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nScorpion Mk.I Report

K. Nordstrom and J. Gates, Scientific Instrumentation Limited

Contract Scientific Authority: D. Erickson, DRDC Suffield

Defence R&D Canada

Contract Report

DRDC Suffield CR 2009-049

January 2009

Canada

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Contract Number: W7702-05R071/001/EDM

Contract Scientific Authority: D. Erickson (403-544-4048)

Defence R&D Canada – Suffield

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Abstract

This contract report documents the work accomplished during the contract W7702-05R071/001/EDM, entitled “Design and construct sensor and controller module for augmenting an existing explosive ordnance disposal (EOD) robot” undertaken by Scientific Instrumentation Limited (SIL). It covers the removal of the existing control system and nervous system to the Foster-Miller Talon EOD robot, although the previous system detail is excluded here, and replacement with a commercial off the shelf (COTS) control system. It demonstrated the ability to re-use an existing robot with a new command and control system without complete redesign. The delivered EOD robot is the basis of the nScorpion robot for 12RJ. The nScorpion Explosive Ordinance Disposal (EOD) / Improvised Explosive Device (IED) robot system (northern scorpion - *paruroctonus boreus*) is an advanced demonstration robot intended to advance EOD/IED robotics state of the art. The project goal is to demonstrate autonomy for current robotics and augment soldiers’ and EOD/IED technicians’ capability. By implementing an open control system on top of the original gear motors, arm and chassis, it will allow apples- apples performance comparison with the existing EOD robots.

Executive summary

The nScorpion is an advanced demonstration robot built under project 12RJ intended to advance the state of the art in Explosive Ordnance Disposal (EOD) / Improvised Explosive Device (IED) robotics. The goal of this research project is to demonstrate a higher degree of autonomy for current robotics and augment the capability of soldiers or EOD/ IED technicians. By improving overall autonomy, nScorpion intends to show that humans can supervise individual or teams of robots and in some cases remain one step back from dangerous situations. While autonomous robots will not exceed human performance, it can remove some of the positive control burden (a factor in current EOD operations) and demonstrate a future when humans team with autonomous robots. This contract delivered a re-designed EOD robot for scientific experimentation from an existing COTS EOD robot baseline. This work extracted the closed and proprietary controls system and replaced it with a similar, in deed more advanced, control system. This work was done with little support and assistance from the original equipment manufacturer. The result to date is that the cost-effective controller module works similarly to the original inside the original footprint. The work demonstrates that it is feasible to reuse a robot chassis without the expense and time to develop a machine from the start for the purpose of scientific experimentation or operational requirement. It demonstrate that it is possible to augment our current fleet of EOD robots with the additional controller, sensors, and improved software using the original manufacturer or a third party company.

Table of contents

List of figures

List of tables

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1. Introduction

The nScorpion is an advanced demonstration robot built under project 12RJ intended to advance the state of the art in Explosive Ordnance Disposal (EOD) / Improvised Explosive Device (IED) robotics. The goal of this research project is to demonstrate a higher degree of autonomy for current robotics and augment the capability of soldiers or EOD/ IED technicians. By improving overall autonomy, nScorpion intends to show that humans can supervise individual or teams of robots and in some cases remain one step back from dangerous situations. While autonomous robots will not exceed human performance, it can remove some of the positive control burden (a factor in current EOD operations) and demonstrate a future when humans team with autonomous robots. This contract supports the work on advanced EOD robotics by adding an "intelligence" module on top of an existing teleoperated robotic platform. The robot was a Foster-Miller Talon minus the proprietary controller board, control station, proprietary secondary electronics boards, video MUX transceiver, etc. The Talon parts reused included the chassis, motors, batteries, Freewave Modems, COTS electronic compass, drive tracks, sprockets, road wheels, arm assembly complete and operator control station. The robot was returned with the addition of an interface module integrated and tested to confirm operational capability. Foster-Miller did not assist the contractor with detailed information regarding the as-built components. Mechanical and electrical drawings were not available, although some approximations and images were be available during the design phase. The contractor was not bound to employ all the previous components and could substitute the originals, although that was discouraged for the majority of the drive train and arm mechanisms. This interface module took the form of sensors/transducers, microcontroller(s), and supporting components (which should include HVAC, memory, power electronics, wireless modem, interface ports amongst others) to fuse the data and operate the aforementioned robot. The primary goal is to allow for the control of the robot's operation as the OEM equipment did. The secondary goal was to provide a "bolt-on" module that could be made into a retrofit kit for a fleet of EOD robots.

1.1 EOD Operations: Life of an EOD robot

Figure 1 [1] illustrates various EOD operations against suspect IED in Iraq. These images demonstrate a sample of the generic EOD / IEDD scenario. All operations in Figure 1 resulted in IED detonation without human casualties; in subfigures (a) and (b) the EOD robot was destroyed by touching disturbed earth above an IED; in subfigure (c) the EOD robot was destroyed when it touched the suspect barrel; in subfigure (d) the EOD robot was destroyed by command detonated IED, and in subfigures (e) and (f) EOD robots successfully neutralized IED without damage.

In general, an EOD operation is requested when a suspect device, disturbed ground, weapons cache, or suspicious vehicle is found in the path of friendly forces. The suspect threat area is cordoned off and maneouvre units defend the EOD team as they move in to investigate. The EOD team arrives and makes an assessment of the situation

(a)

(b)

(c)

(d)

(e)

(f)

Figure 1: EOD Robot operations against IED. All operations above resulted in IED detonation without human casualties; (a) and (b) EOD robots were destroyed by touching disturbed earth above an IED; (c) EOD robot was destroyed when it touched the suspect barrel; (d) EOD robot was destroyed by a command detonated IED; (e) and (f) EOD robots successfully neutralized IED without damage.

and the threat. When the situation merits it, EOD techs dismount and deploy an EOD robot to investigate. The current state of the art (SOA) for EOD robotics is camera-based teleoperation: the robot is driven by camera feedback up to the suspect threat by an EOD technician sitting at a control station. Given the delicate nature of an EOD operation, the EOD robot movement to target must be slow and methodical and requires several independent controls. Once the suspect threat is examined, the EOD technicians determine the proper procedure and then attempt to neutralize the device. In the case of IEDD, the usual neutralization procedure is to counter-charge on the threat and blow in place (BIP- please see Annex D for a complete list of acronyms); cause a sympathetic detonation in the IED explosives and destroy the device in situ.

EOD technicians and civilian SWAT operators prioritized the capability deficiencies in the Nguyen and Bott [2] survey. Feedback was received from CF EOD personnel about current EOD robotics. One of the priority improvements for EOD robots (referred to as semi-autonomy in Nguyen and Bott [2]) was to reduce the time that operators drive the EOD robots. Given that an average EOD operation can last up to 5 hours, operator fatigue is a considerable factor. The video feedback is limited, even with zoom lenses, and gives no perspective to the objects in the field of view so the operators must take additional time to complete a simple movement. It would be preferable if the EOD robot could advance to a suspect threat autonomously and then allow the operator to focus on investigating. This capability deficiency is the motivation for the Perception Module. As can be seen in the subfigures of Figure 1, the EOD robot is aimed at a specific threat in the open. The field of view is limited by height above the ground and is less concerned with the surrounding area. In general, the suspect threat is static and can be approached from a wide angle. It would be advantageous for the operator to receive the texture details of the target in addition to the volumetric geometry. This suggests that a vision system that can focus on the object while approaching may improve the overall capability

In order to advance the ability of the current EOD robotics, onboard complex sensing and computation are required as well as a paradigm shift away from the pure positive control teleoperation philosophy. Autonomous operation implies that the machine itself would need a sensor system capable of distinguishing details on objects as small as EOD targets, like the 68mm diameter PMA-3 AP mine, in a simple- to moderate-complexity environments as seen in Figure 1. The largest bandwidth sensor to date is an electro-optic camera; time-of-flight sensor arrays alone are not sufficient for volumetric mapping in these environments. Therefore, a visual system capable of processing many frames per second is required at a minimum. It must be able to give precise pose estimates from objects of interest below 10cm in size and rapidly adjust this estimate in a volumetric sense so that the nScorpion may move to intercept or manipulate. Since it must be autonomous, the computing power to conduct data fusion levels 0 (pre-processing) through 3 (threat assessment) on the sensor data, as defined by the JDL definitions[3], must be onboard.

Modularity, flexibility, robustness, and cost-effectiveness were the most important design factors applied to the nScorpion. The overall design was partitioned into several pieces and each was required to be a self-contained module, or a system of modules, which could be interchanged or pulled outright from the design and used elsewhere as needed. This mandate will allow design reuse, and equivalent experimentation and operation by simply moving the modules to other platforms or situations. This also made it possible to demonstrate a number of side issues: one, that multiple contractors possess the skills and experience to build said modules independently, and two, that hardware has become a commodity and can be left to the private sector where practical.

1.2 Overview

This report outlines the nScorpion EOD robot design modifications to the existing EOD robot and the hardware and software that make up the retrofit kit. Section 2. describes the design of the nScorpion, Section 3. comments on the evaluation of the design in its current form, and Section 4. summarizes the capabilities and outlines some improvements to the nScorpion.

2. Design

This section outlines the design result delivered under this contract. Section 2.1 describes the hardware design and Section 2.2 describes the software design. Further hardware details are available in the attached annexes. Annex C describes the technical specifications of the nScorpion Mk.I.

2.1 Hardware Design

2.1.1 Overview

Figure 2.1 shows a system overview of the nScorpion EOD robot. The brown blocks are actuators, the yellow boxes are transducers, blue boxes are controllers, the green box is a FPGA drive board, and the white boxes are chassis components: torso and head. The Perception Module is not dealt with in this paper.

Figure 3 displays the electrical schematic for the new control system. This system was overlayed on top of the existing transducers and actuators once the original equipment manufacturer control system was removed.

2.1.2 Controllers

The nScorpion has 3 CPU located at various locations within the robot itself. The Interface Module (IM) is a Steroid Stamp 555 (SS555) / FPGA (Field Programmable Gate Array) electronics board stack that controls the robot drive functions and some internal sensors. The Distance Sensing Module (DSM) is an SS555 located above the right track receives data from the ultrasonic and infrared time of flight sensors. The Localization Module (LM) is housed in the right electronics bay and estimates pose and trajectory. All SS555 controller run the real-time executive for multiprocessor systems (RTEMS) operating system.

2.1.3 FPGA

The SIL control board is a mother board for the command Interface Module SS555 that runs the robot. The control board houses a Xilinx FPGA to operate the lower functions. This FPGA can be programmed separately using the debug connector available. The FPGA runs at a faster speed and has dedicated hardware to control the driver boards, sensor feedback, and onboard components.

2.1.4 Bluetooth Communications

The following configuration is used with the Wireless Blue Tooth (Grid Connect-Blue Port) Serial Modems. There may be other configurations that work, but this is the setup that was used at SIL during testing. 115.2K baud, no handshaking, using only Tx and Rx. Note: Using the above configurations, it does not matter which device is on the DSM and which is on the PC.

2.1.5 Distance Sensing Module

Figure 5 describes the wiring of the DSM. This module was made as a "bolt-on" sensing module that can be removed without any impact to the robot function. For practical purposes, the time of flight sensors needed to be placed outside the chassis in an advantageous position so that the sensor data could be recovered. For ultrasonic and infrared data, the higher from the ground the better the data returns with less ground-effect interference. This decision was made so that the time of flight sensors would be housed in separate modules so they could be positioned arbitrarily around the vehicle or any vehicle. Another advantage of this system is that it allows the same module to be used on any ground vehicle with an adjustment to the cable lengths. The ultrasonic sensors sense out to around 5m and the infrared sense out to about 1m given the type of texture, angle of intercept, and material in view. The orthogonal phenomena of longitudinal sound waves and lateral radiation improves the overall probabilities that the sensors detect obstacles in the overlapping range. If the target object is metallic then the response from the IR will occur for greater distances even when the aspect ratio is small and the ultrasonic waves encounter an oblique corner.

In Figure 5 the SS555 controls and reads the 16 sensor modules via connectors CN5, CN4A and CN4B. Sensors are enabled via CN8A and CN5.

The DSM uses a firing sequence with dead time so that transducers are not sensing cross talk and secondary echos. This firing sequence can be varied and could be modified so it varies with the situation.

2.1.6 Localization Module

The Localization Module is a controller deidcateddedicated to localization calculations. It is a SS555 mounted in the right e-bay that takes in data from the inertial sensor and estimates the pose based on feedback from the IM and the sensors. The current software uses a 6 DOF kinematic Kalman filter to smooth pose estimation. There is no GPS at present, and all translations are from an arbitrary origin.

2.2 Software Design

2.2.1 Software Development Toolchain

The SS555 developer kit from Intec Automation was used to develop the device interface and control applications in the head controller. This software was later ported to run on RTEMS as a full multi-tasking application. Microsoft Visual tools were used to develop the demonstration application.

2.2.2 Low-level Hardware drivers

The MPC555 Time Processor Unit (TPU) has functions for quadrature encoders complete with input capture. The TPU is used capture the index pulse for calibration and system alignment. This is an important step in startup procedures to know the current system state. The PWM function of the MPC555 is used to provide a programmed pulse with a specified repetition rate. No special TPU functions were required.

2.2.3 RTEMS configuration options

The same RTEMS build was used for compiling the DSM SS555 software as was used for the nScorpion Robot SS555 software. See README and configure.ac in the libbsp/powerpc/SS555 directory. Changes to be made to configure.ac. The RTEMS system configuration rebuild needs the following options:

- UARTS_USE_TERMIOS=1
- UARTS_IO_MODE=1
- RTEMS_BSPOPTS_SET([WATCHDOG_TIMEOUT],[*],[0x3000])

When built this way, you should be able to use tcgetattr(3) and tcsetattr(3) to configure the ports for raw or cooked serial transfers at the desired baud rates. All of the usual functions, such as open(2), close(2), read(2), and write(2), as well as getc(3) and putc(3), should work. The watchdog timer is also enabled and set for 0x3000 counts of 1/20 of a millisecond.

2.2.4 Program Flashing

To re-program the SS555, the cover needs to be removed. With the power off and the top cover removed, the BDM cable can then be plugged into connector CN2. With the BDM cable in place, power can then be applied and the programming procedure may commence. When the program is compiled under linux it will create an ELF type file nscorp.exe in the o-optimize subdirectory. This needs to be converted to an s19 type file before it can be flashed. This is done with a batch file containing the line powerpc-eabi-objcopy -O srec o-optimize\nscorp.exe nscorp.s19 which uses the Motorola objcopy provided with theSS555 . This created an s19 file which can be flashed with the Motorola provided software.

2.2.5 Sensor Block Connectors

There are 4 high-density D-sub cables that come from the DSM Main Module. Each D-sub cable contains the lines for 2 individual sensor modules (for a total of 2 ultrasonic sensors and 2 infrared sensors).

2.2.6 Power Connector

The DSM requires 5Volt and 12Volts DC to operate. There is no power conditioning done to these voltages. When the entire system is configured, the power loads were measured as follows: 5Volts @ 400mA (typ.) – SS555, Bluetooth, 8 infrared sensors 12Volts @ 235mA (typ.) – Compass/Tilt Module, 8 ultrasonic sensors

2.2.7 Serial Data Connector

The serial data connector D9 can plug directly into a PC or into the supplied Bluetooth module.

2.2.8 DSM Mode Switch

On the side of the DSM module is a “mode selection” switch. This switch dictates if the SS555 is in Distance Mode (using the data from the distance sensors), or if it is in Compass mode (using the data from the onboard compass module). The switch toggles an digital input line on the SS555 (AN4Bpin15). When this pin is high, the DSM is in DISTANCE mode, otherwise it is in COMPASS mode. When the switch is in the DISTANCE mode, serial commands sent to the SS555 over the Serial Data Connector will be for configuring what units the SS555 will send distance information in. When the switch is in the COMPASS mode, serial commands sent to the SS555 over the Serial Data Connector will be sent directly to the compass, allowing the user to customize the compass data how they see fit. See the “Serial Commands” section of this document for more information.

2.2.9 DSM Serial Protocol

Distance Mode When the mode selection switch is in the DISTANCE mode, distance data is sent from the module using the following formatting:

Hence, when the SS555 has the ultrasonic reading for sensor #3, the SS555 will transmit the following string: C=164<cr> Which reflects a reading of 164 on ultrasonic sensor #3. Packet data will be sent for a particular sensor as soon as it is ready. This means that sensor data will not be sent in sensor# order, but rather as a result of the firing table (US_firing_time[] and IR_firing_time[]) and the required wait (US_read_dwell[] and US_read_dwell[]) and sampling time.

Sensor Number	ultrasonic reading	infrared reading
1	A=[value]<cr>	0=[value]<cr>
2	B=[value]<cr>	1=[value]<cr>
3	C=[value]<cr>	2=[value]<cr>
4	D=[value]<cr>	3=[value]<cr>
5	E=[value]<cr>	4=[value]<cr>
6	F=[value]<cr>	5=[value]<cr>
7	G=[value]<cr>	6=[value]<cr>
8	H=[value]<cr>	7=[value]<cr>

Table 1: Sensor reading protocol: DSM Sensor Numbering Reference Note: <cr> is a carriage return (ASCII value of 13)

2.2.10 Serial Commands

The SS555 is also capable of receiving serial data commands from the PC. The commands are four characters long, case-insensitive, and do not require CR or LF termination.

2.2.11 Distance Mode Commands

When the mode selection switch is in the DISTANCE mode, the following commands apply:

1. RAWM – abbreviation of "raw mode", the SS555 will send out the infrared and ultrasonic readings in raw counts (instead of engineering units). The infrared sensors will display the 8-bit reading as generated by the infrared sensors. The ultrasonic sensors will display the 10-bit reading as sampled from the SS555 A/D.
2. NORM – abbreviation of "normal mode", the SS555 will send out the infrared and ultrasonic readings in engineering units. Both infrared and ultrasonic sensor data is sent out in centimeters using this mode. On power up, this is the default mode when DISTANCE mode is selected.

2.2.12 DSM Compass Mode Commands

When the mode selection switch is in the COMPASS mode, any serial data coming from the PC to the SS555 will be relayed onto the TCM2 (compass / tilt / magnetometer sensor). The user can now program the TCM2 with all of the commands found in the "TCM2 Electronic Sensor Module User's Guide".

2.2.13 IM Commands

Annex A details the commands to send the IM SS555 to control the robot. Annex B details the commands that the IM SS555 sends the FPGA to control the low-level actuators and the transducers. These commands include a set get/set commands that allow the controller to poll the current state of actuators and transducers or set their respective states. There are velocity commands for the motors, and soft upper and lower threshold limits to avoid damaging the arm and wrist motors. They follow a simple two character format as detailed in Annexes A and B.

2.2.14 Client GUI

Figure 6 demonstrates the client GUI used to control the robot. The client software is a Visual basic graphical interface that takes input from a Logitech joystick to allow a user-friendly way to control the motors. This software communicates over the freewave modem to a SS555 processor on the robot. This processor monitors some sensors itself, and communicates with a FPGA for control over the motors. The command box allows the user to enter in a manual command and press "Send Cmd" to send the command. The box underneath shows the response from theSS555 , for any command. The "emergency stop" button will stop all motors. The "Motor Status" button will request the current position and speeds of the motors and display the values in the appropriate boxes. This command is also sent once a second automatically. A second command the CU command is also sent once a second to get the current from the gripper. The video TX, 5V, and 12V power can be toggled with the check boxes. The elbow and shoulder speeds can be sent by entering a number into the box and clicking on the send button. The brake statuses can be set by checking which ones to activate and clicking the "Set Brakes" button. Communication between the client and the SS555 are of a command response type, over a serial. The SS555 will not send anything that wasn't requested. Communication between the SS555 and the FPGA are also a command response type, but over a data bus. The SS555 will set an address line to note the specific command, and either set data lines to contain data that is to be sent to the FPGA, or be ready to accept data from the data lines that the FPGA is sending to the ss555.

Joystick commands

The left stick controls the left track motor, right stick the right track motor. Button 9 cycles through the speed multiplier, from 3 to 6 to 9 to 12. In order to make moving forward easier, the values are synchronized if the sticks are close enough in position. The left top buttons, 5 and 5, control the shoulder, 5 to move it in, 7 to move it out, release both to stop. The right top buttons, 6 and 8 control the elbow, 6 to move it in, 8 to move it out, release both to stop. The 4 buttons on the right side control the wrist and gripper, 1 to move the wrist counter clockwise, 3 to move it clockwise, release both to stop. Button 4 to open the gripper, 2 to close, and release both to stop.

2.3 Sensor Calibration

2.3.1 Ultrasonic Sensors

The ultrasonic sensors are calibrated locally on the sensors themselves. There was the ability for piece-wise linear calibration added to the code, but this basically was not used. To calibrate a given ultrasonic sensor, apply power to the module and allow several minutes warm-up time before calibration. Place the target at the desired distance for the full scale voltage output (5 meters). This can be either the minimum range or the maximum range between the sensor and the target. Push and hold "MAX VOLT RANGE SET" button on sensor and wait for the LED indicator to stop flashing and the transducer generates a "chirp" sound. Release. Like the above, place target at the minimum desired measurement distance (30 centimeters). Push "MIN VOLT RANGE SET" in the same manner. To perform the “SCALE Adjust” or “GAIN Set” calibration, please refer to the manufacturer’s documentation. When performing a calibration, be very careful that the readings are not contaminated by cross talk or sensor echoes.

2.3.2 Infrared Sensors

The infrared sensor calibration numbers are hard coded into the SS555. The tables are found in the init.c file. Calibration is done using a piecewise-linear extrapolation. Changing these calibration numbers will require a recompile and flashing of the SS555. To calibrate a given infrared sensor, place the SS555 into “raw mode” (by sending the RAWM command). The SS555 will now be sending out data in raw counts. Record the raw counts for various distances to a target (the current calibration tables use the following distances: 10cm, 20cm, 30cm, 40cm, 50cm, 60cm, 70cm, and 80cm). When performing a calibration, be very careful that the readings are not contaminated by cross talk or sensor echoes.

3. Discussion

SIL was able to replace the existing proprietary control system above the actuators and sensors with a new system and still place it inside the same footprint. Essentially, the design involved pulling the nervous system from the chassis and replacing it. Redesign for this new robot was done without help from the original equipment manufacturer, and included all the original mechanical parts, chassis, motors and transducers. In fact, major subcomponents of the original design were subcontracted elements like the Freewave RF modems and the TCM2 compass module. This original modular design makes it easy to repair these systems as well as improve them.

This Foster-Miller Talon design was chosen as the baseline because it was made available by the CF for this work. This could have been repeated with another OEM baseline design. This is important because it means that any fleet of EOD robots could be retrofitted to use new advancements. Perhaps one consequence of this is that advanced capability can be gradually introduced to operational personnel inside the original footprint. Another implication is that the EOD robots can evolve over time and, with little external evidence,

This work demonstrates that is possible to employ any company of merit to duplicate the control work; i.e. that electronics and particularly control systems have become a commodity. It also demonstrates that it is just as feasible, in fact more practical, to re-use an existing design that is proven than to develop one from scratch when the situation warrants it. In the case of a proof-of-concept system, such as the nScorpion, it is a cost-effective alternative. The only time when this decision should not be made is when the inherent limitations of the mechanical or electrical system would preclude it from demonstrating the desired behaviour. For example, suppose you had a teleoperated system that cannot drive above 5 kph because the latency restricts the stopping time for an operator at the maximum range and therefore the vehicle is incapable of driving above 5 kph. If you wanted to automate that system so that it could reliably stop on its own in half the latency time (i.e. making 10kph a realistic top speed) but the current vehicle was not capable of attaining 10 kph then it make sense to redesign.

Given that the goal was to compare the performance of this scientific platform to in-service EOD robots, it is a success that the finished design uses all the original electromechanical parts so that real comparisons can be made. If the system can complete a task as an EOD technician would do, then the time and difficulty used to gauge the practical limitations and planning numbers to use with an automated EOD robot versus a teleoperated one.

The delivered system needed some small modifications. The OEM driver board for the arm motors was faulty and did not deliver as much torque as the other board. The time-of flight sensors units needed to be installed on mount brackets above the tracks due to a lack of surface area. Another improvement beyond the original scope of the contract is to install and wire a laser range finder or wide beam laser at the wrist so that items in view can be easily located with the system. This would allow hand-off from the visual system that gets close to the target object from visual range to the hand that closes in and attempts to manipulate it.

4. Conclusions

The purpose of the nScorpion is to conduct experiments in automated EOD operations for comparison to teleoperated EOD robots in an apples-apples context. There are a number of improvements that should be undertaken before system integration is complete:

1. Fix / replace the faulty Foster-Miller motor drive board;
2. Mount the ultrasonic / infrared sensors on the 4 corners of the chassis;
3. Install a Hokuyo URG laser at the end of the arm and cable it down to the IM board from low-level control;
4. Reinforce the new cable holes and make sure they are waterproof and dust proof.

The nScorpion is an advanced demonstration robot built under project 12RJ intended to advance the state of the art in Explosive Ordnance Disposal (EOD) / Improvised Explosive Device (IED) robotics. The goal of this research project is to demonstrate a higher degree of autonomy for current robotics and augment the capability of soldiers or EOD/ IED technicians. By improving overall autonomy, nScorpion intends to show that humans can supervise individual or teams of robots and in some cases remain one step back from dangerous situations. While autonomous robots will not exceed human performance, it can remove some of the positive control burden (a factor in current EOD operations) and demonstrate a future when humans team with autonomous robots. This contract delivered a re-used EOD robot design replacing existing the OEM control robot baseline. This work extracted the closed and proprietary controls system and replaced it with a similar, in deed more advanced, control system. This work was done with little support and assistance from the original manufacturer. The result to date is that the cost-effective controller module works similarly to the original inside the original footprint. The potential application of this module is important, it demonstrates that it is feasible to reuse a robot chassis without the expense and time to develop a machine from the start for the purpose of scientific experimentation or operational requirement. It is possible to augment our current fleet of EOD robots with the additional controller, sensors, and improved software using the original manufacturer or a third party company.

References

1. Erickson, David, Ceh, Matt, Anderson, Dale, , and Lanz, Edward (2007). mini-RNV: a response to IED threat. In Carapezza, Edward M., (Ed.), *Proceedings of SPIE – Volume 6538 Sensors, and Command, Control, Communications, and Intelligence (C3I) Technologies for Homeland Security and Homeland Defense VI*, Vol. 65380S, Orlando, FL.

2. H.G., Nguyuen and J.P., Bott (2000). Robotics for Law Enforcement: Beyond Explosive Ordnance Disposal. (Technical Report 1839). US Navy SPAWAR. SPAWAR Systems Center San Diego.

3. U.S. Department of Defense Data Fusion Subpanel of the Joint Directors of Laboratories, Technical Panel for C3 (1991). Data fusion lexicon. Technical Report.

4. Nordstrom, Kevin (2006). nScorpion Software usage. (Technical Note SIL document 70). Scientific Instruments Limited.

5. Foster-Miller. Talon Product Brochure. online.

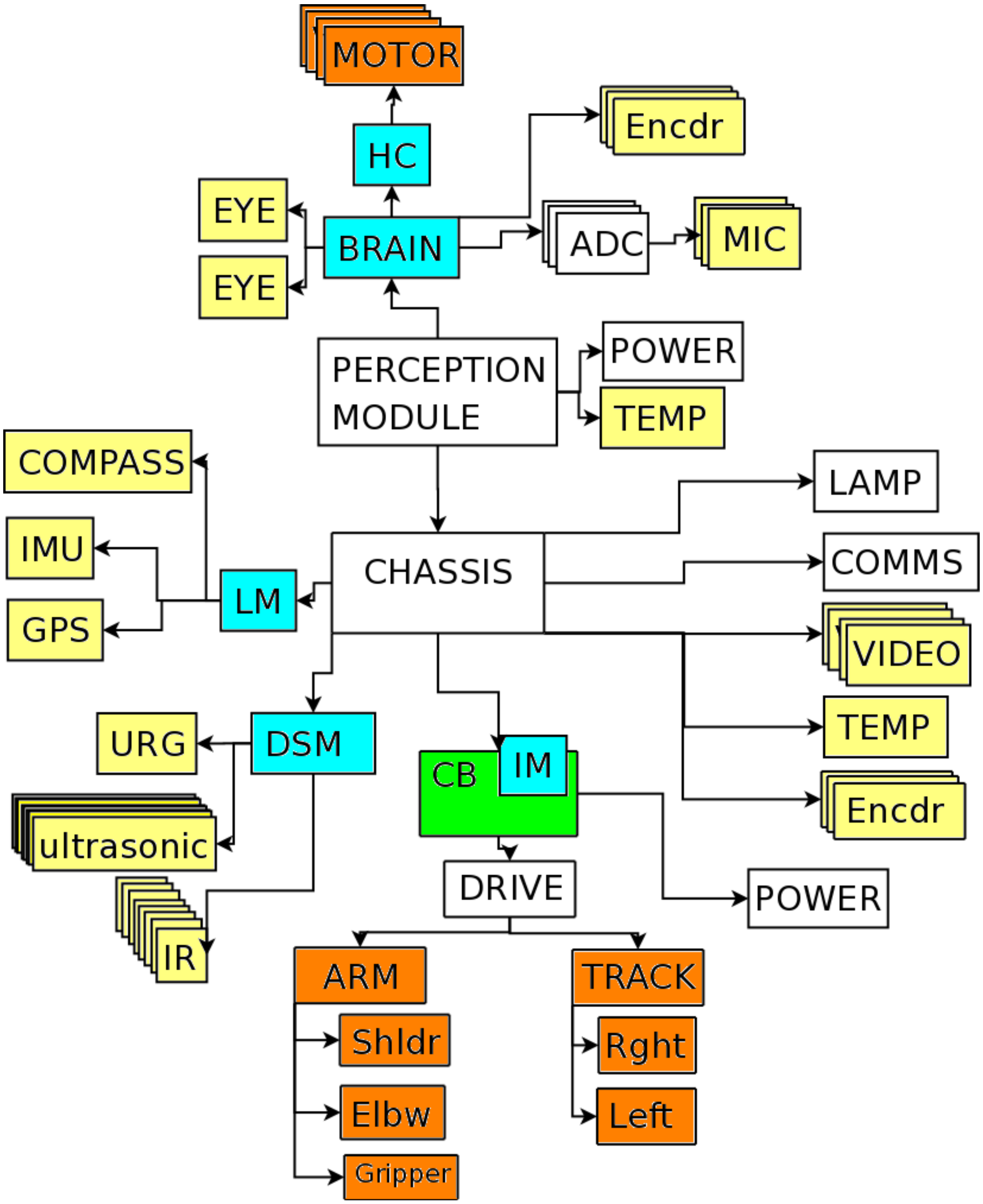


Figure 2: nScorpion Overview Schematic

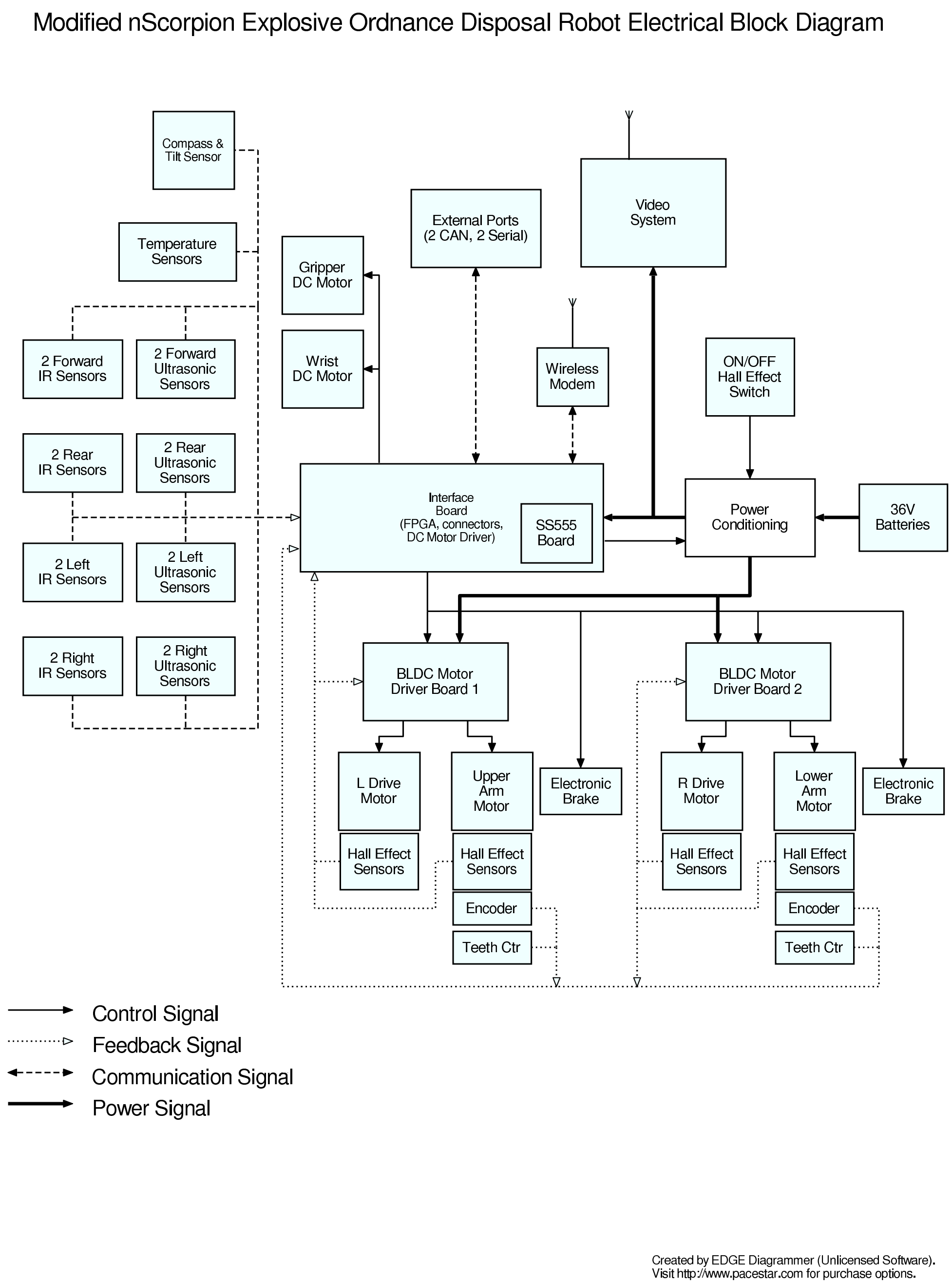


Figure 3: nScorpion Mk.I Schematic

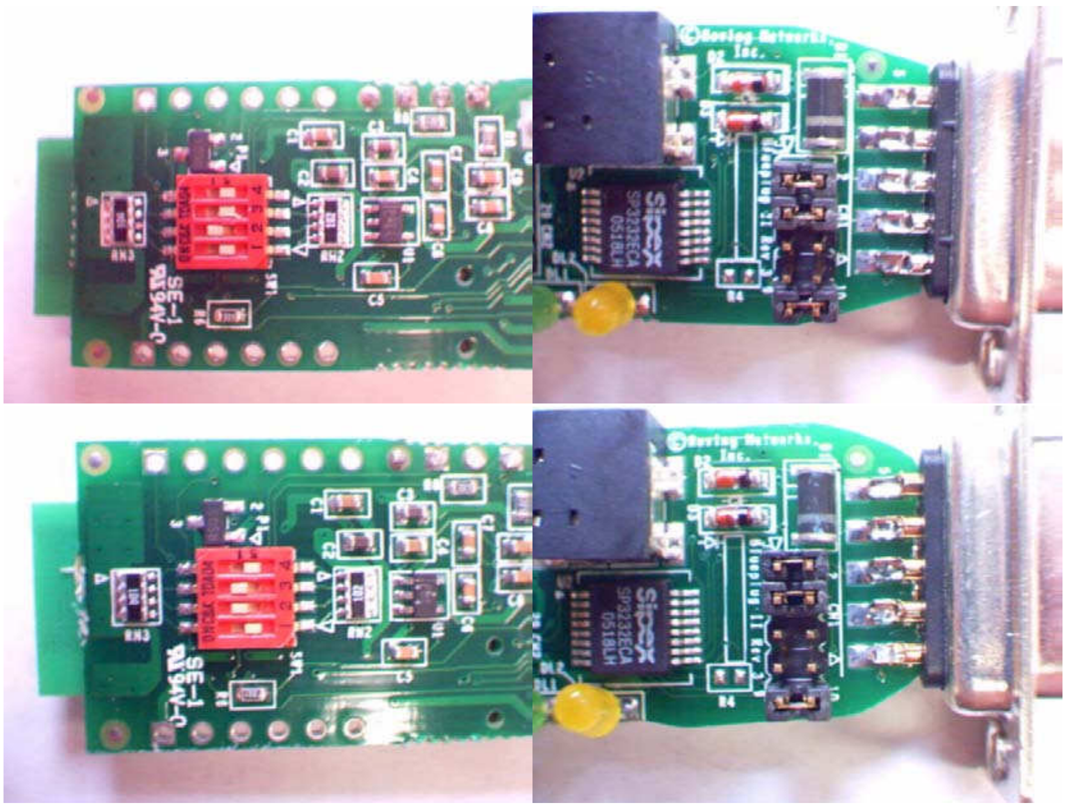
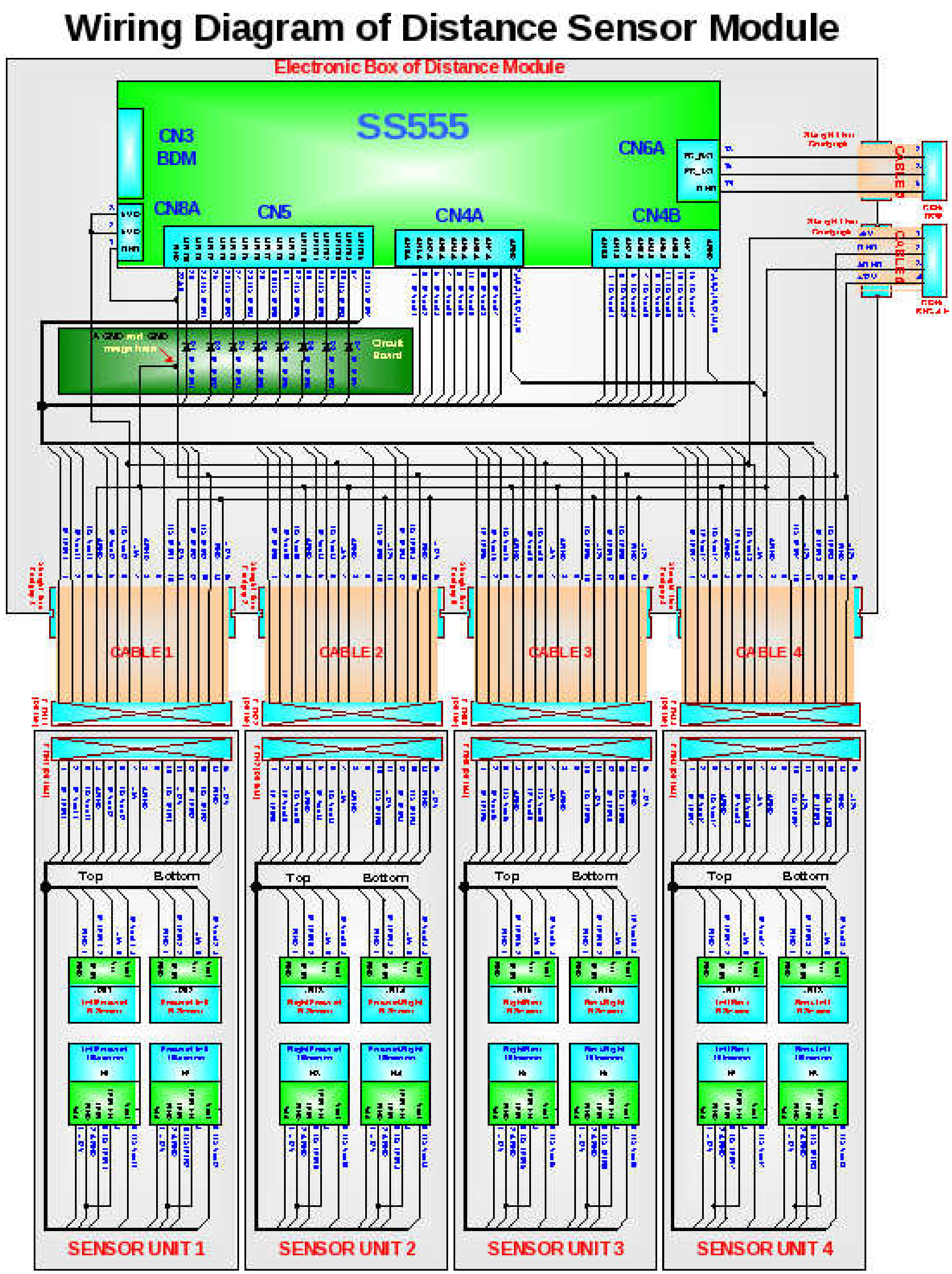


Figure 4: Bluetooth Hardware: (top) device 1 (bottom) device 2



Note: 1. All diodes are **1N4148**. All straight thru cordgrips are suggested using **LTF 7 (P/N 3207)**

2. **Cable 1** to **Cable 4** are molded premium **VGA** monitor extension cable **(AK32201.8** recommended). In case of this application, the male end **(HD D-SUB15** male connector) should be cut in a certain length based on the requirement of wiring between the sensor unit and the electronic box to allow each cable feed into the box.

3. **Cable 5** and **Cable 6** can be the same type as one of **Cable 1** ~ **Cable 4** except their connector. **Cable 5** will use a standard **DB9** connector for **RS232** port, and **Cable 6** will apply a 4-pin male video connector for power supply.

4. **AGND** and **GND** should be merged on the circuit board.

Figure 5: DSM wiring diagram

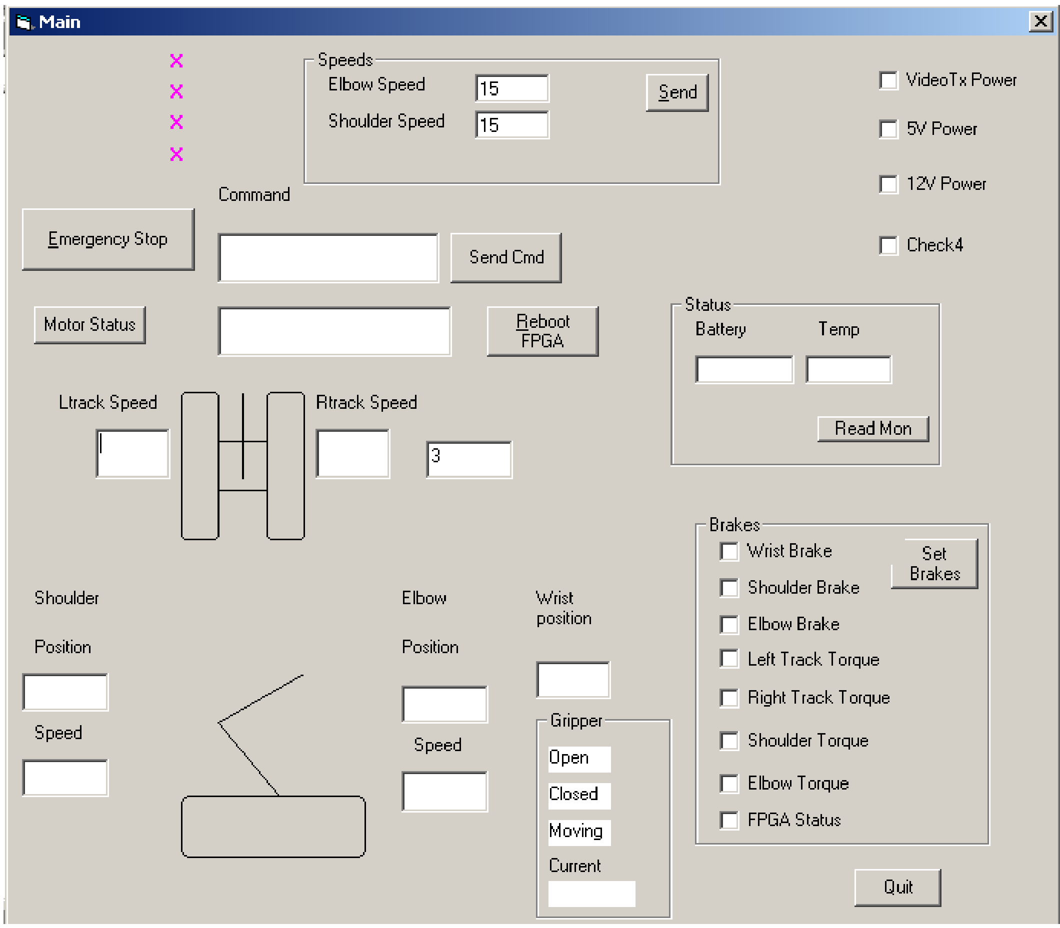


Figure 6: Client GUI

Annex A
SS555 Commands

Upon receiving a command the SS555 will reply with the command plus the returned data (if any). Line terminated with <CR>.

(RM) - Read monitors , returns the battery voltage, temperature, compass info. Returns RM a b c

(PI) – Ping command to see if robot still alive

(RB) – Reboot, possible parameters,SS555 (reboot the SS555), FPGA (reboot the FPGA), BOTH (reboot both)

command: RB param

(VT) – Video Tx on/off. Parameter is 1 for on, 0 for off. command: VT param

(PF)- Distance module 5V on/off. . Parameter is 1 for on, 0 for off. command: PF param

(PT) Distance module 12V on/off. . Parameter is 1 for on, 0 for off. command: PT param

(AS) All stop

(GO) Gripper open

(GC) Gripper close

(GS) Gripper stop

(SS) Set shoulder speed command: SS x

(SM) Move shoulder (0 for stop, 1 for move one way, 2 for moving the other way) or position desired command: SM x

(ES) Set elbow speed command: ES x

(EM) Move elbow (0 for stop, 1 for move one way, 2 for moving the other way) or the position desired command: EM x

(TS) Track speeds (valid speeds from -127 to 127) command: TS leftspeed rightspeed

(WM) Move wrist (0 for stop, 1 for move one way, 2 for moving the other way) (speed: 0 to 63) command: WM position speed

(BS) 1/0 Enable/disable brakes command: BS x

	7	6	5	4	3	2	1	0
				Left Track Torque	Right Track Torque	Shoulder Torque	Elbow Torque	

(MS) Motor status (l/r track speed, shoulder/elbow/wrist position Shoulder/elbow speeds) command:

MS Returns MS a b c d e f g

(BV) Brake Values command:BV Returns BV x Where x is integer with value:

7	6	5	4	3	2	1	0
Wrist on/off	Gripper open	Gripper Close	Gripper Moving				
Wrist Brake	Shoulder Brake	Elbow Brake	Left Track Torque	Right Track Torque	Shoulder Torque	Elbow Torque	FPGA status

FPGA status is a status of the internal modules of the FPGA, and will read 1 if everything is OK.

(CU) Gripper Current Returns CU x Where x is the current of the gripper motor.

(RF) Read from FPGA. Parameter is the address of the command to the FPGA. command: RM param

(WF) Write to FPGA. Parameter1 is the address of the command, parameter 2 is the data to write to the FPGA.

Annex B
FPGA Commands

The SS555 will set the address register for the command and either put data on the data lines, or expect The SS555 will set the address register for the command and either put data on the data lines, or expect to receive data from the FPGA. This data is copied from [4].

Monitor commands

1 – Track Speed Monitor

SP = speed

	7	6	5	4	3	2	1	0
Left	Direction	SP	SP	SP	SP	SP	SP	SP
Right	Direction	SP	SP	SP	SP	SP	SP	SP

2 – Shoulder Position

u=Unused, PV=Position Value

	7	6	5	4	3	2	1	0
Shoulder Position	u	u	u	u	u	u	PV	PV
	PV	PV	PV	PV	PV	PV	PV	PV

3 – Elbow position

u=Unused,PV=Position Value

	7	6	5	4	3	2	1	0
Elbow Position	u	u	u	u	u	u	PV	PV
Position Value	PV	PV	PV	PV	PV	PV	PV	PV

4 – Status Monitor

7	6	5	4	3	2	1	0
Wrist on/off	Gripper open	Gripper Close	Gripper Moving				
Wrist Brake	Shoulder Brake	Elbow Brake	Left Track Torque	Right Track Torque	Shoulder Torque	Elbow Torque	FPGA status

21 – Gripper Current command

u=Unused CV= Current Value

	7	6	5	4	3	2	1	0
Current Value	u	u	u	u	u	u	CV	CV
Current Value	CV	CV	CV	CV	CV	CV	CV	CV

22 – Wrist position

u=Unused PV= Position Value

	7	6	5	4	3	2	1	0
Wrist Position	u	u	u	u	u	u	PV	PV
Wrist Position	PV	PV	PV	PV	PV	PV	PV	PV

Commands to set values

6 – Set Track Speeds

SP = speed

	7	6	5	4	3	2	1	0
Left Track	Direction	SP	SP	SP	SP	SP	SP	SP
Right Track	Direction	SP	SP	SP	SP	SP	SP	SP

7 – Set Elbow position

u=Unused PV= Position Value ; (1023 for Move indefinitely, 1 for move other way, 0 stop)

	7	6	5	4	3	2	1	0
Elbow Position	u	u	u	u	u	u	PV	PV
Position Value	PV	PV	PV	PV	PV	PV	PV	PV

8- Set Elbow speed

u=Unused SV= Speed Value ; (0 Stop)

	7	6	5	4	3	2	1	0
Unused	u	u	u	u	u	u	u	u
Elbow Speed	SV	SV	SV	SV	SV	SV	SV	SV

9– Set Shoulder position

u=Unused PV= Position Value ; (1023 for Move indefinitely, 1 for move other way, 0 stop)

	7	6	5	4	3	2	1	0
Shoulder Position	u	u	u	u	u	u	PV	PV
Position Value	PV	PV	PV	PV	PV	PV	PV	PV

10 – Set Shoulder speed ; (0 stop)

	7	6	5	4	3	2	1	0
Unused	u	u	u	u	u	u	u	u
Shoulder Speed	SV	SV	SV	SV	SV	SV	SV	SV

11 – Set Brake status; (0 for off, 1 for enabled)

u=Unused

7	6	5	4	3	2	1	0
u	u	u	u	u	u	u	u
Wrist Brake	Shoulder Brake	Elbow Brake	Left Track Torque	Right Track Torque	Shoulder Torque	Elbow Torque	

12 – Gripper commands; (0 for off, 1 for on)

	7	6	5	4	3	2	1	0
Unused	u	u	u	u	u	u	u	u
	Gripper open /close	Gripper Enable	u	u	u	u	u	u

13 – Soft Limits for Elbow

	7	6	5	4	3	2	1	0
Lower Limit	High Byte Lower Limit							
Lower Limit	Low Byte Lower Limit							

14 – Soft Limits for Elbow

	7	6	5	4	3	2	1	0
Upper Limit	High Byte Upper Limit							
Upper Limit	Low Byte Upper Limit							

15 – Soft Limits for Shoulder

	7	6	5	4	3	2	1	0
Lower Limit	High Byte Lower Limit							
Lower Limit	Low Byte Lower Limit							

16 – Soft Limits for Shoulder

	7	6	5	4	3	2	1	0
Upper Limit	High Byte Upper Limit							
Upper Limit	Low Byte Upper Limit							

17 – Set Wrist Speed/Position SP=Speed PV= Position Value ; (1023 for Move indefinitely, 1 for move other way, 0 stop)

	7	6	5	4	3	2	1	0
Wrist Speed	SP	SP	SP	SP	SP	SP	PV	PV
Position Value	PV	PV	PV	PV	PV	PV	PV	PV

18 – Soft Limits for Wrist

	7	6	5	4	3	2	1	0
Lower Limit	High Byte Lower Limit							
Lower Limit	Low Byte Lower Limit							

19 – Soft Limits for Wrist

	7	6	5	4	3	2	1	0
Upper Limit	High Byte Upper Limit							
Upper Limit	Low Byte Upper Limit							

20 – Set Current Threshold for Gripper

	7	6	5	4	3	2	1	0
Unused	Unused							
Threshold	Threshold							

Annex C
Technical Specifications[1]

Vehicle Specifications

Height (arm stowed): 11 in. (27.9 cm) Height (arm extended): 62 in. (1.5m)

Width: 22.5 in. (57.2 cm) Length: 34 in. (86.4 cm)

Horizontal reach: 52 in. (1.3m)

Below grade reach: 34 in. (86.4 cm)

Ground clearance: 2.75 in. (7 cm)

Weight 85 to 120 lb (34 to 54 kg) (Mission profile dependent)

Maneuverable Speed 0 to 5.2 mph (8.3 km/hr), variable speed settings 0 to 7.6 ft/sec (1.8 m/sec)

Maneuverability Control Intuitive joystick control at all speeds

Obstacle Navigation 45 deg stairs, 56 deg slide slope, 15 in. (38 cm) of snow, demolition rubble

Payload Capacity 100 lb (45 kg)

Drag Capacity 200 lb (91 kg)

Arm Lift Capacity

20 lb (9 kg) at full extension

25 lb (11 kg) max capacity

Intuitive joystick controls for upper and lower arm

180 deg pitch lower arm/270 deg pitch upper arm

Gripper Capacity 40 in.-lb of gripping strength

6 in. (15.2 cm) wide opening manual 340 deg wrist

OCU controllable 360 deg rotating wrist (optional)

[1] from [5]

Operator Control Unit (OCU) Dimensions

Height: 9 in. (22.9 cm)

Width: 16 in. (40.6 cm)

Length: 19 in. (48.3 cm)

Weight: 33 lb (15 kg)

Robot Battery Endurance

Lead Acid, 300 W-hr, 36 Vdc, 2 hr at full speed (rechargeable)

Lithium Ion (optional) 750 W-hr, 36 Vdc, 4 hr at full speed

OCU Battery Endurance

120/240 V AC converter (standard), continuous AC power,

nickel metal hydride 3.6 A-hr 24 Vdc for 3.5 hr (rechargeable)

Rechargeable Lithium Ion (optional) 8 hr

Non-Rechargeable Alkaline (optional) 1 hr

OCU/Robot Communications Wireless Options

- Digital/analog (standard), 500 to 800m line of sight (LOS)
- High gain antenna (optional) extends range to 1200m LOS Fiber Optics
- Kevlar wrapped (optional), 300m
- Buffered (optional), 500m Cameras
- Four fixed-focus color cameras, each with dimmable LED lights (standard)

Available Options

- Auto-focus color zoom camera (40:1) 4x digital - 10x optical
- Auto-focus color zoom camera (300:1) 12x digital - 25x optical
- Pan/tilt/mast
- Floodlights
- Infrared cameras

• Camcorder

• MV-14 night vision attachment to zoom cameras

Up to seven cameras can be attached, including two zoom cameras.

The OCU adjusts zoom camera(s) and individually displays images from each camera or from four cameras at one time on a quad split screen.

Environmental

Waterproof harnessing and connectors. All cameras, antennas, manipulators, electrical and communication boxes are submersible to 90 ft (27m) when properly configured. OCU is water resistant and designed to operate in a heavy down- pour without protection. Equipment operates in all climates, weather, temperatures and conditions including mountains, deserts, snow/ice, demolition rubble and heavy wet mud.

Audio One-way audio (robot to/from OCU)

Two-way audio (robot to/from OCU) optional

Electrical Isolated firing circuits (optional) Two RS 232 ports available for payload interface

Plug-in/pull-out subcon waterproof connectors

Optional Sensors

Radiological, biological, chemical, temperature, gas

Additional Tools/Accessories

Recoilless PAN disrupter mount RE12-12 disrupter mount

Shotgun mount

Portable X-ray mount (pending)

Wire cutting tool

GPS compass

Heavy duty tracks and sprockets

Annex D
List of abbreviations/acronyms/initialisms

ADC Analog to Digital Conversion

ABI Application Binary Interface

ADO Adaptive Dispersed Operations

ALFUS Autonomy Levels for Unmanned Systems

AM Ante Meridiem

AMR Autonomous Mobile Robotics

API Application Programmer Interface

AO Area of Operations

AOR Area of Responsibility

ANSI American National Standards Institute

ASCII American Standard Code for Information Interchange

ASD Autonomous Systems Development

ASW Anti-Submarine Warfare

BDM Background Debug Mode

BIP Blow in place

BIT Built-In Test

BOM Bill of Materials

BSP Board Support Package

BUGS Basic UXO Gathering System

C4ISR Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance

CAN Control Area Network

C/A Course Acquisition GPS

COM Communication

CMAC Cerebellar Model Articulation Controller

CPU Central Processing Unit

CR Carriage Return

CVAP Computational Vision and Active Perception Laboratory

DAC Digital to Analog Conversion

DM Domain Model

DMU Dynamic Measurement Unit

DOF Degrees of Freedom

DOG Difference of Gaussians

DGPS Differential GPS

DIS Detection Information Section

DRDC Defence Research and Development Canada

DRES Defence Research Establishment Suffield

DSM Distance Sensing Module

ECEF Earth-Centred, Earth-Fixed

EEPROM Electrically Erasable Programmable Read Only Memory

EOD Explosive Ordnance Disposal

FCS Future Combat Systems

FOB Forward Operating Base

FPGA Field Programmable Gate Array

FFCV Family of Future Combat Vehicles

FLA Four Letter Acronym

FOG Fibre Optic Gyroscope

GCC GNU Compiler Collection

GPS Global Positioning System

GUI Graphical User Interface

HAAW Heavy Anti-Armour Weapon

HC Head Controller

HRI Human-Robot Interaction

IEC International Electrotechnical Commission

IED Improvised Explosive Device

IEEE Institute of Electrical and Electronics Engineers

IM Interface Module

IMU Inertial Measurement Unit

IP Intellectual Property

IP Internet Protocol

IP54 Ingress Protection or International Protection rating 54

ISO International Standards Organization

ISTAR Intelligence, Surveillance, Target Acquisition and Reconnaissance

JAUS Joint Architecture for Unmanned Systems

JDL Joint Directors of Laboratories

JTA Joint Technical Architecture

KTH Kungl Tekniska Hogskolan

LAAW Light Anti-Armour Weapon

LAN Local Area Network

LF Line Feed

LM Localization Module

LOC Lines of Code

MAV Medium Aerial Vehicle

MCU Micro Controller Unit

MDARS Mobile Detection Assessment and Response System

MGRS Military Grid Reference System

MMI Man Machine Interface

MMU Memory Management Unit

MPIO Multi-Purpose Input/Output

MPC555 Motorola Power PC 555

MSL Mean Sea Level

NBC Nuclear, Biological, Chemical

NEMA National Electrical Manufacturers Association

NIST National Institute of Standards and Technology

NSU Navigational Sensor Unit

NTP Network Time Protocol

OCU Operator Control Unit

OCS Operator Control Station

OEM Original Equipment Manufacturer

OPI Office of Primary Interest

PC Personal Computer

PGR Point Grey Research

PID Proportional Integral Differential

PM Post Meridiem

PM Perception Module

PMA Yugoslavian anti-personnel mine

POST Power-On Self Test

PWM Pulse Width Modulation

PUCA Pick up carry away

QADC Queued Analog Digital Conversion

RA Reference Architecture

RC Radio Controlled

RF Radio Frequency

RFP Request For Proposal

RGA Rate Gyro Accelerometer

RMS Root Mean Square

RNV Remote Neutralization Vehicle

RPG Rocket Propelled Grenade

RPY Roll, Pitch, Yaw

RSTA Reconnaissance Surveillance and Target Acquisition

RTEMS Real-Time Executive for Multiprocessor Systems (originally Real-Time Executive for Missile Systems and then Real-Time Executive for Military Systems)

RTK Real-Time Kinematic

SAE Society of Automotive Engineers

SI System International

SIL Scientific Instrumentation Limited

SLAM Simultaneous Localization and Mapping

SMA Senior Military Advisor

SS555 Steroid Stamp 555

STA Sensing Target Acquisition

STRV Shape-shifting Tracked Robotic Vehicle

SUGV Small UGV

TADM Teleoperated Air-Dropped Munition

TCP Transmission Control Protocol

TEAM Technologies Enabling Adaptive Manoeuvre

TLA Three Letter Acronym

TPU Time Processor Unit

TNA Thermal Neutron Activation

UAV Unmanned Aerial Vehicle

UAV-FW Unmanned Aerial Vehicle-Fixed Wing

UAV-RW Unmanned Aerial Vehicle-Rotor Wing

UGS Unattended Ground Sensors

UGV Unmanned Ground Vehicle

UMS UnManned Systems (from NIST 1011 v1.1)

US United States

USA United States of America

USV Unmanned Space Vehicle

UTC Universal Time Coordinated

UTM Universal Trans Mercator

UUV Unmanned Underwater Vehicle

UXO Unexploded Ordinance

UxV Unmanned (Aerial, Ground, Underwater, Space) Vehicle

VBIED Vehicle-Borne Improvised Explosive Device

VSLAM Visual Simultaneous Localization and Mapping

WG Working Group

WGS World Geodetic System

Annex E
Notation

α latitude angle

β longitude angle

μ Statistical mean of a variable population

μ_x Distance mean along x-axis

μ_y Distance mean along y-axis

σ^2 Variance of a variable population

σ_x^2 Distance variance along x-axis

σ_y^2 Distance variance along y-axis

σ Standard deviation of a variable population

σ_x Standard deviation distance along x-axis

σ_y Standard deviation distance along y-axis

θ rotation about the modified y-axis in radians for Euler RPY

ϕ rotation about the modified x-axis in radians for Euler RPY

ψ rotation about initial z-axis in radians for Euler RPY

$\forall$ for all

$\in$ is an element , in

$\mathbb{Z}$ Integers Set

ℓ Local Coordinate Frame of Reference (Robot ego-centric)

$\mathbf{p}_\ell$ Local Coordinate Frame pose (Robot ego-centric)

p_{rpy} JAUS-compliant

$\mathbf{p}_W$ World Coordinate Frame pose

$\mathbf{p}_{W-UTM}$ World Coordinate Frame pose with UTM

$\mathbf{q}$ quaternion vector

$\mathbf{q}^\star$ quaternion conjugate

q_s quaternion scalar component

q_x quaternion imaginary projection along the i axis

q_y quaternion imaginary projection along the j axis

q_z quaternion imaginary projection along the k axis

s^2 Variance of a variable sample

s Standard deviation of a variable sample

x_ℓ x displacement in local pose

x_W x displacement in global pose

y_ℓ y displacement in local pose

y_W y displacement in local pose

z_ℓ z displacement in global pose

z_W z displacement in global pose

D Displacement vector

G Units of gravity ($9.81\frac{m}{s^2}$) at sea-level

R Rotation Matrix

T Transformation Matrix

W World Coordinate Frame of Reference

Annex F
Definitions (from Merriam-Webster[2])

autonomous 1: a. existing or capable of existing independently b. responding, reacting, or developing independently of the whole.

contralateral occurring on or acting in conjunction with a part on the opposite side of the body.

fovea a small rodless area of the retina that affords acute vision.

intensity 1: the quality or state of being intense; especially : extreme degree of strength, force, energy, or feeling 2 : the magnitude of a quantity (as force or energy) per unit (as of area, charge, mass, or time).

intelligence 1 a. (1) : the ability to learn or understand or to deal with new or trying situations : REASON; also : the skilled use of reason (2) : the ability to apply knowledge to manipulate one's environment or to think abstractly as measured by objective criteria (as tests) b. Christian Science : the basic eternal quality of divine Mind c. : mental acuteness : SHREWDNESS 3 : the act of understanding : COMPREHENSION

ipsilateral situated or appearing on or affecting the same side of the body.

luminance 1 : the quality or state of being luminous 2 : the luminous intensity of a surface in a given direction per unit of projected area.

proprioceptive 1: of, relating to, or being stimuli arising within the organism

reflectance the fraction of the total radiant flux incident upon a surface that is reflected and that varies according to the wavelength distribution of the incident radiation – called also reflectivity.

saccade a small rapid jerky movement of the eye especially as it jumps from fixation on one point to another (as in reading).

stochastic 1 : RANDOM; specifically : involving a random variable 2 : involving chance or probability : PROBABILISTIC

striation 1 a: the fact or state of being striated b: arrangement of striations or striae 2: a minute groove, scratch, or channel especially when one of a parallel series 3: any of the alternate dark and light cross bands of a myofibril of striated muscle.

[2]By permission. From Merriam-Webster's Collegiate® Dictionary, Eleventh Edition ©2006 by Merriam-Webster, Incorporated (www.Merriam-Webster.com).

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robots, autonomous robotics, EOD, IED, COHORT, ALS, AIS program

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