Project Review Meeting – March 31, 2009

Project Title:
NSRP Panel Portable Multiple Process Robot Development

Presented by
Servo-Robot Inc.
to
Advanced Technology Institute
General Dynamics – Electric Boat
Marinette Marine Corp.
Northrop Grumman Ship Systems

Date: March 31, 2009

Title: NSRP Panel Portable Multiple Process Robot Development
Contract Reference: Subcontract Number 2008-335

Executive Summary

The following report summarizes the work done by Servo-Robot Inc. to develop a multi-process portable robot under the auspices of project number N07-133 - Increasing Automation in the Shipbuilding Process.

There is a growing Navy shipyard interest in increasing the amount of material processing that can be done using portable equipment, including welding, plasma cutting and plasma gouging. Many times it is easier to bring the equipment to the work rather than the other way around. Unfortunately, there has been a lack of affordable, easy to use and properly supported portable robotic equipment in North America. All production portable welding robots on the market up to now have been manufactured in Asia and most have not been updated or improved for years.

This next generation portable robot prototype developed in this project demonstrates the basic functionality required by the three supporting shipyards with respect to capabilities, ease of use and high performance. It also shows the "sensor ready" capability needed for future enhancements which will allow even more intelligence to be deployed.

Recommendations for future work include the approval of Phase 2 Funding at an amount of approximately $625,000 which will allow this portable robot to be brought to market at an affordable price with exactly the right capabilities and with the required additional sensor options to achieve even more productivity.

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1.0 Acknowledgements

The three sponsoring shipyards were NGSS, GDEB and Marinette Marine. The technology advisor was Bruce Halverson of Marinette Marine. Thanks to them for their valuable input at the start of the project and for their helpful feedback along the way.

2.0 Introduction

2.1 Project Identification

Both the United States Navy and commercial shipyards have continually expressed the need for a lightweight affordable portable robot built in North America to improve welding and cutting productivity. Presently most Navy shipyard welding is done manually or with a very low level of mechanized equipment and less than 5% is done using robotic or automated methods. This situation limits flexibility which in turn makes it difficult to achieve significant improvements in productivity and quality. Therefore this project was defined to develop a portable robot which could fill this identified void.

2.2 Concept Description

The goal of this program was to develop a portable multi-process robot able to perform well as a “teach and play” system, but in addition have the capability to be expanded to have increased intelligence utilizing real-time sensing for tracking, process monitoring and weld quality inspection. This robot is applicable to welding and cutting requirements for both submarine and surface ships and can be used on light to heavy weldments.

3.0 Scope and Approach

3.1. Scope

This portable robot was designed to handle multiple welding processes including GMAW and FCAW as well as plasma cutting and gouging. This robot is designed for in-position (down-hand) welding of components having standard joint types like lap fillet, T-fillet, butt and groove.

3.2. Approach

The first thing done to clearly define the needs of each of the participating shipyards (GDEB, NGSS and Marinette Marine) was to survey each one. A survey in the form of a spreadsheet (Appendix 1) was used to gather the wish list of engineering and production personnel closest to the needs of the welding facility. A combination of phone calls and onsite visits were used to further refine and clarify the needs.

For GD their needs were separated into two categories – those for the “hull butts” and those for their general fabrication areas. The general fabrication of modules and other components fits into the scope of this portable robot which is viewed as a “general purpose” robot. The “hull butt” welding requires some unique characteristics including the ability to carry 350 pounds on a trailing cart with a brake and it needs to be capable of welding in all positions including vertical and overhead. The needs for the general purpose robot were then transformed into functional requirements which drove the functional specifications for the hardware, controls and software.

Out of the functional specifications came the building of the portable robot body and controller, the customizing and programming of the teach pendant, the development of the interface software and finally the complete integration of all the components. The prototype was then tested for proper performance and finally it was prepared to perform the demonstration on typical fillet and groove joints representing standard ship components.

4.0 Team Roles and Actions

The team consisted of Servo-Robot Inc, Servo Robot Corporation (Milwaukee, WI) and the three participating shipyards. Bruce Halverson from Marinette Marine was designated the National Shipbuilding Research Program (NSRP) Technical Representative (PTR) and monitored the technical work and reviewed the quarterly reports for compliance with the technical requirements of the Subcontract. Beyond establishing the initial “wish list” information and helping to refine the prioritized wants and needs, the actual development was done by the Servo-Robot team. This team consisted of personnel in disciplines including project management, software, mechanical and electrical control as well as welding.

The outside contact people involved included:

Lee O’Connell	General Dynamics – Electric Boat (GDEB)
Lee Kvidahl	Northrup Grumann Ship Systems (NGSS)
Bruce Halverson	Marinette Marine Corporation – Fincantieri Marine Group
Luke Blessing	Advanced Technology Institute (ATI)

5.0 Prior Related Work

This project built on previous Servo-Robot Inc. work and R&D associated with portable robots including:
1. Over ten years of experience at GDEB with several Servo-Robot portable robots supplied from Japan. These systems were used with and without laser vision seam tracking.
2. Development of the multi-bead/multi-layer software with EWI under ManTech funding. This project used a standard arc welding portable robot called the SE-NAVI/PC but the software was modified to allow for extensive adaptive welding capability for large grooves having multiple passes.
3. Development of the Servo-Robot IT Platform. This platform uses the latest digital technology including Ethernet and TCP/IP which can greatly increase the power, flexibility and expandability of the portable robot control and the interfacing of sensors.

6.0 Hardware Developed

The hardware developed and interfaced in this program includes the robot body, robot controllers, the teach pendant and the welding equipment. The welding equipment includes the power source, feeder and peripherals. See Appendix 2 for a description of the system architecture.

6.1 Robot Body

The goals associated with the robot body itself were to make it the lightest, most flexible and quickest it could possibly be. Specifically the target weight was 25 pounds which would make it easy for the average welder to pickup the robot and move it to the next part to be welded. The flexibility is related to the maximum stroke and adjustment allowed for each axis as well as the ability to quickly program the robot for different jobs. The speed comes into play mainly in the rapid traverse capability to reduce move times as well as for precision weaving when the axes need to respond quickly. See Appendix 3 which shows the robot body functional requirements as outlined by the participating shipyards and the actual target values for this development. The following sections describe the developments associated with the robot body. See Appendix 4 for a CAD model view of the robot body.

We selected an integrated motor package to put the drivers on board the robot body to reduce cables, extend the possible distance between the robot body and the control unit, improve the immunity against electromagnetic effects, reduce weight and improve the environmental impact (reduced footprint). See Appendix 5 for the detailed calculations which defined what type and size motor was required to meet the performance requirements. See Appendix 6 for the information about the motors that were selected to meet these requirements. This innovative motion control involves a SmartMotor which is a complete, compact and user-friendly integrated control system that features a brushless DC servo motor, motion controller, encoder and amplifier. These motors facilitate efficient multi-axis coordinated motion with highly flexible on-board and expandable I/O. Communication protocols available with the SmartMotors include traditional DeviceNet and ProfiBus as well as the newer Ethernet method which was chosen for this project for its advantages.

The unregulated 42Vdc power supply for the motors is installed inside the control unit. The two power inputs for each motor allow for a safe shutdown of the motor power without losing the axis position information. One Ethernet switch inside the robot is used to link the three motors while the Ethernet switch inside the control unit is used to connect the teach pendant to the robot or the control unit.

6.2 Safety Circuits

The safety circuits of the overall robot system comply with requirements from Robotic Industry Association (RIA), American Welding Society (AWS), and National Electrical Manufacturers Association (NEMA). Note this is a key issue because this robot can potentially move in an unexpected manner compared with a “dumb” tractor. The robot is rated for Class 3 safety control as defined in EN 1050. It employs a safety circuit with double redundancy and utilizes self checking components. When the emergency stop is triggered, or if a critical error occurs while the robot is executing a program, it enters the “Pause” state. After the emergency is cleared, the “Resume” button brings the welding torch back to the position where it stopped. The robot can only restart when the Start button is pressed. See Appendix 7 describing the methodology used to determine the actual safety classification.

Safety-related parts of control systems must be designed so that a single fault in any of these parts does not lead to the loss of the safety function. Whenever reasonably practicable, the single fault shall be detected at or before the next demand upon the safety function.
The emergency stop mushroom on the teach pendant has 2 contacts that feed two electrical circuits connected to the redundant safety loops. The status of the Ethernet switch inside the robot and the external safety contacts on the control unit are also part of the safety loops. A redundant safety relay is triggered as soon as one of the safety loops is open. The outputs of the safety relay cuts the power to the motors when it is triggered.

6.3 System Controllers

6.3.1 RobotNet Master Controller

The ROBONET/MASTER compact control unit is designed for use with all Servo-Robot sensors and drive systems. The ROBONET controller is linked to the ROBONET drive system as well as to the welding equipment. With respect to the welding equipment interface, the welding power source is controlled through two analog outputs, two digital outputs and 4 digital inputs. The analog outputs control the welding voltage and the wire feed speed or current, depending on the type of welding power source. One digital output controls the arc start/stop while another digital output selects the welding schedule. The digital inputs are used for the arc established signal from the power source and the indication that there is both water flow (if a water cooled torch is used) and shielding gas flow present. See the I/O chart in Appendix 8 for a complete explanation. See Appendix 9-10 for a view of the controller interior and exterior.

6.3.2 RoboNet Drive

The ROBONET/DRIVE compact control unit is designed for use with the ROBONET/MASTER camera controller and the precision cross-slides chosen for this robot. See Appendices 9-10 for a view of the controller interior and exterior. This controller contains the 42 Vdc power supply of the motors. One part of this power is sent directly to the motors for the control electronics. The power for the servo drives section of the motors is sent through a safety relay so that the motor stops as soon as an emergency stop is triggered.

6.4 Teach Pendant

The teach pendant has a 800 X 600 pixel color LCD touch screen, 64MB of main memory, 64 MB of flash memory and a StrongARM CPU. The operating system is Windows CE and it communicates with the control unit through an Ethernet link. A key point in this connectivity is that the teach pendant can be connected to either the robot or the control unit. This allows flexibility in the use of the system depending on where the controller is mounted in relation to where the robot is used. See Appendix 11 for an overview of the teach pendant.

6.5 Sensors

The prototype portable robot deliverables did not require any external sensors be included. We however designed the controller, robot body and teach pendant to be "sensor ready" so that a true plug & play approach can be taken with the sensor of choice. The sensors that can be interfaced to the robot include tracking, web-cam weld joint viewer and automated weld inspection.

7.0 Software Developed

7.1 Teach Pendant

One problem that has plagued users of industrial robots over the years, whether they are the larger six axes type or the portable three axes type, is the complexity of the programming. This complexity starts at the multiple layers of screens required to be accessed to get the robot to do what is needed.

The philosophy in this project was to make the programming as easy (intuitive and idiot proof) as possible for the welder operating the robot. In fact we took this to an extreme because we characterized our potential user as having: poor eyesight, big fingers (wearing work gloves), and minimal ability to read, either because of poor English skills or the fact that English is not the person's native language. With this in mind, as a first step we've accomplished simpler programming by limiting the number of screens that need to be accessed on a regular basis to two, one for the initial teaching and the other for the operation. See Appendices 12 and 13 showing these two screens. If the welder runs into any problem with how to operate or program the robot, he has access to a simple Help Screen. If the problem goes beyond this level and involves a possible problem with the electrical or mechanical components of the robot, the operator or his maintenance department can go to the Service Screen. Of course the end goal is to develop a totally pictorial interface screen which will make it even easier to use and will overcome the inherent difficulty in putting too much on a relatively small screen.

The robot is programmed using a teach pendant using color interactive multi screens, which benefit from the power offered by the Windows CE OS used. This pendant is used to move the robot through the desired motions which is the primary way larger six axes robots used in industry for arc welding or cutting are presently programmed. It was not part of the scope of this project to develop the ability to do offline programming, which entails creating programs offline and downloading them to the robot. This capability could be developed as a part of a future project.

The teach pendant is used by the welder to create the weld programs which include position points as well as all the welding parameters including current, voltage and travel speed. In addition, the weaving parameters can be attached to specific weld position points so that the weaving can be used exactly when needed.

7.2 Robot Control Software

This software is at the core of the overall portable robot system and connects the robot to the controllers to the teach pendant. See Appendix 14 for an overview of the programming structure. The robot controller is based on the AutoTrac/P software. In order to support the robot functionalities, we added a Robot Module, a Program Library and a special interface for the SmartMotor.

The Program Library contains up to 10 programs. Each program contains up to 100 path positions and the welding parameters associated with each position. The System/Task Library contains the general configuration data for the complete system.

The software running on the Teach Pendant communicates with the Robot Module through the HMI Server. When the operator modifies a parameter or the operating condition, the Teach Pendant software sends the new information to the Robot Module and modifies its display accordingly.

The SmartMotor Interface is a low level driver for the controller that is embedded in the SmartMotor. It converts the commands received from the Axis Interface and transmits them to the motors through the Ethernet interface. It also interprets the messages received from the motors, such as status and position, and formats the information for the Axis Interface.

Before developing the SmartMotor Interface, we tested the communication with the motor to measure the response time and verify its limits. For the first prototype, we had to limit the performance of the robot to use the standard commands available in the embedded controller. However, it is possible to upload programs into the motor. In order to increase the performance of the robot, we will have to use this capability to put into the motor some low level control functions that are not natively available.

The AutoTrac/P Module is the main sequencer of the system. It periodically triggers the Robot Module that takes the appropriate action depending on the operating condition.

The Robot Module handles the robot programs. It stores them into the Program Library while the operator teaches the robot. It retrieves the information from the library in order to execute a program. It performs the trajectory interpolation and sends to the AutoTrac/P Module the next position to be reached at each control cycle. The AutoTrac/P Module transmits the new positions to the X, Y and Z motors through the Axis Interface. At each cycle, the current position of each axis is also sent to the Robot Module by the AutoTrac/P Module. The Robot Module uses this information to maintain the required travel speed to make sure that the programmed path is correctly followed.

When the welding starts, the AutoTrac/P Module triggers the Robot Module that goes through the arc start sequence. The Robot Module sets the welding conditions through the analog outputs and informs the welding power source to turn on the arc through a digital output. In the case of the PowerWave 455 source, one digital output and two analog outputs are used to set the welding conditions. The digital output selects one of the two schedules programmed on the power source. The analog outputs set the wire feed speed and the “trim” value.

When the “arc established” digital signal is received from the welding power source, the Robot Module starts the robot motion. At each programmed point, new welding parameters can be set. The welding parameters set at a point are used until the next point is reached, unless the operator overrides them in real time with the teach pendant. When the robot reaches a point where the welding is deactivated, the travel stops and the controller goes through the programmed arc stop sequence.

At each programmed point in a robot program, the operator can activate or deactivate the welding. If the welding condition changes from the deactivated state to the activated state when a programmed point is reached, the motion stops and the Robot Module goes through the arc start sequence. If the welding condition changes from the activated state to the deactivated state when a programmed point is reached, the motion stops and the Robot Module goes through the arc stop sequence. If an emergency stop is triggered or if the operator pauses or stops the execution of a program, the robot stops and the Robot Module goes through the arc stop sequence.

When an emergency stop happens or a pause is triggered, the current position of the robot is memorized. The operator can jog the robot to move the welding torch away from the weld area to clean it or for any other operation. When he is ready to continue welding on the programmed path, the operator pressed the start button on the teach pendant. The robot brings the torch back to where it was when the welding stopped and waits there. This allows the operator the move back over the weld to restart before the stop position. He then presses again the start button and the welding restarts.

A welding enable/disable button is available on the teach pendant to enable or disable the welding independently from a program. This allows the operator to test a welding program without actually welding. A small LED lamp next to the welding enable/disable button indicates the current status of the system. It is turned off when the welding is disabled. It blinks when the welding is enabled but it is not yet activated during a program execution. It is turned on while the welding arc is on.

8.0 Status, Further Work & Feedback From March 31 Meeting

8.1 Status

The goal was to produce a prototype portable robot which would demonstrate the basic functionality required per this contract. The portable robot demonstrated March 31, 2009 at Servo-Robot Inc. in front of the supporting shipyards and ATI showed this was accomplished. This demonstration showed the full functionality of the robot from the standpoint of showing its' ability to be easily programmed and to weld successfully.

8.2 Further Work

There is a great amount of future work that is needed to continue to propel this portable robot development forward so it can meet the present and future needs of the Navy and commercial shipbuilding industry, as well as the general fabrication companies throughout the United States. The following list of further work needed to really achieve the goal of making this portable robot a friendly powerful extension of the welder himself includes:

- Complete the integration of the different components to make the portable robot production ready
- Review all the components used for the prototype and determine if there is a way to simplify the design or choose different components to reduce the cost and simplify the assembly
- Develop the manufacturing techniques to enable this robot to be built in relatively low quantities but in a manner that will meet the cost targets required by the shipyards to deploy these in large quantities
- Complete the interfacing of all desired sensors including seam tracking, automated weld inspection and process monitoring
- Develop capability to automatically configure the control logic so no matter what power source is plugged in, it will automatically configure itself correctly.
- Improve greatly the Human Machine Interface (HMI), because although we made substantial progress on this prototype, we need to make a quantum leap in ease of use to really attract the largest users of this robot which are the welders and not the programmers. This work was limited by time constraints.

8.3 Feedback from March 31 Meeting

The following represents the feedback received at the review meeting from ATI and the shipyards. It represents both technical items with the robot itself as well as ideas as to how best to market and sell this robot to the shipyards. See Figure 15 showing the lab setup where the live welding demo took place.

Technical

1. Could the pendant be made wireless because cables are one of the weaknesses of any device because they are subject to damage easily.
2. The <u>normal</u> straight stiffener welding is probably not a good first application for the portable robot with respect to justifying its cost compared to the existing “Mogi” style trackless tractors that are presently doing some of this welding due to the higher cost and the fact the rail setting time is to long. However, on very thin stiffeners where small precision welds are needed to be made at much higher travel speed (60”+) there now may be an opportunity.

Here a camera for tracking would be most desirable to maintain perfect wire positioning. To be noted that rail setting time is drastically reduce by portable robot because the welding line is interpolated from program points quickly entered.

3. Panel splicing on thin material where the butt weld does not lend itself to trackless tractors is a possible application.
4. Circular deck cutouts ranging from 1-3' in diameter would be a good candidate for a portable robot if we can get the robot to turn such a tight radius.
5. Definitely the ability to change processes from GMAW to SAW is very desirable to be able to sell the flexibility. Note the robot will have to be beefed up and better balanced to carry the heavier SAW torch.
6. Being able to run two torches on both sides of the stiffener web with only one tracking camera guiding the robot would be an interesting solution to consider. Note we'd have to be able to enter two different look-ahead distances for each torch because they will be staggered by a few inches.
7. Definitely need canned "macros" to allow for easy entry of intermittent weld skip sequences. Also would be nice to have back-step capability easily programmable such that the robot could go to the end of a seam if needed and weld in set distances with skips back to the start point. This is for distortion control.
8. Adding a temperature sensor that would measure the HAZ for example would be extremely helpful for HSLA steels. First measure it and then the dream would be to do adaptively control the welding parameters to maintain a required maximum temperature.

General

1. To move forward into a Phase 2 we will need to wait for a proposal request and then submit our proposal that stresses innovation that will result in a high ROI and that will be supported by several major shipyards. Money could become available starting fiscal (Oct. 2009).
2. To help market this ATI is willing to put some of our report pictures on their website under this project heading. SRI will provide such information shortly.
3. The people we need to excite in the Navy are the Program Managers like for the new destroyer or new LCS ship because they are the ones in the big picture who need to reduce the cost of ship manufacturing.

9.0 Appendices

9.1 Survey of Needs/Wants for Participating Shipyards

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9.15 Robot Demonstration Cell

9.1 Survey of Needs/wants for Participating Shipyards

Category	System Requirements	Comments
General	All components less than 30-in in height from hull	Yes
	Weight of Each Component Less Than 45-lbs	Yes
	Integration with EB specified welding equipment	Yes-see other spreadsheet tab
	Vertical carrying capacity of 350-lbs while maintaining travel speed	Yes - 350-lbs after motor & gear change
Body	32	Yes
	x-axes: 20-m minimum travel length	Yes
	Maximum travel speed greater or equal to 3.5-m/min	Yes
	Y axis: 150-mm stroke	Yes
	Ability to mechanically adjust Y axis stroke	Only through the motors
	Z axis: 150-mm stroke	Yes
	Ability to mechanically adjust Z axis	Only through the motors
	Insulated torch holder	Yes
	4th axis to manually adjust work angle (side to side) +/- 15°	Yes
	5th axis to manually adjust travel angle +70° / -15°	Yes
	Ability to operate beteeen 25°F and 250°F	No: 32° to 104°F
	Easy mounting / unmounting of robot carriage from rail	Yes
	Capable of traveling in all positions (flat, horizontal, vertical, overhead)	Yes
	Wide pressure-guide roller (won't gouge track)	Yes

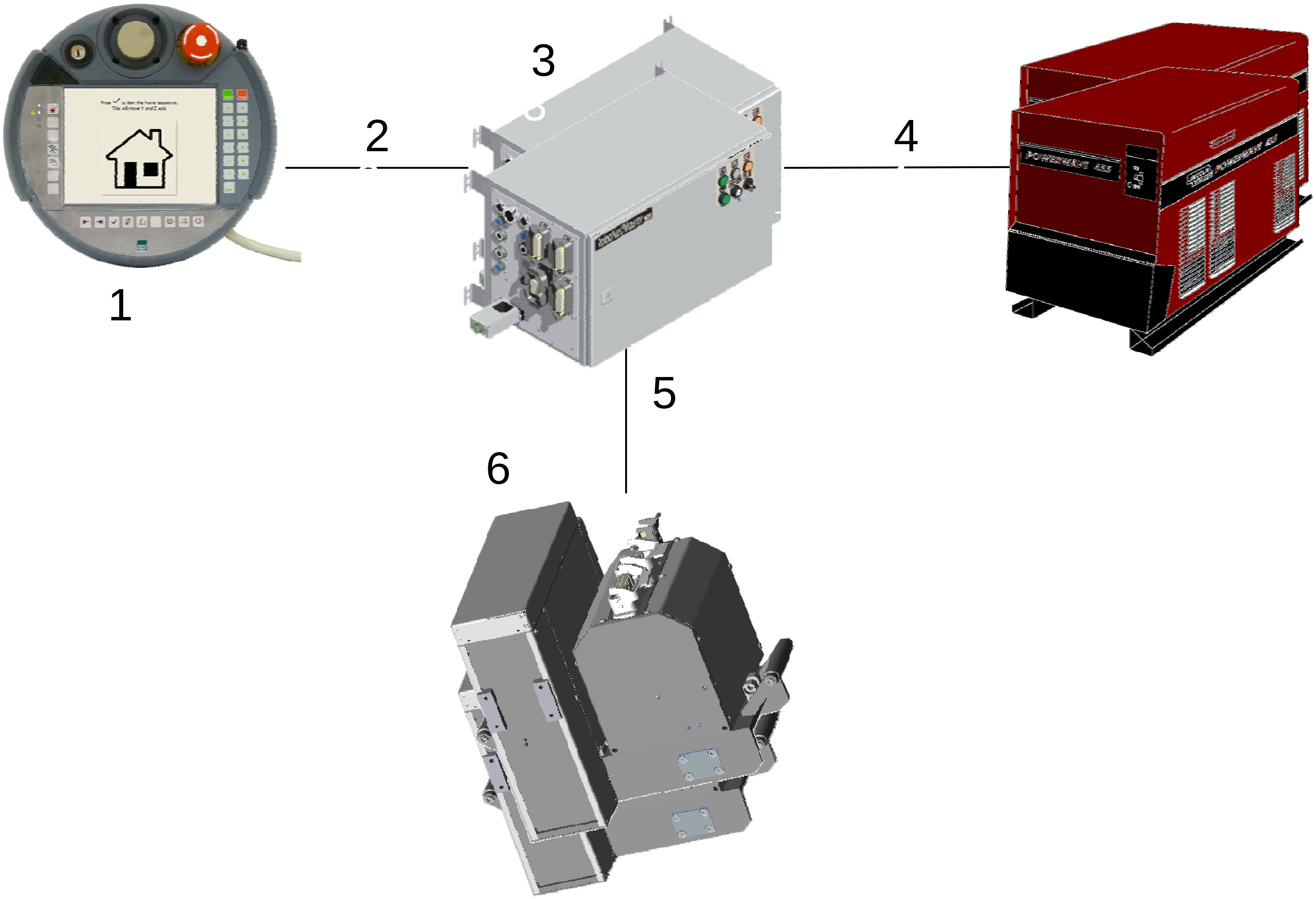
	Durability of gearbox and safety factor for specified load	Yes
	Left hand and right hand operation compatible	Yes
	Minimum back lash when starting or stopping	Yes, weight of unit stops back lash
	Durability - able to withstand dust, heat, freezing temps, shipyard environment, ect.	Yes-within operating temp allowed for system
Idler Carriage	Equipped with Idler Carriage	Yes-Use GDEB supplied idler carriage
	Wide pressure-guide roller (won't gouge track)	Yes
	Wire feeder and spool mounted on body or carriage	Yes
	Other equipment may be mounted to carriage such as servo-drivers and power module	Yes
	Cable bundle support	Yes-use GDEB supplied support
	Ability to align with body carriage	Yes, idler carriage attached to body
	Capable of being mounted ahead or behind the body carriage	Yes
(supplied by GDEB)		Yes - Use GDEB supplied brake
	Braking mechanism switch connected to the controller as emergency stop input	Yes
	Easy mounting / unmounting of carriage from rail	Yes
	Ability to operate beteeen 25°F and 250°F	No:32°F to 104°F
Control / Software	AC servo controlled x-axis with teach capability	Yes
	Servo motor drive for y, z axes	Yes
	Robotic teach & play-back programming method	Yes
	Automatic modes	Yes
	Linear interpolation between teach points	Yes-for path, maybe for weld parameters
	Capable of storing a minimum of many points per program	Yes – Maximum of 99

	Programmable torch weaving	Yes
	Capable of storing 10 welding programs	Yes
	Capable of shifting travel path in y and z directions	Yes
	Ability to operate beteeen 25°F and 120°F	No: 32° to 104°F
	Left hand and right hand operator compatible	Yes
	Memory back-up system (power-outages)-Weld Programs	Yes
	Memory back-up system (power-outages)- Travel Path	Yes
	Capability to store multiple positioning programs	Yes
Pendant	Ability to input multiple welding programs (different programs for different passes)	Yes
	Ability to program position (x, y, z) (teach capability)	Yes
	Ability to adjust WFS, voltage, and travel speed during welding	Yes
	Ability to adjust weaving amplitude, frequency, dwell times during welding	Yes
	Ability to program start, end, burnback, and other parameters (pulse arc settings)	Yes
	English units	Yes
	Metric units selectable	Yes
	Back-lit screen	Yes
	Ability to plug pendant into carriage	Yes
	Weld, no weld	Yes
	Approximately 6-ft cable length	Yes
	Ability to adjust x, y, z axes	Yes
	Ability to program new start locations	Yes
	Ability to stop in process, then restart at that location	Yes
	Ability to calibrate voltage and current (WFS) between the welding power-supply and the controller	Yes

	Ability to calibrate position	Yes
Process Control	Voltage command signal	Yes
	Current command signal	Yes
	Current feedback	Yes
	Arc detection signal	Yes
	Gas fault	Yes
	Wire fault	Yes
	Water fault	Yes
	Arc start stabilization	Yes
	Burnback control	Yes
	Pre- and post-purge gas control	Yes
	Ability to calibrate voltage and current (WFS) between the welding power-supply and the controller	Yes
Cables / Disconnects	Controller to body specifed length of 50-ft (15.24-m) minimum	Yes
	Cable, water, and gas disconnects at both ends	Yes
	Cables able to withstand electrical interference	Yes
	50-ft leather cover to protect cables	Yes-get from GDEB local welding distributor
Track	Ability for all components to mount to the same track	Yes
	Durable track	Yes - Use Gullco Kat Rail supplied by GDEB
	Ability to be rolled to the radius of the hull	Yes
	Ease of attachment, detachment, and portabiity	Yes, robot
	Overall (circumferential) dimensional stability of track	Yes - Use Gullco Kat Rail supplied by GDEB
	Ability to a support one welding sytem per quadrant	Yes
Ground Fault	Ground fault safety circuit to protect from possible contact with welding wire or work piece	Yes

Manuals/ Schematics	Include maintenance & troubleshooting. Includes pertinent schematics and operating manuals Identification of signals on the electrical diagrams Block diagram with cable connections. Drive and idle carriage manual, schematics, and parts catalog	Yes will be supplied with system
Option	Ability to add joint tracking capability (Simple vision system)	Yes
Option	Ability to add adaptive fill capability (advanced vision system)	Yes standard Adaptive available
	Ability to Use a Bevel Cutting System on Same Track	Yes, on same tractor
	Ability to Use a Gouging System on Same Track	Yes, on same tractor

9.2 System Architecture

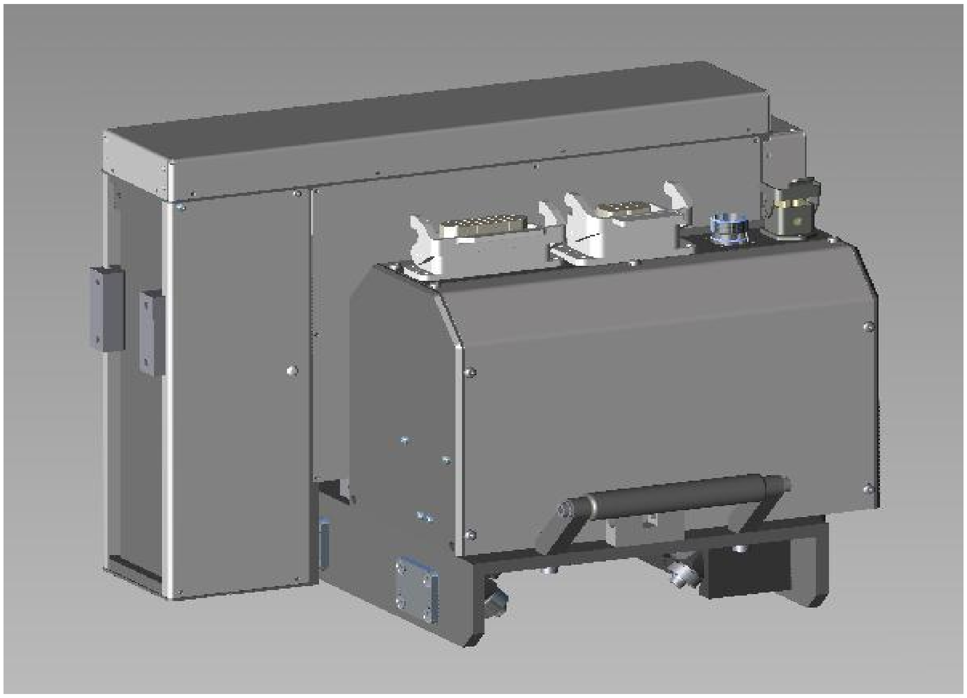


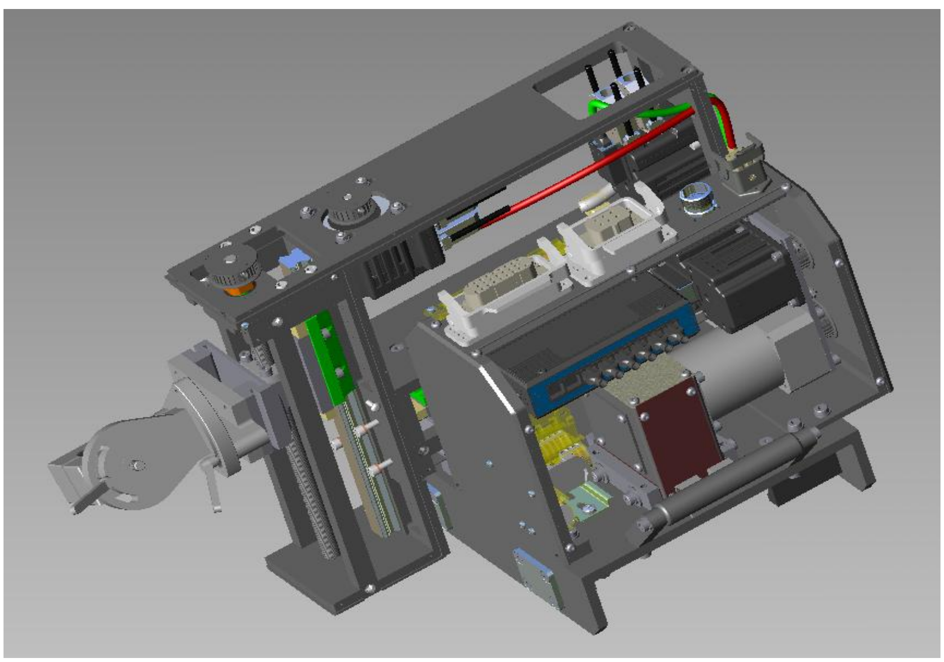
1- Teach pendant user interface
2- Teach-controller comm
3- Portable robot Controller
4- Power Source comm.
5- Motor interface
6- Portable robot (no software)

9.3 Robot Body Functional Requirements

Functional Requirements	Target Value
3 Axes (x, y, z) programmable motion	Yes
x-axis: Travel length	20 meters
Maximum X-axis travel speed	3.5 meters/minute
Y axis total stroke	150mm
Ability to mechanically adjust Y axis stroke	Only through the motors
Z axis total stroke	150mm
Ability to mechanically adjust Z axis	Only through the motors
Insulated torch holder	Yes
4th axis to manually adjust work angle (side to side) +/- 15°	Yes
5th axis to manually adjust travel angle +70° / -15°	Yes
Ability to operate beteeen normal factory heat	Capable of running between 32° to 104°F
Easy mounting / unmounting of robot carriage from rail	Yes
Capable of traveling in all positions (flat, horizontal, vertical, overhead)	Yes - however optimized to the flat or slightly inclined position
Wide pressure-guide roller (won't gouge track)	Yes
Durability of gearbox and safety factor for specified load	Yes
Left hand and right hand operation compatible	Yes
Minimum back lash when starting or stopping	Yes, weight of unit stops backlash
Durability - able to withstand dust, heat, freezing temps, shipyard environment, etc.	Yes-within operating temp allowed for system

9.4 Robot Body CAD Models





9.5 Motor Size Calculations

Table 1 Robot Specifications

Payload F (N)	25*9.8
Payload distance (m)	0.2
Slide speed (m/min)	3.5
Slide acceleration (mm/s^2)	90
Travel speed (m/min)	3.5

Table 2 Lead Screw MDK 1402-3

Diameter (mm)	14
Lead P (mm)	2
Length (mm)	300
Efficiency (screw, bearings, etc.)	0.7
Inertia (kg·cm²/mm)	2.96x10^{-4}

Table 3 Timing Belts (transmission ratio i = 1.11)

Pulley 1	A6C3-18H3708	Dp1=29.1 mm
Pulley 2	A6C3-20H3712	Dp2=32.33 mm
Timing Belt	A6G 3-060 037	Breaking Strength 1064 N

1.1 Selection of Slide Motor

The Y axis slide is used for the selection of motors because its load will be maximum when the robot is installed sideways and the Y axis has to lift its own weight, the Z axis and the payload.

The maximum load on the Y slide is:
F = 25 kg (payload) + 5 kg (Z slide) + 5 kg (Y slide) (1-1)

1. Torque Computation for Maximum Load

$$M_L = \frac{FP}{2\pi\eta} = \frac{35\times 9.8\times 0.002}{2\times\pi\times 0.7} = 0.156\ (Nm) \qquad (1\text{-}2)$$

2. Lead Screw Inertia

$$\begin{aligned} Is &= 2.96\times 10^{-4}\times 300\times 10^{-4}\,kgm^2 \\ &= 8.88\times 10^{-6}\,kgm^2 \end{aligned} \qquad (1\text{-}3)$$

3. Moment Caused by Angular Acceleration

Angular speed of the motor given by axis speed and lead:

$$\omega = \frac{2\pi}{60}\frac{v}{P} = \frac{2\pi \times 3500}{60 \times 2} = 183 \quad (rad/s) \rightarrow (1750rpm) \tag{1-4}$$

Acceleration time:

$$t = \frac{v}{a} = \frac{3500/60}{90} = 0.648 \quad (s) \tag{1-5}$$

Moment caused by acceleration:

$$\begin{aligned} M_a &= (I_m + I_L) \times \frac{\omega}{t} \\ &= (7.27 \times 10^{-6} + 8.88 \times 10^{-6}) \times \frac{183}{0.648} \\ &= 0.0045 \quad (Nm) \end{aligned} \tag{1-6}$$

4. Moment Caused by Linear Acceleration

$$M_{a2} = \frac{maP}{2\pi\eta} = \frac{35 \times 0.09 \times 0.002}{2\pi \times 0.7} = 0.00143N \tag{1-7}$$

5. Total Moment on the Motor

$M=M_L+M_{a2}+M_a=0.156+0.00142+0.0045=0.162$ Nm (1-8)

The motor SM2315DT that we used for the prototype has a continuous torque Tc=0.40 Nm. Its safety factor would be: 0.40 Nm/0.162 Nm = 2.47.
The motor SM2316DT has a continuous torque Tc = 0.52 Nm. Its safety factor would be: 0.52 Nm/0.162 Nm = 3.2. We will use this motor for the next version of the robot because of the better firmware of its drive.

1.2 Travel Axis Motor Selection (with Planetary Gearbox)

The robot must be able to support a total load of 350 pounds (159 kg) while moving upward on a vertical rail. The diameter of the gear in contact with the rail is 66.675 mm. The diameter of the second gear is 36.525 mm.

1. Moment Applied on Gear 2

$$\begin{aligned} M_2 &= FD/2 = \left(159kg \times 9.8m/s^2\right) \times \left(66.675mm/(2 \times 1000mm/m)\right) \\ &= 51.9Nm \end{aligned} \tag{1-9}$$

2. Moment Applied on Gear 1

$$M_1 = M_2 \frac{D_1}{D_2} = 51.9 \times \frac{36.525}{66.675} = 28.43 Nm \tag{1-10}$$

3. Moment Applied on the Motor

The ratio of the planetary gearbox (GBPH-0602-NS-070) is 70. Its efficiency is estimated at 90%.

$$M = M_1 / (70\eta) = 28.43 / (70 \times 0.9) = 0.45 Nm \tag{1-11}$$

The motor SM2315DT installed in the prototype does not have a sufficient torque for the specified load. The motor SM2316DT will be used for the next version of the robot, as well as a harmonic drive reducer that has a ratio of 160.

9.6 Smart Motor Information

Ethernet Overview

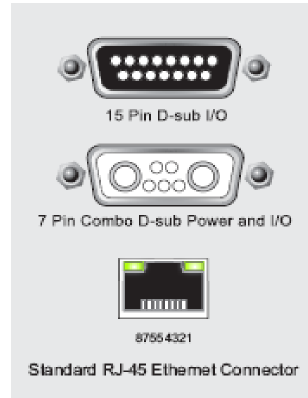
Ethernet is a local area network (LAN) architecture that supports a data transfer rate of 10/100 Mbps. Ethernet is the most common LAN in use today for exchange of information between the front office and the factory floor. The Ethernet SmartMotor™ operates at 10/100 Mbps and allows a SmartMotor™ to respond to ASCII commands sent from an Ethernet host. Ethernet Hubs and Switches should be used to separate subnets and optimize communications.

Features Include:

- All SmartMotor commands and capabilities fully implemented via Ethernet
- Standard TCP/IP ASCII over Ethernet protocol via port 10001
- Use of onboard I/O via Ethernet Gateway,SmartMotor program, or RS232 commands
- Ability to run 1000 SmartMotor subroutines via Ethernet
- Online diagnostics of the SmartMotors via SMI2 software and RS232 connection
- Capable of DHCP addressing or Static IP address
- 250 micro second interrupt driven subroutine with the -PLS firmware
- Gateway Baud Rates:10/100 BASE-T auto-detected

Note: This option DOES NOT apply to all Models

Ethernet



Ethernet Pinout

1	Tx+	5	NC
2	Tx-	6	Rx-
3	Rx+	7	NC
4	NC	8	NC

Required Code

The following code is required to be in the SmartMotor for operation of the Ethernet Gateway.

```
OCHN(RS4,1,N,19200,1,8,C)
END
```

Note: If –PLS firmware is used and over travel limit switches are not connected, use the following.

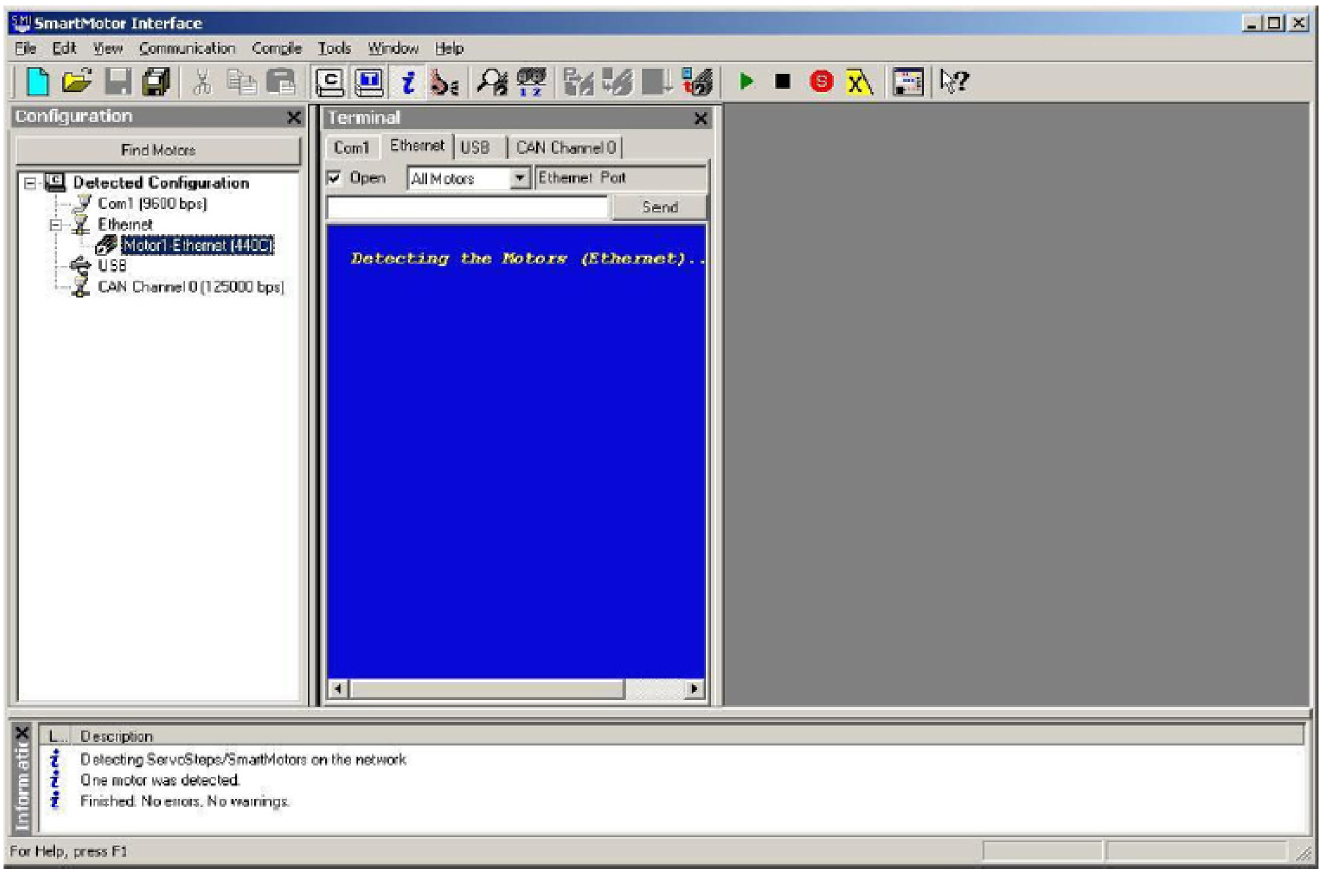
```
OCHN(RS4,1,N,19200,1,8,C)
UCI
UDI
ZS
END
```

IP Addressing

The Ethernet SmartMotor will default to using Dynamic Host Control Protocol (DHCP). If a DHCP server is available, the SmartMotor will use the IP Address given to it by the host (server).

If a Static IP is desired, the SMI2 software should be used to set the IP Address.

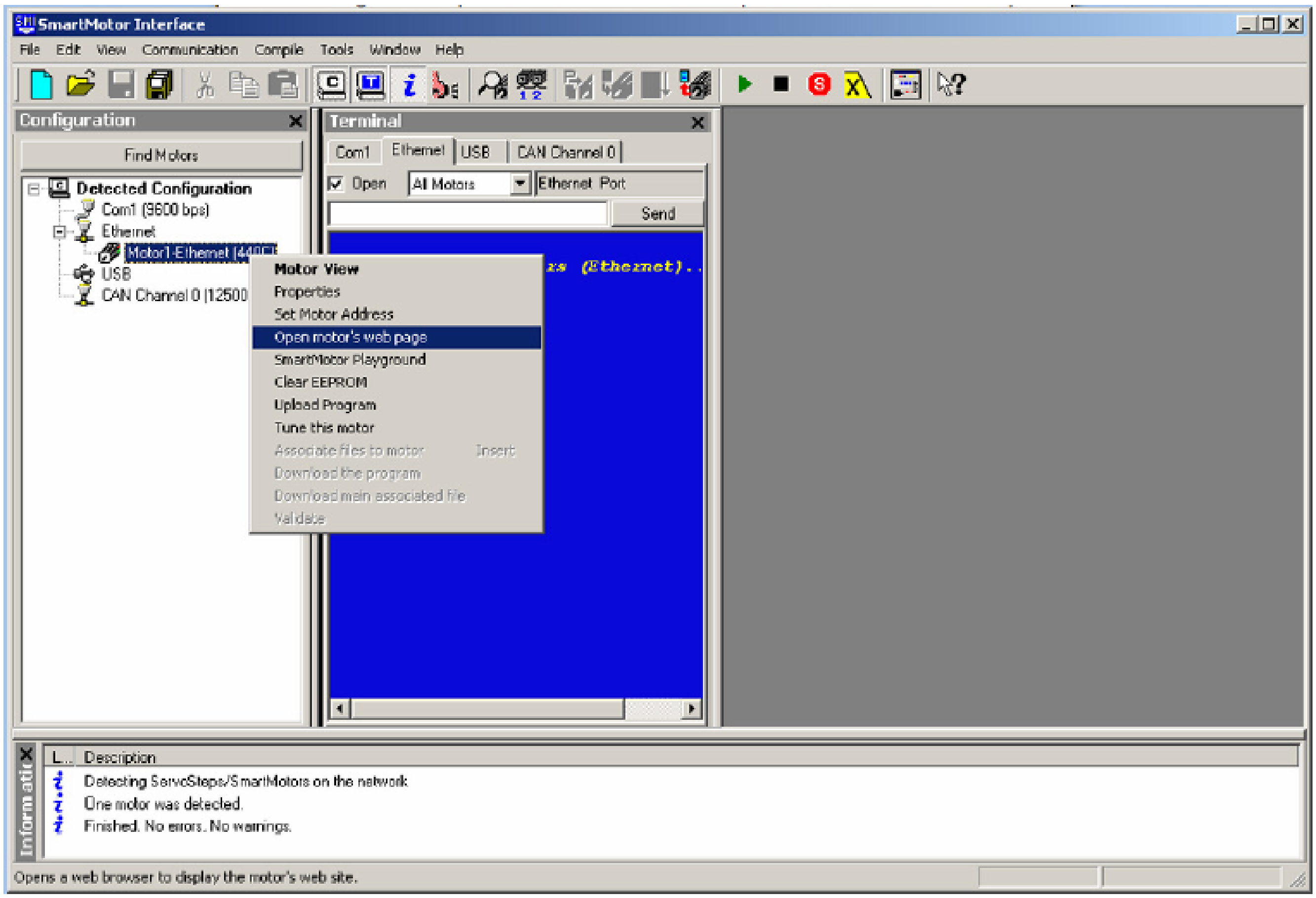
Note: Whether Static or Dynamic Addressing is used, the SMI2 software should be used for startup.
The following image shows detection of the Ethernet SmartMotor using SMI2.



Setting a Static/Dynamic IP Address

Using the SMI2 Software to change IP Addressing.

Right click the Ethernet label in the Configuration window. Select “Detect Network Motors”.

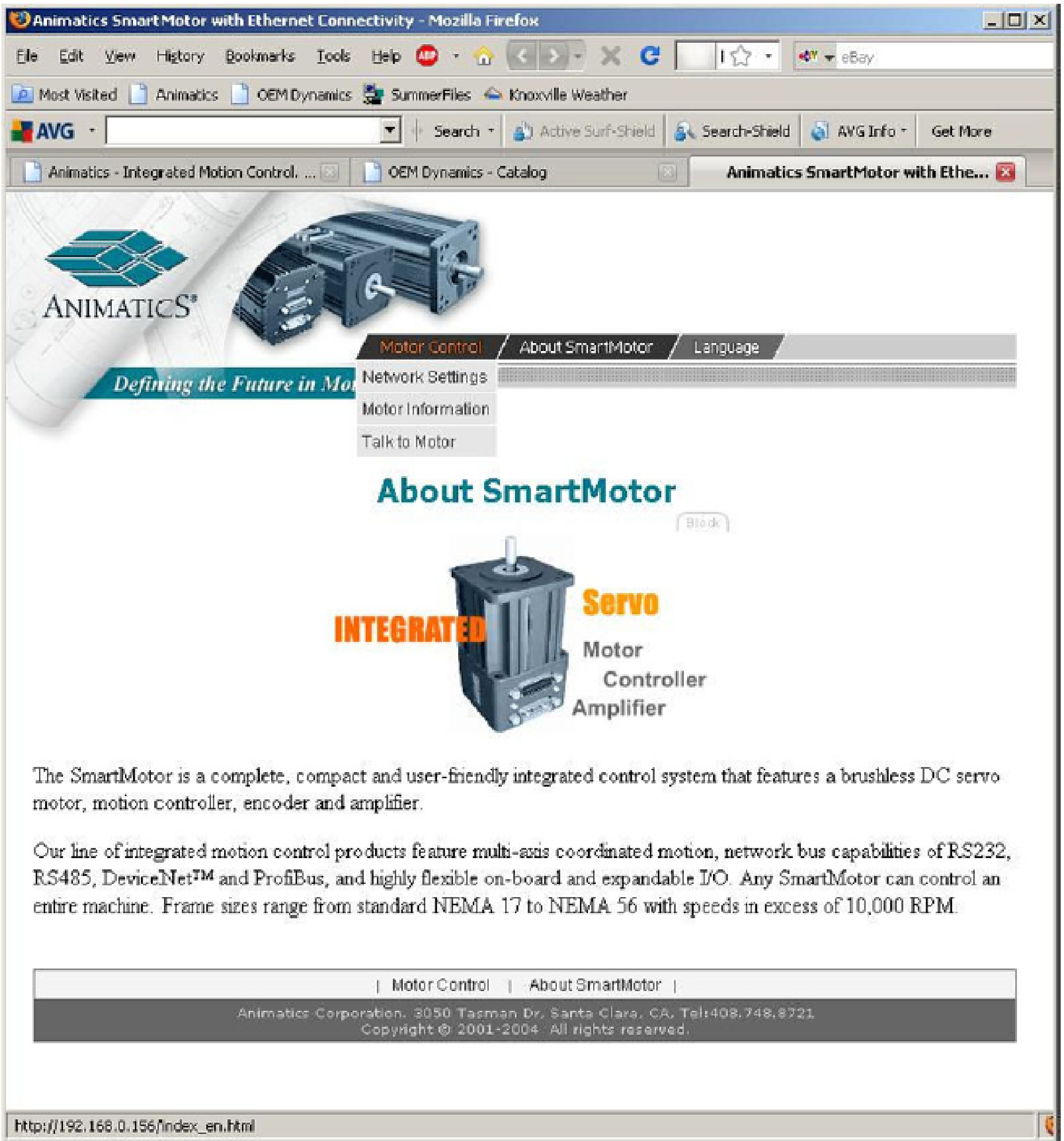


When a SmartMotor is detected, it will be listed below the Ethernet label. Right click on the label for a popup window with available options.

Configuration Using the Ethernet SmartMotor Web Browser

The Ethernet SmartMotor IP Address is set using a web browser. The following pages show the steps to change from Static to Dynamic IP addressing.

Note: The address 192.168.0.156 is indicated in the lower left corner of the window. The address used in this networking example is Static. The submenu "Motor Control" is selected and offers 3 options. Network Settings will be selected for this example.



Animatics SmartMotor with Ethernet Connectivity - Mozilla Firefox

Network Settings

○ Obtain a dynamic IP address automatically

◉ Specify a static IP address:

IP Address:	192.168.0.156
Subnet Mask:	255.255.255.0
	Update

Note 1: This page contains a Java Applet. You may need to install a Java virtual machine (version 1.2 or later). You can download one from Sun's Java web site.
Note 2: If you change the IP address you must reload the browser with the new IP address.
Note 3: Click here for an explanation about IP address and subnet mask.

Dynamic IP address setting

It is recommended that you select the option **"Obtain a dynamic IP address automatically"**, when you want to connect the motor to a network with a server, because the DHCP server makes sure that the motor and the computers are on the same subnet. In this case, the motor tries to find a server on power up. If a DHCP server is found, the motor gets an IP address from the server. Otherwise, if a DHCP server is not found on the network, the motor uses a procedure called "Auto-IP" to select an IP address from the range: 169.254.0.1 .. 169.254.255.1.

Even after an IP address has been assigned using Auto-IP, the motor keeps looking for a DHCP server, getting a new IP address from the DHCP server when one is found.

Using a Static IP address

If you select the option **"Specify a static IP address:"**, and enter an IP address, you need to make sure that:

- The motor's IP address is in the same subnet of the computers on the network. (usually this means that the first 3 numbers of the motor and computer IP addresses are the same), and
- No other device on the network is using that IP address.

| Motor Control | About SmartMotor |

Animatics Corporation, 3050 Tasman Dr, Santa Clara, CA, Tel:408.748.8721

Applet Network started

9.7 Safety Risk Classification Methodology

RISK PARAMETERS

S = Severity of injury:
1 = Slight (normally reversible) injury
2 = Serious (normally irreversible) injury, including death

Choice: Injury could be serious. (e.g.: the robot may crush operator's on rail)

F = Frequency and / or exposure to the hazard
1 = Seldom to quite often and / or exposure time is short
2 = Frequent to continuous and / or exposure time is long

Choice: Seldom. However, the exposure time might be long.

P = Possibility of avoiding the hazard
1 = Possible under specific conditions
2 = Scarcely possible

Choice: Possible (e.g.: by respecting all the security specifications)

Conclusion : Security category #03 (S2, F1, P1)

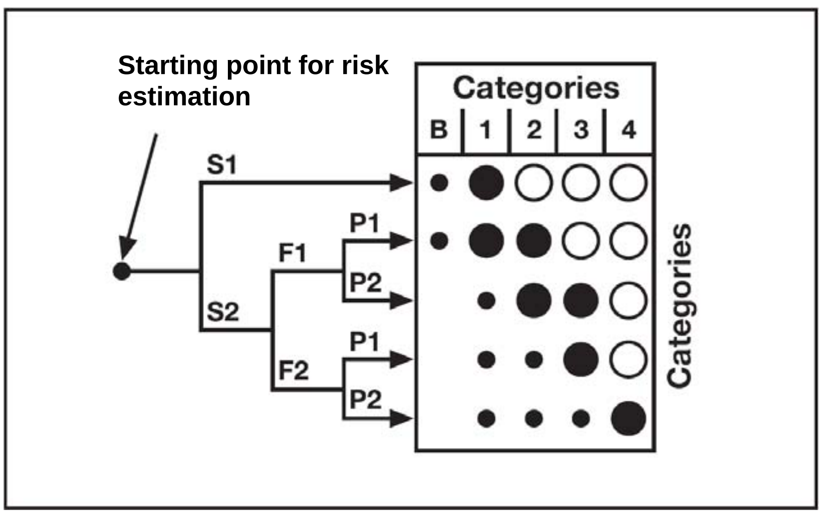


Figure 01: Risk graph from EN 954

CATÉGORY 3

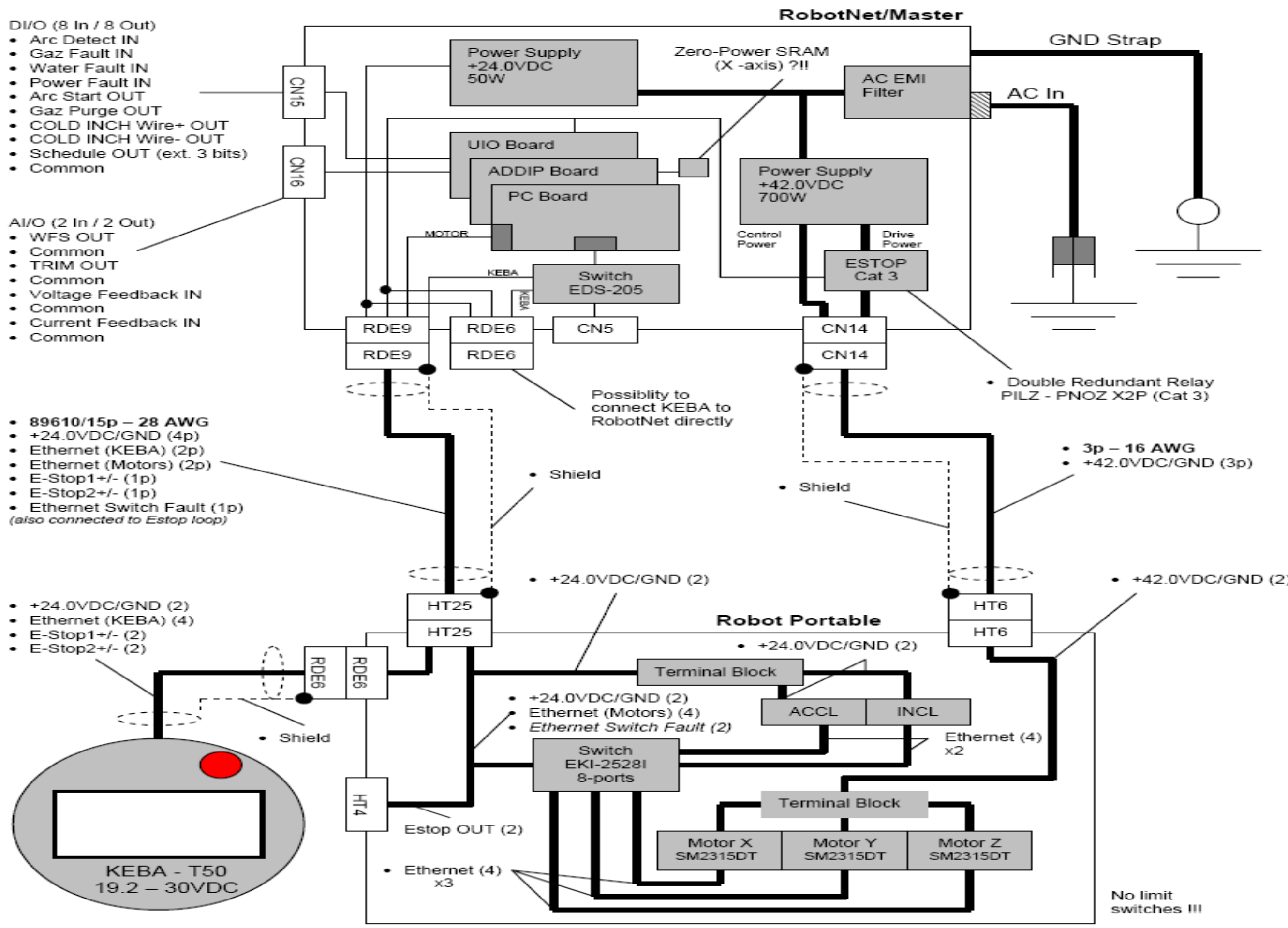
Safety-related parts of control systems must be designed so that a single fault in any of these parts does not lead to the loss of the safety function. Whenever reasonably practicable, the single fault shall be detected at or before the next demand upon the safety function. This does not mean that all faults will be detected. The accumulation of undetected faults can lead to an unintended output signal and a hazardous situation at the machine.

The emergency stop muchroom on the teach pendant has 2 contacts that feed two electrical circuits connected to the redundant safety loops. The status of the Ethernet switch inside the robot and the external safety contacts on the control unit are also part of the safety loops. A redundant safety relay is triggered as soon as one of the safety loops is open. The outputs of the safety relay cut the power to the motors when it is triggered.

Reference:

PILZ GmbH (June,2005).Compact Safety Relays PNOZ X.

9.8 Portable Robot Block Diagram



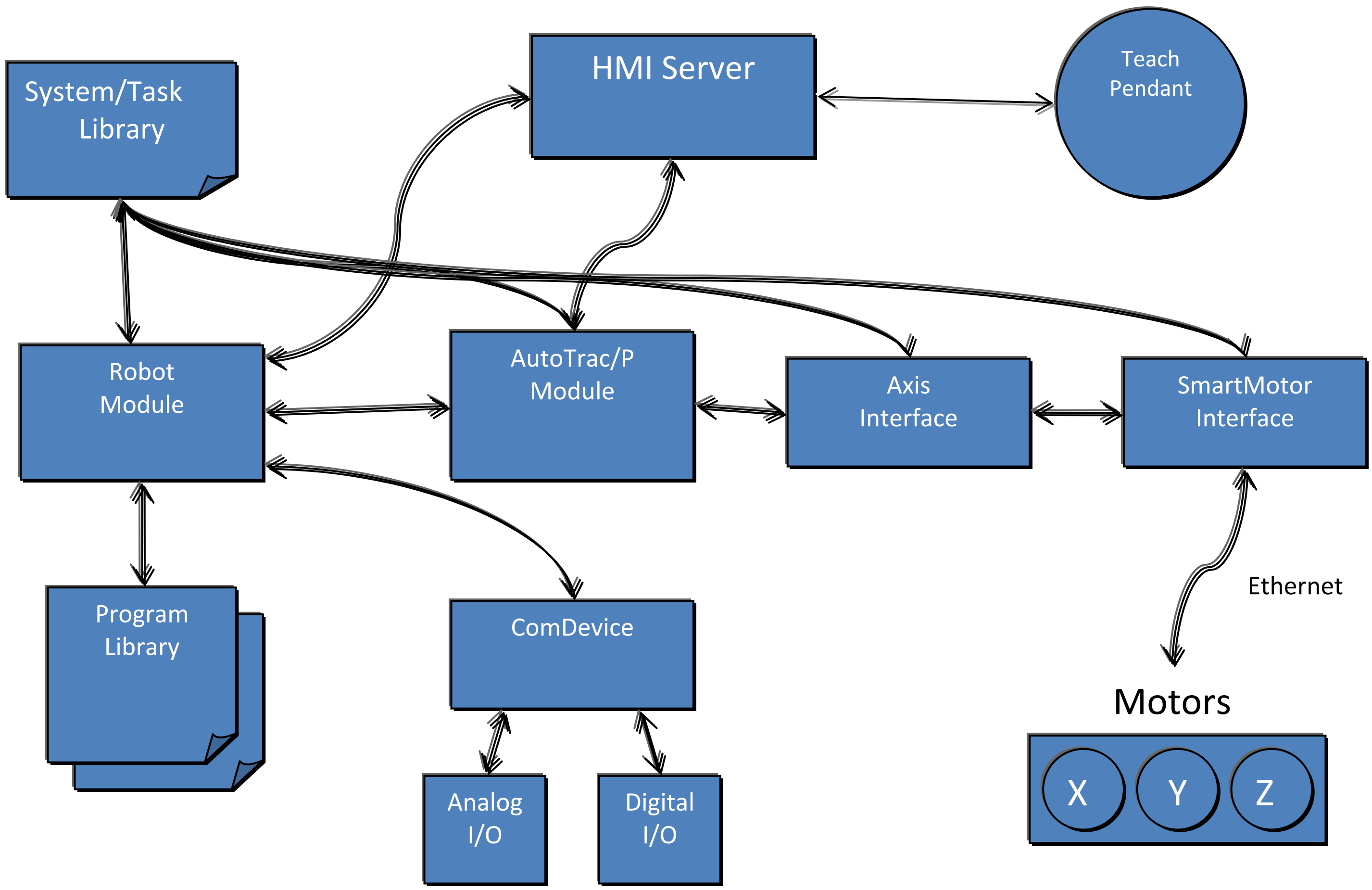
9.9 RobotNet Master Photos & 9.10 RobotNet Drive Photos

9.11 Teach Pendant Home Screen

9.12 Teach Pendant Teaching Screen

9.13 Teach Pendant Running Screen

9.14 Robot Control software



9.15 Robot Demonstration Cell