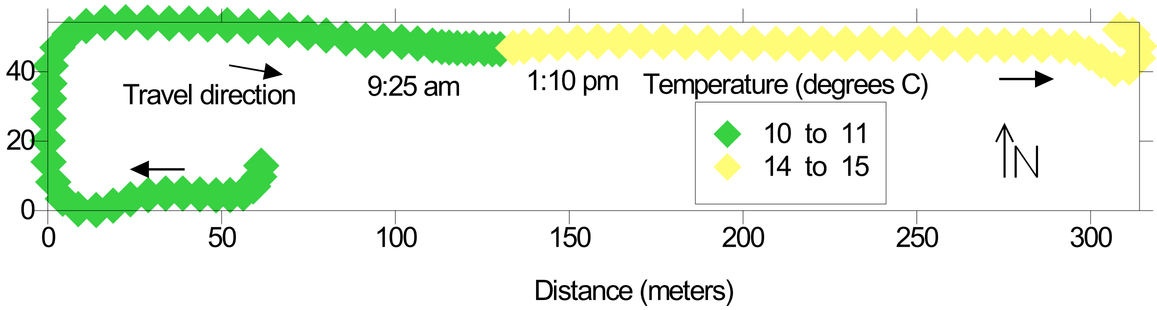


Figure 12. Temperature map of morning to mid-day.

Roadside slope assessments entailed measuring three repetitions of distance to the nearest roadside object with the ultrasonic sensors and recorded with the DLS while driving south on California State Highway 113 north of Davis, CA. The slope of the roadside varied widely and ranged from a ditch (with a negative slope), to flat sections, to inclined sections sloping upwards approximately 35 degrees. GPS latitude and longitude were also recorded to geo-reference the roadside distance data. Roadside slopes were also manually measured with a tape measure, to the top of the vegetation, and locations were recorded with a GPS unit with centimeter accuracy (Model RTK GPS, Trimble Navigation Ltd., Sunnyvale, CA).

Geo-referenced slope measurements were compared with those measured with a tape to validate the distance sensor calibration and slope calculations. Results are given in Table 8. The resulting slope measurements from the DLS averaged 3.2 degrees lower than those measured with a tape measure. Inaccuracies may have resulted because the ultrasonic sensor did not measure distance to a point but distance to the nearest object in an area, and with uneven terrain, roadside slopes were not exact values. However, the system could estimate the slope within a few degrees, allowing possible spray lockouts for roadside slopes outside those practical for spraying.

Spray deposition assessments with geo-referencing were also determined. The Legacy 6000 system with Roadway Management Software contained geo-referenced corrections for different positions on a spray boom. However, the software did not support automatic correction for an offset between the GPS antenna and the boom. That is, the software assumed that the antenna was located at the center of the spray boom as is the case in the IHAS vehicle. Thus the correction for an offset between the GPS antenna and the boom must be done manually using some type of geographic information system (GIS) software package.

As the data logging system recorded environmental conditions and spray valve activation, GPS coordinates were assigned to locations at which valves were triggered for spray. Due to limitations on the number of inputs that could be recorded by the Legacy 6000 system, the spray status (i.e., on or off) of 8 of the 24 IHAS valves were recorded by the Legacy 6000 system. Valve numbers 2, 5, 8, 11, 14, 17, 20, 23 were interfaced to the Legacy 6000 system corresponding to target locations 0.5 m, 1 m, 1.4 m, 1.9 m, 2.4 m, 2.8 m, 3.3 m, and 3.7 m from

Table 8. Measured roadside slope versus actual slope.

On-board measurement Distance (cm)	Slope (degrees)	Actual Slope (degrees)
321.1	-4.3	-1.2
319.7	-4.1	-0.6
319.3	-4.0	-1.2
341.9	-6.9	-5.4
339.3	-6.6	-4.8
339.3	-6.6	-4.8
210.8	18.0	18.4
215.2	16.8	20.0
194.9	22.8	23.6
185.8	25.7	27.5
195.4	22.6	30.3
214.9	16.8	26.7

the edge of the truck. Normally, the IHAS is operated in "expanded pattern" mode where three valves (the one directly targeting the weed plus the two adjacent valves) are activated for each weed to be sprayed. Thus in expanded spray pattern mode, when a weed is to be sprayed by one of the 16 valves not interfaced to the Legacy 6000 system, one of the 8 valves that is interfaced to the Legacy 6000 system will also be activated because it will be adjacent to an activated valve and thus will also be activated as part of the expanded spray pattern. This allows the complete GPS spray logging of the entire 3.6 m (12 foot) region scanned by the IHAS when operated normally. If the operator deactivates the expanded pattern mode, the spray activation of the 16 valves not interfaced to the Legacy 6000 system will not be recorded.

The DLS recorded the GPS location of the GPS antenna when a valve was activated. The GPS location of the actual spray deposition must be calculated from the truck location at the time of valve actuation, the distance from the GPS antenna to the spray nozzle, the time of flight of the spray packet, and the vehicle travel speed. Since the GPS antenna was mounted on the camera frame, the distance in the direction of travel from the GPS antenna to the spray nozzle was the same as the distance from the camera to the spray nozzle stored in the VCS. The spray packed time of flight was also stored in the VCS for each nozzle.

A spray test was conducted to verify the geographical relationship between the logged locations and the actual locations of spray deposition. GPS antenna locations were recorded with the on-board system as solenoid valves were triggered for green spray targets under normal IHAS operation. A centimeter-accurate GPS sensor (Model RTK GPS, Trimble Navigation Ltd., Sunnyvale, CA) was used to determine the actual locations of spray deposition on the ground. Three repetitions at three different travel speeds (0.9 m/s, 2.7 m/s, and 4.5 m/s) were executed to gather data from spray deposition locations and valve-trigger locations from the data logging system; data results are given in Table 9.

Table 9. Geo-referenced offset between valve triggers and actual spray deposition.

	Offset between GPS map location and actual spray deposition		
	In the direction of travel (m)		Perpendicular to the Direction of travel (m)
Vehicle Speed (m/s)	Raw Data	Post-Process Corrected	
4.47	6.93	0.10	0.12
4.47	6.70	-0.13	-0.17
0.89	3.51	0.23	0.16
0.89	3.42	0.14	-0.21
0.89	3.48	0.20	0.26
0.89	3.27	-0.01	0.02
2.68	5.05	0.00	0.50
2.68	4.93	-0.12	0.16
2.68	5.15	0.10	0.51
2.68	5.15	0.10	0.18
0.89	2.96	-0.32	0.54
0.89	3.04	-0.24	0.26
4.47	6.78	-0.05	0.62
4.47	6.89	0.06	0.07
4.47	6.91	0.08	0.59
4.47	6.73	-0.10	-0.25

As Table 9 indicates, large discrepancies existed between the raw (uncorrected) recorded valve-trigger locations and the locations of spray deposition in the direction of travel. A portion of these differences resulted from the physical offset between the GPS antenna and the location of the spray valves and the time of flight for spray packets. Additionally, because the valve-trigger data was recorded once per second while spray valves were activated at up to a 10 Hz rate, the location differences also varied as a function of vehicle speed. To correct for both of these sources of error, a plot of the raw position offset error versus vehicle travel speed was made (figure 13). A linear regression analysis was used to develop a correction equation based upon travel speed. When this equation was used to correct the spray deposition location in the direction of travel, the resulting differences were within the expected uncertainty of the system.

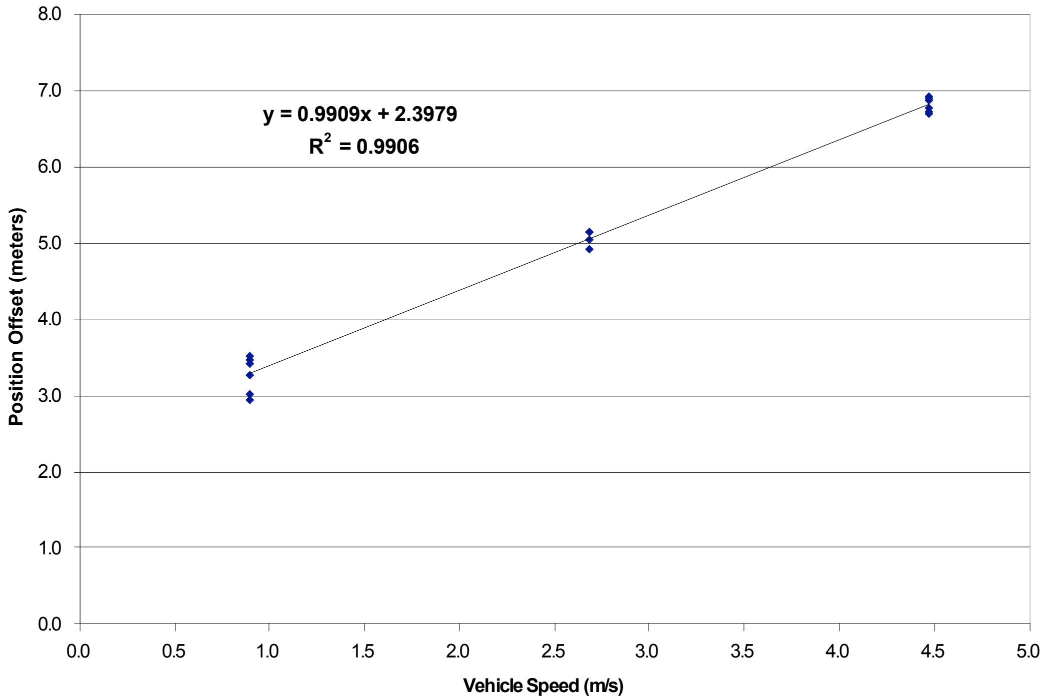


Figure 13. Plot of position offset in the direction of travel of GPS map data from actual spray deposition versus vehicle travel speed.

The IHAS/Legacy spray lock-out function was tested for each of the predetermined and programmed thresholds: maximum wind speed, minimum temperature, maximum temperature, minimum roadside slope, and maximum roadside slope. The thresholds were set to values typically achievable on the day of the test. Note that Appendix D provides programming information for the Legacy.

The Legacy system is capable of alarming the driver if the truck is within 1000 ft of a “hazard”, for example a school location. The locations of the hazards must be pre-defined in a road markers map. For use with the IHAS truck, hazard markers are placed around the perimeter of schools in a road-markers map. This map file is then used by the Legacy system to alarm the driver when the spray truck is too close to a school. The driver must then shut off spray until there is an acceptable distance between the truck and the school (the alarm will stop). ***Note that the truck will not automatically turn the spray off. It is the responsibility of the driver to act when the alarm sounds.***

Conclusions

A commercial prototype displacement-based precision valve control system (VCS) was successfully developed and installed on a Caltrans herbicide spray vehicle. The VCS was designed to serve as the main controller in the commercial IHAS prototype completed and described in this document. The VCS was designed to function in a parallel “add-on” mode and was compatible with the existing Raven variable-rate herbicide injection system. Additionally, the interface allows Caltrans to operate the vehicle in a non-IHAS mode if desired.

A fluid handling system was designed for the IHAS and functions in a parallel "add-on" mode to allow compatibility with, non-IHAS, variable-rate herbicide injection systems currently used on Caltrans herbicide spray vehicles. An IHAS valve tower with 3-way valves (one per spray nozzle) served as the basis for the IHAS fluid handling system. This design has two benefits. First, provides a means of maintaining a constant pressure at the valve and is independent of the number of valves activated. Second, it allows bypass spray mix to be recycled in a small loop through the pump and 3-way valves. This provides a small fluid buffer to minimize variation in herbicide concentration as the number of spray valves activated varies.

Two different control methods were developed (boom switch and ration rate) for the IHAS and was compatible with the existing Raven chemical injection controller. The response times of the Raven controller in IHAS mode were characterized, and results indicate that the system was able to maintain spray mix concentrations within 10% of the desired level throughout the range of flowrates possible in IHAS mode. Also, results found that fluid pressure at the valves was very consistent over the range of flowrates possible in IHAS mode. In general, the boom switch and ratio rate control modes gave comparable performance, with the ratio rate mode showing a reduced ability to respond to rapid demand changes at high application rates. The boom switch mode had the advantage of “looking ahead”, so the VCS could anticipate upcoming spray demand changes and reduces concentration delays associated with the Raven response time.

A commercial prototype weed mapping system (WMS) for IHAS was successfully developed. The WMS uses color machine vision to map weeds growing along the roadway shoulder. Eight 3-CCD video cameras were deployed, four on each side of the spray vehicle for detecting weeds in both direct sunlight and in shadows along the roadway shoulder. The WMS successfully identified weeds of 3.81 cm^2 or larger. 3-CCD technology successfully eliminated false detection non-plant scenes such as black and white gravel or dark cracks in bare soil surfaces.

A DGPS data logging system (DLS) was installed for capturing location and environmental information while actively spraying roadside shoulders. Environmental conditions can affect the quality of herbicide application due to excessive wind, and ambient temperatures may degrade applied chemicals. Additionally, roadside slopes result in the spray trajectories missing intended targets. These conditions are now monitored, with later data retrieval capabilities, to ensure accurate spray applications in addition to having the capability to lock-out automated spray applications based on pre-determined off-limit areas.

The prototype IHAS can enhance Caltrans effectiveness at minimizing herbicide release into the environment and providing protection along areas that are environmentally sensitive.

Appendix A: Adaptive Equipment VCS Manual

Adaptive
Equipment
Gainesville, FL

Valve Control System

Documentation r1
August 24, 2001

Customer: **University of California**
Davis, CA

AE Contacts: **Ward Simonton**
Roy Harrell

2512 NE 1st Blvd
Unit 400
Gainesville, FL 32609
352-372-7821

I. SAFETY

A. Basic Safety Practices

- All personnel responsible for servicing or operating this system should read this documentation.
- Electrical power should be turned off and locked out before servicing the system. The main electrical cabinet contains 120 VAC connections. Service should not be performed without removing power beforehand. Reference wiring diagrams UC.WD.01-08.
- One system stop is provided: a red palm button mounted on a remote electrical box referred to as OI/S (Operator Interface/Switches). When the red palm button is pressed, the Master Control Relay in the control panel will be de-energized and power to the control relays for the spray nozzles will be removed.
- On a system stop, power will not be removed from sensors, pilot lights, or interface electronics.

II. SYSTEM FUNCTIONALITY

A. Overview

The Valve Control System (VCS) is a truck mounted system designed to energize and de-energize 12 valves at rates up to 30 Hz each for the purpose of road side spraying. Valves can be placed into one of three modes: OFF, ON (valves are on continuously), and AUTOMATIC (valves are controlled based on a dynamic spray pattern). Spray patterns must be transferred to the control system through an Ethernet communication port using direct addressing of controller memory. Travel speed and distance is measured using a radar sensor with displacement output. The effects of a range of operating speeds, spray flight travel times, and distance between spray pattern sensor and valves are accommodated for in the controls.

B. Specifications

1. Max operating travel speed = 10 mph
2. Range of spray pattern band[1] widths = 6” to 12”
3. Range of spray pattern bands per block or image = 3 to 7
4. Max number of bands between spray pattern sensor and spray boom = 40
5. Max time of flight for nozzle stream = 0.5 s
6. Programmable minimum valve open time (for entire valve set)
7. Programmable valve lead time (for entire valve set)

[1] A band is a columnar section of a spray pattern block or processed image.

III. SYSTEM OPERATION

A. Cabinet Startup

All circuit breakers should be in the On position (UC01.WD.01 and UC01.EL.01). The SLC505 PLC (programmable logic controller) is the primary control device in the system. When 120 VAC power is applied to the main control panel, the SLC505 will initialize provided that it is in Run Mode. The mode of the SLC505 is set by a key on the unit. OI/S can be used to power up the PC as described in Section III.C.

B. Cabinet Shutdown

Before removing 120 VAC power from the cabinet, the PC should be made to go through a controlled shutdown as described in Section III.C below. Once the white status light on OI/S goes from ON to OFF indicating that the PC has completed a shutdown, then power can be removed from the cabinet.

C. PC Power up and Shutdown

OI/S (see Section III.D below for a complete description of OI/S functionality) can be used to remotely power up and shutdown the PC using the three position selector switch. For this switch to be active, (a) the red pushbutton (for Stop Spraying) must be depressed, (b) the PLC must be powered and in Run Mode, and (c) 24 VDC control power must be available. Turning the switch momentarily to the right will initiate power up on the PC; the PC will boot, load the WinNT operating system, perform an Auto Login, and load two applications (an operator interface (OI/PC) and a sample program for PLC interfacing). The status light on OI/S will go from ON to OFF when the PC has completed the boot process (2 minutes) and is ready for operation.

To shutdown the PC, the selector switch on OI/S can be turned momentarily to the left. The PLC then sets a flag that is read by the sample interfacing program running on the PC noted above; this PC program resets the PLC flag as an acknowledgement, then it launches a WinNT shutdown application. When the status light on OI/S goes from ON to OFF (50 seconds after the PC acknowledgement), the PC should have completed the shutdown. Note that there is no positive feedback on this process.

Note: If the PC is booted using the OI/S switch, then it should be shut down with this switch also. This is due to PC power up and shutdown interlocks embedded in the PLC control software.

The PC can also be booted using the switch located on the PC enclosure. This switch (when toggled to the right) is identical to many off-the-shelf PC power buttons: (a) momentary action when PC is not powered=power up signal; (b) momentary action when PC is powered=sleep signal; (c) action of greater than 4 seconds=power down signal. There is no connection with this switch and the PLC control system.

Note: If the PC is booted using the switch on the PC enclosure, it should be shut down with this switch also. This switch may be used if the PLC is not powered or not in run mode.

D. Operator Interface/Switches (OI/S)

OI/S is a hard wired PLC interface. There are four panel devices on OI/S.

1. The three position selector switch requests the PLC to control PC power up and shutdown as described above.

2. The green pushbutton enables spraying.

3. The red palm button <u>disables</u> spraying and <u>enables</u> PC power control when depressed.

4. The panel light is used to signal several events:
   (a) PC power up in progress;
   (b) PC shutdown in progress;
   (c) spraying has been initiated but there is no spray pattern data available; or
   (d) invalid parameter data (e.g. bandwidth, number of bands, etc) has been entered into the controller.

E. Operator Interface/Touch Panel (OI/TP)

OI/TP is a PLC interface and operates over a continuous RS232 communication channel. Its primary function is to allow the truck operator to individually set valves to either OFF, ON, or AUTO mode. OI/TP also displays to the operator the following information: spraying status, the relative spray rate averaged over a 1.0 second period, and whether or not the main control cabinet is overheated. OI/TP is a programmable interface and can be configured for many other operator functions.

F. Operator Interface/PC (OI/PC)

OI/PC is a software application on the PC that allows for configuring both valve/nozzle and vision parameters in the PLC. When OI/PC loads, the current PLC parameters are read and displayed. Parameters can be edited, and when the proper values are entered, can be updated to the PLC. OI/PC operates over Ethernet and performs PLC communication on an event-driven basis.

G. Spraying

The spray pattern for the set of 12 valve/nozzle pairs will depend upon the mode configuration for each valve (OFF, ON, AUTO) and the spray pattern sent to the PLC. To begin spraying, the red palm button on OI/S must be released and the green push button pressed momentarily. Spraying is then enabled. Nozzles whose valves have been configured in ON mode will begin spraying immediately. AUTO mode for those nozzles so configured will be initiated when the truck speed is greater than approximately 1.5 mph. Control parameters used for AUTO mode are updated dynamically as the truck speed changes.

IV. ELECTRICAL OVERVIEW

A. Electrical System Documentation

Refer to UC01.WD.01-08, UC01.EL.01-03, and the Cables & Connectors table for a complete description of the electrical system. All are bound together in a separate binder.

B. Power

The following table outlines power requirements for the control system.

Qty	Device	Voltage	Load (A)	Power (W)	Cable #	Service	Manufacturer
1	input power	120 VAC	10.0	1200	1	10	
1	PC	120 VAC	1.7	200	2	6	Dog Bytes
1	monitor & cabinet fans	120 VAC	1.3	150	3	6	
1	PLC	120 VAC	0.6	75	4	2	Allen-Bradley
1	24 Vdc power supply	120 VAC	0.6	76	5	2	idec
			AC load =	**501**			
12	valves (set 1)	12 VDC	12.0	144	7	16	UCD
1	ground speed sensor	12 VDC	0.3	3.6	"		Raven
12	valves (set 2)	12 VDC	12.0	144.0	8	16	UCD
1	boom switch interface	12 VDC			"		
			12V load =	**292**			
1	24 Vdc output	24 VDC	1.3	30	6	2	
24	solid state relays	24 VDC	0.48	11.5			Phoenix
4	solid state relays	24 VDC	0.06	1.4			Weidmuller
5	solid state relays	24 VDC	0.10	2.4			Phoenix
1	touch panel	24 VDC	0.75	18.0			AD
			24V load =	**33**			

C. Controller

The controller for the VCS is an Allen-Bradley SLC505 programmable logic controller. This controller has one RS232C serial port and one 10 Mb Ethernet port to support processor communications. Ladder logic is used to program the controller.

D. Valve Control

Twelve PLC 24 VDC outputs are used for independent valve/nozzle control (UC01.WD.03). Each output controls a solid state relay, the output of which is 12 VDC. For future expansion, additional outputs have been installed in Slot 2.

E. Boom Switch Interface

Five PLC 24 VDC outputs are used to interface with the Raven boom switch box (UC01.WD.03). Each output controls a solid state relay, the output of which is 12 VDC. The five outputs are used to transmit a 0-31 decimal value to indicate a normalized rate of spraying over a one (1) second period.

F. Spray Pattern Sensor Triggering

Two PLC 24 VDC outputs are used for independent sensor triggering and vision frame acquisition (UC01.WD.03). The sensor, or camera, trigger output controls a solid state relay, the output of which is a 5 V TTL pulse signal. The frame acquisition output also controls a solid state relay, the output of which is a 5 VDC pulse signal. A spare TTL and a spare generic 5 VDC solid state relay are included to match sensor and frame electronics needs.

G. PC Control

One PLC 24 VDC output is used for controlling the power up and shutdown of the PC (UC01.WD.04). The PLC output controls a mechanical relay, the output of which is used to connect the Power Control input on the PC motherboard to PC common (O VDC).

H. Raven Radar Sensor

The pulse output of the Raven radar sensor is used to track truck position change and to calculate truck speed. The output of the sensor is used to drive a high speed counter module located in slot 5 of the PLC (UC01.WD.05). Due to the sensor having a 12 VDC output, an 1800 ohm resistor is used to reduce the voltage that is input to the counter module.

I. Cabinet Fan

An electrical cabinet fan and vent is included to assist in cooling during operation or system testing. The fan may or may not be required depending upon future testing and environmental conditions. Regardless of whether the fan is actively used, periodic cleaning and replacing of the vent filter elements will be required. Frequency will depend also on environmental conditions.

V. SOFTWARE OVERVIEW

A. PLC

The primary control software for the VCS is sprayer.rss, a ladder logic program for the AB SLC505 PLC. RSLogix500, a Rockwell Software development application, was used to write and debug the software. The program is divided into three separate routines: MAIN, which contains the majority of the control logic; UPDATE, which performs calculations when system parameters has been updated; and NEW_IMAGE, which performs the required calculations and logic upon each instance of an image boundary being crossed.

B. PC Operator Interface (OI/PC)

The PC operator interface, ValveControlOI.exe, is a Visual Basic program that provides a means to configure valve/nozzle and vision parameters in the PLC. This program uses four screens for displaying data, editing data, and sending data to the PLC.

C. Sample Power Up and Shutdown PC Application

The Visual Basic program ShutdownTest.exe is a sample method of how to interface with the PLC regarding PC startup and shutdown. This program is designed to load during the WinNT automatic login procedure and communicate to the PLC that the PC is ready for operation. Every two seconds afterwards, the program checks to determine if the PLC has requested a PC shutdown event. If so, the program will acknowledge the request and then initiate a WinNT shutdown procedure.

D. Spray Pattern Emulator

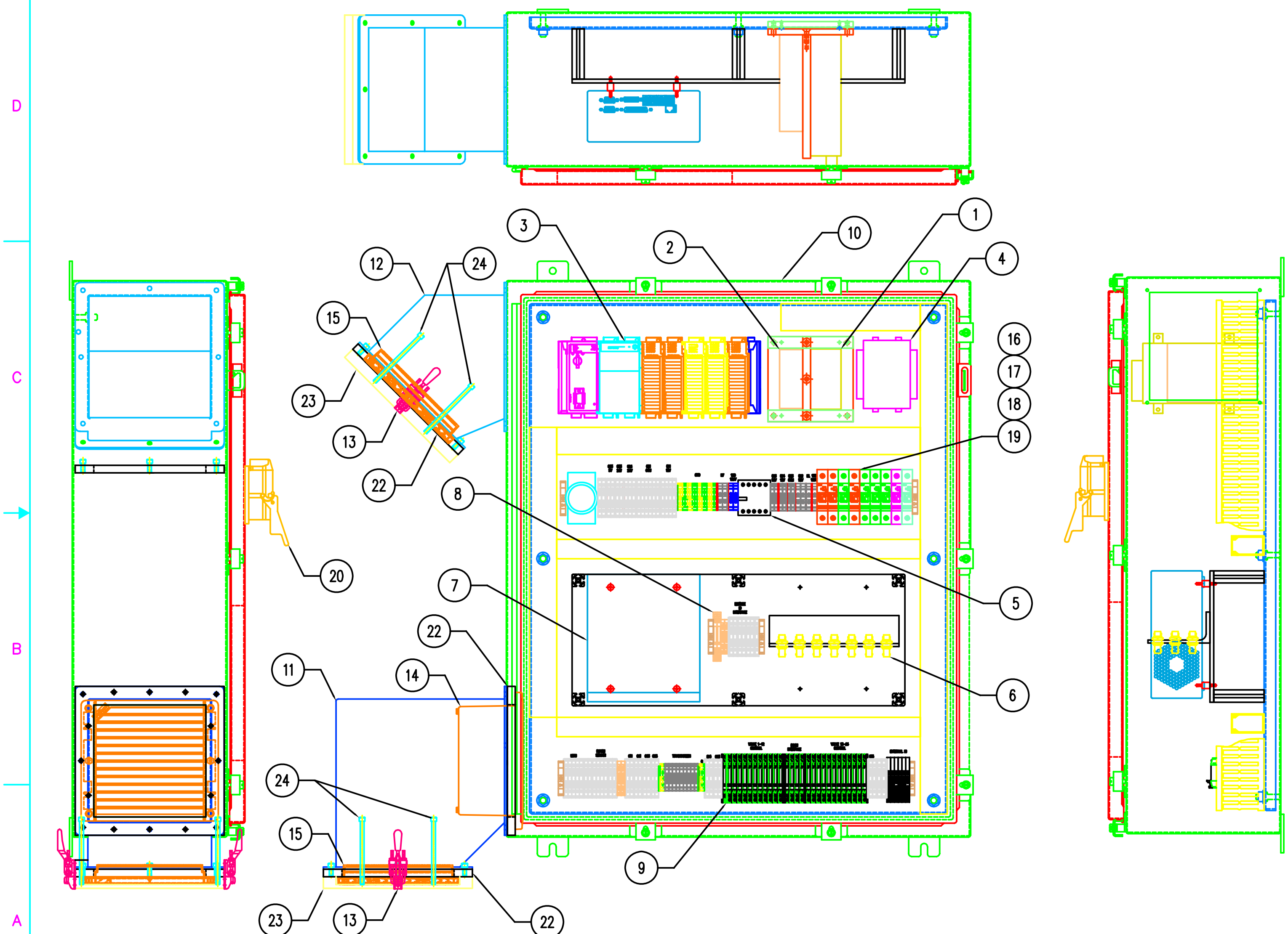
The Visual Basic program Emulator R3.exe generates various spray patterns to emulate processed vision data. Data generated to emulate a spray map is displayed graphically. Patterns include random, checkerboard, vertical striping, and sinusoidal. Each pattern can be configured for frequency, etc. Patterns can be dilated. These patterns can be transmitted in real time to the PLC for live spraying tests.

E. PLC-PC Communication

Each of the Visual Basic programs described above use OPC software for PLC-PC communication. OPC, “OLE for Process Control,” is a software standard providing a means for applications on personal computers to exchange data with other personal computer applications and with control computers such as programmable logic controllers. OPC is analogous to TCP/IP in that it is a layered software protocol independent of the hardware. However, unlike TCP/IP, OPC has a user layer that is designed for embedded configuration and communication in applications such as those written in Visual Basic and C.

The VCS uses two purchased programs to embed OPC functionality: AB Ethernet Suite Top Server and OPC Data ActiveX Control. The former contains both an Ethernet driver to establish communication with the SLC505 PLC and an OPC server. The latter encapsulates the many OPC function calls into an ActiveX container to greatly simplify programming. The ActiveX control can be used in C programs in addition to Visual Basic programs. Both the AB Ethernet Suite Top Server and the OPC Data ActiveX Control were purchased from Software Toolbox, Matthews, NC.

Appendix B: VCS & WMS Electrical Schematics from Adaptive Equipment

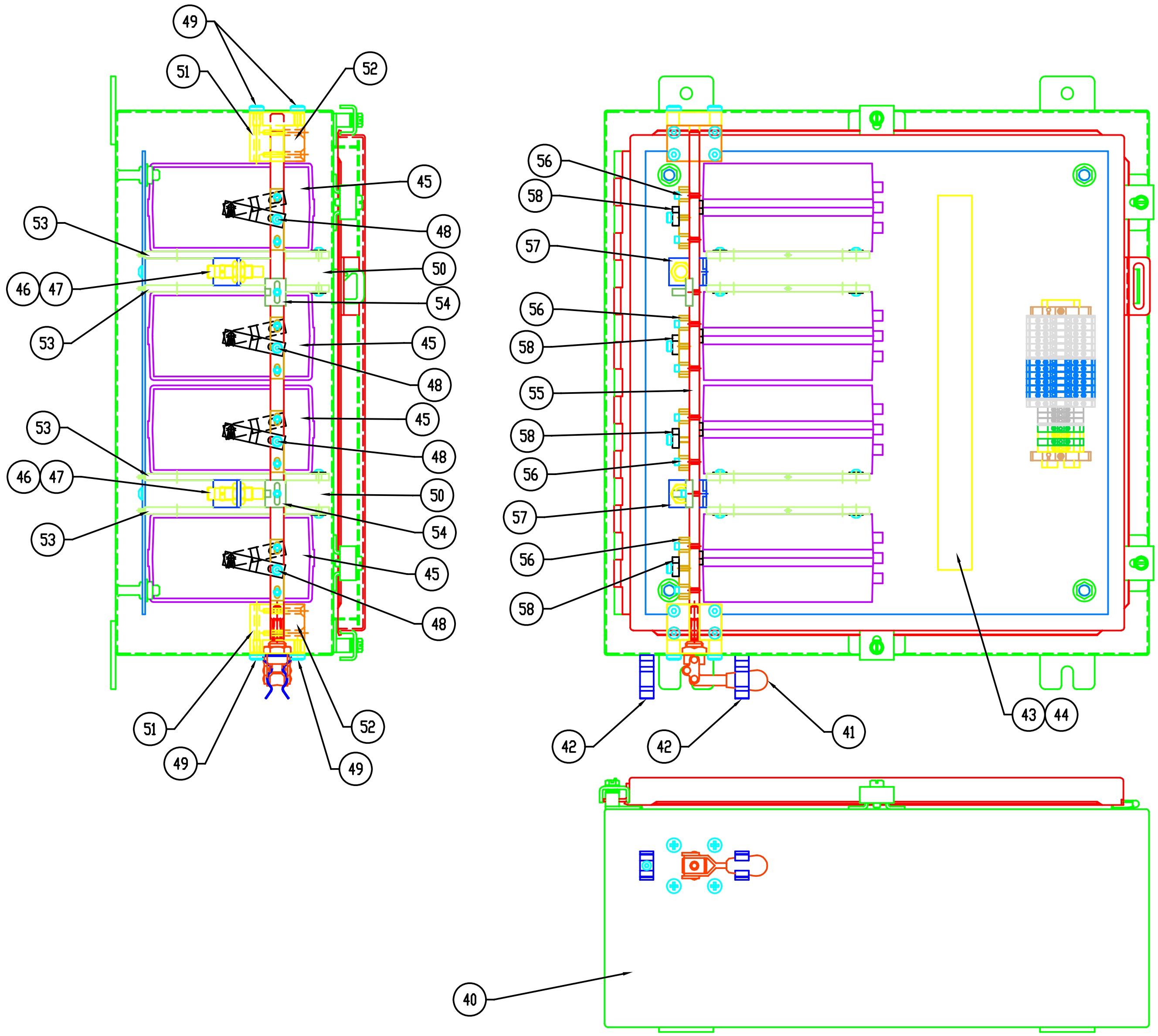


REVISIONS

UC02.EL.01

Adaptive Equipment Gainesville, FL	CUSTOMER UNIV OF CALIFORNIA DAVIS, CA
PROJECT VALVE CONTROL SYSTEM	
UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE INCHES	UNSPECIFIED TOLERANCES LINEAR ±0.005 [0.000] ±0.01 [0.00] ±0.03 [0.0] ANGULAR ±0.5°
DRAWN MB 10/29/03	3RD ANGLE PROJECTION
CHECKED WS 03/02/04	
ASSEMBLY	
MATERIAL n/a	
FINISH n/a	HARDNESS n/a
TITLE MAIN CABINET	
SCALE n/a · SIZE D · DRAWING NO UC02.EL.01	REV 0

REVISIONS



UC02.EL.02

Adaptive Equipment
Gainesville, FL

CUSTOMER: UNIV OF CALIFORNIA
DAVIS, CA

PROJECT: VALVE CONTROL SYSTEM

UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE INCHES

UNSPECIFIED TOLERANCES: n/a

3RD ANGLE PROJECTION

DRAWN	MB	10/29/03
CHECKED	WS	10/29/03

ASSEMBLY

MATERIAL: n/a

FINISH: n/a

HARDNESS: n/a

TITLE: VIDEO SWITCH CABINET

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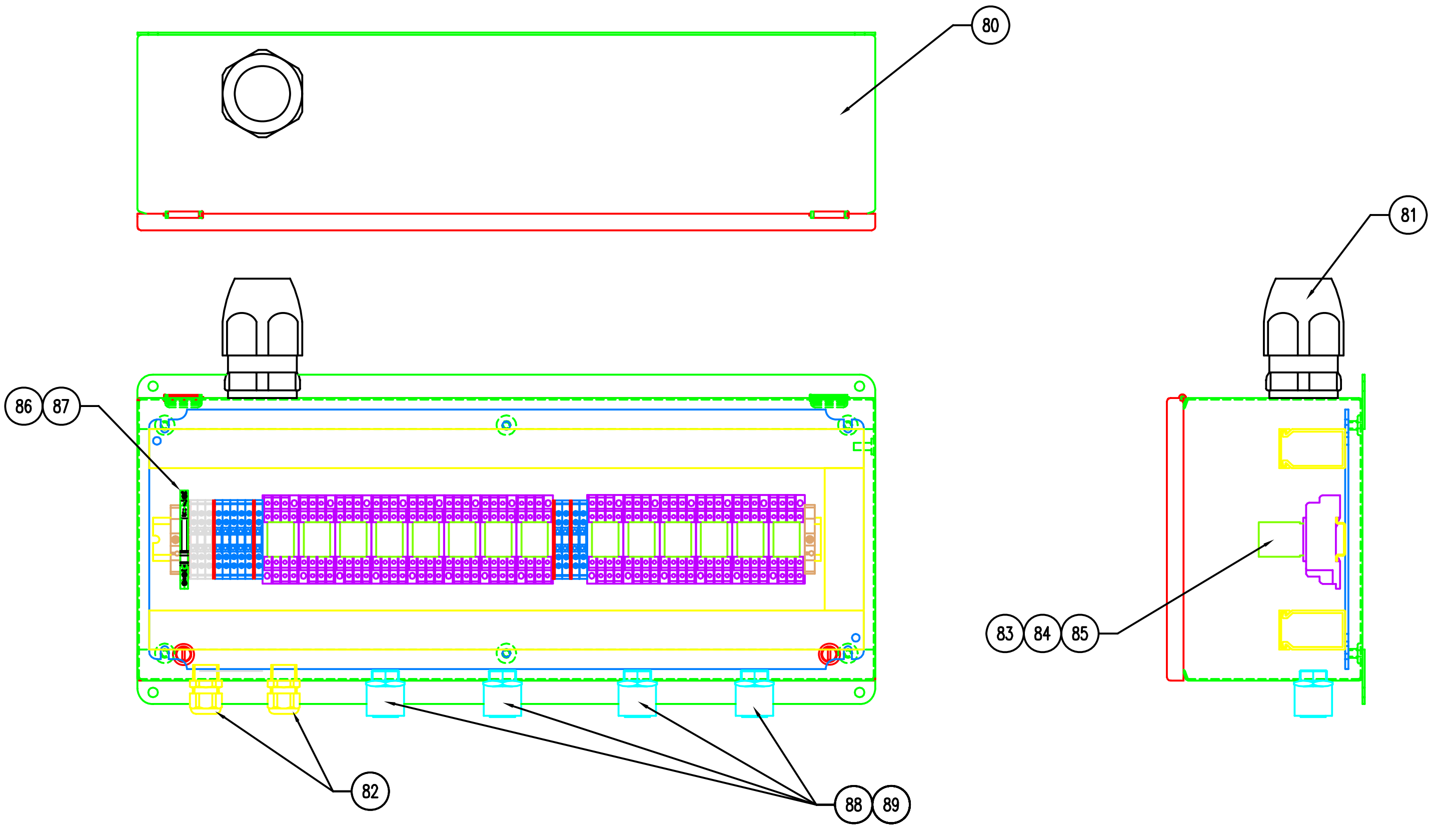

REVISIONS

Adaptive Equipment
Gainesville, FL

CUSTOMER
UNIV OF CALIFORNIA
DAVIS, CA

PROJECT VALVE CONTROL SYSTEM

UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE INCHES			UNSPECIFIED TOLERANCES n/a	3RD ANGLE PROJECTION
DRAWN	MB	11/10/03		
CHECKED	WS	11/10/03		

ASSEMBLY

MATERIAL n/a

FINISH n/a HARDNESS n/a

TITLE VALVE RELAY CABINET

SCALE	SIZE	DRAWING NO	REV
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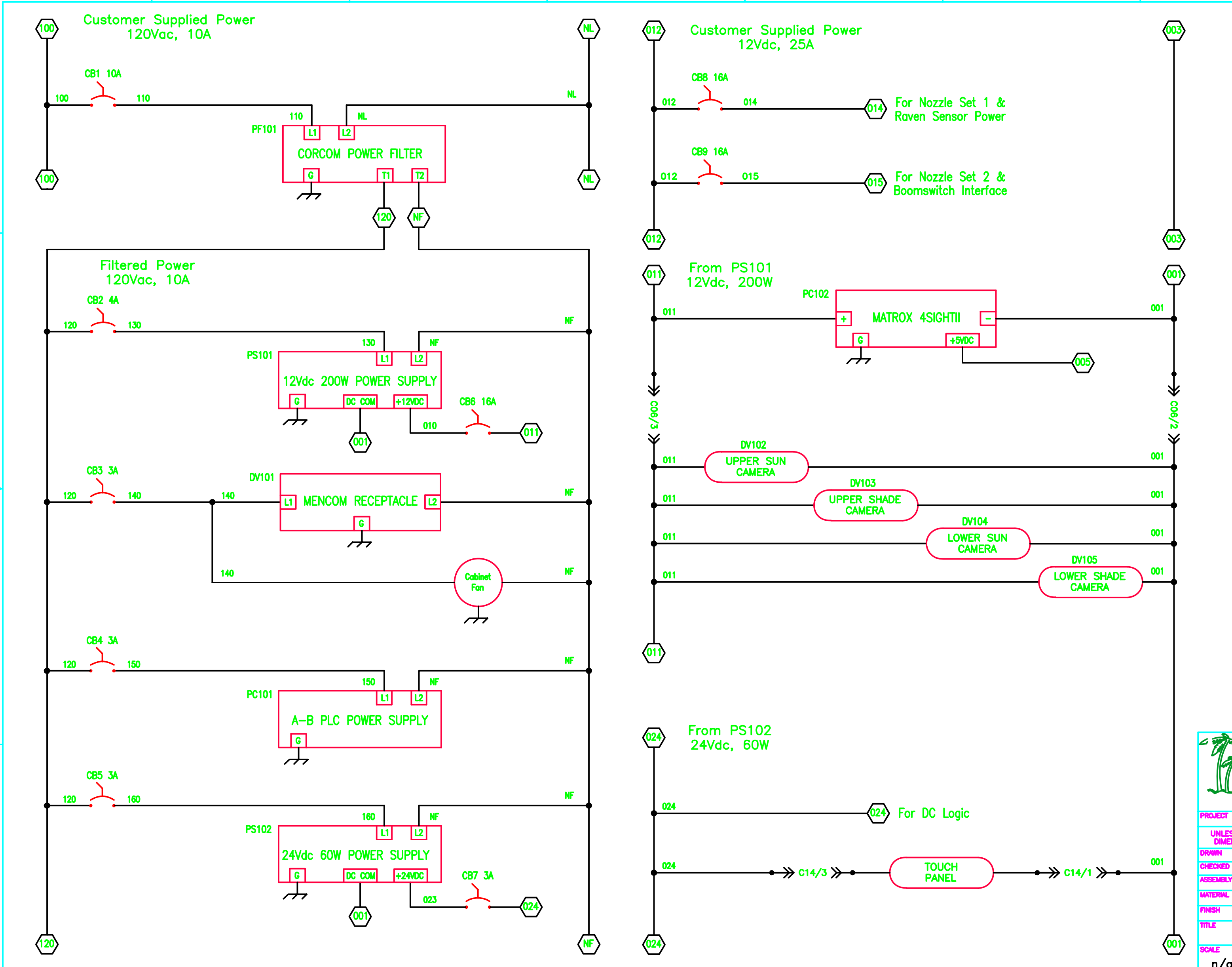
UC01.EL.03



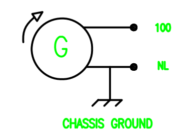
REVISIONS

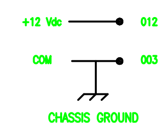
		DWN	DSN	APV	ENG	MM/DD/YY
0	PRELIMINARY					

WIRING DIAGRAMS	DESCRIPTION
UC02.WD01	POWER DISTRIBUTION
UC02.WD02	OPERATOR INTERFACE
UC02.WD03	PLC IO MODULES 1 & 2
UC02.WD04	PLC IO MODULES 3 & 4
UC02.WD05	PLC IO MODULE 5
UC02.WD06	VALVE DIR. CONTROL (A)
UC02.WD07	VALVE DIR. CONTROL (B)

CABLE DIAGRAMS	DESCRIPTION
UC02.CB01	CABLE LAYOUT
UC02.CB02	IMAGING CABLE DETAIL
UC02.CB03	HITACHI BREAKOUT CABLE
UC02.CB04	VIDEO EXTENSION CABLE
UC02.CB05	MAIN CABINET BNC CONNS

C#/# indicates cable and conductor nums.





Adaptive Equipment
Gainesville, FL

CUSTOMER: UNIV OF CALIFORNIA
DAVIS, CA

PROJECT: VALVE CONTROL SYSTEM

UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE MILLIMETERS

UNSPECIFIED TOLERANCES: n/a

DRAWN	WS	10/20/03
CHECKED	BC	03/01/04

3RD ANGLE PROJECTION

ASSEMBLY

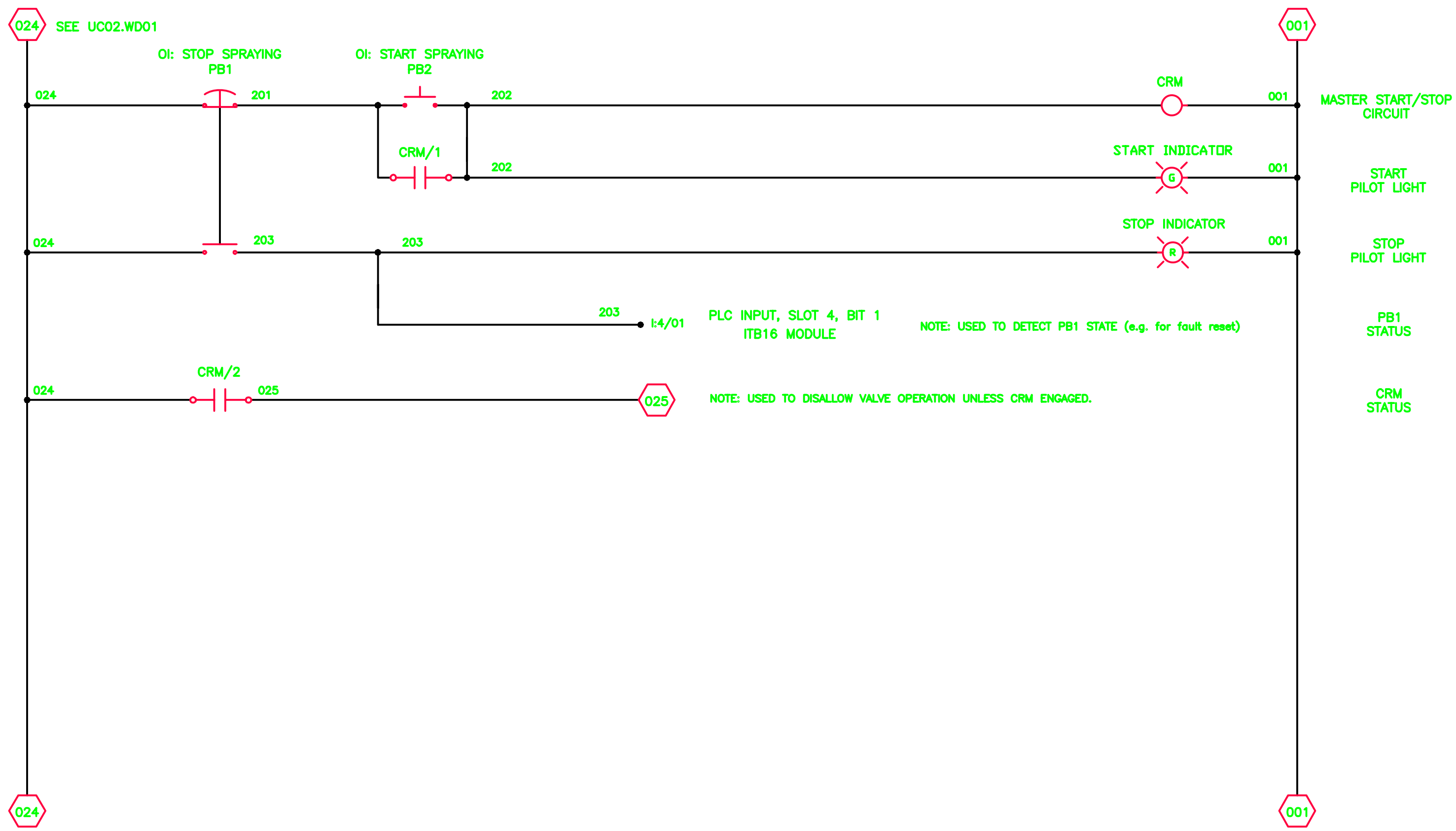
MATERIAL: n/a

FINISH: n/a — HARDNESS: n/a

TITLE: POWER DISTRIBUTION

SCALE: n/a — SIZE: D — DRAWING NO: UC02.WD01 — REV: 0

UC02.WD01



REVISIONS

		DWN	DSN	APV	ENG	MM/DD/YY
0	PRELIMINARY					

WIRING DIAGRAMS	DESCRIPTION
UC02.WD01	POWER DISTRIBUTION
UC02.WD02	OPERATOR INTERFACE
UC02.WD03	PLC IO MODULES 1 & 2
UC02.WD04	PLC IO MODULES 3 & 4
UC02.WD05	PLC IO MODULE 5
UC02.WD06	VALVE DIR. CONTROL (A)
UC02.WD07	VALVE DIR. CONTROL (B)

CABLE DIAGRAMS	DESCRIPTION
UC02.CB01	CABLE LAYOUT
UC02.CB02	IMAGING CABLE DETAIL
UC02.CB03	HITACHI BREAKOUT CABLE
UC02.CB04	VIDEO EXTENSION CABLE
UC02.CB05	MAIN CABINET BNC CONNS

Note:

Conductors in cable C14 regarding UC02.WD02: 024 (3), 001 (1), 201 (8), 202 (9), 203 (10).

UC02.WD02

Adaptive Equipment
Gainesville, FL

CUSTOMER: UNIV OF CALIFORNIA
DAVIS, CA

PROJECT: VALVE CONTROL SYSTEM

UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE MILLIMETERS

UNSPECIFIED TOLERANCES: n/a

3RD ANGLE PROJECTION

DRAWN	WS	10/20/03
CHECKED	BC	03/01/04
ASSEMBLY		

MATERIAL: n/a

FINISH: n/a — HARDNESS: n/a

TITLE: OPERATOR INTERFACE

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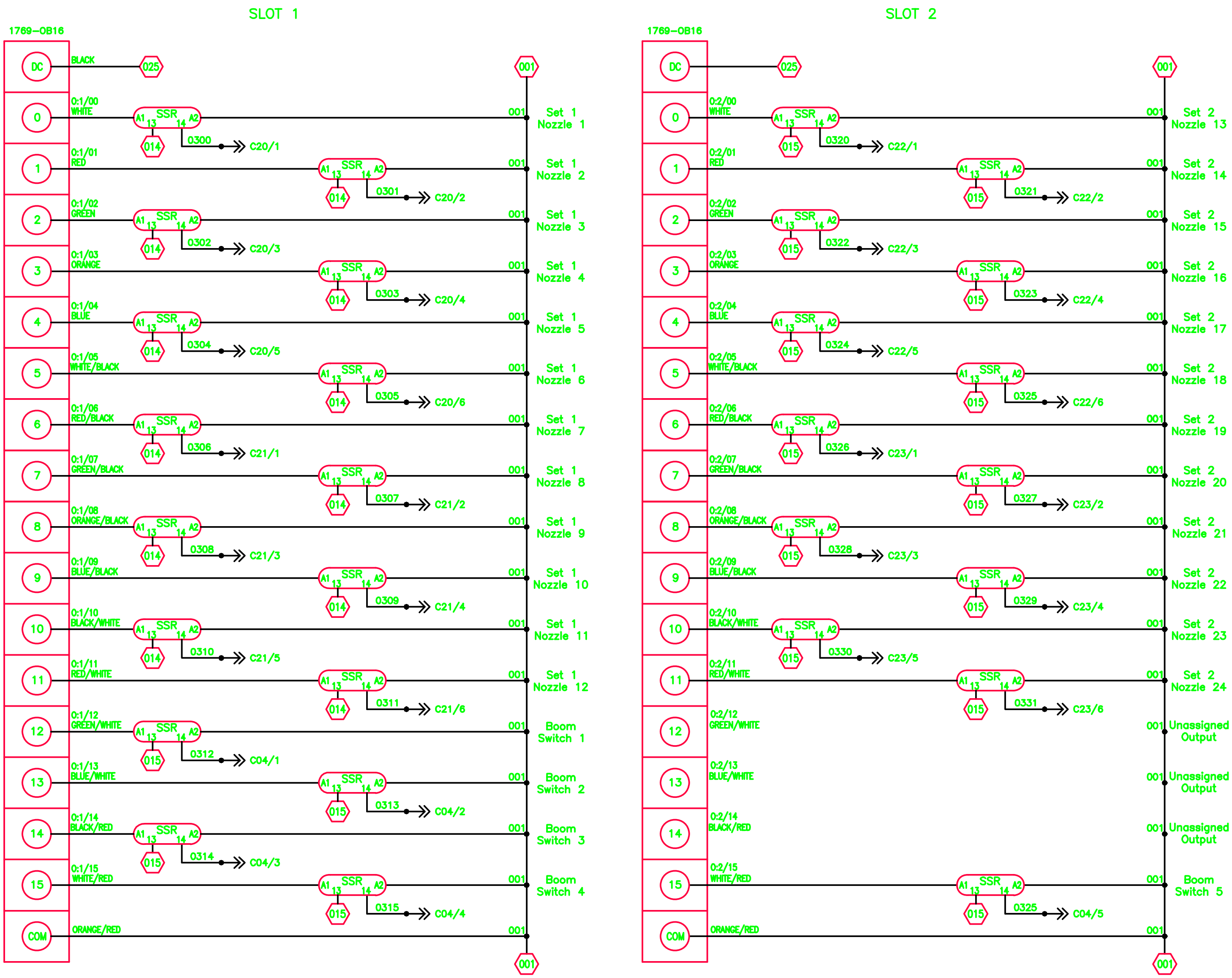

REVISIONS

O	PRELIMINARY	DWN	DSN	APV	ENG	MM/DD/YY

WIRING DIAGRAMS	DESCRIPTION
UC02.WD01	POWER DISTRIBUTION
UC02.WD02	OPERATOR INTERFACE
UC02.WD03	PLC IO MODULES 1 & 2
UC02.WD04	PLC IO MODULES 3 & 4
UC02.WD05	PLC IO MODULE 5
UC02.WD06	VALVE DIR. CONTROL (A)
UC02.WD07	VALVE DIR. CONTROL (B)

CABLE DIAGRAMS	DESCRIPTION
UC02.CB01	CABLE LAYOUT
UC02.CB02	IMAGING CABLE DETAIL
UC02.CB03	HITACHI BREAKOUT CABLE
UC02.CB04	VIDEO EXTENSION CABLE
UC02.CB05	MAIN CABINET BNC CONNS

Notes:

1. Set 1 = Near truck spraying (0–6').
2. Set 2 = Far truck spraying (6–12').
3. Refer to UC02.WD06 for relay connections.
4. C#/# indicates cable and conductor nums.

UC02.WD03

Adaptive Equipment
Gainesville, FL

CUSTOMER: UNIV OF CALIFORNIA, DAVIS, CA

PROJECT: VALVE CONTROL SYSTEM

UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE MILLIMETERS

DRAWN	WS	10/28/03
CHECKED	BC	10/28/03

UNSPECIFIED TOLERANCES: n/a

3RD ANGLE PROJECTION

ASSEMBLY

MATERIAL: n/a

FINISH: n/a HARDNESS: n/a

TITLE: PLC IO MODULES 1 & 2

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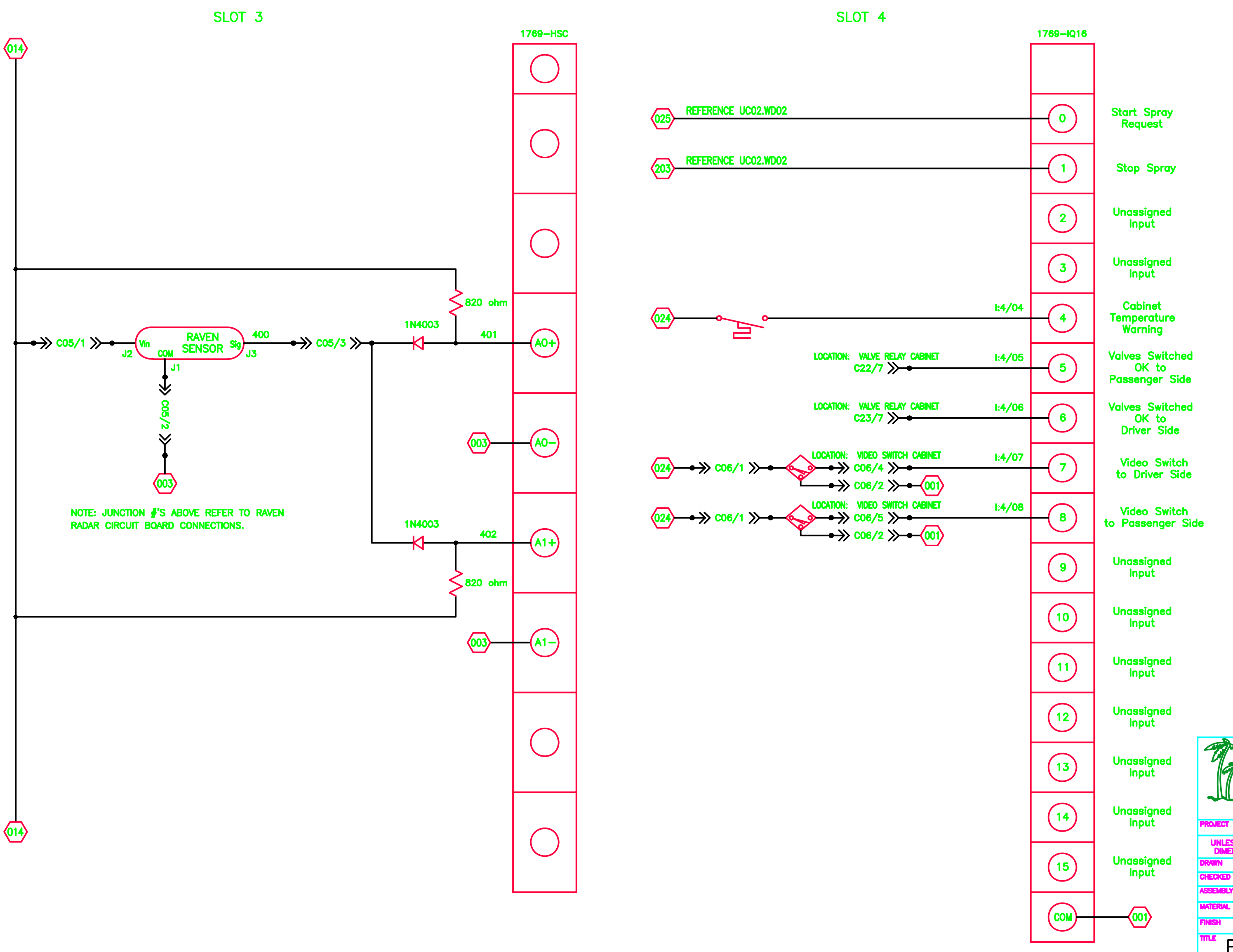

REVISIONS

		DWN	DSN	APV	ENG	MM/DD/YY
0	PRELIMINARY					

WIRING DIAGRAMS	DESCRIPTION
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UC02.WD02	OPERATOR INTERFACE
UC02.WD03	PLC IO MODULES 1 & 2
UC02.WD04	PLC IO MODULES 3 & 4
UC02.WD05	PLC IO MODULE 5
UC02.WD06	VALVE DIR. CONTROL (A)
UC02.WD07	VALVE DIR. CONTROL (B)

CABLE DIAGRAMS	DESCRIPTION
UC02.CB01	CABLE LAYOUT
UC02.CB02	IMAGING CABLE DETAIL
UC02.CB03	HITACHI BREAKOUT CABLE
UC02.CB04	VIDEO EXTENSION CABLE
UC02.CB05	MAIN CABINET BNC CONNS

Notes:
1. See UC02.WD06 for relay connections.
2. See UC02.CB02 for imaging cable layout.
3. C#/# indicates cable and conductor nums.

Adaptive Equipment
Gainesville, FL

CUSTOMER
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DAVIS, CA

PROJECT VALVE CONTROL SYSTEM

UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE MILLIMETERS

UNSPECIFIED TOLERANCES n/a

3RD ANGLE PROJECTION

DRAWN	WS	2/20/04
CHECKED	BC	03/01/04

ASSEMBLY

MATERIAL n/a

FINISH n/a HARDNESS n/a

TITLE PLC IO MODULES 3 & 4

SCALE	SIZE	DRAWING NO	REV
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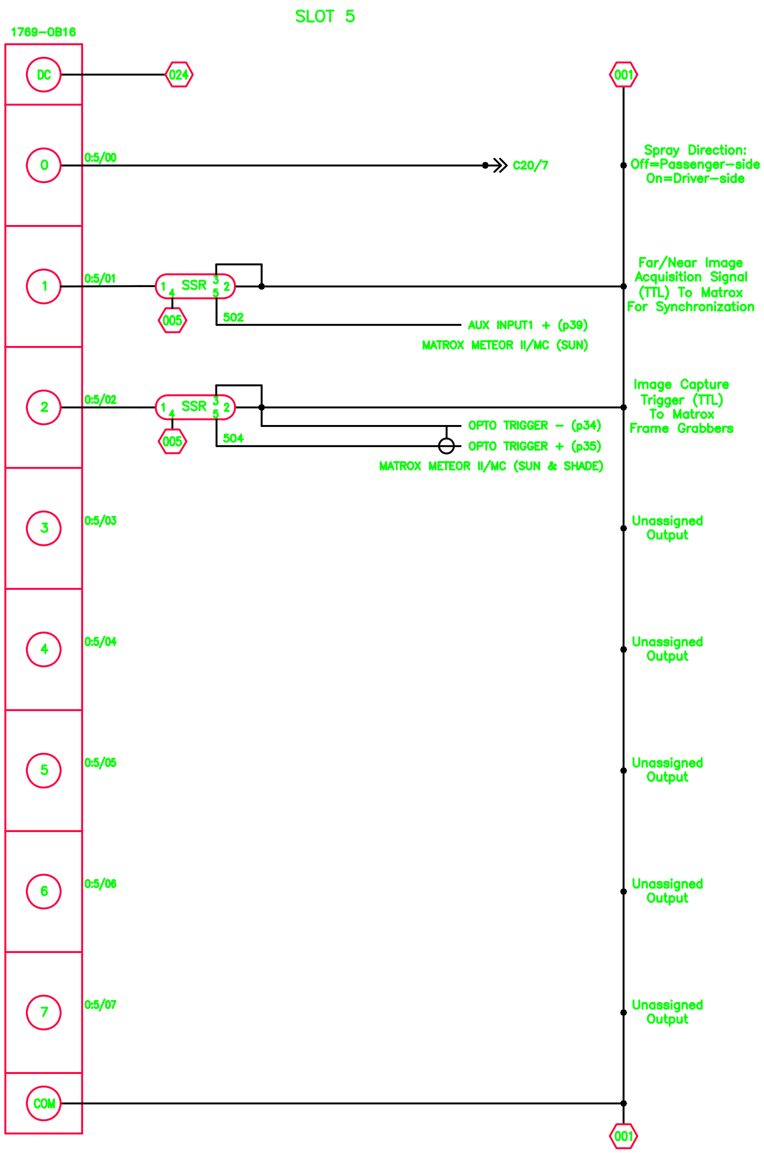
UC02.WD04



REVISIONS

		DWN	DSN	APV	ENG	MM/DD/YY
0	PRELIMINARY					

WIRING DIAGRAMS	DESCRIPTION
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UC02.WD02	OPERATOR INTERFACE
UC02.WD03	PLC IO MODULES 1 & 2
UC02.WD04	PLC IO MODULES 3 & 4
UC02.WD05	PLC IO MODULE 5
UC02.WD06	VALVE DIR. CONTROL (A)
UC02.WD07	VALVE DIR. CONTROL (B)

CABLE DIAGRAMS	DESCRIPTION
UC02.CB01	CABLE LAYOUT
UC02.CB02	IMAGING CABLE DETAIL
UC02.CB03	HITACHI BREAKOUT CABLE
UC02.CB04	VIDEO EXTENSION CABLE
UC02.CB05	MAIN CABINET BNC CONNS

Notes:
1. C#/# indicates cable and conductor nums.

Adaptive Equipment
Gainesville, FL

CUSTOMER
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DAVIS, CA

PROJECT VALVE CONTROL SYSTEM

UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE MILLIMETERS

DRAWN	WS	12/23/03
CHECKED	BC	03/01/04

UNSPECIFIED TOLERANCES n/a

3RD ANGLE PROJECTION

ASSEMBLY

MATERIAL n/a

FINISH n/a HARDNESS n/a

TITLE PLC IO MODULE 5

SCALE	SIZE	DRAWING NO	REV
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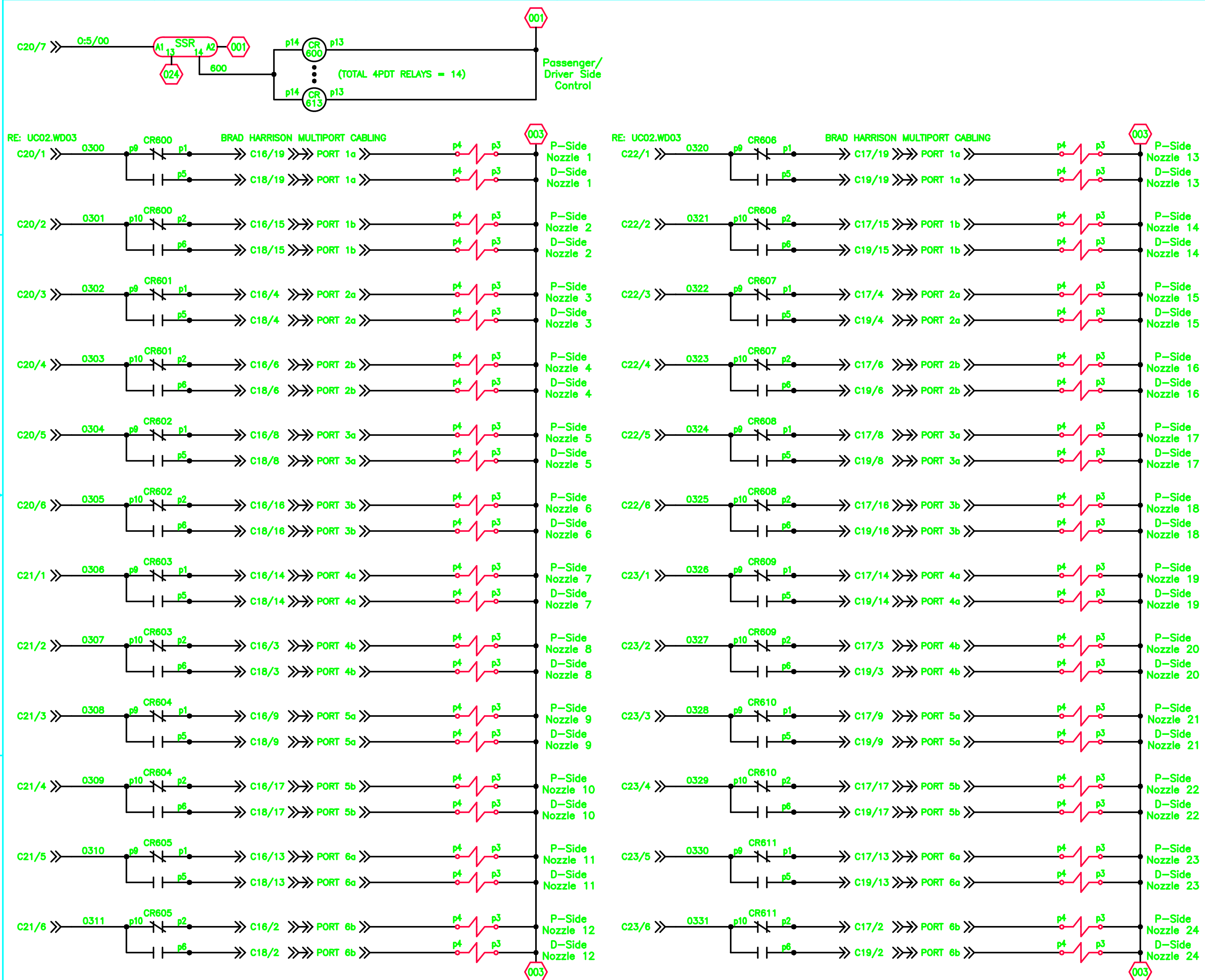
UC02.WD05



REVISIONS

0	PRELIMINARY	DWN	DSN	APV	ENG	MM/DD/YY

WIRING DIAGRAMS	DESCRIPTION
UC02.WD01	POWER DISTRIBUTION
UC02.WD02	OPERATOR INTERFACE
UC02.WD03	PLC IO MODULES 1 & 2
UC02.WD04	PLC IO MODULES 3 & 4
UC02.WD05	PLC IO MODULE 5
UC02.WD06	VALVE DIR. CONTROL (A)
UC02.WD07	VALVE DIR. CONTROL (B)

CABLE DIAGRAMS	DESCRIPTION
UC02.CB01	CABLE LAYOUT
UC02.CB02	IMAGING CABLE DETAIL
UC02.CB03	HITACHI BREAKOUT CABLE
UC02.CB04	VIDEO EXTENSION CABLE
UC02.CB05	MAIN CABINET BNC CONNS

Notes:
1. C#/# indicates cable and conductor nums.
2. PORT: Multiport Splitter cable (a=output 2, b=output 1).
3. See UC02 Cables & Connectors for cable color codes.
4. Location of relays: Valve Directional Relay Cabinet.
5. "P-side" = passenger side, "D-side" = driver side.

Adaptive Equipment
Gainesville, FL

CUSTOMER
UNIV OF CALIFORNIA
DAVIS, CA

PROJECT VALVE CONTROL SYSTEM

UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE MILLIMETERS

DRAWN	WS	11/20/03
CHECKED	BC	11/20/03

UNSPECIFIED TOLERANCES n/a

3RD ANGLE PROJECTION

ASSEMBLY

MATERIAL n/a

FINISH n/a

HARDNESS n/a

TITLE VALVE DIR. CONTROL (A)

SCALE	SIZE	DRAWING NO	REV
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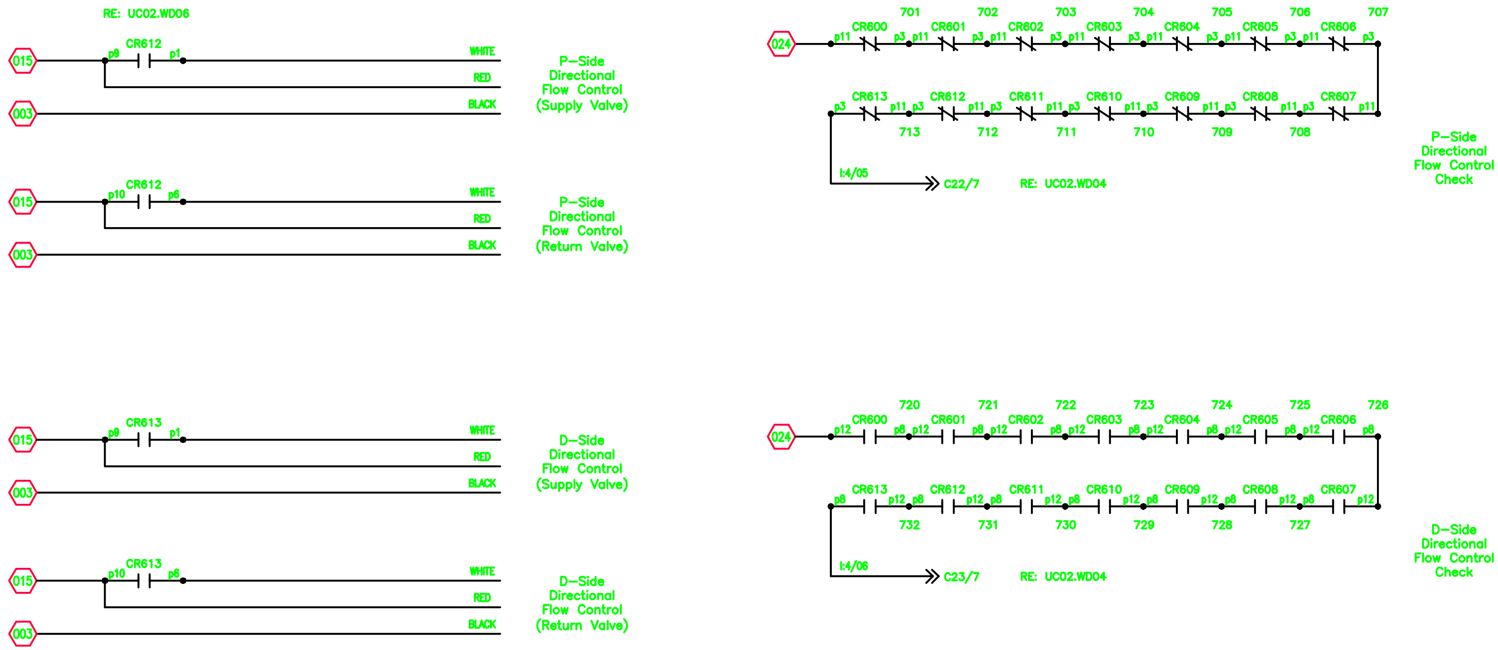
UC02.WD06



REVISIONS

O	PRELIMINARY	DWN	DSN	APV	ENG	MM/DD/YY

WIRING DIAGRAMS	DESCRIPTION
UC02.WD01	POWER DISTRIBUTION
UC02.WD02	OPERATOR INTERFACE
UC02.WD03	PLC IO MODULES 1 & 2
UC02.WD04	PLC IO MODULES 3 & 4
UC02.WD05	PLC IO MODULE 5
UC02.WD06	VALVE DIR. CONTROL (A)
UC02.WD07	VALVE DIR. CONTROL (B)

CABLE DIAGRAMS	DESCRIPTION
UC02.CB01	CABLE LAYOUT
UC02.CB02	IMAGING CABLE DETAIL
UC02.CB03	HITACHI BREAKOUT CABLE
UC02.CB04	VIDEO EXTENSION CABLE
UC02.CB05	MAIN CABINET BNC CONNS

Notes:
1. C#/# indicates cable and conductor nums.
2. Location of relays: Valve Directional Relay Cabinet.

Adaptive Equipment
Gainesville, FL

CUSTOMER: UNIV OF CALIFORNIA, DAVIS, CA

PROJECT: VALVE CONTROL SYSTEM

UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE MILLIMETERS

UNSPECIFIED TOLERANCES: n/a

3RD ANGLE PROJECTION

DRAWN	WS	11/25/03
CHECKED	BC	03/01/04

ASSEMBLY

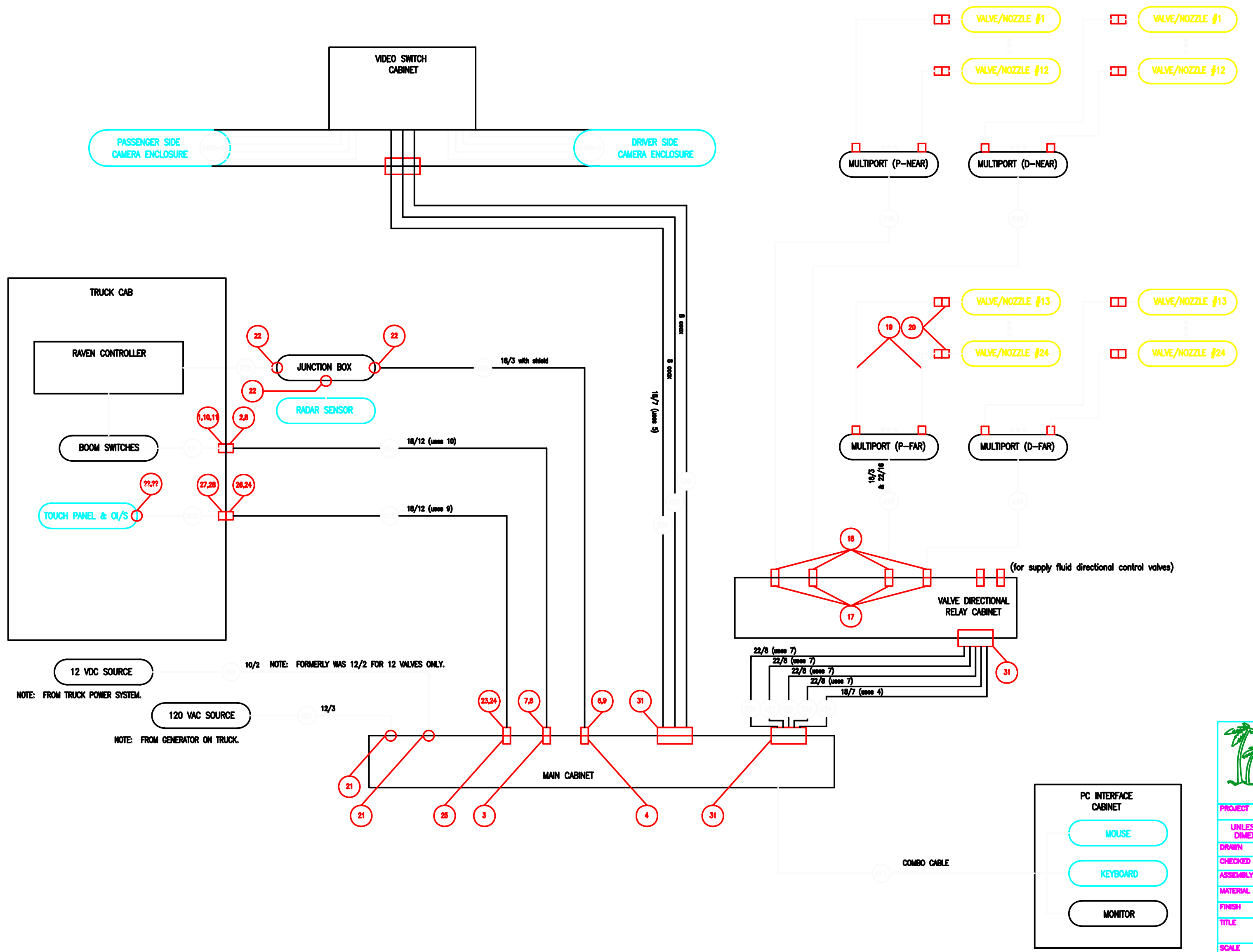
MATERIAL: n/a

FINISH: n/a HARDNESS: n/a

TITLE: VALVE DIR. CONTROL (B)

SCALE	SIZE	DRAWING NO	REV
n/a	D	UC02.WD07	0

UC02.WD07



REVISIONS

0	PRELIMINARY	DWN DSN	APV ENG	MM/DD/YY	

WIRING DIAGRAMS	DESCRIPTION
UC02.WD01	POWER DISTRIBUTION
UC02.WD02	OPERATOR INTERFACE
UC02.WD03	PLC IO MODULES 1 & 2
UC02.WD04	PLC IO MODULES 3 & 4
UC02.WD05	PLC IO MODULE 5
UC02.WD06	VALVE DIR. CONTROL (A)
UC02.WD07	VALVE DIR. CONTROL (B)

CABLE DIAGRAMS	DESCRIPTION
UC02.CB01	CABLE LAYOUT
UC02.CB02	IMAGING CABLE DETAIL
UC02.CB03	HITACHI BREAKOUT CABLE
UC02.CB04	VIDEO EXTENSION CABLE
UC02.CB05	MAIN CABINET BNC CONNS

Notes:

1. CXY = cable identifier.
2. XY = connector style.
3. ——— = cable in flexible conduit.
4. See UC02.EL.01 for main cabinet details.
5. See UC02.EL.02 for video switch cabinet details.
6. See UC02.EL.03 for valve relay cabinet details.

Adaptive Equipment
Gainesville, FL

CUSTOMER: UNIV OF CALIFORNIA DAVIS, CA

PROJECT: VALVE CONTROL SYSTEM

UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE MILLIMETERS

UNSPECIFIED TOLERANCES

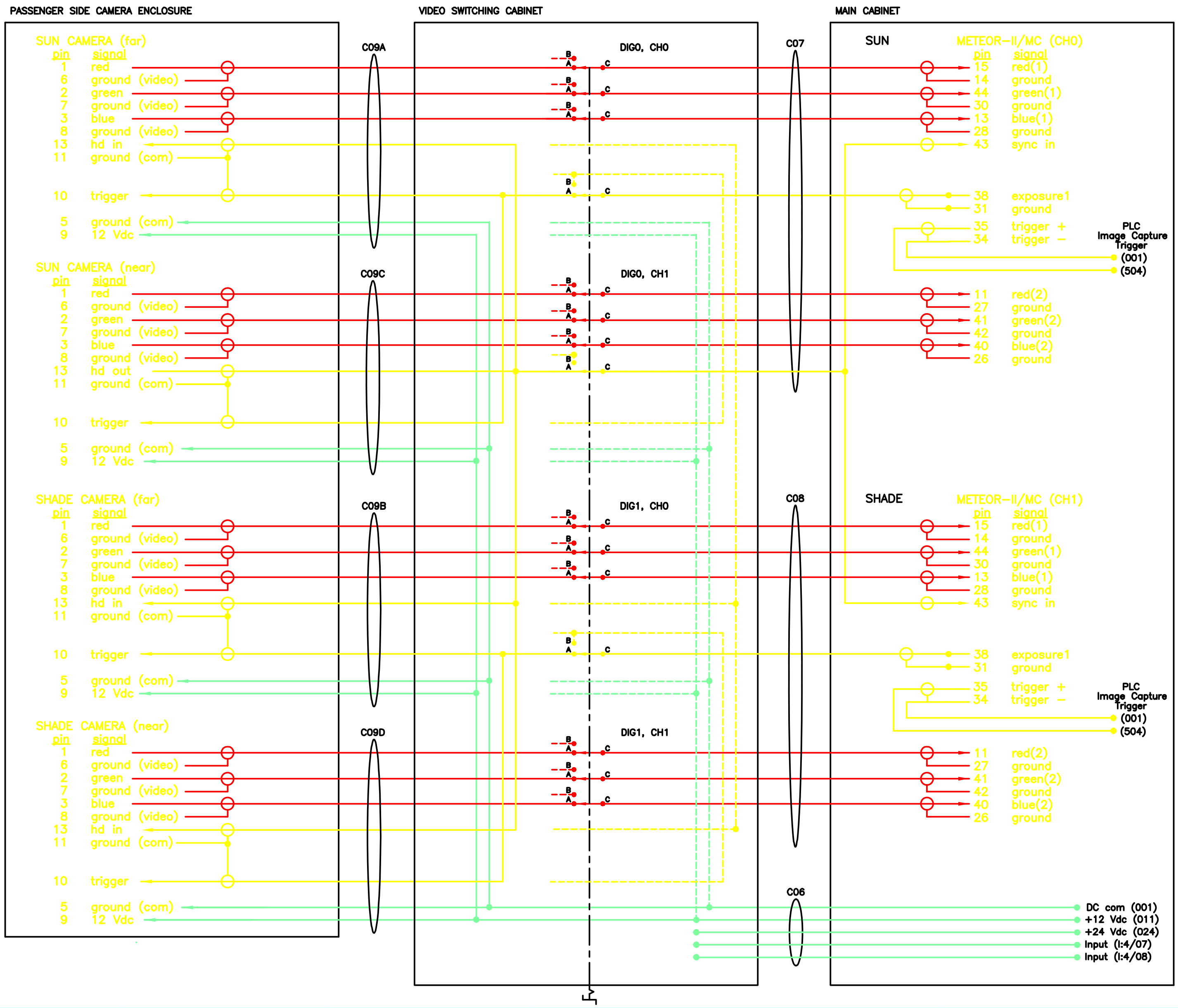
3RD ANGLE PROJECTION

DRAWN	WS	1/06/04
CHECKED	MB	1/06/04
ASSEMBLY		
MATERIAL		
FINISH	HARDNESS	n/a

TITLE: CABLE LAYOUT

SCALE	SIZE	DRAWING NO	REV
n/a	D	UC02.CB01	0

UC02.CB01



REVISIONS

0	PRELIMINARY	DWN	DSN	APV	ENG	MM/DD/YY

WIRING DIAGRAMS	DESCRIPTION
UC02.WD01	POWER DISTRIBUTION
UC02.WD02	OPERATOR INTERFACE
UC02.WD03	PLC IO MODULES 1 & 2
UC02.WD04	PLC IO MODULES 3 & 4
UC02.WD05	PLC IO MODULE 5
UC02.WD06	VALVE DIR. CONTROL (A)
UC02.WD07	VALVE DIR. CONTROL (B)

CABLE DIAGRAMS	DESCRIPTION
UC02.CB01	CABLE LAYOUT
UC02.CB02	IMAGING CABLE DETAIL
UC02.CB03	HITACHI BREAKOUT CABLE
UC02.CB04	VIDEO EXTENSION CABLE
UC02.CB05	MAIN CABINET BNC CONNS

NOTES:

1. Hitachi HV-D30 camera cables (x4): (6) BNC/coax & (2) conductors
2. Matrox MeteorII/MC cables (x2): (8) coax/BNC (28) conductors
3. Intermediate cabling: (2) 8-coax with BNC connectors (1) 18/7
4. Switching for the two camera sets: (4) 4 channel BNC AB boxes with "A" used for passenger-side cameras and "B" used for driver-side cameras.
5. --------- represents cabling for the driver side camera box for camera cables C10A-C10D.

Adaptive Equipment
Gainesville, FL

CUSTOMER: UNIV OF CALIFORNIA
DAVIS, CA

PROJECT: VALVE CONTROL SYSTEM

UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE MILLIMETERS

UNSPECIFIED TOLERANCES: n/a

3RD ANGLE PROJECTION

DRAWN	WS	1/05/04
CHECKED	RH	03/03/04

ASSEMBLY

MATERIAL: n/a

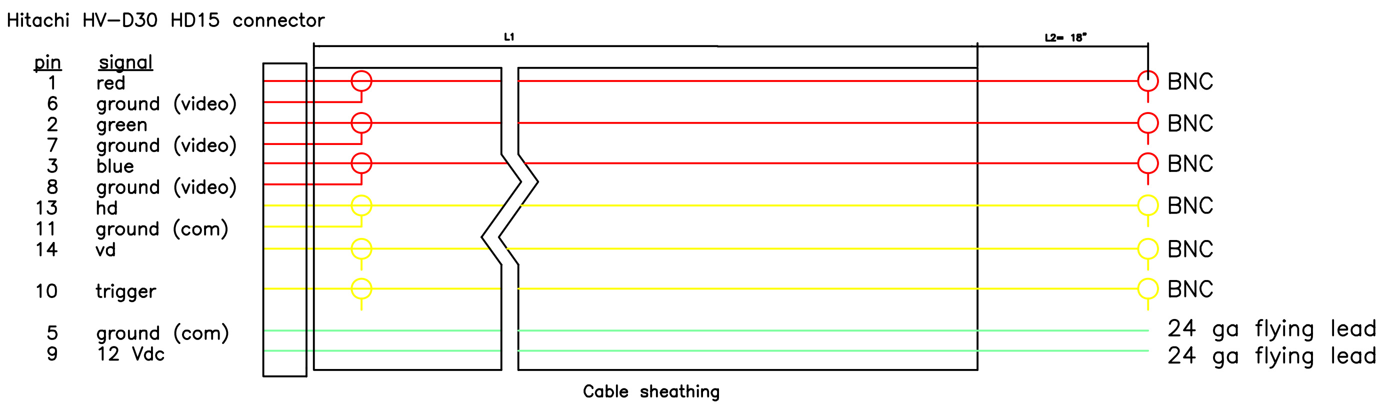
FINISH: n/a

HARDNESS: n/a

TITLE: IMAGING CABLE DETAIL

SCALE	SIZE	DRAWING NO	REV
n/a	D	UC02.CB02	0

UC02.CB02



FAB NOTES:
1. If possible, ground vd coax to pin 11 same as the hd signal.
2. Cable will be in wireway, so no IP rating required for the sheathing.
3. HD15 connector must be male; metal OK, molded not required.

LENGTH A: L1=90" with quantity four (4) cables.
LENGTH B: L1=120" with quantity two (2) cables.
LENGTH C: L1=48" with quantity two (2) cables.

REVISIONS

		DWN	DSN	APV	ENG	MM/DD/YY
0	PRELIMINARY					

WIRING DIAGRAMS	DESCRIPTION
UC02.WD01	POWER DISTRIBUTION
UC02.WD02	OPERATOR INTERFACE
UC02.WD03	PLC IO MODULES 1 & 2
UC02.WD04	PLC IO MODULES 3 & 4
UC02.WD05	PLC IO MODULE 5
UC02.WD06	VALVE DIR. CONTROL (A)
UC02.WD07	VALVE DIR. CONTROL (B)

CABLE DIAGRAMS	DESCRIPTION
UC02.CB01	CABLE LAYOUT
UC02.CB02	IMAGING CABLE DETAIL
UC02.CB03	HITACHI BREAKOUT CABLE
UC02.CB04	VIDEO EXTENSION CABLE
UC02.CB05	MAIN CABINET BNC CONNS

Adaptive Equipment
Gainesville, FL

CUSTOMER: UNIV OF CALIFORNIA
DAVIS, CA

PROJECT: VALVE CONTROL SYSTEM

UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE MILLIMETERS

UNSPECIFIED TOLERANCES: n/a

3RD ANGLE PROJECTION

DRAWN	WS	2/04/04
CHECKED	BC	03/03/04
ASSEMBLY		

MATERIAL: n/a

FINISH: n/a HARDNESS: n/a

TITLE: HITACHI BREAKOUT CABLES

SCALE	SIZE	DRAWING NO	REV
n/a	D	UC02.CB03	0

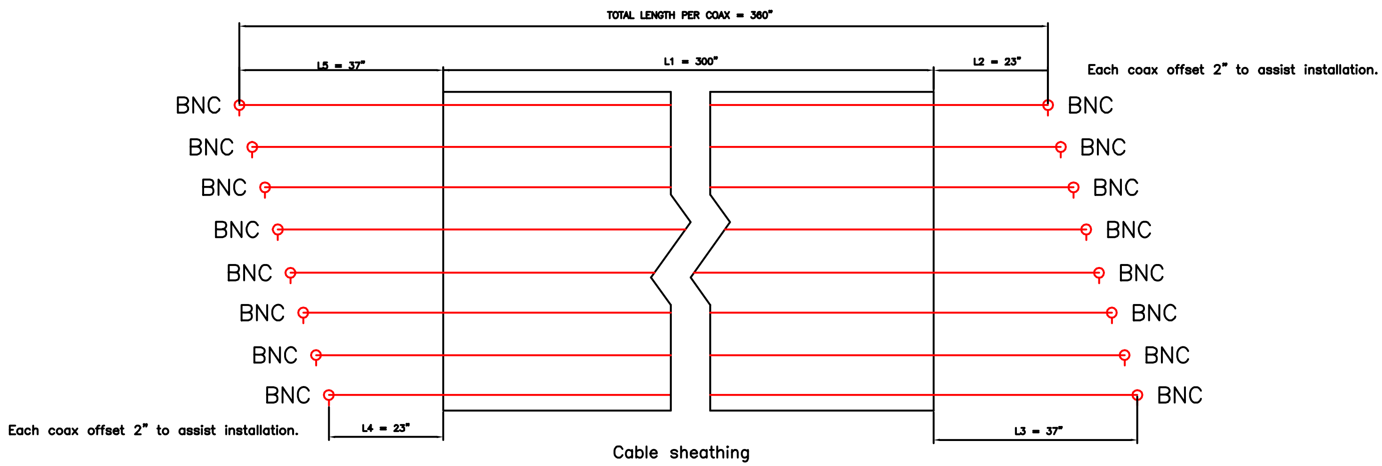
UC02.CB03

REVISIONS

0	PRELIMINARY	DWN	DSN	APV	ENG	MM/DD/YY

WIRING DIAGRAMS	DESCRIPTION
UC02.WD01	POWER DISTRIBUTION
UC02.WD02	OPERATOR INTERFACE
UC02.WD03	PLC IO MODULES 1 & 2
UC02.WD04	PLC IO MODULES 3 & 4
UC02.WD05	PLC IO MODULE 5
UC02.WD06	VALVE DIR. CONTROL (A)
UC02.WD07	VALVE DIR. CONTROL (B)

CABLE DIAGRAMS	DESCRIPTION
UC02.CB01	CABLE LAYOUT
UC02.CB02	IMAGING CABLE DETAIL
UC02.CB03	HITACHI BREAKOUT CABLE
UC02.CB04	VIDEO EXTENSION CABLE
UC02.CB05	MAIN CABINET BNC CONNS



SHEATHING: Cable will be in wireway, so no IP rating required.
TYPE: flexible coaxial cables.
QTY: two (2) cable bundles.

Adaptive Equipment
Gainesville, FL

CUSTOMER: UNIV OF CALIFORNIA, DAVIS, CA

PROJECT: VALVE CONTROL SYSTEM

UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE MILLIMETERS

DRAWN	WS	11/14/03
CHECKED	BC	11/14/03

UNSPECIFIED TOLERANCES: n/a

3RD ANGLE PROJECTION

ASSEMBLY

MATERIAL: n/a

FINISH: n/a

HARDNESS: n/a

TITLE: VIDEO EXTENSION CABLE

SCALE	SIZE	DRAWING NO	REV
n/a	D	UC02.CB04	0

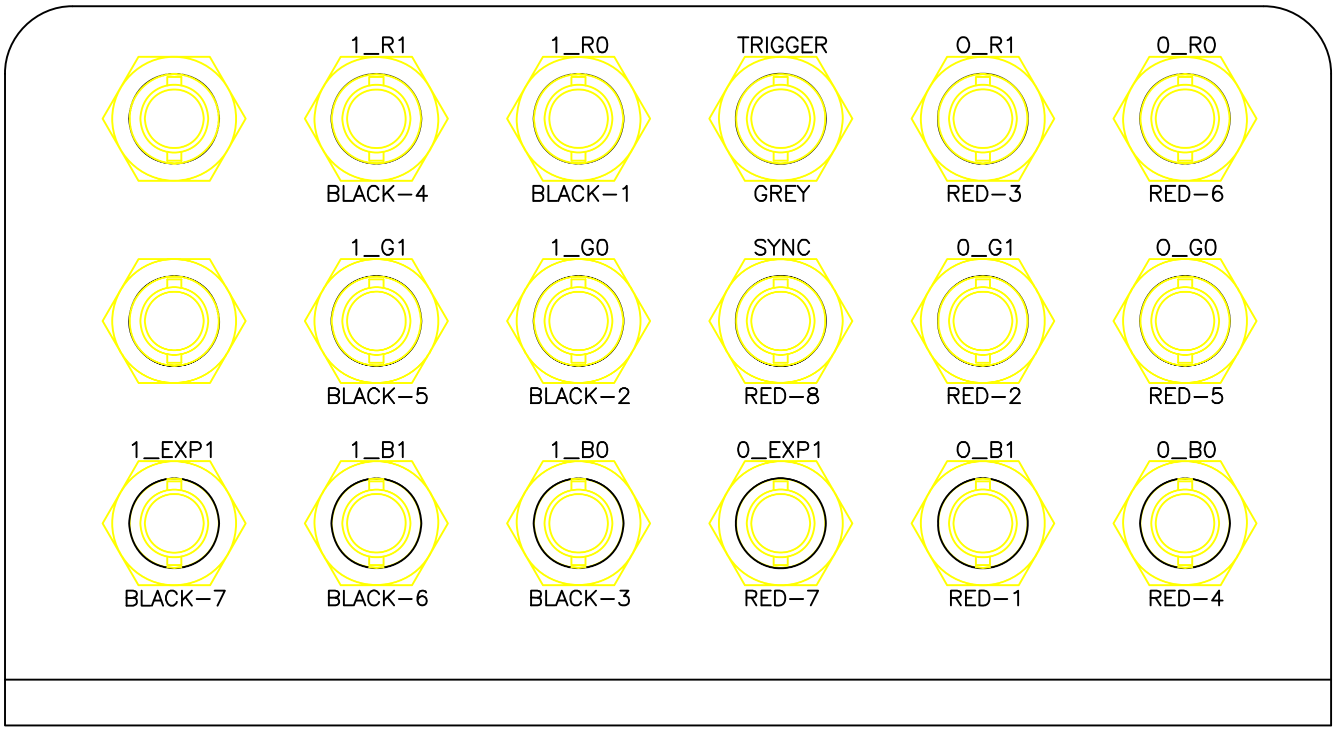
UC02.CB04

REVISIONS

0	PRELIMINARY	DWN	DSN	APV	ENG	MM/DD/YY

WIRING DIAGRAMS	DESCRIPTION
UC02.WD01	POWER DISTRIBUTION
UC02.WD02	OPERATOR INTERFACE
UC02.WD03	PLC IO MODULES 1 & 2
UC02.WD04	PLC IO MODULES 3 & 4
UC02.WD05	PLC IO MODULE 5
UC02.WD06	VALVE DIR. CONTROL (A)
UC02.WD07	VALVE DIR. CONTROL (B)

CABLE DIAGRAMS	DESCRIPTION
UC02.CB01	CABLE LAYOUT
UC02.CB02	IMAGING CABLE DETAIL
UC02.CB03	HITACHI BREAKOUT CABLE
UC02.CB04	VIDEO EXTENSION CABLE
UC02.CB05	MAIN CABINET BNC CONNS



Adaptive Equipment
Gainesville, FL

CUSTOMER: UNIV OF CALIFORNIA
DAVIS, CA

PROJECT: VALVE CONTROL SYSTEM

UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE MILLIMETERS

UNSPECIFIED TOLERANCES: n/a

3RD ANGLE PROJECTION

DRAWN	WS	03/03/04
CHECKED	BC	03/03/04

ASSEMBLY

MATERIAL: n/a

FINISH: n/a

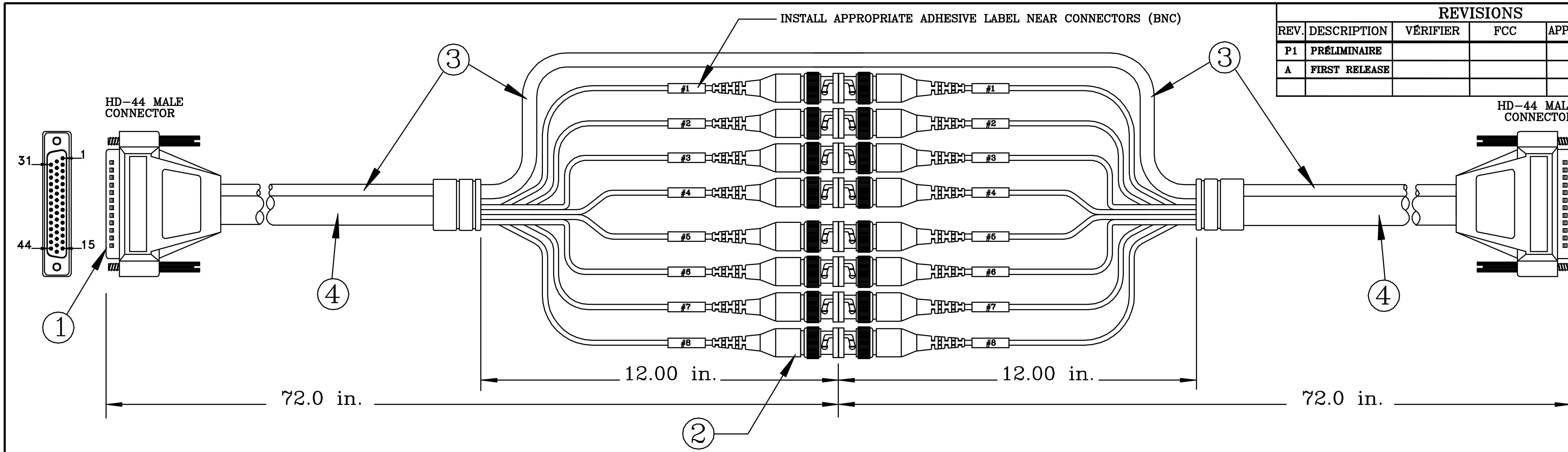
HARDNESS: n/a

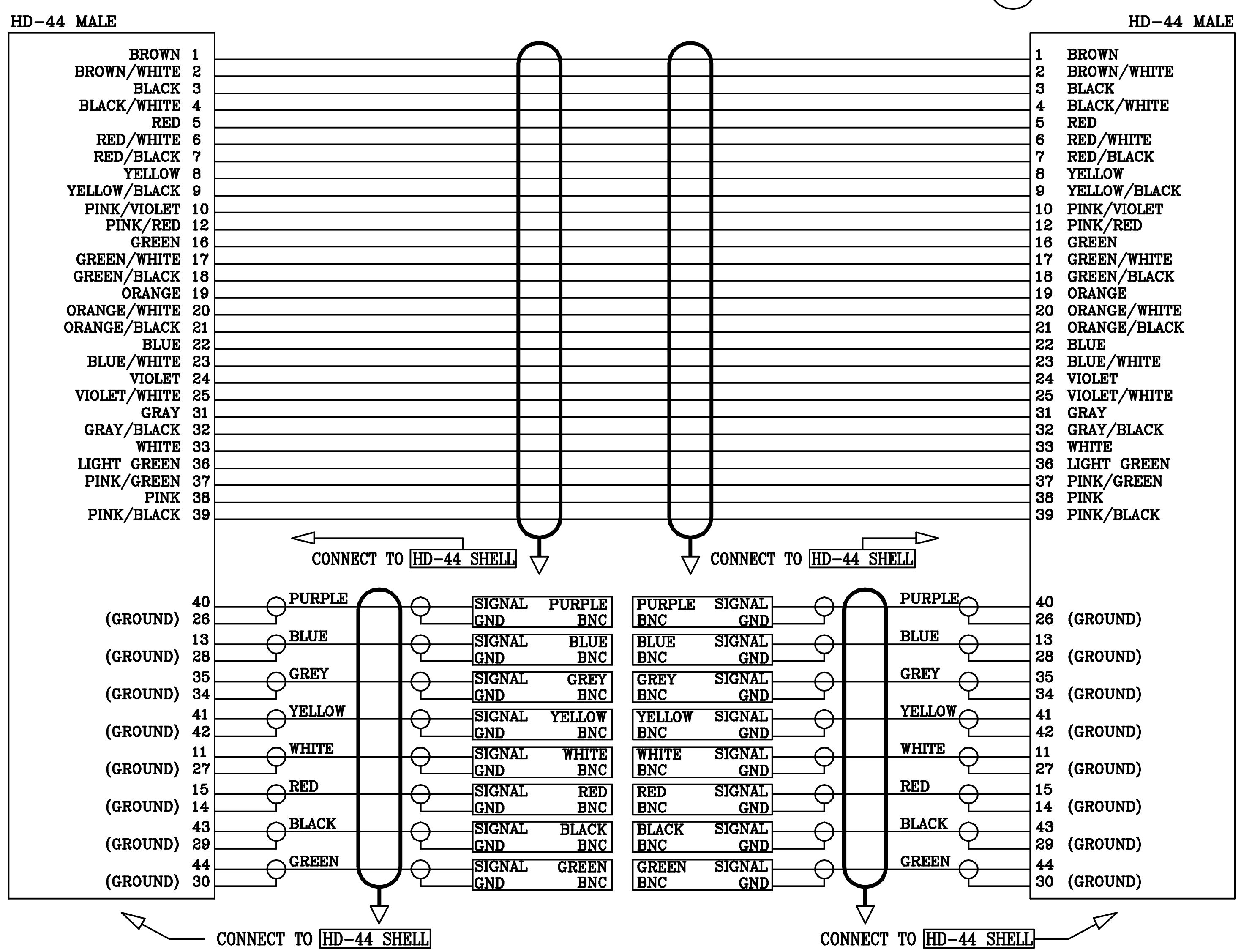
TITLE: MAIN CABINET BNC CONNS

SCALE	SIZE	DRAWING NO	REV
n/a	D	UC02.CB05	0

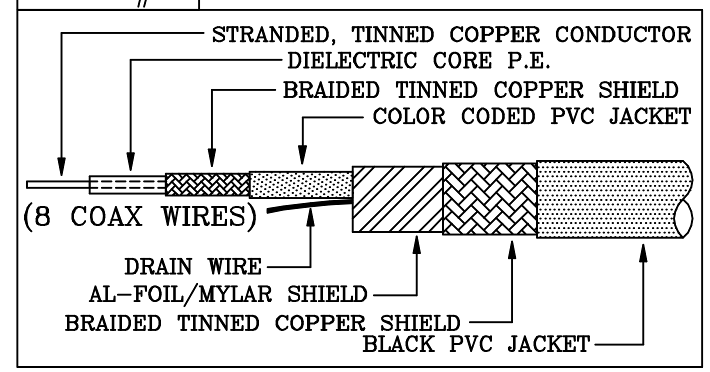
UC02.CB05

REVISIONS					
REV.	DESCRIPTION	VÉRIFIER	FCC	APPROBATION	DATE
P1	PRÉLIMINAIRE				JUNE '99
A	FIRST RELEASE				NOV '99





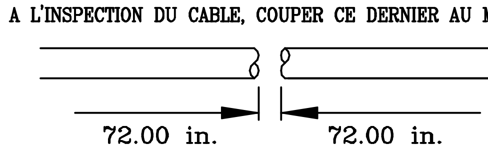
ITEM #4



SECTION FOR INTERNAL MATROX USE

CETTE SECTION S'APPLIQUE SEULEMENT À: MATROX(Q.A.)

1: SUITE A L'INSPECTION DU CABLE, COUPER CE DERNIER AU MILIEU.



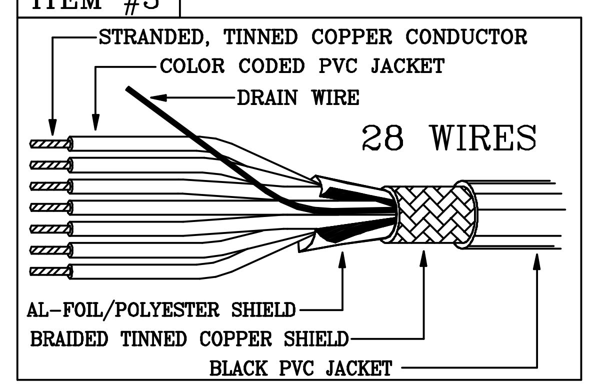
2: VÉRIFIER LE CODE DE COULEUR SUR 1 DES 2 CABLES RESTANTS.

3: INSÉRER LES 2 PARTIES DE CÂBLES DANS UN MÊME SAC PUIS SCELLER CELUI-CI.

NOTE

- ALL DIMENSIONS ARE INCHES
- THE SECTION INSIDE THE CONNECTOR HOOD (PVC MOLDED) MUST BE SHIELDED WITH A COPPER FOIL. THE COPPER FOIL MUST CONNECT TO THE SOCKET AND TO THE OVERALL BRAIDED TINNED COPPER SHIELD WITH A 360° TERMINATOR.

ITEM #3



ITEM	MANUFACTURER	PART NO	DESCRIPTION	QUNT.
4	SPACE SHUTTLE HIFI WIRE CO. LTD	UL-2919	COAX :(UL-1354, 28 AWG (7x0.127mm) + AL/MYLAR + 93% BRAIDED SHIELD, 75 OHM) x 8 COAX + OVERALL 85% BRAIDED + DRAIN WIRE JACKET: PVC, THICKNESS 1.2 mm	–
3	-------	----	MULTICONDUCTOR CABLE (28 WIRES)	–
2	TROMPETER	UPL20-5	BNC PLUG FOR RG-179 (75 Ohm)	16
1	LONG SHAN	708HD44M	HD-44 MALE CONNECTOR	2

TOLERANCES (in inches)		
.X	.XX	.XXX
± 4.0	± 2.00	± _.___

matrox ltee
1055 boul. St-REGIS
Dorval, Qc, H9P-2T4

Group: IMAGING	Projet: CORONA	Title: HD44-TO-HD44		
Dessinateur: R. GIRARD	File Name: 15903_01A.DWG	Drawing No.: 15903-05-01	Rév.: A	Sheet: 1 OF 1

Appendix C: IHAS User Manual

1. Pre-spray checklist and System Startup

- Open carrier valve on undercarriage of truck.
- Start truck, allow several minutes warm up time and air-brake charging.
- Place diesel engine switch (for driving pump) in truck cab, to “ON” position.
- Toggle video switch box for spray application side (passenger or driver).
- Prime centrifugal pump.
- Place kill switch (on outside of truck, passenger side, next to pump) for diesel engine driving pump to “UP” position.
- Start motor for engine pump, ensure pressure stabilization.
- Once pressure stabilization has occurred, kill diesel motor for driving pump, replacing kill switch to “UP” position.
- Open main AE control cabinet vents.
- Switch generator power switch to “ON”, start generator.
- Power system up by turning “10A” switch to “ON” position.
- Touch panel indicates system is initializing, and this message is removed once system has initialized and is ready to spray.

2. Spray applications from inside driver cab and touch panel interface

- Turn diesel motor (driving pump) on with remote switch (inside driver cab).
- Pull red stop spraying button out.
- Direct truck to spray location.
- Start moving, engage green spray button.
- Speed boundaries are 2 – 10 mph.
- Check touch panel occasionally for speed, spraying messages, etc.
- Press red stop spraying when completed spray application.
- Can re-engage green button after stop spraying has been pushed for continued application, if desired (pull out red stop button for this activity).
- Recommendation: power system down when switching side to spray (with video switch box), toggle red switch, power system up.

3. System Shutdown

- When completed spraying, turn switch for diesel engine driving pump to “OFF” position.
- Press System Shutdown button in top right hand corner of Main System Menu.
- When message flashes “System Must Now Be Shut Down”, turn 10A switch on generator to “OFF” position.
- Turn generator power switch to “OFF” position.

Notes:

If using touch screen to go through a series of spray application tests, then must shut down system through the touch screen. Once the touch screen indicates “System Must Now Be Shut Down”, then cycle AC power off. Process takes a few minutes.

If use monitor to re-configure the system and/or re-compile the system vision program, then must shut down system through the computer (ctrl-alt-del, choose shut down). After monitor indicates it is safe to power down, then cycle AC power off.

4. Touch panel overview

Figures C1 - C7 show the majority of the touch panels that the driver interfaces with during system spray applications. These figures show the main features and will be discussed starting in the upper right of Figure 1 and proceeding clockwise. Italics indicate a system message to the user. No italics indicate the user must press the button for further access. Some menus require a 4 digit code for access. The code is currently set to 3791. Pressing the “ENTER” button after entering the password allows access to embedded menus.

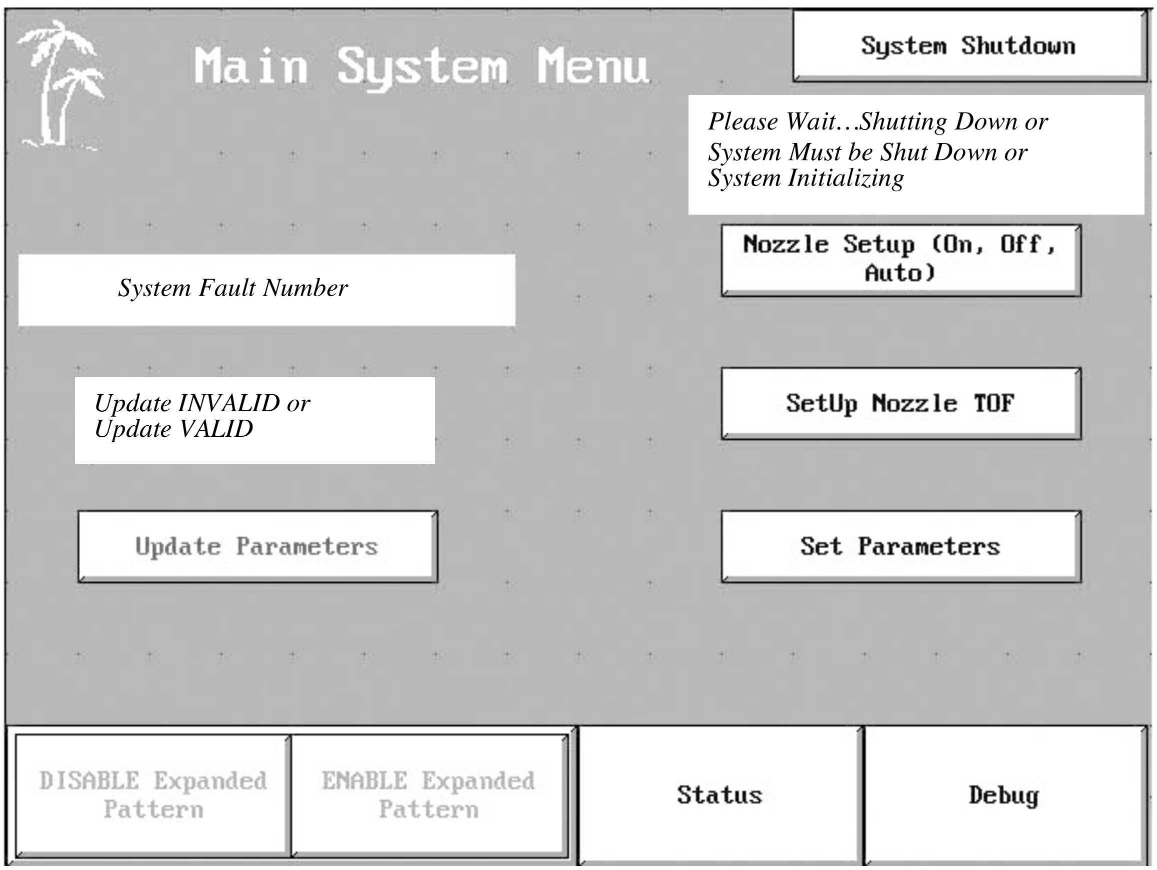


Figure C1. Main system menu after system has been powered up.

During the initial power up sequence, a message flashes below the System Shutdown button indicating that the system is initializing.

Active buttons for user interfacing are: System Shutdown, Nozzle Setup (On, Off, Auto), Setup Nozzle TOF, Set Parameters, Debug, Status, Enable/Disable Expanded Pattern, and Update Parameters.

If any parameter or sets of parameters are changed, press Update Parameters for these to become the default parameters for the current spray application.

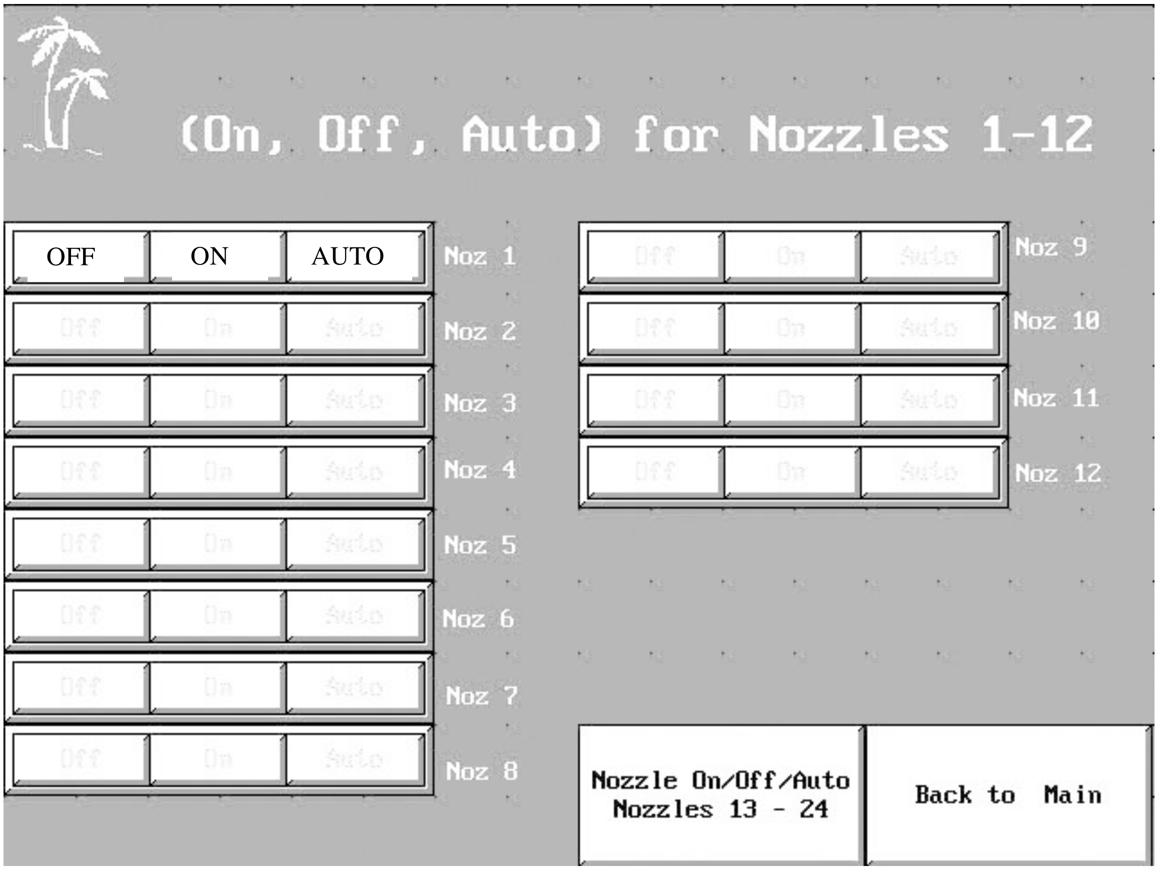


Figure C2. Nozzle buttons for manual or automatic control.

Each nozzle has the option to be turned on, off, or set to automatic mode. Automatic mode is the default spray mode for the vision system. Turning a nozzle on will activate the nozzle to the open position when spraying is initiated, turning a nozzle off will remove the nozzle from the spray application.

Pressing Nozzle On/Off/Auto Nozzles 13-24 gives access to nozzles 13-24.

Back to Main takes the user back to the Main System Menu.

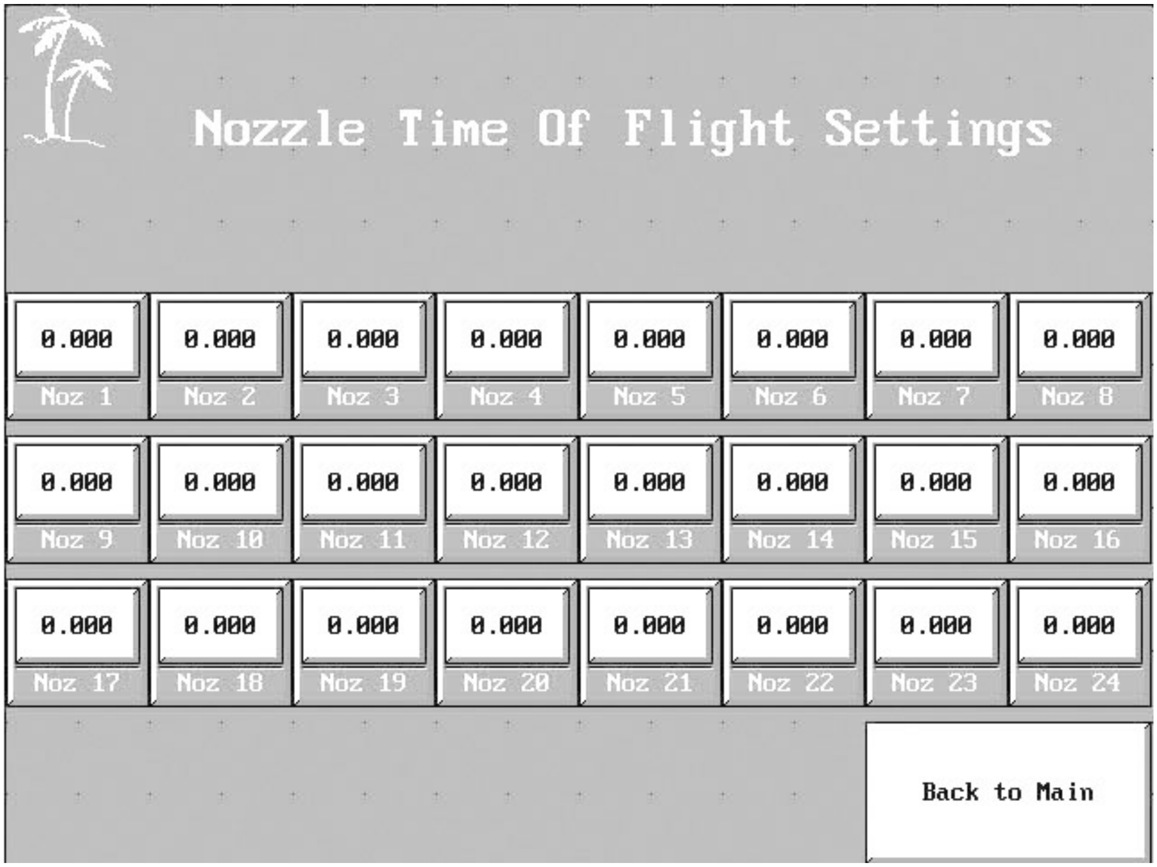


Figure C3. Nozzle time of flight menu.

Each nozzle time of flight can be adjusted. Pressing the respective nozzle button takes the user into the menu requiring a password. Once the password is entered correctly, the nozzle time of flight can be adjusted (see Table 1 for nozzle time of flights and boom spacing).

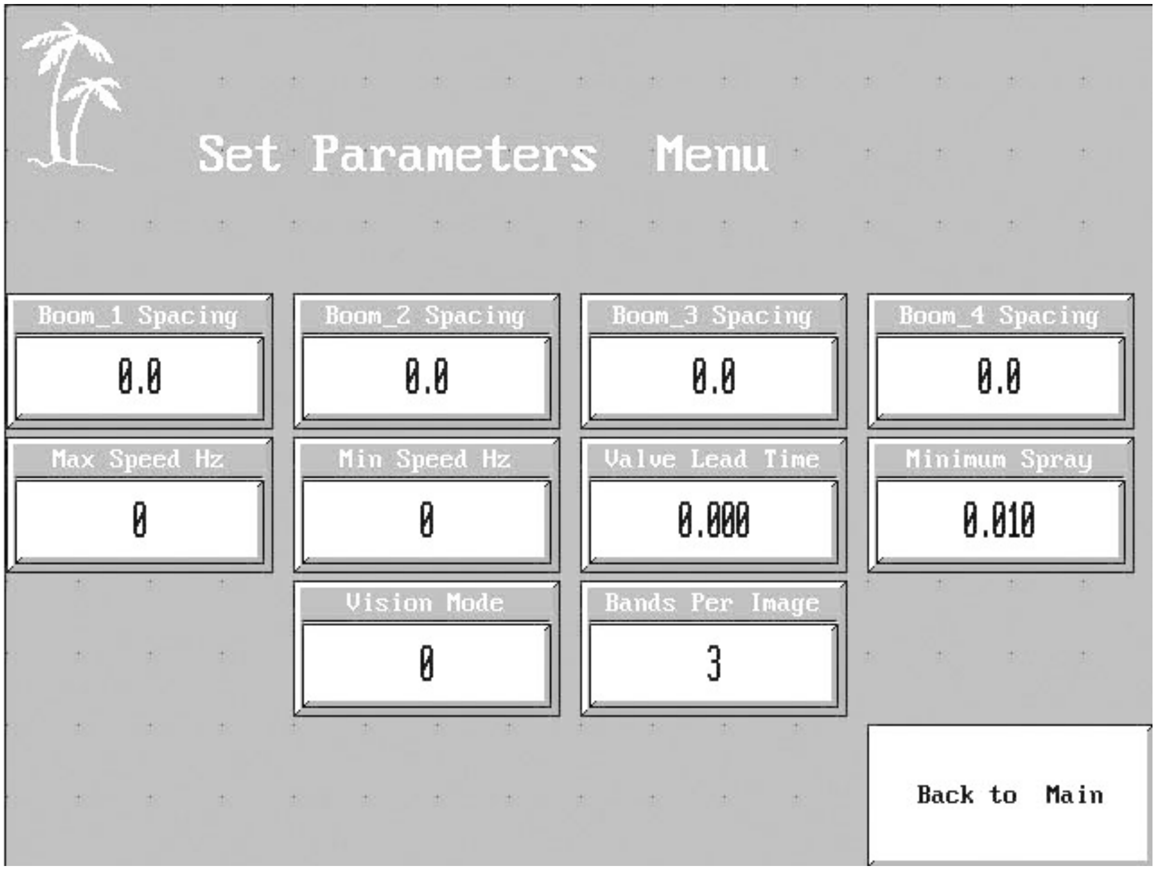


Figure C4. Main spray parameters menu.

Access to these menus requires the password.

Table C1 shows boom spacing for the current configuration. Minimum boom spacing is 108". Speed parameters are set to 125 and 625 Hz (minimum and maximum speeds for pulse train used to monitor speed from the Raven sensor). Valve Lead Time (0.015 s) and Minimum Spray (0.01 s) are options for targeting nozzle spray to targets.

Vision modes options: 1 = vision spraying, 2 random spray, 3 = checkered spray, 4 = sinusoid spray, 5 = vertical spray. Vision Mode 1 is the default spray mode with the system. All other modes are for demonstration purposes, for system adjustment or system demonstration.

Bands Per Image is used to adjust the number of cells around the target that are sprayed in addition to the active target.

Table C1. Finalized time of flight for nozzles and noted boom distances.

Passenger side

Boom	1	2	3	4
Nozzles	1-6	7-12	13-18	19-24
	------------------ time of flight, ms -----------------------			
	127	159	171	252
	132	169	190	266
	142	184	211	280
	152	189	232	294
	162	209	254	308
	172	219	276	324
Distance to nozzle orifice from mid-camera lens, ft	8.95	9.95	10.95	11.95

Driver side (equivalent nozzle heights with passenger side are assumed)

Boom	1	2	3	4
Nozzles	1-6	7-12	13-18	19-24
	------------------ time of flight, ms -----------------------			
	131	112	275	286
	107	275	287	281
	124	127	280	295
	101	138	253	249
	110	149	266	253
	119	152	281	279
Distance to nozzle orifice from mid-camera lens, ft	10.98	11.98	10.98	12.98

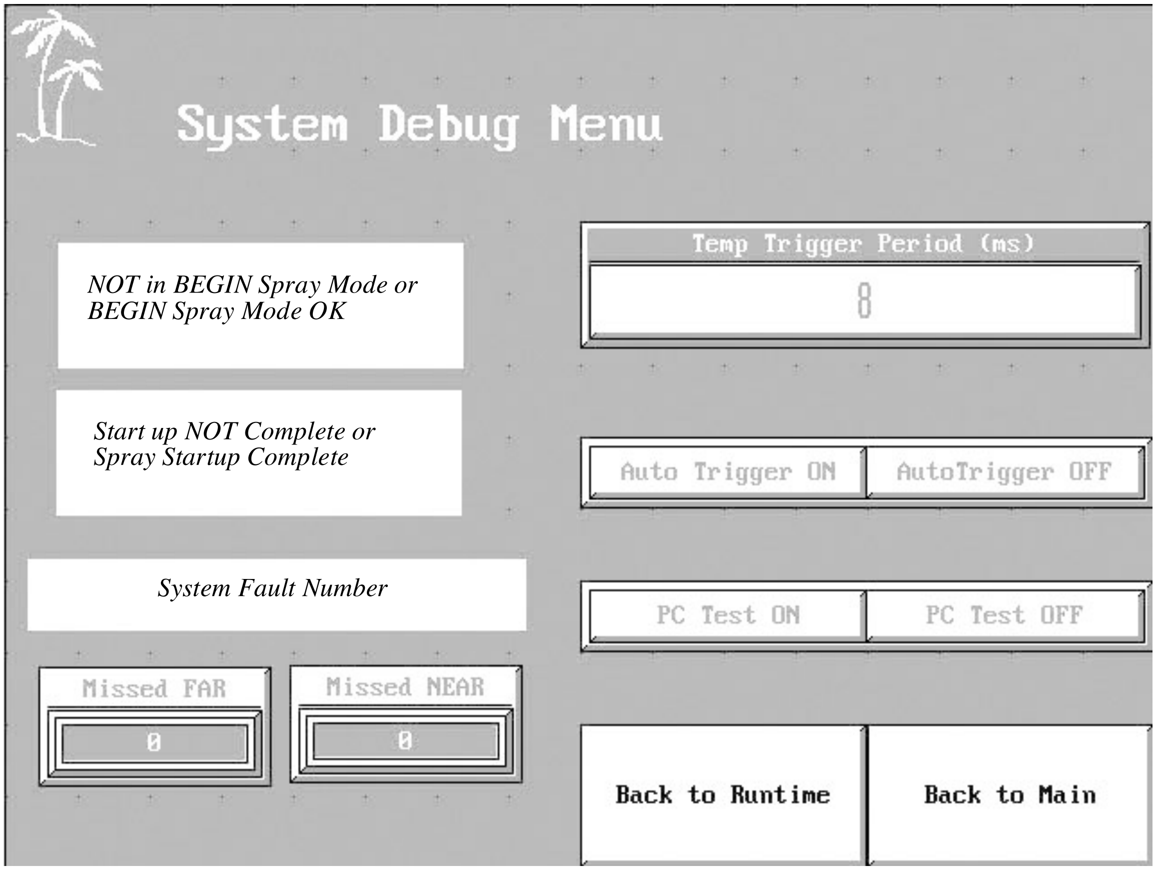


Figure C5. System debug menu.

Temp Trigger Period sets the camera trigger for capturing images. During stationary analysis of camera images, cycling the Auto Trigger OFF and Auto Trigger ON will initiate image capture.

PC test ON sprays without vision mode. However, this will give a diagonal pattern, and will override whatever setting is made for vision mode. This is basically used to check system targeting and time of flight values.

PC Test OFF should be activated for all other testing procedures.

Update Parameters after selecting the PC Test option for system to acknowledge change.

PC test OFF is default upon system power up.

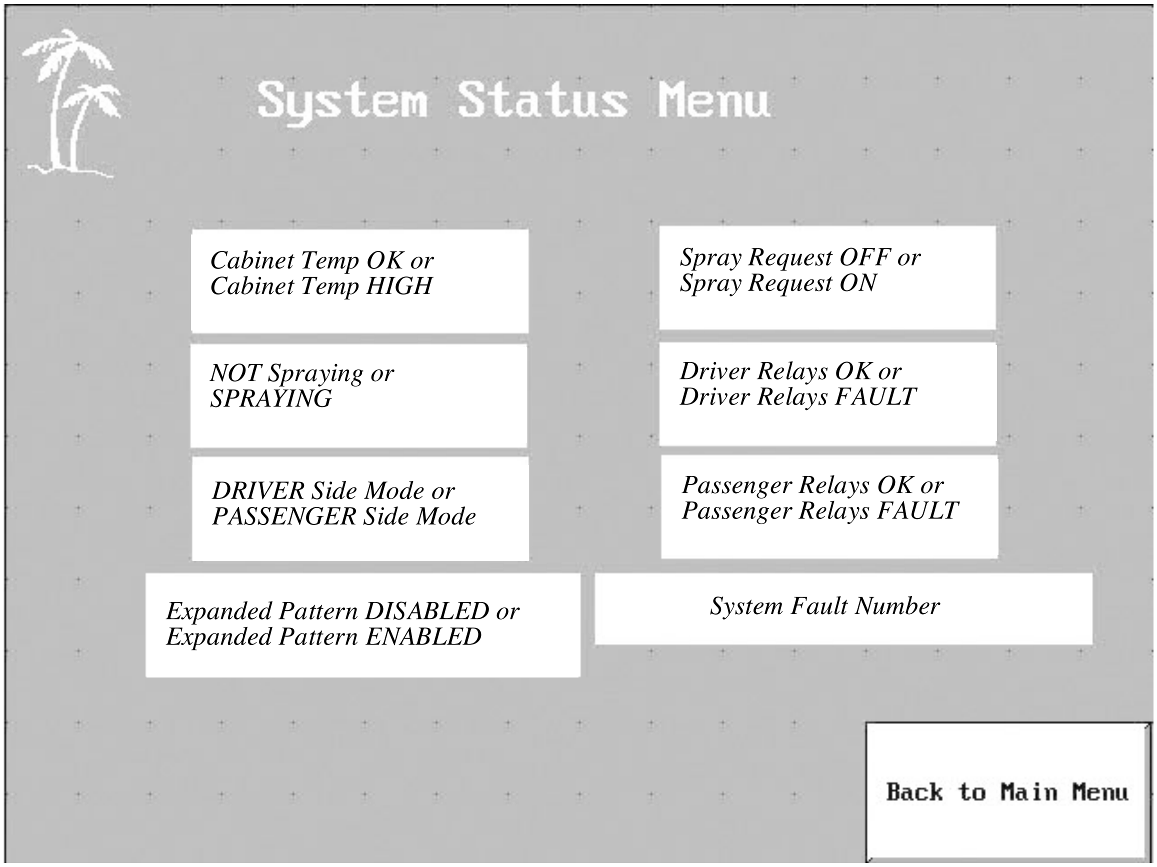


Figure C6. System status menu.

Basic information on system operation during spraying and stationary testing. Each indicator will highlight a single message.

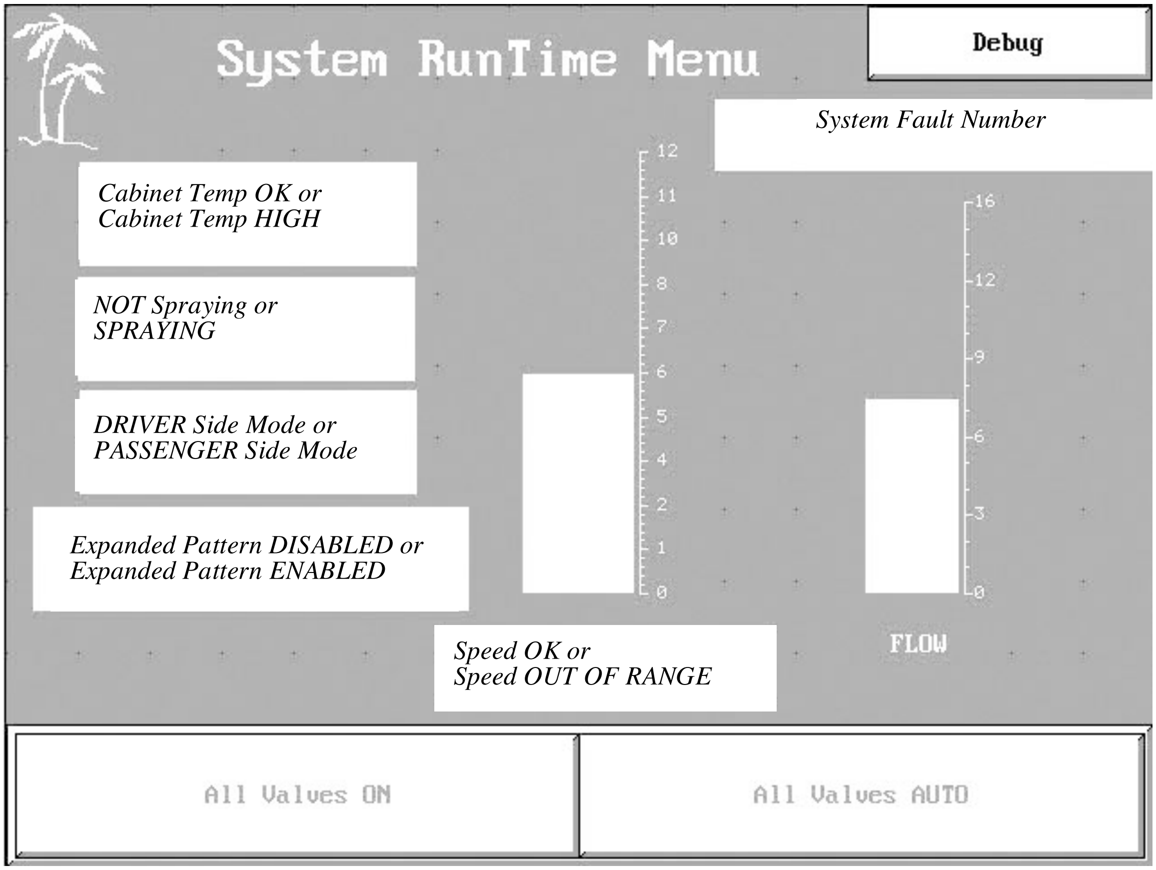


Figure C7. System runtime menu.

This menu appears when the green start spraying button has been pushed and relays information, on the indicators, to the driver during the spray operation.

5. Additional information and discussion

As requested from AE, the 5th bit on the boom switch control cable is available for monitoring passenger side spraying (on = 1) versus driver side spraying (off = 0). This option implies previous data collection with LabView could be re-initiated. This bit is available on Cable 4, Pin 5.

Spraying without vision

If spraying without vision and with forward movement, e.g., for demonstration purposes, set vision mode to option desired and run system under normal operation conditions.

The current option for spraying without vision and stationary is as follows (this will only send signals to the main AE control cabinet versus sending to main AE control cabinet and Raven control system in driver cab):

- Truck battery power off and 24 Vdc switched off in main AE control cabinet.
- An additional AE box (FG-AE) is required to connect to the white AE box (Raven-AE) that resides on top of the Raven speed sensor box. Inside the FG-AE is a cable for interfacing to the Raven-AE and an external function generator.
- Use the function generator to select square wave for artificial speed (pulse train).
- Truck battery power on, 24 Vdc switched on in main AE control cabinet.
- Function generator needs 12 V peak-to-peak square wave (with 6 V off-set) output to mimic Raven radar sensor.
- Set function generator to 550 Hz for 10 mph, 300 for 5 mph, etc.
- Power system up and perform stationary testing as needed.

Appendix D: Data Logger User Manual

System Overview

The RMS version of the Mid-Tech Legacy 6000 was designed for use with roadside spray trucks but was intended to control chemical application and map the controlled output. On the IHAS truck, we have implemented the Legacy system for measuring and mapping environmental conditions including wind speed, wind direction, ambient temperature, and roadside slope. In the case that any of these measured conditions falls outside specified minimum and maximum values, the data logging system triggers the spray controller to shut off spray. The measured environmental conditions and points where valves have turned on are recorded with GPS coordinates to produce maps of areas sprayed with environmental data.

This manual is to be used with the *Legacy 6000 RMS-EXT Users Guide (Mid-Tech part num: 98-05064)* for configuration and use of the data logging system. Information on the system components can be found in the *Legacy 6000 Fieldware Users Guide (Mid-Tech part num: 98-05053)* and PLC spray controller information can be found in the *IHAS Spray Checklist & PLC Operator Users Guide*.

System Details

The data logging system consists of several pieces connected through a Control Area Network (CAN). The CAN is a communication backbone between individual modules. Each sensor plugs into a module that measures the sensor's output voltage and communicates the resulting data on the network. Wind speed, wind direction, temperature, and roadside distance sensors connect to Product Control Modules (PCM). PLC controlled spray valves interface with a Switch Sense Module. A radar measuring vehicle speed connects to a Power Speed Module. A Global Positioning System (GPS) connects to an operator interface console module. The PLC spray controller connects to the CAN through a Gateway Module. Most of the modules in the system are Mid-Tech products and are described further in the *Legacy 6000 Fieldware Users Guide*. Connection diagrams are pictured on pages 20 and 21.

Each PCM setup and calibration is critical for the PLC Lockout line to work properly and for data to be logged correctly. Although repeated setup and calibration procedures are not required for daily operation, a condition may arise that would require a reentry of these values. Detailed step by step processes are outlined in the PCM Setup and PCM Calibration sections of this manual.

Spray Configuration

Spray Configurations have been created in the RMS Office program and imported into the Legacy 6000. Three spray configurations have been loaded for truck operation. "Driver Side" is a spray configuration that has valve configurations set to map while spraying on the driver's side, "Passenger Side" is a spray configuration in which valves are configured for mapping the passenger's side, and "Alternate Sides" is configured for mapping on either side with channel 10 indicating the side that is being sprayed (OFF is drivers side, ON is passenger side).

The mapping configurations in the Legacy are to be used with the expanded spraying pattern in the PLC. This is because the Legacy module is connected to every third valve in the bank and will sense every trigger only if three valves are fired at a time.

The preset spray configurations may be selected in the Vehicle Setup menu in the Legacy console. Note that when post-processing data from the "Alternate Sides" configuration, the spray pattern must be mirrored and translated to the other side of the truck if channel 10 is indicated ON.

See the *Legacy 6000 RMS-EXT Users Guide* for more detail on Spray Configuration selection.

Legacy 6000 PCM Setup

Chapter 2 of the *Legacy 6000 Fieldware Users Guide* outlines setup procedures for the console, vehicle configuration, and Product Control Modules. However, specific PCM values may be entered to ensure proper operation. Listed below are specific values to be input for PCM setup.

PCM #1 Configuration

- Favorite: Pump
- Application: Liquid
  - Application Name: W_SPEED
  - Configuration: Standard
  - PCM Link: None
- Drive Type: No Drive
- Units: Gal/Min
  - Basis: Time
- Primary Sensor: Pressure Analog
  - Input: E
  - Sensor Name: W_SPEED
  - Cal # Basis: None
  - Nozzle Const: 1.35
  - Alarm Units: psi
  - Min Alarm: OFF
  - Max Alarm: OFF
  - Alarm Delay: 10s
  - Sensor Output: 0-5.0V
- Secondary Sensor: None
- Monitor 1: None
- Monitor 2: None
- Monitor 3: None
- Monitor 4: None

PCM #2 Configuration

- Favorite: Pump
- Application: Liquid
  - Application Name: W_DIR
  - Configuration: Standard

PCM Link: None
Drive Type: No Drive
Units: Gal/Min
Basis: Time
Primary Sensor: Pressure Analog
Input: E
Sensor Name: W_DIR
Cal # Basis: None
Nozzle Const: 1.35
Alarm Units: psi
Min Alarm: OFF
Max Alarm: OFF
Alarm Delay: 10s
Sensor Output: 0-5.0V
Secondary Sensor: None
Monitor 1: None
Monitor 2: None
Monitor 3: None
Monitor 4: None

PCM #3 Configuration

Favorite: Pump
Application: Liquid
Application Name: TEMP
Configuration: Standard
PCM Link: None
Drive Type: No Drive
Units: Gal/Min
Basis: Time
Primary Sensor: Pressure Analog
Input: E
Sensor Name: TEMP
Cal # Basis: None
Nozzle Const: 1.35
Alarm Units: psi
Min Alarm: OFF
Max Alarm: OFF
Alarm Delay: 10s
Sensor Output: 0-5.0V
Secondary Sensor: None
Monitor 1: None
Monitor 2: None
Monitor 3: None
Monitor 4: None

PCM #4 Configuration

Favorite: Pump
Application: Liquid

Application Name: SLOPE
Configuration: Standard
PCM Link: None
Drive Type: No Drive
Units: Gal/Min
Basis: Time
Primary Sensor: Pressure Analog
Input: E
Sensor Name: SLOPE
Cal # Basis: None
Nozzle Const: 1
Alarm Units: psi
Min Alarm: OFF
Max Alarm: OFF
Alarm Delay: 10s
Sensor Output: 0-5.0V
Secondary Sensor: None
Monitor 1: None
Monitor 2: None
Monitor 3: None
Monitor 4: None

Calibration

Calibrations must be executed for the Power Speed Module and each of the Product Control Modules before the first use and after any electrical modification of the Legacy 6000 system. Calibrations are not required each time the truck is used or each time a new data file is generated. To begin, simply enter the Calibration menu.

Calibration of the Power Speed Module can be executed as stated in Chapter 3 of the *Legacy 6000 Fieldware Users Guide*. In the initial calibration, the speed sensor had a Quick Cal number of 770, resulting with a frequency of 580 Hz equal to a ground speed of 10 mph.

The voltage output of each analog sensor is displayed by the Legacy console as a pressure value (psi). When the data is written to a file, each value is recorded as a flow rate (gal/min). In order to simplify the post-process calculations, a specific calibration routine was formulated so that each sensor must be calibrated to a specific pressure value and to a specific nozzle constant.

In the case of wind speed measurement, the calibrated pressure displays the numerical value of the wind speed in miles per hour (displayed value 25.0 psi = measured value 25.0 mph). Given the correct nozzle constant, the flow rate recorded in a map by the Legacy 6000 is simply the square root of the measurement (logged value of 5.0 gal/min = measured value 25.0 mph).

The routine is executed by first calibrating the 'pressure sensor'. When asked to relieve all pressure from the system, simply connect the Calibration Zero Module to Input E of PCM #1, and then hit Enter. Then connect the 2.5V Calibration Set Module to Input E of PCM #1 and hit Begin Pressure Set. Pause a moment and then hit Enter. The actual value that must be entered is 33.6 psi.

Because nozzle constants of 1.35 were entered in each of the PCM setup procedures, flow rate calibrations are not necessary. The nozzle constant already simplifies the post-process calculation by equating the actual measured value (in mph, degrees, cm, etc.) to the numerical value of the square of flow rate.

In order to calibrate wind direction, repeat the steps conducted for wind speed. In this case, the calibrated pressure displays the numerical value of the wind direction in degrees from the front of the truck (displayed value 121 psi = measured value 121 degrees from truck front). Note that the angle measurements may wrap around to 540 degrees. To achieve these calculated values, connect the calibration modules to Input E of PCM #2, conduct the procedure as described for PCM #1, and enter an actual pressure value of 270.

To calibrate the temperature sensor (PCM #3), the routine is similar to those of the wind speed sensor. Connect the Current Calibration Module to Input E of PCM #3. Enter the pressure sensor calibration for PCM #3. Press enter to zero the sensor input on 4 mA. Connect the 2.5V Calibration Module to Input E of PCM #3. Press the set pressure button on the Legacy and enter an actual pressure value of 25.6 psi. For this particular sensor, the numerical value of pressure is equal to the numerical value of temperature in degrees Celsius.

The roadside distance sensors' input (PCM #4) is calibrated using the same method as PCM #1. Connect the Calibration Zero Module to Input E of PCM #4 and zero the input. Connect the 2.5V Calibration Module to Input E and press the set pressure button. Enter an actual pressure value of 762.5 psi. This numerical pressure value is offset from the numerical measured value by 50. (30 psi actually represents 80 cm from the nearest object, 762.5 psi actually represents 812.5 cm from the nearest object).

Setting Lockout Thresholds

The Environment Data Logging System is equipped with the ability to disable the spray valves in the case that one of the environmental conditions falls outside some preset threshold values. In order to set these values, a monitor and keyboard must be connected to the Matrox computer. The Matrox is linked to the PLC/CAN Gateway Module via serial port COM 1. Using HyperTerminal, the operator can change the threshold values. Settings for the terminal program include: 9600 baud, 8 data bits, no parity, 1 stop bit, and no flow control.

When connected, the following menu title will be displayed:

Spray Lockout Threshold Setup Menu
Select 'w' for wind, 't' for temperature, or 's' for slope

When wind is selected, the following prompt is displayed:

Old setting for maximum wind speed (mph)
50
Enter new maximum wind speed (mph)

The minimum accepted wind speed threshold is 1, the maximum accepted value is 67.

When temperature is selected, the two following prompts are shown:

Old setting for minimum temperature (F)
40
Enter new minimum temperature (F)

Old setting for maximum temperature (F)
105
Enter new maximum temperature (F)

The minimum accepted temperature threshold is 32, the maximum accepted threshold is 132.

When roadside slope is selected, the following two prompts are displayed:

Old setting for minimum roadside slope (degrees)
-10
Enter new minimum roadside slope (degrees)

Old setting for maximum roadside slope (degrees)
40
Enter new maximum roadside slope (degrees)

The minimum value for the roadside slope thresholds is -23 degrees, the maximum is 65 degrees.

After the threshold values are set, they are retained even during loss of power.

System Operation

Normal Operation (without school avoidance map)

The following is a checklist of tasks to operate the Environment Data Logging System. A more detailed discussion can be found in the *Legacy 6000 RMS-EXT Users Guide.*

1. Pre-spray checklist for everyday operation without school maps

- Insert Flash card in Legacy Console.
- Turn on Battery Power Switch on side of truck.
- Turn on Legacy console.
- Press the “ARM” button on the upper right corner of the console.
- Press “Create new job using settings from the previous job”
- Select a new job name (easiest way is to use second button from top right)
- Enter ARM setup and select a “Map File” name
- Press the begin ARM button on the upper right corner

2. Post-spray checklist and System Shutdown

- Exit ARM Operation.
- Turn off Legacy console.
- Turn off Battery Power switch on side of truck.
- Remove Flash Card from Legacy Console.

ARM parameters may be changed in the ARM setup pages. The first time a new map is to be created, a new job must be created along with several items of information that must be input into the Legacy file. Unless there has been an electrical change in the system, there should be no reason to run a Calibration. Additionally, no fluid is controlled by the Legacy so there is no need to Prime or Agitate.

The remaining three menus must be completed before data can be mapped. Listed below are parameters for two of the three menus. Critical values are underlined.

- Product Setup
- W_SPEED
    - In Use: Yes
    - Product: Wind Speed
    - Correction Factor: 1.0
    - Initial Quantity: 0.0
- W_DIR
    - In Use: Yes
    - Product: Wind Direction
    - Correction Factor: 1.0
    - Initial Quantity: 0.0
- TEMP
    - In Use: Yes
    - Product: Temperature
    - Correction Factor: 1.0
    - Initial Quantity: 0.0
- SLOPE
    - In Use: Yes
    - Product: Roadside Slope
    - Correction Factor: 1.0
    - Initial Quantity: 0.0

ARM Setup

- Map File: File Name (Any name is OK, just don't leave blank)
- Base Map File: None
- Collection Interval: 1s
- Alarm: Off
- Range: 1000 ft
- Slope Inc/Dec: 15 degrees
- Speed Source: Radar
- GSO Speed: 0.1 MPH

As stated in the checklist above, after these values have been entered for the first time, a new file can be created by simply pressing the button "create new file using settings from the previous file". However, the map file name, in the ARM setup, must be added for each new job that is created.

<u>Hazard Operation (with school avoidance map)</u>

The Legacy system is capable of alarming the driver if the truck is within 1000 ft of a "hazard". The locations of the hazards must be pre-defined in a road markers map. For use with the IHAS truck, hazard markers are placed around the perimeter of schools in a road-markers map. This map file is then used by the Legacy system to alarm the driver when the spray truck is too close to a school. The driver must then shut off spray until there is an acceptable distance between the truck and the school (the alarm will stop). **Note that the truck will not automatically turn the spray off. It is the responsibility of the driver to act when the alarm sounds.**

The following is a checklist of tasks to operate the Environment Data Logging System with a school avoidance map. When a new job is created in the Legacy console, there is no method to transfer a predefined school map to the new job. Thus, this file transfer must be done on a PC before the flash card is inserted into the Legacy Console.

1. Pre-spray checklist for operation with school maps

- On a PC, create all new job folders required for the day on the Legacy Flash Card.
- On a PC, transfer the school map file and other ARM setup files to each of the new job folders.
- Insert Flash card in Legacy Console.
- Turn on Battery Power Switch on side of truck.
- Turn on Legacy console.
- Press the "ARM" button on the upper right corner of the console.
- Select a new job that was created on the PC
- Press the begin ARM button on the upper right corner

2. Post-spray checklist and System Shutdown

- Exit ARM Operation.
- Turn off Legacy console.
- Turn off Battery Power switch on side of truck.
- Remove Flash Card from Legacy Console.

Data Conversion

After collected with the Legacy system, the data may be processed with the Mid-Tech RMS Office software and later processed with ArcView, SSToolbox, or some other GIS package. Because the Legacy system will only log data from the Product Control Modules (PCM's) in one unit: flow rate, every measurement made is recorded in units of gallons per minute. However, with a few simple conversions, the recorded numerical values can be converted back to the measured values with the desired units.

Wind Velocity

In order to calculate the absolute wind velocity, collected data must be used to determine wind velocity relative to the truck and the truck velocity relative to the ground. The following equations may be used to calculate absolute wind velocity in x-y coordinates where positive y is north and positive x is east.

Relative wind velocity may be determined by finding wind speed and wind direction relative to the truck. Measured values of relative speed and direction are:

$$s_1 = Q_1^{\,2}$$
$$\phi = Q_2^{\,2}$$

where: s_1 is relative wind speed (mph), ϕ is the direction from which the wind is blowing relative to the front of the truck (degrees), Q_1 is the recorded flow rate from PCM #1, and Q_2 is the recorded flow rate from PCM #2.

The resulting vector is:

$$v_1 = -s_1\left(\sin(\phi)x + \cos(\phi)y\right)$$

Truck ground displacement may be determined by the change in latitude and longitude coordinates from adjacent GPS samples.

$$\Delta y = (N + h)(lat_2 - lat_1)$$
$$\Delta x = (N + h)(lon_2 - lon_1)\cos(lat_1)$$

where: N is the radius of the earth (miles), h is the altitude above sea level (miles), lat_1 and lon_1 are the latitude and longitude of the first point (radians), and lat_2 and lon_2 are the latitude and longitude of the second point (radians). (Note that longitude values in the Western Hemisphere must be negative).

Truck velocity is the resulting vector of:

$$v_2 = \frac{\Delta x + \Delta y}{t}$$

where: v_2 is the resulting velocity vector and t is the time interval between GPS data points (hours). Adding the vectors of truck velocity and relative wind velocity yields absolute wind velocity.

$v = v_1 + v_2$

where v is the absolute wind velocity in mph.

Temperature

Ambient temperature can be calculated easily from the recorded flow rate value from PCM #3. The basic equation is:

$$T = {Q_3}^2$$

where: T is the ambient temperature (degrees C) and Q_3 is the numerical flow rate from PCM #3 (gal/min).

Roadside Slope

Roadside slope can be determined from distance measurements made to the nearest point from ultrasonic distance sensors on the sides of the truck. The distance measurement is calculated as:

$$d = {Q_4}^2 + 50$$

where: d is the distance from the sensor to the nearest roadside point (cm) and Q_3 is the numerical flow rate from PCM #4 (gal/min).

The angle of the roadside slope □ may be calculated as:

$$\phi = \arctan\left(\frac{188 - d \cdot \sin 40}{d \cdot \cos 40}\right)$$

where, 188 is the height of the ultrasonic sensor (cm), and 40 is the angle of the sensor relative to the ground plane (degrees). Note that angles defining roadside slope calculation are given in figure D1.

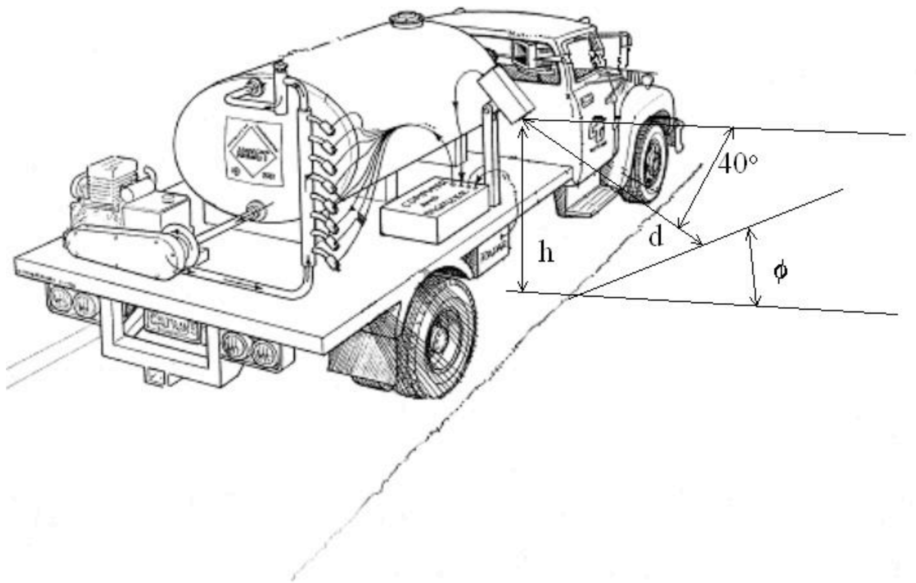
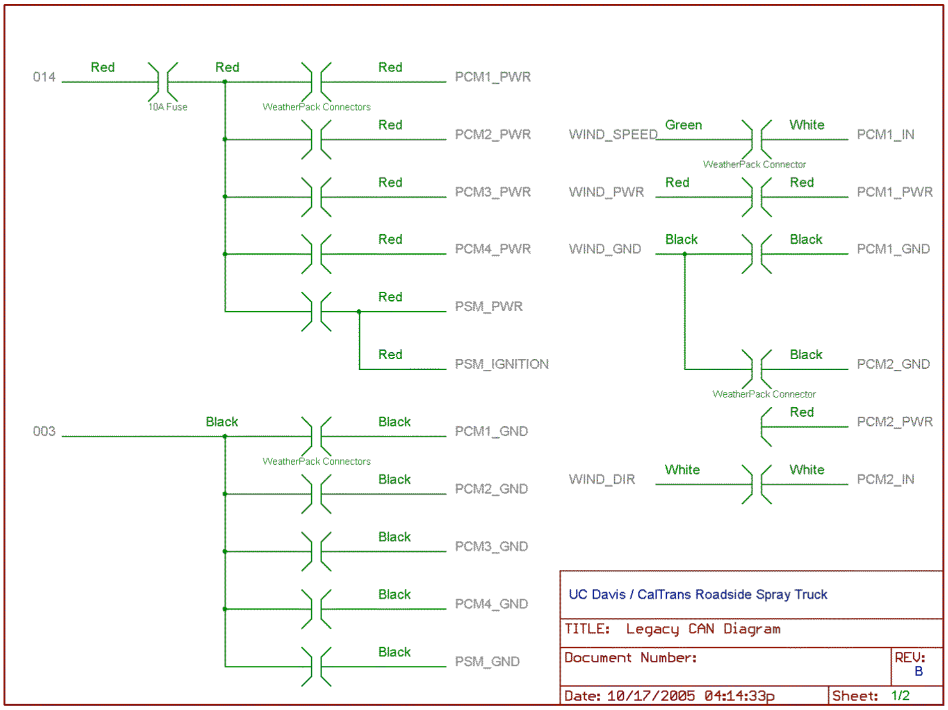


Figure D1. Diagram of spray vehicle with roadside slope geometry.

Wire Diagrams

Figures D2-D5 show electrical connections for the IHAS Data Logging System. The number values correspond to the numbering system defined in the PLC documentation. Example values include (For more information on the Mid-Tech Legacy wiring, consult the *Legacy 6000 Fieldware Users Guide*). :

000	=	Truck Chassis
001	=	PLC Ground
003	=	Truck Battery Ground
014	=	Truck Battery Power (13.8V)
024	=	PLC Power (24V)
300-331	=	Valve Control Lines
400	=	Ground Speed Signal Output



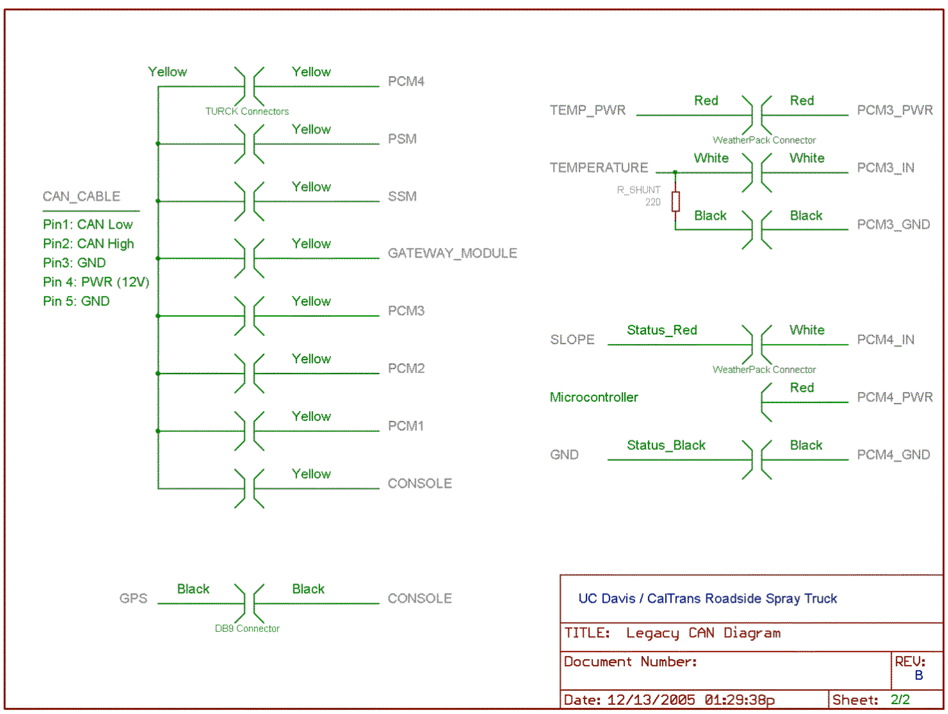


Figure D2. Wiring diagrams for Legacy CAN.

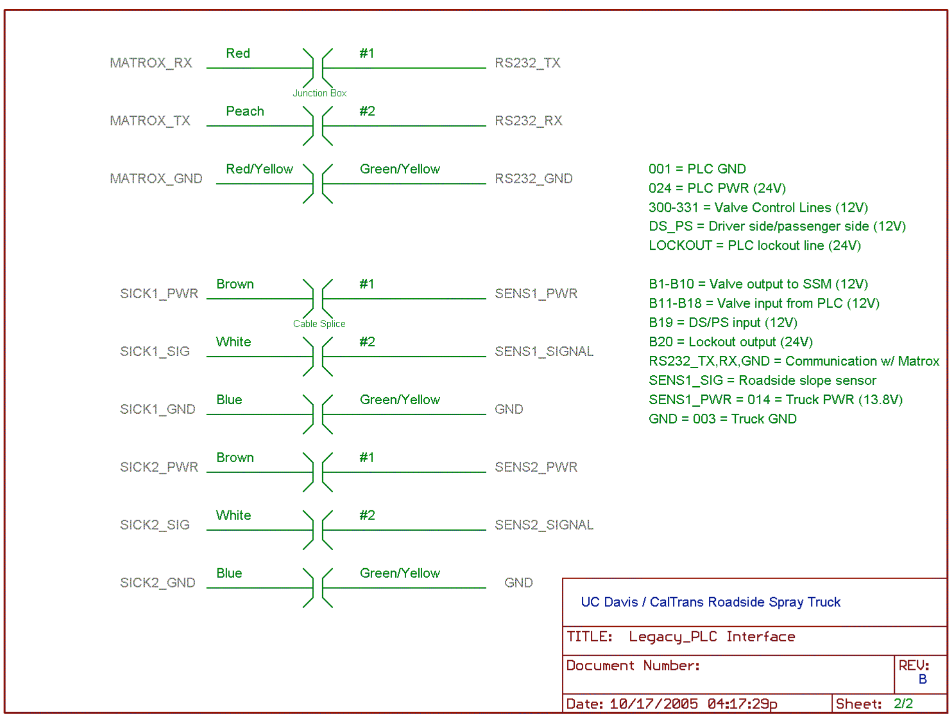


Figure D3. Wiring diagrams for interfacing Legacy to PLC.

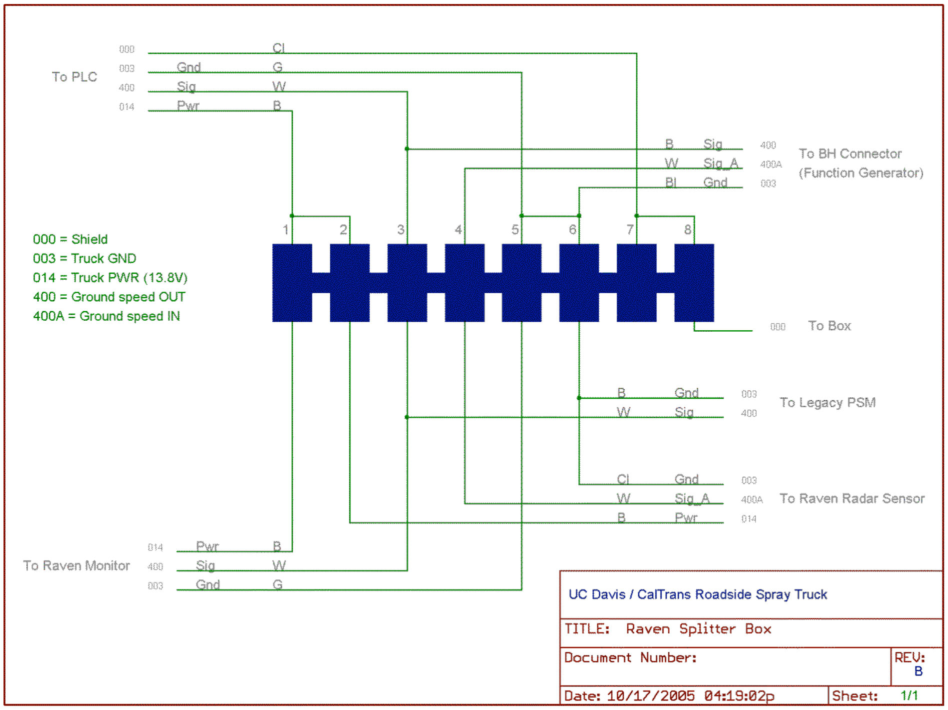


Figure D4. Wiring diagram for Raven splitter.

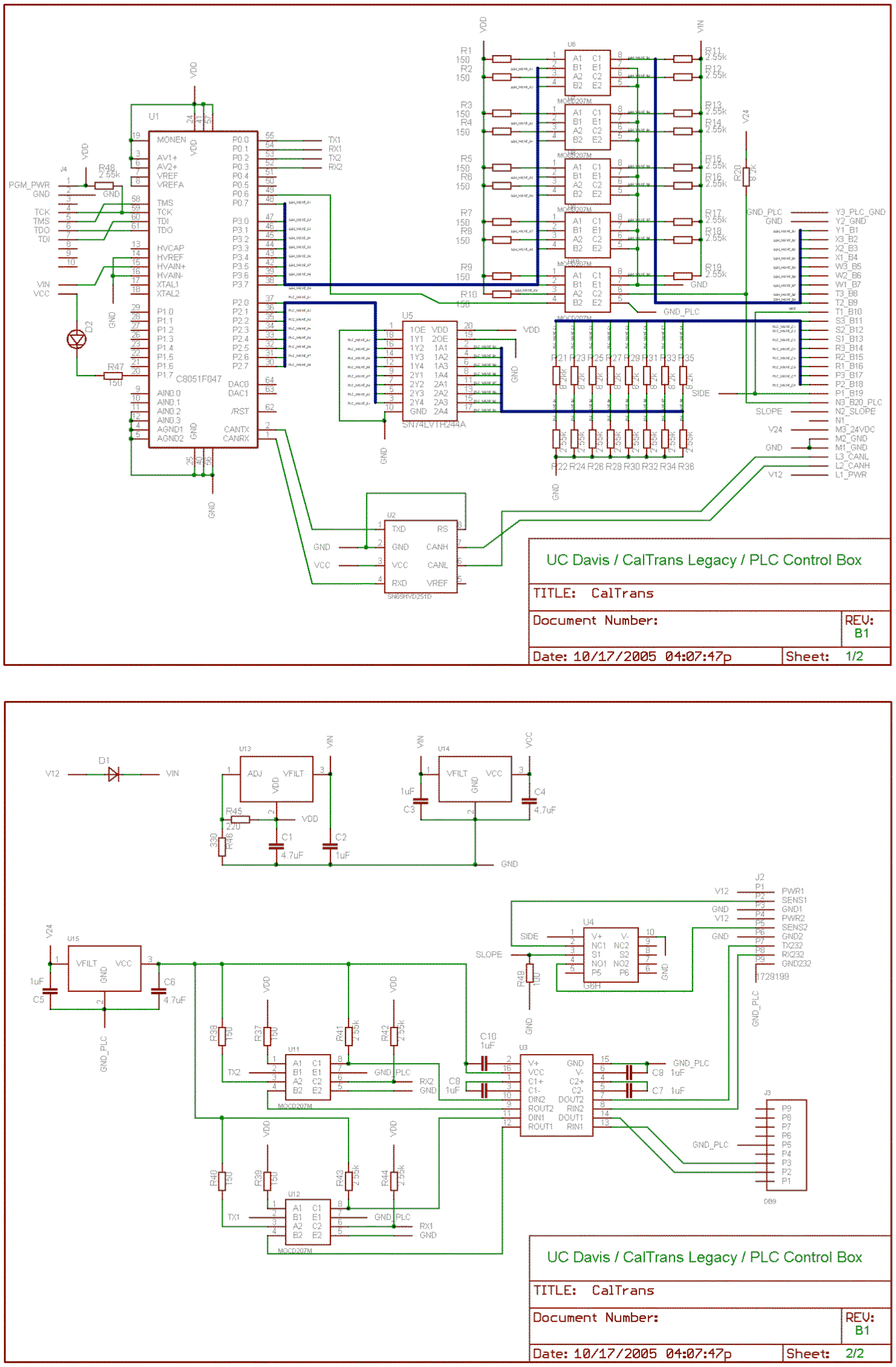


Figure D5. Wiring diagram for Legacy connections to PLC control box.

Appendix E: Sensor Specifications

GILL INSTRUMENTS

WindSonic

Wind Speed & Direction Sensor

WINDSONIC

ALL WEATHER SENSING TECHNOLOGY

MAINTENANCE FREE - 2 YEAR WARRANTY

- *LOW START SPEED*
- *CORROSION FREE, UV STABLE MATERIAL*
- *NO CALIBRATION REQUIRED*
- *ROBUST CONSTRUCTION*
- *TRUE 0-359° OPERATION (no dead band)*
- *WIND SPEED & DIRECTION FROM A SINGLE UNIT*

- *AGRICULTURE*
- *HVAC*
- *POLLUTION CONTROL*
- *PORTABLE WEATHER STATIONS*
- *ROADSIDE WEATHER STATIONS*
- *TUNNELS*
- *MARINE*

At last, a real low cost alternative to conventional cup/vane/ propeller wind sensors in a single unit - WindSonic from Gill Instruments. Utilising our expertise as the world's leading sonic manufacturer, WindSonic is based on our existing, highly successful, proven ultrasonic technology. Ideal for applications that demand economic wind sensing, WindSonic is suitable for land-based and marine environments.

A lightweight unit, WindSonic is of a robust, high strength construction designed to withstand installation and use with no fear of the damage commonly experienced with more fragile cups, vanes or propellers. Without the need for expensive on-site calibration or maintenance and with a corrosion free exterior, WindSonic is a true fit and forget unit.

The flexible design enables you to easily configure WindSonic to deliver the information you require. By using the software provided it is possible to select the output rate and choose the units of measurement that suit your application. Ensuring accuracy and reliability, WindSonic automatically transmits an anemometer status code with each output to indicate its operating status. Available in three options, providing a number of different digital and analogue outputs.

Maintenance free, quick and easy to install, WindSonic is designed to be mounted using a standard pole fitting and comes complete with all screw fittings, a mating marine grade connector and comprehensive user manual.

The unit is supplied with a 2 year warranty as standard.

CUSTOMER SELECTABLE	
Output	1, 2 or 4 outputs per second
Parameters	Wind Speed & Direction or U and V (vectors)
Units of Measure	m/s, knots, mph, kph, ft/min

WIND SPEED	
Range	0 – 60 m/s (116 knots)
Accuracy	+/- 2%
Resolution	0.01 m/s (0.02 knots)

WIND DIRECTION	
Range	0 to 359° – no dead band
Accuracy	+/- 3°
Resolution	1°

ANEMOMETER STATUS

Message supplied as part of standard output

POWER REQUIREMENT	
Anemometer	9-30Vdc @ 14.5mA typical
	Start up time <1 second

OUTPUTS	
Option 1	RS232
Option 2	RS232 + RS422 + RS485 + NMEA*
Option 3	RS232 + RS422 + RS485 + NMEA* + 0-5V or 4-20mA
Option 4	SDI-12 + RS232

* NMEA 0183 Version 3

ENVIRONMENTAL	
Ingress Protection	IP65
Operating Temperature	-35°C to +70°C
Storage Temperature	-40°C to +90°C
Operating Humidity	<5% to 100%
EMC	EN 61000-6-2 : 2001
	EN 61000-6-3 : 2001

MTBF	
	15 years

MATERIALS	
External Construction	LURAN S KR 2861/1C ASA/PC

DIMENSIONS	
Size	142 x 160 mm
Weight	0.45 kg

WARRANTY	
	2 years

OPTIONAL FACTORY CALIBRATION	
	Traceable to national standards

ACCESSORIES	
Pipe Mounting	44.45 mm (1.75 in) diameter
WindCom - Display & logging software *	
Cables	
Display	

* download WindCom free from www.gill.co.uk

GILL INSTRUMENTS

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ISO9001 UKAS

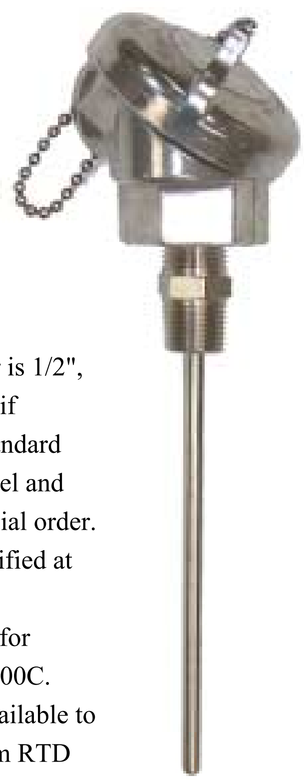
The WindSonic is part of the Solent range of ultrasonic anemometers. The range is in continuous development and therefore specifications may be subject to change without prior notice.

GENERAL PURPOSE INDUSTRIAL

- **Accurate Platinum RTD**
- **Rugged construction**
- **Splashproof**

General purpose large version

This is the all purpose model for general heavy duty industrial or commercial temperature measurement. It features a large threaded cast aluminum head with gasket. Electrical connections are made through the 3/4" NPT female opening suitable for piping or standard electrical fittings. The standard process connector is 1/2", although 3/4" NPT is available if specified at order time. The standard sheath is 1/4" O.D. stainless steel and other sizes are available to special order. The sheath length must be specified at order time. The standard assembly is rated for measuring temperatures up to 200C. 400C and 600C versions are available to special order. We use a thin film RTD sensor to DIN 43 760 or IEC 751 or wire wound if requested.



ORDERING DATA

TS-GPL-R-100- ( ) - ( ) - ( )

	stem	connection	temp(C)
	inches	8 = 1/2" NPT	400
		12 = 3/4" NPT	600

e.g. TS-GPL-R-100-4-8 general purpose industrial probe with large head and 100 ohm RTD, 4" long stem and 1/2" NPT process thread rated for standard 200C operation.

- **Accurate Platinum RTD**
- **Rugged construction**
- **Splashproof**

General purpose small version

This is the all purpose model for general light duty industrial or commercial temperature measurement. It features a small threaded cast aluminum head with O-ring seal. Electrical connections are made through the cable gland with rubber grommet. The standard process connector is 1/4", although 1/2" NPT is available if specified at order time. The sheath is 1/4" O.D. stainless steel. The sheath length must be specified at order time, although 4" and 6" lengths are normally available from stock. The assembly is rated for measuring temperatures up to 200C and uses a thin film RTD sensor to DIN 43 760 or IEC 751.

ORDERING DATA

TS-GPS-R-100- ( ) - ( ) - ( )

	stem	connection	temp(C)
	inches	4 = 1/4" NPT	400
		8 = 1/2" NPT	600

e.g. TS-GPS-R-100-6-4-400 general purpose industrial probe with small head and 100 ohm RTD, 6" long stem and 1/4" NPT process thread rated for 400C operation.

ENERCORP instruments ltd

25 Shorncliffe Rd, Toronto, ON, M9B 3S4 Tel 1(800)ENERCORP or (416)231-5335 Fax 1(877)ENERCORP or (416)231-7662

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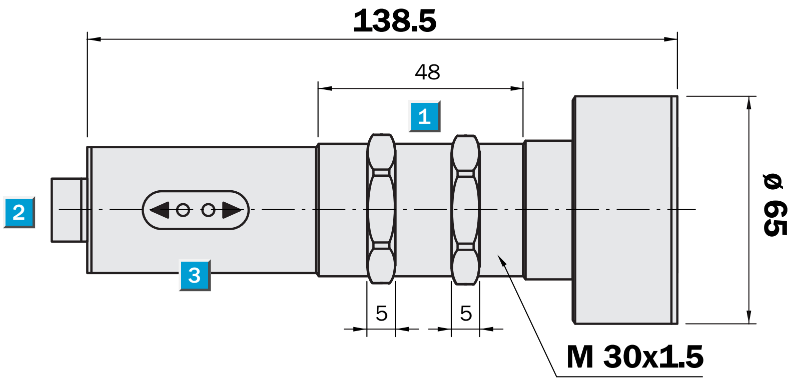
Operating scanning range 800 … 6000 mm

Ultrasonic sensor

- High measurement accuracy thanks to time-of-flight measurement
- Independent of material shape (including films, glass and bottles)
- Teach-in
- Insensitive to dirt, dust and fog
- Operating scanning range up to 6,000 mm
- Binary outputs or analog output

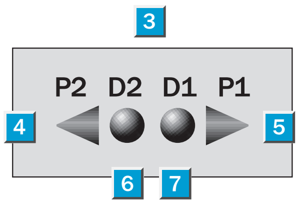
CE

Dimensional drawing



Adjustments possible

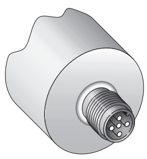
All types



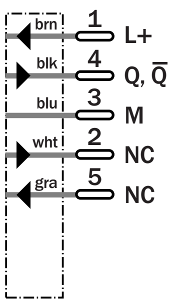
1	Fastening nuts, width across 36 mm
2	Connection plug M 12
3	Control and display panel
4	Setting key 2
5	Setting key 1
6	2
7	1

Connection types

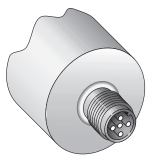
UM 30-15111



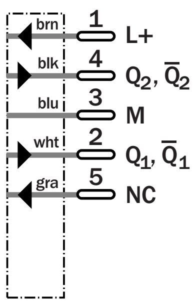
5-pin, M 12



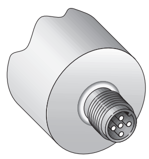
UM 30-15112



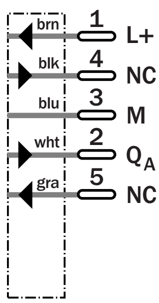
5-pin, M 12



UM 30-15113



5-pin, M 12



Accessories

Mounting systems

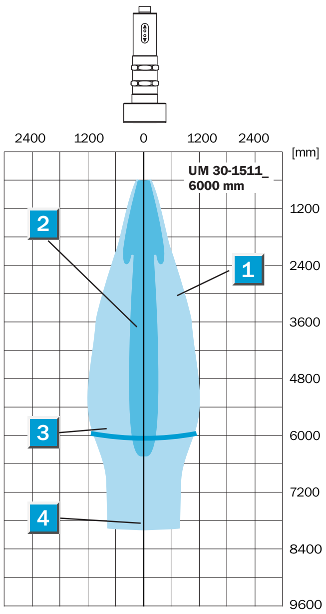
Technical data	UM 30-	15111	15112	15113
Operating scanning range (limiting scanning range)	800 ... 6000 mm (8000)	■	■	■
Ultrasonic frequency	80 kHz	■	■	■
Resolution	1 mm	■	■	■
Reproducibility	± 0.15 % of final value	■	■	■
Accuracy	≤ 2 % of final value	■	■	■
Supply voltage V_S	12 ... 30 V DC [1]	■	■	■
Ripple	± 10 %	■	■	■
Current consumption [2]	≤ 70 mA	■	■	■
Switching outputs, reversible[3]	Q: PNP, V_S –2 V, I_{max} = 500 mA	■		
	Q_1, Q_2: 2 x PNP, V_S –2 V, I_{max} = 500 mA		■	
Analog output, reversible[3] [4]	Q_A: 4 ... 20 mA/0 ... 10 V			■
Response time [5]	240 ms	■	■	■
Switching frequency	2/s	■	■	
Switching hysteresis	100 mm	■	■	
Standby delay	2 s	■	■	■
Connection type	Plug M 12, 5-pin	■	■	■
Enclosure rating	IP 65	■	■	■
Ambient temperature [6]	Operation –20 °C ... +70 °C	■	■	■
	Storage –40 °C ... +85 °C	■	■	■
Weight	360 g	■	■	■
Housing material	Nickel-plated brass	■	■	■

1) Limit values
2) Without load
3) Outputs short-circuit protected
4) Automatic switching between voltage and current outputs dependent on load

Current output 4 ... 20 mA:
R_L ≤ 500 Ω, V_S ≥ 20 V;
R_L ≤ 100 Ω, V_S ≥ 12 V
Voltage output 0 ... 10 V:
R_L ≥ 100 kΩ; V_S > 15 V

5) Only with UM 30-____3: Recovery time according to EMV EN 50 319
6) Temperature compensation at –20 ... +50 °C

Detection ranges



1	Aligned plate 500 x 500 mm
2	Pipe diameter 27 mm
3	Operating scanning range
4	Limiting scanning range

Order information

Type	Part no.
UM 30-15111	6 025 659
UM 30-15112	6 025 664
UM 30-15113	6 025 669

Appendix F: IHAS Direct Nozzle Injection Research Study

Direct Nozzle Injection of Pesticide Concentrate into Continuous Flow for Intermittent Spray Applications

D. Downey, T. G. Crowe, D. K. Giles, D. C. Slaughter

Abstract. *A direct nozzle injection system was developed to intermittently inject concentrated solutions into continuous carrier liquid flow through a straight–stream spray nozzle used for targeted roadside spraying of post–emergent herbicide during pre–emergent herbicide application. The injection system was based on a 12 VDC direct–acting electrical solenoid valve with a 0.56 mm valve orifice and metering plate with a 0.2 mm diameter orifice. A conductivity–based sensor was used to measure the instantaneous concentration of NaCl tracer simulating a pesticide solution. Injection pulse durations ranged from 10 to 100 ms into carrier flows of 1.5 and 2.6 L/min from 1.55 and 2.18 mm nozzle orifice diameters, respectively. Lag times between initiation of the injection valve actuation and emission of the concentrate material from the spray nozzle were on the order of 25 ms. Concentrations of 1% (v/v) from injected solution into the flow emitted from the nozzle could be achieved within 100 ms after valve actuation. Increasing the injection pulse duration did not reduce lag time nor increase the temporal rate of concentration increase in the emitted spray; however, increasing the injection pressure increased the rate of concentration increase. Analysis of the injection event, using standard mixing criteria, determined that the injection mixing events were Gaussian in nature and did not represent ideal plug flow or short–circuiting events. For an intermittent, target–detecting system with a detector–to–nozzle distance of 4 m and a ground speed of 5 m/s, the direct nozzle injection system is a feasible configuration for spot spraying if the sum of detection time and time of flight for the emitted spray is less than 800 ms. For a prototype machine vision–based roadside sprayer, detection and spray flight times were less than 67 and 400 ms, respectively; therefore, feasibility of spot spraying using at–nozzle injection was established.*

Keywords. *Injection, Microliter, Nozzle, Orifice plate, Pesticide, Precision agriculture, Spray.*

In arid climates, roadside weed control reduces fire hazards, decreases weed seed production, and improves driver visibility; the operational goal is removal of all vegetation in a narrow strip adjacent to a road or freeway. Targeted application of foliar–active pesticides is a strategy to reduce pesticide use rates, non–target deposition, and potential environmental contamination. Application of spray exclusively to target plants minimizes the amount of pesticide discharged into the environment and maintains effective weed control.

Roadside weed control provides an opportunity for development and deployment of weed sensing and targeted application systems. Unlike many agricultural applications, where discrimination between crop and weed plants is necessary for selective application, the detection of the presence of any vegetation against soil or other non–vegetative surface is an easier and more tractable problem. Near–infrared and visible light measurement strategies have been developed and commercialized for detecting weeds for boom spraying of post–emergent herbicides (e.g., Weedseeker, NTech Industries, Inc., Ukiah, Cal., and the Detectspray system described by Felton and McCloy, 1992). Slaughter et al. (1999) reported the development of a machine–vision system for offset (boomless) selective spraying (fig. 1). The system operated in the visible light spectrum and used a color lookup table to categorize regions in the field of view as vegetation or non–vegetation.

The detection and spray system developed by Slaughter et al. (1999) was further refined through the development of an injection mixing system that provided the manifold of spray nozzles with a solution of chemicals and adjuvants (Gillis et al., 2002). The system used a commercial injection controller, with a bypass loop to separate potable water from concentrate, to meter the appropriate amount of chemical into the clean water carrier flow to the nozzle supply system. The system was designed as an intermittent sprayer, with the spray discharge actuated only when target weeds were detected. Two techniques were developed for integrating injection mixing into the intermittent sprayer; however, all nozzles received a common spray mix.

Injection sprayers can provide a constant application rate by metering the supply of chemical and controlling flow rate, however, achieving a steady–state response of injected chemical less than 1 s after an initiated change has been difficult to achieve. Chi et al. (1988) injected fluids at rates of 3 to 20 mL/s; the system measured pump speed and pressure drop as indicators of the direct injection system and

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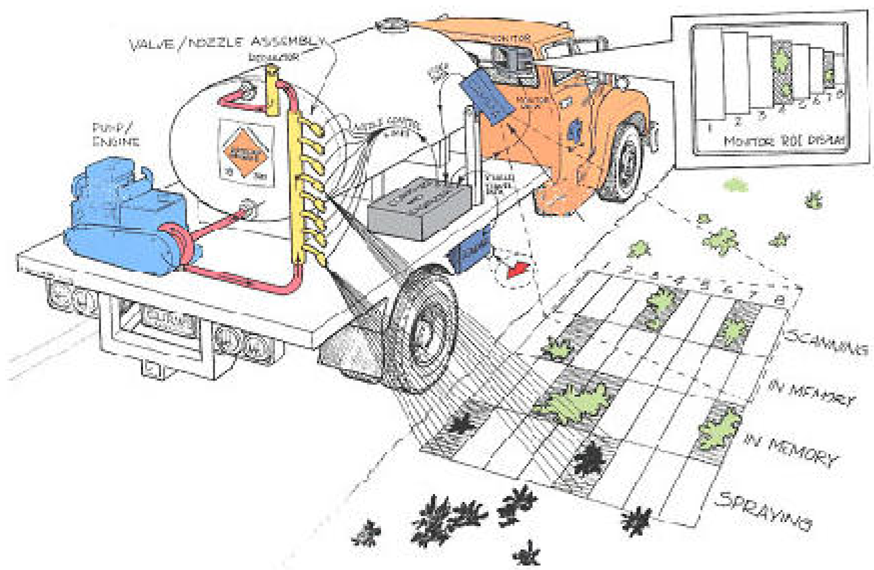

Figure 1. Prototype roadside sprayer using machine vision to detect vegetation for intermittent targeted spraying (from Slaughter et al.,1999).

reached steady state within 5 s after altering the injection rate. Tompkins et al. (1990) measured time from initiation of injection to steady−state concentration from individual nozzles; sample collection of nozzle flow mixture began 1 s after start of concentrate injection. Miller and Smith (1992) developed a prototype direct nozzle injection spray boom and used a 0.56 mm orifice for direct injection into a straight−stream nozzle for several injection pressures; however, measurement of the mixed carrier flow and injection stream occurred within 3 to 5 s after sampling. Zhu et al. (1998) developed a sampling system to measure time for injected concentrate to reach a set level at spray nozzles due to ground speed changes; the system also measured uniformity of the injection mixture over time. Concentration changes were observed within 10 s; however, this was predicated on the common agricultural chemical injection equipment used. Sumner et al. (2000) evaluated lag times of direct injection into a spray boom and a direct nozzle injection sprayer system using string collectors. The system was adequate for measuring lag times from 0.5 to 4 s. Womac et al. (2002) developed a variable−concentration direct−injection system that partitioned flow through parallel, fixed−ratio, diluent−driven (in−line) chemical pumps and a bypass branch. Injection events were measured with a 1 rpm rotary driven device with 104 sampling vials for each nozzle; flow assessments were made over 1 to 55 s.

Design Needs

The utility and commercial value of the weed−sensing offset sprayer could be greatly expanded by additional capabilities. Conventional vehicle and spray systems are often used for broadcast application of pre−emergent herbicides. In such an application, the spray is continuous and designed to uniformly cover the entire boom application area. During the pre−emergent application, a post−emergent herbicide can be spot applied when the driver visually detects a weed patch ahead of the spray truck. When the weeds are seen, the driver manually operates a switch that actuates an injector pump to add post−emergent herbicide to the flow of pre−emergent herbicide. However, the injected material is added to the liquid flow to the entire boom, not just individual nozzles, thereby usually covering an area much larger than the weed patch. Additionally, the lead time for the injected material to reach the nozzles requires that injection be started long before the weed patch is reached. The result is that spraying a small weed patch requires an excessive amount of chemical that is wastefully applied to the area surrounding the weed patch.

Achieving an intermittent, high spatial resolution, selective application of post−emergent herbicide during a continuous application of pre−emergent herbicide requires that small volumes of liquid be quickly injected into a continuous liquid flow entering a nozzle. For example, the system developed and described by Slaughter et al. (1999) and Gillis et al. (2002) was designed to treat weeds on a 15 × 15 cm grid at ground speeds of 15 km/h. These conditions approximately correspond to a 28 ms event during which 2 mL of tank mix are dispensed to spray a weed within a single 15 × 15 cm cell. Assuming that an active formulation comprised 2% of the total spray applied, the injected volume per spray event would be approximately 40 μL.

The successful implementation of the system is further complicated by the dynamics of the vehicle motion and various electromechanical components, the fluid mixing through the flow passages, and the flight times of liquid from nozzles to targets. The complete spray event can be described as the following sequence of steps: (1) the detection system determines the location of a target; (2) the detection system actuates a valve for injection of the active ingredient into the continuously flowing liquid stream; (3) the valve opens; (4) liquid flows through the valve and into the flow passageway where it mixes with the flowing carrier liquid; (5) the mixture of carrier and injected liquids passes through a nozzle; and (6) the liquid travels from the nozzle to the target. Previous work on the system (fig. 1) determined that the time required for detection (step 1) was less than 150 ms (Slaughter et al., 1999), and current processor speeds allow this process to be completed in under 67 ms. A study of spray flight times (Giles et al., 2003) found maximum flight times for spray mixes to be 450 ms. With a typical nozzle−to−camera spacing of 4 m on the vehicle, approximately 800 ms is allowable for the combined detection, processing, and spray event. Therefore, if 517 ms is required for detection and spray transport, a maximum of 283 ms is allowable for injection and discharge of the concentrated herbicide. If the injection event can achieve emission of a lethal concentration of herbicide from the nozzle in less than 283 ms, then the process is feasible.

The minimal design information that must be known is timing of the initial valve actuation and duration of the injection necessary to deposit a lethal concentration of injected chemical on the target weed. Therefore, temporal characteristics of the injection event must be determined and integrated into the system control algorithm and system timing. These characteristics include the delay between electrical actuation of the injection valve and the mixing characteristics of the liquid injection into the carrier stream.

Objectives

The goal of this work was to determine the feasibility of intermittent at−nozzle injection for use with a weed detection system, concurrently with broadcast application of a pre−emergent herbicide. The specific objectives of this work were:

- Design and fabricate a device for intermittent injection of liquid into a continuously flowing liquid stream entering a spray nozzle.
- Determine the flow characteristics of the device in order to establish the operating conditions necessary to achieve a desired liquid delivery.
- Characterize the temporal mixing response of the system in order to determine the transient operating conditions necessary to achieve a desired concentration of injected chemical at a desired time of discharge.

Materials and Methods

Injection Flow System, Valve, and Controls

The machine−vision based offset sprayer first reported by Slaughter et al. (1999) and most recently described by Gillis et al. (2002) used three−way, direct−acting, 12 VDC solenoid valves to control the flow of tank mix from a liquid supply manifold and into straight−stream spray nozzles. Three−way valves were required in order to maintain system pressure during intense transient periods of weed detection and spraying and to facilitate retrofit and operation of the weed detection system with existing roadside sprayers (Gillis et al., 2002). The valve used was a standard, commercial component (7 W, 2.4 mm dia. orifice, model 651064, KIP, Inc., Farmington, Conn.). The normal, or unpowered, position of the valve returned the incoming fluid to a bypass manifold, which returned the fluid to the spray pump for recirculation. When powered, the valve diverted flow to the spray nozzle, which was close−coupled to the valve. Details of the valve were reported by Gillis et al. (2002) and Crowe et al. (2005).

In spray operation mode, the tank mix, whether prepared as a batch in the reservoir tank or prepared by an in−line mixing system described by Gillis et al. (2002), entered the three−way valve and was routed to the spray nozzle by actuating the electric solenoid. This three−way valve will be referred to as the "carrier" valve in this study. Because this work focused on applications where the active ingredient would be injected into a continuously operating nozzle, the carrier valve was maintained in the powered position during all testing. The spray nozzles used were straight−stream nozzles identical to those used on the roadside sprayers, with orifice diameters of 1.55 and 2.18 mm (models SS0005 and SS0010, Spraying Systems Co., Wheaton, Ill.). The liquid supply pressure to the carrier valve was maintained at 360 kPa for all testing; steady−state flow rates through the 1.55 and 2.18 mm orifice diameters were 1.52 and 2.60 L/min, respectively.

The valve controlling the injection of liquid into the carrier flow was a two−way, normally closed, direct−acting, 12 VDC, 0.65 W solenoid valve (model 971012−KIP Jr., KIP, Inc., Farmington, Conn.). Due to the requirement for relatively low flow rates of injected liquid into the carrier flow, the fluid connection between the injection valve and the carrier valve included a provision for a standard agricultural flow regulating plate with 0.2 mm diameter orifice (model CP4918−8, Spraying Systems Co., Wheaton, Ill.). A schematic diagram of the carrier and injection valves is shown in figure 2, and photographs of the components are shown in figure 3. A 5 cm diameter, 0.7 cm thick, brass plate was machined to provide a seat for the orifice plate between the

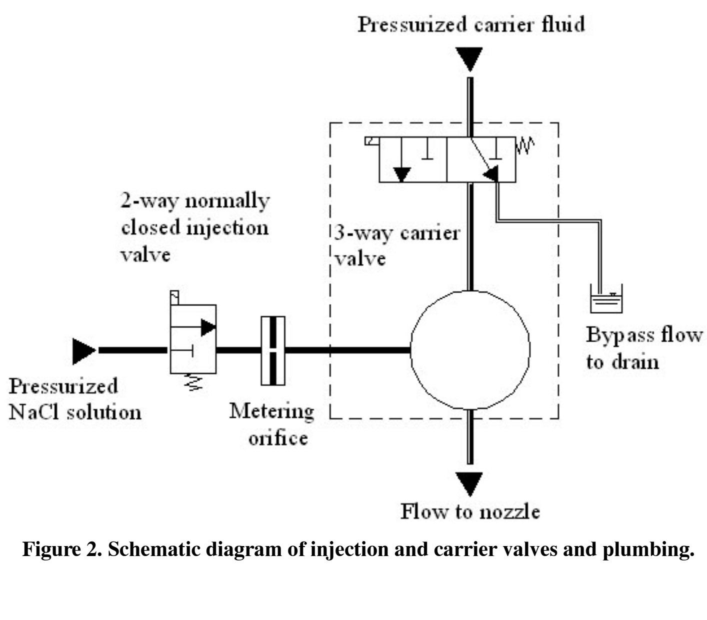

Figure 2. Schematic diagram of injection and carrier valves and plumbing.

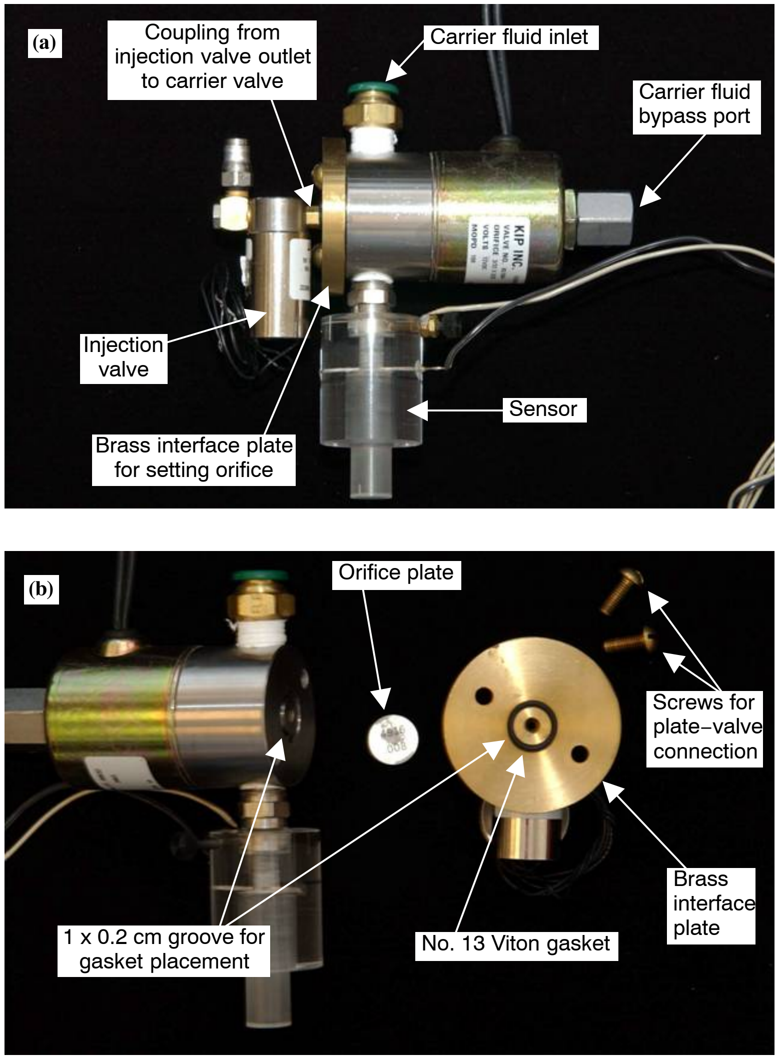

Figure 3. Fabricated components used for placing orifice plate in the injection flow path: (a) injection valve attachment, and (b) internal component view.

injection valve outlet and the carrier valve passageway leading to the spray nozzle. The brass plate was attached to the base of the carrier valve. The center of the brass plate was drilled and tapped to 10−32 machine screw thread. The brass plate and the base of the carrier valve were both machined to create a 1 cm diameter by 0.2 cm deep groove to provide a seat for two rubber gaskets. Viton O−rings (No. 013) were placed in each groove, and the orifice plate was positioned between the O−rings to create a sealed passage from the center of the brass plate, through the orifice plate, to the body of the carrier valve. The injection valve outlet was attached to the center hole of the brass plate with a 10−32 male−male coupling.

The injection and carrier valves were both actuated through field−effect transistors (FET) with 12 VDC. The carrier valve was actuated and fully open for the injection events reported in this work. The injection valve was opened for short periods, i.e., 10 to 100 ms, through a square wave input signal into the FET. All reported pulse times refer to the duration of the electrical pulse sent to the injection valve; opening and closing times of the valve were significant only for the 10 ms pulse. Previous work with similar valves determined the transient time of the valves to be approximately 2 to 4 ms for opening or closing events.

Measurement of the Transient Response of the Injection

Characterization of the injection event required measurement of the instantaneous concentration of injected liquid in the liquid emitted from the spray nozzle. Commercial liquid conductivity sensors designed for static and in−line flow stream measurements were unsuitable for the application in this experiment; therefore, a custom sensor, designed specifically for discharge from straight−stream nozzles, was developed. Crowe et al. (2005) reported the development and evaluation of the sensor used in this experiment; a brief summary is presented here. The real−time measurement technique of injected concentrate was based on a change in the electrical conductivity of the emitted liquid. Distilled water was used as the carrier fluid, and a 25,000 ppm NaCl solution was used as the injection liquid. From the conductivity of the emitted fluid, the concentration of injected liquid was determined through a calibration equation developed and reported by Crowe et al. (2005).

The sensor was fabricated with a pair of electrodes: one electrode was in contact with the emitted fluid jet (1 cm downstream from the nozzle orifice), and the stainless steel nozzle served as the other electrode, in order to measure electrical resistance of the fluid element. The sensor housing

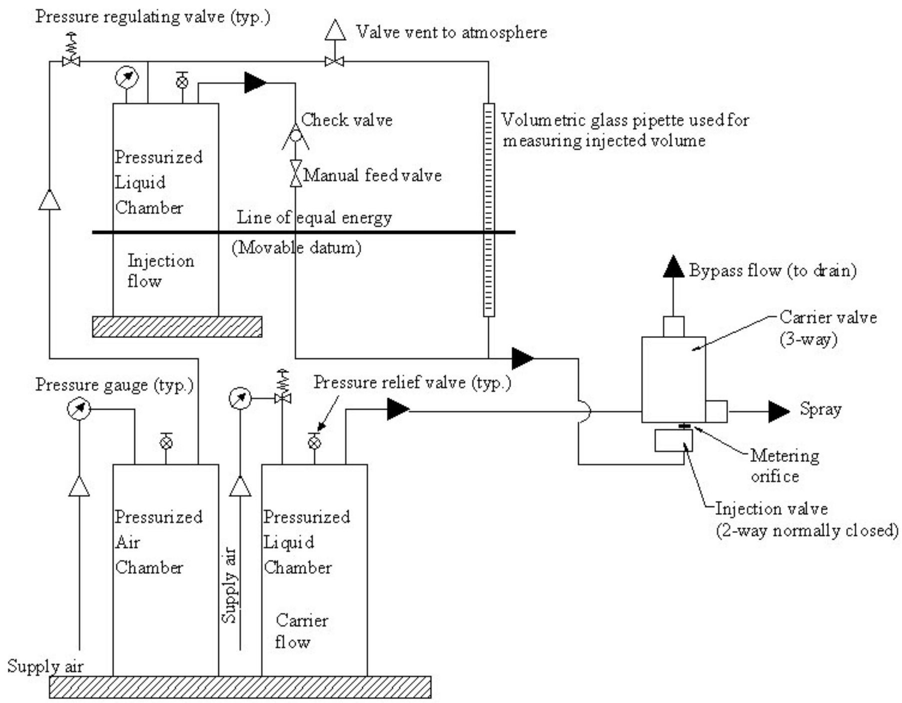

Figure 4. System for measuring injected volumes (from Crowe et al., 2005).

was fabricated from acrylic rod and secured to the straight–stream nozzle body. The downstream sensor electrode was constructed of stainless steel tube extending across the centerline of the emitted liquid jet. The velocities of carrier fluid exiting the straight–stream nozzles (1.34 and 1.16 m/s) established that the transit time for fluid to reach the sensor electrode for electronic measurements of injection events was less than 1 ms. Voltage data from the sensor were recorded using a digital storage oscilloscope (model TDS 3012B, Tektronix, Inc., Beaverton, Ore.) for each injection event. The oscilloscope captured data at a rate of 10 to 25 kHz during the transient injection events.

Injection volumes were independently measured for each injection event and used to establish the validity of the sensor described by Crowe et al. (2005). The carrier valve was actuated to establish a stable continuous flow stream; an injection pulse was initiated, and the resultant electrical signal from the sensor was captured with the oscilloscope and used, through the calibration equation, to calculate a concentration curve for each injection event. Additionally, for each injection event, the absolute volume was measured with a pipette (1 mL total volume, with 0.1 mL major gradations and 0.01 mL minor gradations). The setup for the physical measurement system is shown in figure 4. The pressurized air chamber provided an equalized pressure for the volumetric pipette and pressurized injection container, effectively providing an equal hydraulic energy line of fluid head. The location of the liquid was annotated before and after each injection event, providing the absolute volume injected. This physical measurement was used to validate the sensor measurement system by scaling and integrating the concentration curves, described in detail by Crowe et al. (2005).

Experimental Design

The experiment was designed to yield information relating the characteristics of injection to controllable parameters of the injection event. The response variables were: (1) injected volume, (2) the time delay between injection valve actuation and initial measurement of emitted spray liquid with injected material, and (3) the time history of concentration of injected material in the emitted spray during the event. The controllable parameters were: (1) supply pressure of liquid to the injection valve, and (2) the duration of the injection pulse. A parametric design was used with injection liquid supply pressures of 250, 300, 350 and 400 kPa, injection pulse durations of 10, 30, 60 and 100 ms, and two spray nozzles (1.55 mm and 2.18 mm orifice diameters).

Results

Volume from Injection Events

Injection events were measured volumetrically for the range of pressure and pulse duration test conditions; results are shown in figure 5. The injected volumes for the test conditions ranged from 27 to 157 μL. The relationships between the supply pressure of the injection liquid, pulse duration, and carrier nozzle flow rate were apparent in the results. Specifically, the injected volume increased linearly with pulse duration; data for a 10 ms pulse, consisting primarily of transient valve operation (opening and closing of the pintle), are shown in results but were not within the linear region of volume–pulse duration response. Injected volumes increased with supply pressure of the injected liquid and were higher for the larger spray nozzle, corresponding with the higher carrier flow rate.

Concentration of Injected Liquid In Emitted Spray Fluid

Temporal profiles of the concentration of injected fluid in the emitted spray from the nozzles are shown in figures 6 and 7. Data are shown for the injection pressures of 250 and 400 kPa, the minimum and maximum, respectively. Intermediate pressures of 300 and 350 kPa resulted in similar

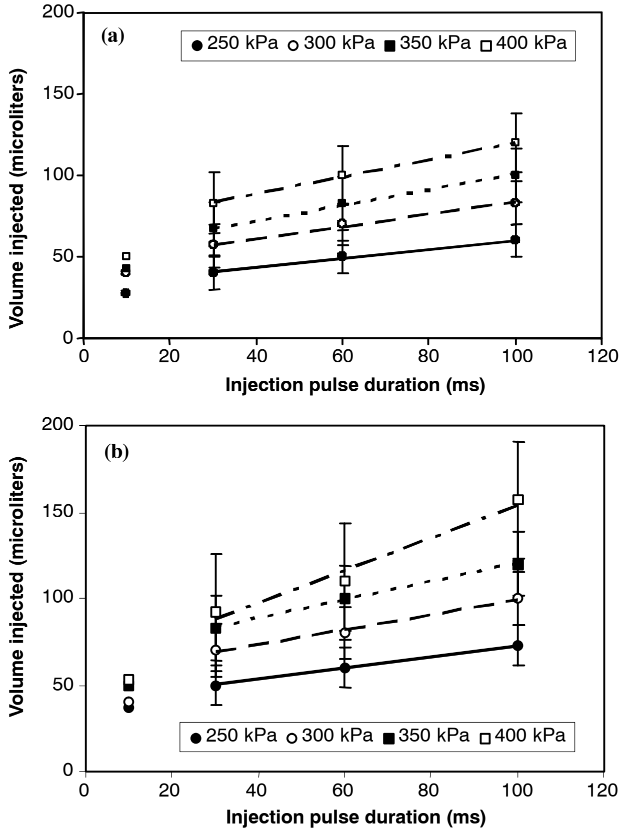

Figure 5. Injected volumes for different pulse durations and injected liquid supply pressure for (a) 1.55 mm and (b) 2.18 mm diameter nozzles (lines show linear trends; standard error bars are shown for measured data).

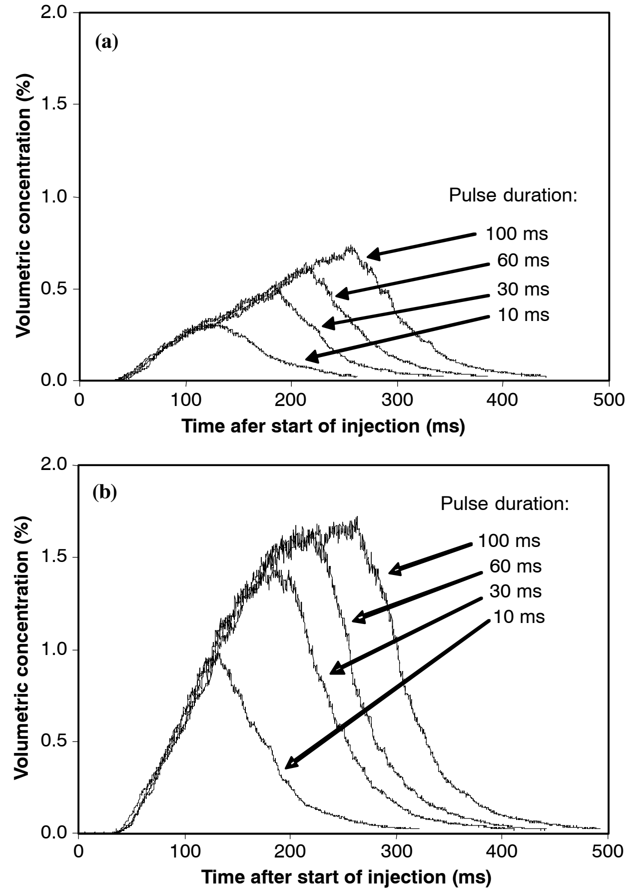

Figure 6. Temporal response of injected concentrate in discharged spray based on the total flow from 1.55 mm diameter nozzle for (a) 250 kPa and (b) 400 kPa liquid injection pressures.

trends, bounded by the data results shown. Concentration of injected fluid in the discharge was 0.15% to 1.75 % based on nozzle, pressure, and pulse duration. These concentrations are within the useful range for post−emergent herbicides, i.e., glyphosate, for roadside weed control. The results indicate that: (1) the time delay between the leading edge of electrical actuation pulse to the valve and the initial detection of injected liquid in the spray emission from the nozzle was less than 50 ms; (2) longer duration injection pulses resulted in longer emission events and higher peak levels of concentration; (3) peak concentrations of emitted liquids increased with increasing pulse duration to a limit that was reached with 60 ms pulses; (4) significant mixing of the injected concentrate and carrier fluid occurred within the flow passageway between the valve orifice and the spray nozzle; (5) increased injection pressure did not appreciably lengthen the discharge event nor the temporal rate of increase or decrease in concentration, only the peak concentration level and duration of peak concentration level; and (6) with the higher carrier flow rate, the concentration of injected liquid tended to reach steady state more quickly and remained at a relative steady−state level for a longer period of time.

Figure 8 and table 1 show peak injected concentrations (volumetric percentage) for the different pulse durations over all injection pressures for both nozzle diameters. These results show similar trends and validate the measured volumes reported in figure 5. Peak concentrations, on a percentage basis of the total flow, increased linearly with pulse duration and injection pressure. In addition, as previously indicated, data for the 10 ms pulse were not within the linear region of this response. Injection volumes were slightly higher for the larger diameter nozzle; however, peak volumetric percentages were lower, corresponding with the higher carrier flow rate with the large nozzle diameter.

Mixing Characteristics of the Injected Fluid

Observation of the temporal characteristics of the injected concentrate in the emitted fluid indicated that mixing of concentrate in the carrier fluid was significant and warranted a formal analysis of the process. Mixing characteristics were based on several assumptions, specifically, carrier flow was assumed to be at steady state, the liquid densities were equal (carrier flow and injected concentrate), and no reaction occurred due to mixing the miscible fluids. Estimates of time parameters from the residence time curves (concentration versus time) were not influenced by the sensor electrode positioning.

Classical mixing and plug flow characteristics of enclosed volume spaces were described by Levenspiel (1979). These time−based concepts are based on several aspects of the concentration versus time curve of a tracer injected into a mixing regime. The time a tracer first appears is indicated by t_f (table 2), the time that 10%, 50%, and 90% of the tracer has passed are symbolized by t_{10}, t_{50}, and t_{90}, respectively. The theoretical residence time (T) of a mixing reactor is given by the ratio of volume space (or void volume, 1.5 mL in this

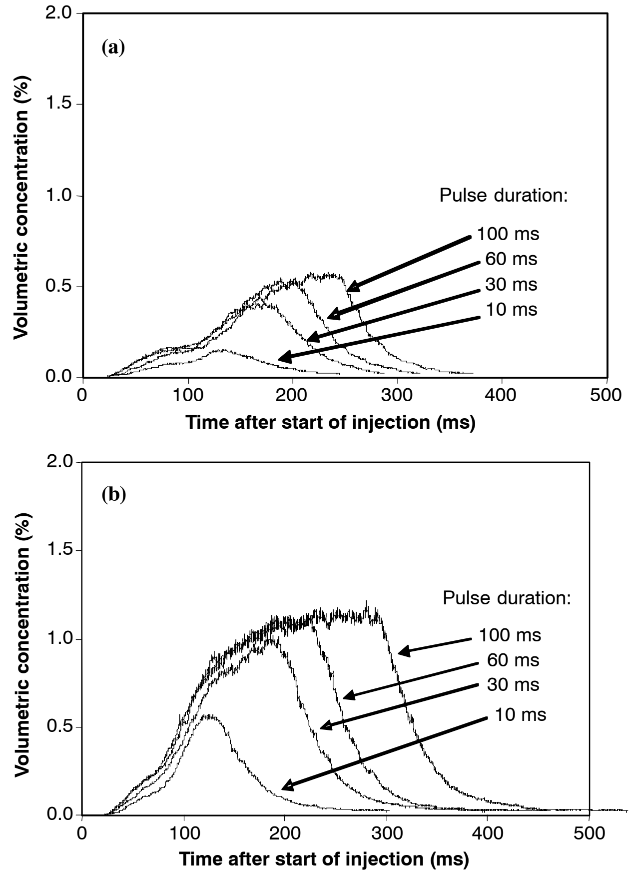

Figure 7. Temporal response of injected concentrate in discharged spray based on the total flow from a 2.18 mm diameter nozzle for (a) 250 kPa and (b) 400 kPa liquid injection pressures.

study) versus flow rate. The mean residence time of the concentration curves is defined as the centroid of the distribution calculated by a summation of the areas of discrete time intervals (Levenspiel, 1979). Based on the steady−state flow rates for the spray nozzles used in this study and a measured void volume in the carrier valve body where the injection valve was tapped, the carrier valve had T values of 0.059 and 0.035 s for nozzles with 1.55 and 2.18 mm diameter nozzles, respectively.

Quantitative characteristics of mixing within the carrier valve void are shown in table 3. Values are given as a minimum and maximum over the range of all pulse durations and pressures for the injection events. The ratio t_f/T gives an indication of short−circuiting, that is, an injection event where injected concentrate exits the mixing chamber prior to adequate mixing, or injected concentrate occurs earlier in the steady−state flow stream and takes longer to fully integrate into the flow stream as a confined plug or injection packet. A value of less than 0.5 for t_f/T would indicate that short−circuiting is a problem; results presented here indicate short−circuiting is not a problem. The ratio of t_{90}/t_{10} gives an indication of the spread of the concentration versus time curve. Ideally for plug flow, the ratio is 1.0, and it increases to 21.9 for ideal mixing; the data presented here show that some mixing occurs after injection, which is reasonable for the system, as an instantaneous mix of injected material after exiting the orifice would be ideal, however difficult to attain. Finally, the ratio of t_{50}/t_{mean} (t_{mean} calculated from the

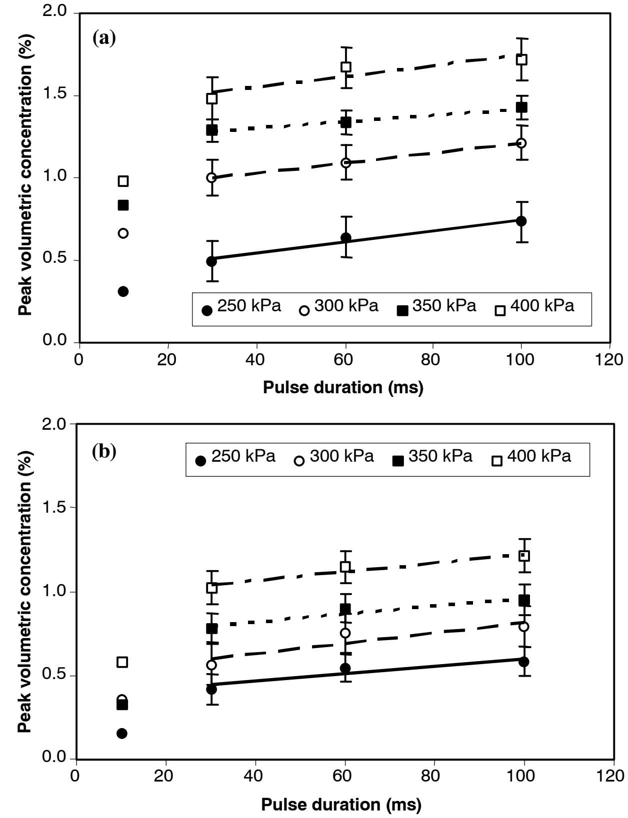

Figure 8. Peak volumetric concentrations for (a) 1.55 and (b) 2.18 mm diameter nozzles (lines show linear trends; standard error bars are shown for measured data).

Table 1. Peak concentrations from a 25,000 ppm injection concentration of liquid into carrier flow discharged from the spray nozzles.

Injection Pressure (kPa)	Pulse Duration (ms)	1.55 mm Nozzle (1.5 L/min)		2.18 mm Nozzle (2.6 L/min)	
		ppm	%	ppm	%
250	10	72	0.31	39	0.16
	30	123	0.49	104	0.42
	60	160	0.64	137	0.55
	100	184	0.74	145	0.58
300	10	167	0.67	89	0.36
	30	250	1.00	141	0.56
	60	273	1.09	187	0.75
	100	303	1.21	198	0.79
350	10	210	0.84	81	0.32
	30	322	1.29	196	0.78
	60	334	1.34	225	0.90
	100	357	1.43	238	0.95
400	10	245	0.99	144	0.57
	30	371	1.48	256	1.02
	60	418	1.67	287	1.15
	100	430	1.72	304	1.21

Table 2. Average delay times (ms), or time the tracer first appears (t_f), for 1.55 mm and 2.18 mm nozzle diameters for all pressures and pulse durations.

Nozzle Orifice Diameter (mm)	Injection Pressure			
	250 kPa	300 kPa	350 kPa	400 kPa
1.55	32.0	31.3	30.5	32.9
2.18	22.1	21.6	23.4	22.6

Table 3. Mixing characteristics for 1.55 mm and 2.18 mm nozzles for injection pressure and pulse duration test conditions.

Mixing Ratio	1.55 mm Nozzle		2.18 mm Nozzle	
	Minimum	Maximum	Minimum	Maximum
t_f/T	0.52	0.56	0.62	0.67
t_{90}/t_{10}	3.06	3.60	2.55	3.48
t_{50}/t_{mean}	0.94	1.00	0.94	1.00

concentration versus time curve) indicates the skewness of the curve, with a value less than 1 indicating that the curve is skewed left and the system is not approaching a plug injection event. The data here show that residence time (and concentration) curves were generally Gaussian, indicating that the injection events were evenly distributed over the time of injection.

Relationship Between Volumetric Measurements and Sensor Measurements

Crowe et al. (2005) validated the electronic measurement system based on a mass balance of the injected NaCl. The total injected mass for each injection pulse was calculated using two independent methods: (1) from the absolute volume measured by the system in figure 4, i.e., the product of the volume of injected solution and concentration of NaCl; and (2) by integrating the concentration versus time data from the electronic sensor response using the carrier flow rate. Figures 9 and 10 show predicted (electronic response) versus measured (volumetric response) results for the nozzle diameters used in this study. Similar representations were presented by Crowe et al. (2005) without an orifice plate in the injection flow path; those results showed that the predicted versus measured mass resulted in a close correlation for all injection events. In the present study, figures 9 and 10 indicate that there was an approximate 10% to 20% discrepancy in the measurement techniques used to quantify the injection events for the 1.55 and 2.16 mm diameter nozzles, respectively.

The discrepancy between integrating the electronic sensor data versus the measured injection events may have been due to the physical configuration of the injection system when using the orifice plate. The void volume between the injection valve orifice and orifice plate was not measured. This volume, consisting of the injection valve orifice, male-male coupling, and brass plate for seating the orifice, was filled with concentrate after an injection event. Follow–

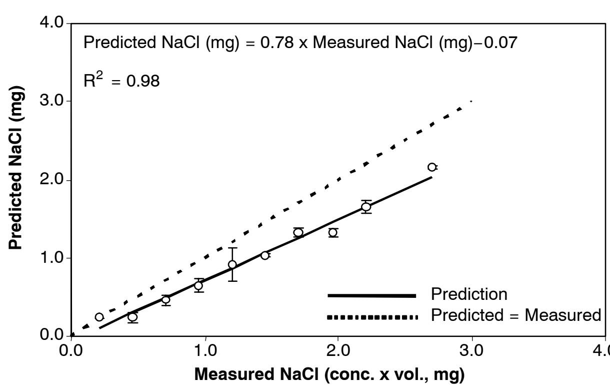

Figure 9. Comparison between predicted mass and measured mass of NaCl of concentrate injected into the spray nozzle for 1.55 mm nozzle orifice diameter.

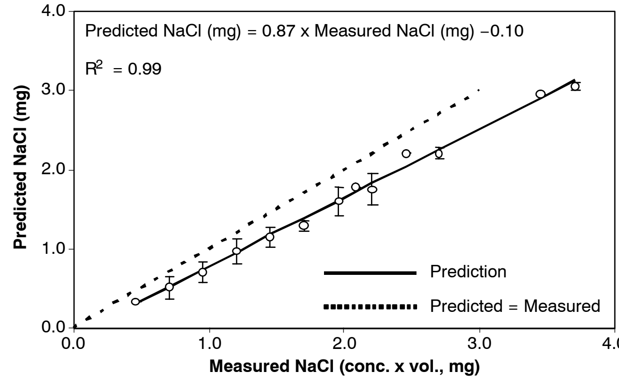

Figure 10. Comparison between predicted mass and measured mass of NaCl of concentrate injected into the spray nozzle for 2.18 mm nozzle orifice diameter.

ing closure of the injection valve orifice, small amounts of concentrate continued to be mixed with the carrier flow and this effect was measured with the sensor, as the concentration versus time plots show low concentrations well after the injection event (figs. 6 and 7). However, the carrier fluid was allowed to flow for sufficient time to ensure that the sensor response returned to zero in all experiments.

Two effects, singly or in combination, may have caused the predicted versus measured discrepancy. One is that the tail ends of the concentration versus time curves were not integrated for the entire time that the residual injection occurred; thus, the predicted response underestimated the dispensed injected volume. The second is that there may have been carrier fluid mixing within the injection side void volume, creating a venturi effect. As the carrier fluid continued to flow, mixing between the carrier flow and residual injected concentrate occurred within the void volume between the two valves. After the carrier flow was mechanically stopped, based on the sensor response returning to zero, the concentrate in the void volume between the two valves was diluted with carrier flow (distilled water), and the resulting concentration within that void volume was less than the known concentration in the injection tank reservoir. This could explain why the mass of salt injected was actually less than the mass expected from calculating the product of volume injected and injected (known) concentration. Without actually measuring static and velocity pressure within the carrier valve void volume, it is uncertain which causation was primary.

Discussion and Conclusions

The motivation for this work was to determine the engineering feasibility of individual nozzle injection of herbicide active ingredient for post-emergent weed control during pre-emergent spraying. Nozzles, valves, and flow conditions were selected to closely approximate those used in a prototype machine-vision activated sprayer deployed for roadside weed spraying. The temporal characteristics of the injection events were determined for a prototype plumbing system consisting of a small, direct-acting, electrical solenoid valve and an in-line metering orifice. It should be noted that a larger diameter orifice plate will result in a different steady-state emitted concentration, and the combination of orifice plate diameter and pressure of the injected solution could be customized to produce a desired steady-state application concentration.

The results of this study supported several conclusions:

- The device developed and fabricated for this study injected concentrated liquid into a continuously flowing liquid stream entering a spray nozzle: injected concentrations ranged from 0.16% to 1.75% of the total flow through the spray nozzle, dependent on injection pulse duration and pressure.
- The flow characteristics of the injection device resulted in injection volumes ranging from 27 to 157 μL for the injection pulses and pressures used in this work. The injected volume increased with pulse duration and supply pressure; additionally, increased volumes were injected into the larger spray nozzle.
- Based on the plumbing configuration and components tested, the typical lag time between actuation of the injection valve and discharge of injected material from the spray nozzle was 20 to 30 ms. Once discharge commenced, the temporal rate of increase in concentration was virtually independent of injection duration and dependent on carrier flow rate and injection pressure.
- The fastest concentration response configuration tested, viz., injection pressure of 400 kPa into the lowest carrier flow (1.55 mm nozzle), resulted in a 1% concentration of injected solution in emitted spray liquid and was achieved within 100 ms after injection valve actuation.
- A typical spray configuration (4 m camera-to-nozzle distance and 5 m/s vehicle ground speed) has approximately 800 ms available for the combined operation of detecting weed, injecting pesticide concentrate, and transporting spray from nozzle to target. Total injection lag times of approximately 100 ms indicate that it is feasible to spot spray weeds with post-emergent herbicide during continuous spraying of pre-emergent herbicide.

This work described a high-speed direct injection system for individual spray nozzles. The immediate application of the work is for an offset roadside sprayer with individual nozzle control based on weed detection. However, the technique of pulsed injection, coupled with an understanding of the fluid mixing and temporal response of the flow, also has application to conventional agricultural spraying, not only for intermittent target detection but also for variable-rate applications where a high spatial resolution is desired, viz., individual nozzle widths. The components used in this project are of commercial grade, immediately available, and proven for handling of aggressive fluids; this suggests that commercial development of the concept may be straightforward.

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