NOMAD XR4000 HARDWARE MANUAL RELEASE 1.0

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WHERE CAN I GET HELP?

1 By email: send a description of your problem, if possible with the source program, to: support@robots.com.

2 By phone: call +1.650.988.7200 and ask for Technical Support.

WHERE CAN I GET SOFTWARE?

For the convenience of timely software distribution, Nomadic has set up a web site for this and future Nomadic software releases. From this FTP site, you can download the most up-to-date software distributed by Nomadic. This includes the Nomadic Host Development Environment, the Nomadic Robot Control Software, and documentation.

To download software from this FTP site, simply go to: **http://www.robots.com** (205.162.4.11) and click on the Downloads link. Please read the software license agreement and click on the “I agree! Take me to the downloads page!” link.

When prompted for a user name and password, type:

Name: robots Password: N0mad1C

The ‘o’ is a ZERO and the ‘i’ is a ONE, the letters ‘N’ and ‘C’ are CAPITALIZED. Since the software is intended to be used by Nomad users only, please keep the FTP site information confidential.

Once you are logged in, you will come to a page that lets you select between Host Development Environment, Robot Control, and Manuals. Select the appropriate link and download the software appropriate for your operating system.

If you have any questions regarding how to obtain or run the software, please email them to: software@robots.com.

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DISCLAIMER AND WARRANTY INFORMATION

Thank you for purchasing a Nomadic Technologies, Inc. product. The Nomad XR4000™ is warranted to the original purchaser (Customer), to be free from defects in materials and workmanship for a period of two years for mechanical components and one year for electrical components. The warranty is effective from the shipping date. During this period, Nomadic Technologies, Inc. will repair or replace, at our discretion, any defective components.

This warranty does not apply to any Nomad or Sensus products which have been damaged by accident, abuse, negligence, improper use, power surges, acts of God or have been repaired, altered, or modified in any way by anyone other than Nomadic Technologies. This warranty does not apply to the batteries or antennae.

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CONVENTIONS

Here are the typographical conventions used in this manual:

1 Typewriter characters denote user input at a terminal, as well as code examples, as in:

```
machine:~/xrdev-3_0_b0-i586- unknown-
linux/$ Nsimulator my_world.setup
my_robot.setup
```

CONTENTS

CHAPTER 1: ROBOT HARDWARE DESCRIPTION

XR4000 OVERVIEW

The Nomad XR4000 is an advanced mobile system that incorporates state of the art drive, control, networking, power management, sensing, communication and software technologies. For serious research in mobile manipulation, high-speed visual servoing, machine learning, and sensor based navigation, the XR4000 offers unparalleled capabilities.

Figure 1. The Nomad XR4000

XR C8 HOLONOMIC DRIVE SYSTEM

Utilizing advanced distributed control techniques and a robust modular mechanical design, the XR C8 (patent pending) is the first holonomic drive system to offer three full degrees of freedom (x, y, theta) without penalties in ground clearance, vibration, or mechanical complexity. It accomplishes this by employing caster wheels that have independently powered steering and translation axes. The XR C8 uses four such wheels, resulting in an eight-axis, underconstrained system. To control such a system, the XR4000 uses a specialized motor controller with three DSP's and a dedicated 32-bit microcontroller to control all eight axes while estimating the dead-reckoned position.

XR POWER MANAGEMENT

The XR power management system provides the Nomad XR mobile robot systems with comprehensive power diagnostic and control capabilities. This system allows the Nomad XR to be powered directly from AC and incorporates a sophisticated two-stage fast battery-charging system. Additionally, voltage information is available for each of the four batteries. Independent power control of different subsystems, knowledge of charge remaining, and the potential for self docking into an AC source allows cognitive decisions to be made by the system regarding task scheduling and other mission priority issues.

XR BASIC SENSING SYSTEMS

The Nomad XR4000 has three standard sensor systems: tactile, ultrasonic, and infrared.

The XR also has many available sensor options including monochrome or color vision, laser, and compass systems. Please refer to: *"Chapter 3 - Hardware Options"* for more details.

The Sensus 150™ Bi-level Tactile System

The Sensus 150 bi-level tactile system provides 100% tactile coverage over the vertical surfaces of the Nomad XR. There are 48 bi-level sensing elements that surround the top and bottom perimeters of the Nomad XR and provide both the exact location of contact as well as information about contact force. Additionally, each door has four "floating" switches that register when any part of the door makes contact with an obstacle. Rugged energy-absorbing rubber molding protects the top and bottom perimeters of the sensing elements. Please refer to the section: *"The Tactile Sensors"* for more details.

The Sensus 250™ Ultrasonic Ranging System

The Sensus 250 three-dimensional sonar system uses 48 sonar transducers precisely positioned at different levels and angles with coordinated firing patterns to provide complete coverage from the floor to the Nomad XR's ceiling. Firing rates and firing order can be configured to provide optimal performance in any environment. This system can give range information from 15 to 650 cm with one-percent accuracy over the entire range. The Sensus 250 is a time-of-flight ranging sensor based upon the return time of an acoustic signal. The sensors used in the Sensus 250 are standard Polaroid transducers driven by the Polaroid 6500 ranging board. Each transducer has a beam width of 25°.

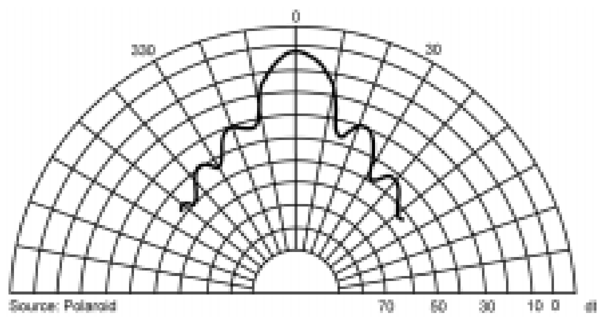


Figure 2. Radial beam pattern of transducer dB values normalized

Please refer to the section: "*Sonar Sensors*" for more details.

The Sensus 350™ Infrared Proximity System

The Sensus 350 infrared system uses 48 IR transceivers positioned at the top and bottom of the Nomad XR. These sensors provide short-range coverage. The Sensus 350 has a very fast sampling rate, making it very useful for short range (up to 90 cm) sensing. Range to an object is determined by the intensity of the light from the emitters reflected back to the detector from an object. The reflectivity of the surface and the level of ambient light will affect the reading. Please refer to the section: "*Infrared Sensors*" for more details.

XR MEMNET™ MULTI-PROCESSOR CONTROL SYSTEM

The XR MemNET control system is a shared memory multi-processor system. At the top level, a series of Linux-based Pentium series processors are networked using TCP/IP over shared memory. While providing standard networking tools, this architecture offers very high communication speeds with low latency. The shared memory interface is full duplex, meaning that there are no collisions and the transfer times are 100% deterministic. This allows for distributed real-time control, something that previously required expensive VME-based systems. Control of subsystems is accomplished through a combination of memory-mapped slave controllers that reside on the bus and remote slave controllers that use the XR SynapseNet Distributed I/O Network.

XR SYNAPSENET DISTRIBUTED I/O NETWORK

The XR4000 SynapseNet is a network of distributed embedded controllers linked using the ARCNET™ real-time token-passing network. The network communicates based on a remote procedure call (RPC) interface between the controllers and the high level Pentium Linux system. This allows for the creation of a very high-speed, low-latency expandable network of embedded controllers. The embedded controller, or "Intellisys 160", is custom designed for the XR4000. It is based on the 68HC11F1 processor and has 128 kbytes of FLASH memory that can be upgraded over the ARCNET network. Thus, it is possible to upgrade the firmware in each embedded controller without replacing ROMs.

CHAPTER 2: ROBOT OPERATION QUICKSTART

Here is a list of steps to follow to get your robot up and running quickly:

- Unpack
- Open the doors
- Install the batteries
- Close the doors
- Boot the XR4000
- Joystick control
- Run a simple demo
- Charge the batteries
- Turn off the XR4000

Please see the following sections for help in each of these steps.

Unpack

Unpack the XR4000 from the shipping box. Undo the latches at the bottom of the shipping box. The entire shell (walls included) then lifts off to expose the robot. Remove the plastic bag around the robot. The robot weighs approximately 115 kg (without the batteries, depending on the individual configuration), so lifting the robot out of the box will require four strong people. Use the cutouts in the base of the box to grab the bottom of the robot. Lift the robot up and then out to clear the box before setting it down gently. It helps to have a another person slide the base of the box clear of the robot while it is being lifted.

Open the Doors

There are three doors, each containing two latches. Open the doors by depressing both latches simultaneously and pulling gently at the latch depressions.

Install the batteries

Lift the metal latch on the left side of the battery compartment (you can use the battery to help).

Slide the batteries in the four empty battery slots on the bottom of the robot between the wheel modules. You will hear a “click” when each battery properly engages. It is possible that the battery latches will protrude and prevent the doors from latching correctly - turn the latches to the center so that they do not protrude. Note that if you receive more than one set of batteries, sort the batteries by set. Make sure that only a single complete set is used at a time. Do not mix the battery sets. Refer to *“Chapter 6: Robot Maintenance”* for proper battery maintenance.

Close the doors

Press each door firmly near the latches until you hear each latch engage. The door should be rigid when fully closed. Make sure that the battery latches do not protrude and prevent the doors from closing.

Primary and Auxiliary Computers

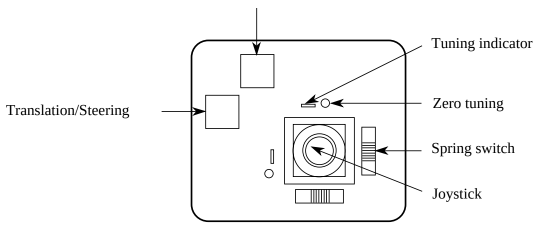
For robots with two CPU cards, they are referred to as “primary’’ and “auxiliary’’. A VGA monitor and keyboard can be hooked up to the primary CPU through the “VGA1” and “Keyboard1” connectors on the Control Panel. The auxiliary CPU hooks up via “VGA2” and “Keyboard2” connectors. Alternatively, the two CPUs are called “lower’’ and “upper’’ due to the fact that the primary CPU is installed lower in the backplane than the auxiliary, which is installed toward the top.

Boot the XR4000

The radio Ethernet is not configured for your network when you receive the robot, so we recommend hooking up a VGA monitor and PC keyboard to Primary Computer connectors “VGA1” and “Keyboard1”. Please refer to the “Software Manual” for instructions on configuring the Ethernet on your robot. When the robot boots, it will move its wheels to orient the steer axes in the base. This requires that the emergency stop buttons on top of the robot are in the up position (or if applicable, the emergency stop box is plugged into the top via a modular cord with the emergency stop button up). Check the buttons before turning the robot on. The power buttons are located in the bottom left of the control panel. There are two gray buttons, labeled “On” and “Standby”. These buttons perform different functions. See *“Chapter 5: The Power System”* for a description of how they are used. For now, turn the robot on by pressing the "On" button. After depressing the On button, the robot will begin its boot sequence, which will take a few minutes. The robot is finished booting when the base "wiggles" as it zeroes all four steering axes.

Joystick control

After the robot boots, it may be controlled via joystick at any time. The supplied joystick attaches to the connector on the control panel. The robot can be controlled by joystick only when one or more of the buttons are held down continuously (and the E-stops are up). Depending on the combination of buttons that are depressed, the robot will behave differently:



Steering and turret buttons: Differential Mode
This is the most intuitive mode, as it is similar to driving a car. The robot moves forward as commanded by the y-axis of the joystick and turns as commanded by the x-axis.

Steering button: X-Y Mode
Moving the joystick moves the robot in the commanded x-y direction without rotating the base. This mode nicely demonstrates the XR4000's ability to accelerate in any direction instantaneously (holonomic motion).

Turret button: Frisbee Mode
The robot locks onto a fixed direction in world coordinates and moves along that direction as commanded by the y-axis of the joystick and rotates as commanded by the x-axis. Changing from Frisbee mode to Differential mode can be done on- the-fly, creating interesting motion.

Note: The button names are the same as for the Nomad 200, although a turret is not applicable on the XR4000.

Run a Simple Demo

When the robot gives the login prompt, type root and run the `sonar_swerve_xr` demo which is located in: `/usr/local/xrdev/examples/swerve`

Unplug the monitor and keyboard and the robot will begin to move, avoiding obstacles. Please refer to the *"Software Manual"* for more information on the software architecture.

Charge the batteries

You can charge the robot's batteries plugging the robot into a wall socket with the supplied IUC power cord (robots are pre-configured for the power grid used in the country they will be operating in). This cord plugs into the side of the XR4000 through a small square cutout between the front and left door. While the power cord is attached and the robot is either in "On" or "Standby" mode, the robot will simultaneously charge and receive power from the AC power cord. Thus, it is recommended that when the robot is in use and stationary that the AC power cord is attached.

Turn off the XR4000

Clean Shutdown (recommended)

Clean shutdown ensures that the onboard computer(s) are shutdown cleanly (filesystems unmounted, etc.). It can only be accomplished after the onboard computer(s) have finished booting. Begin by pressing the red "Off" button on the control panel momentarily. The control panel will then ask for confirmation. Press the Off button again to confirm. The robot software (Nrobot) will then initiate a clean shutdown of the onboard computers. After about 20 seconds the robot will turn off.

Dirty Shutdown

This type of shutdown will force the XR4000 to turn off at any time. It is recommended that this mode be used only when necessary, as it does not ensure that the onboard computer(s) are shutdown cleanly. It is accomplished by holding the red "Off" button on the control panel in a depressed state for approximately 10 seconds until the robot shuts down.

Auto Shutdown

When any of the battery voltages falls below 10.8 Volts, the XR4000 will warn the user of a low battery condition by emitting a high-pitched tone. Upon hearing this, it is recommended that the robot be shutdown or plugged into an AC power source for charging. If the user fails to do either, the power system will attempt to do a clean shutdown after five minutes of a low battery condition. If a clean shutdown fails, it will wait two additional minutes and do a dirty shutdown.

CHAPTER 3: ADVANCED SENSING SYSTEMS AND FEATURES

STANDARD SENSORS

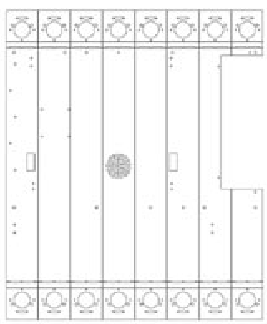
These sensors are included standard on each XR4000 robot system.

Tactile Sensors

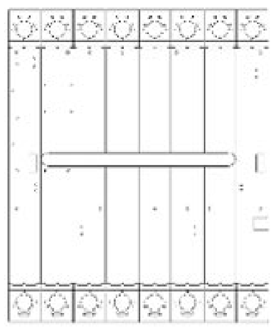
The Sensus 150 bi-level tactile system provides tactile coverage over the vertical surfaces of the Nomad XR4000. Tactile sensors provide information about physical contact with objects in the environment. It is hoped that non-contact or proximity sensing will sense all obstacles and prevent physical contact, but this is not guaranteed. Tactile sensors are often called “collision sensors”.

The Nomad XR4000 has forty-eight bi-level tactile sensors that surround its top and bottom perimeters. Additionally, the XR4000 has 4 “door bumpers” on each door that sense contact between the top and bottom perimeters. Together, these tactile sensors provide tactile information over the entire robot.

Pressing softly on each bumper sensor at the top and bottom perimeter results in the corresponding green LED to be illuminated. Pressing firmly results in the red LED illuminating continuously.



Left



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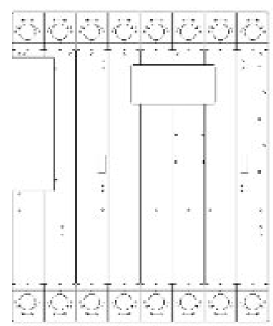

Right

For more information on programming with this sensor, please refer to the “Software Manual”.

Sonar Sensors

The Sensus 250 consists of two rings of 24 sonar proximity sensors. The sonar proximity sensors provide range information to objects that are relatively far away (between 15 and 700 centimeters.) Distance information is calculated by multiplying the speed of sound by the “time of flight” of a short ultrasonic pulse travelling to and from a nearby object. The sensors on the top ring are angled 2.5 degrees downward, and the bottom ring sensors are angled 2.5 degrees upward. This provides more complete sensing in middle of the robot.

It is recommended that any two corresponding sensors on the top and bottom ring be fired simultaneously (i.e. top and bottom sonar sets should have the same firing order.) This allows energy from the bottom sensor to be reflected to the top sensor for reception and vice versa, which results in more complete, robust coverage. When a sonar sensor “fires”, the corresponding green LED flashes momentarily.

Theory of Operation

The Sensus 250 is based on the Polaroid 6500 series ultrasonic ranging board. It emits 16 cycles of a 49.4 kHz square wave through an electrostatic transducer. A blanking period follows, during which the transducer is stabilized. The transducer then acts as a receiver, feeding the detected echoes in a time-variable gain amplifier. The gain factor of this device increases with time to compensate for spreading loss and the attenuation of sound in air. The output of the amplifier then goes to a thresholding circuit. As soon as the threshold is exceeded, the time elapsed since the beginning of the transmission of the pulse is measured, and converted into distance through an appropriate calibration factor.

Sensor Characteristics

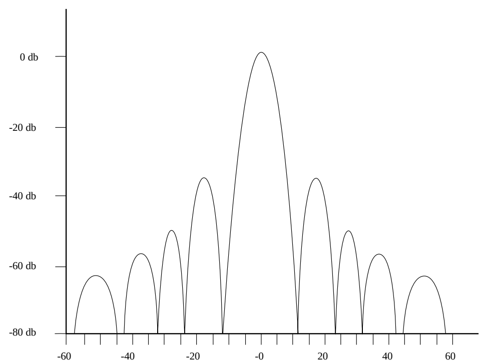

Figure 3. Modeled sound radiation for the Polaroid transducer

The transducer does not emit energy homogeneously in all directions, but instead forms lobes of decreasing intensity, as illustrated above. According to the results of extensive experiments conducted by various researchers (Lang, Kuc, Leonard), the radiation pattern of Polaroid transducers is not symmetric, and varies from one transducer to another. These effects are more significant for the side lobes. The attenuation of ultrasound in air increases with frequency, and depends on temperature and humidity. Typical values for 50 kHz are an attenuation of 0.6 to 1.8 dB/m for variations in temperature from 17 to 28^{o}C and variation in relative humidity from 15 to 70%. The speed of sound in air is expressed as $C=33.4\sqrt{T/273}$ m/sec, T being the ambient temperature in degrees K.

Electronics characteristics

The following three sources of error in range measurements are related to the specifics of the sensor circuitry (Leonard):

- Transmitted Pulse duration

  All the timing is based on the assumption that the start of the transmitted pulse is the part of the returned echo that actually exceeds the detector threshold. If this is not the case, the error can be as much as 23 cm.

- Time Variable gain amplifier

  The ideal exponential curve that would exactly cancel beam spread and attenuation losses is approximated by a 12-step only-piecewise constant function. Even if this function was exactly given, it should be different according to temperature and humidity conditions. Since the returned energy is a function of the incident angle (as shown in the radiation pattern), the visibility angle changes with range.

- Capacitive charge-up in the threshold circuit

  For strong reflected signals, three cycles are enough to charge up to the threshold: the calibration usually accommodates that delay. For weaker signals, charge-ups can take place over a considerably longer time, resulting in erroneously elongated range values. One major source of uncertainty in distance estimation coming from these characteristics is the existence of weak returns, as opposed to strong returns.

- Strong returns possess enough energy to exceed the threshold promptly, giving very accurate measurements.

- Weak returns cause time-delay range errors: the threshold is reached only after a long charge-up and changing gain in the amplifier. The threshold is only exceeded by the random combination of a slow charging-up period, and jumps in the non-linear time variable gain amplifier.

Target characteristics

Targets can be divided into two groups:

- Reflecting objects, of dimensions larger than the wavelength (6.95 mm at 20^{o}C)

- Diffracting objects, of dimensions smaller than the wavelength. Objects whose overall size is smaller than the wavelength are usually rare (one can think of wire fences for instance), but rough surfaces like concrete, or textured walls present small asperities which behave as diffractors. Smooth surfaces such as metallic desks, painted walls and doors are reflectors. Those are the most common in indoor environments, which supports the commonly heard assertion that most indoor surfaces act as mirrors with respect to sound waves. Slightly rounded convex edges with radius of the order of the wavelength produce weak specular echoes: some ornamental (carved) table legs and cardboard boxes often have this characteristic.

One consequence of the reflective properties of surfaces is the multiple echo effect: the sound wave bounces around and eventually reaches the receiver after several reflections. Because of attenuation, the energy level of the incoming wave is very likely to be quite low but sometimes large enough to be detected.

Typical Sonar Data

A good representation of sonar data is the sonar scan: a dot representing the measured distance is drawn on the sonar axis. Repeated measurements over a given angular range give a sonar scan. Sonar scans are the basic data that can be used for map building or navigation purposes. Since the sonar are mounted horizontally on the robot, which can itself be oriented to any angle, one of them can be used directly to make measurements, using the robot to set it at the desired angle and distance with respect to the targets

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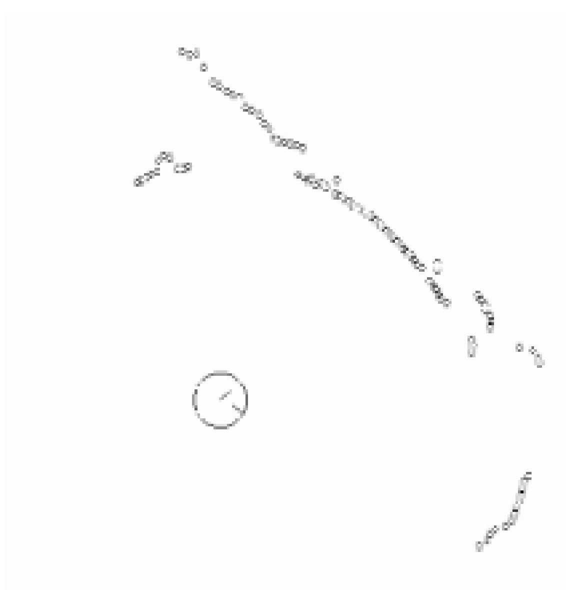

Figure 4. Sonar scan on a flat and smooth surface

Figure 4 shows a typical response to a flat, smooth surface. The central feature is the arc of a circle, centered with respect to the surface's normal. This pattern is caused by the main lobe. Although the sonar is rotating, as long as there is a patch of surface normal to the direction of the wave in the active cone of the main lobe, it gets reflected back. Since we are in the main lobe, where energy is high, the thresholding circuit is promptly triggered, and the measurement is very precise: we get an arc of a circle of constant radius.

When the normal to the surface leaves the main lobe, the energy is reflected away from the source. However, the secondary lobe comes into effect, with the same property: if the normal to the surface is within the secondary lobe, the sound gets reflected. Since the secondary lobe carries less energy than the main lobe, we have a time-delay range error because the thresholding circuit takes more time to be triggered. We also get an arc of a circle, but of a slightly greater radius. Note that the secondary lobe dots may be accidentally aligned with the actual wall, which in the past has induced people to try to match lines to sonar readings, but this is oftentimes not the best approach.

As the sonar rotates further, the secondary lobe also leaves the normal to the surface. Nothing can be seen. There are actually lobes to follow, until the whole half circle, but they are too weak to trigger the thresholding circuit and the plots are drawn to infinity (equal to the maximum detectable distance). One interesting phenomenon can be observed at the junction of the main and secondary lobe: if the scan is detailed enough, one consistently gets readings that are erroneous. They are caused by low energy at the junction of the two lobes. The pattern of Figure 3.2 shows a single frequency (f=49.9KHz), with zero energy at the junction of two lobes. The Polaroid sensor has a finite bandwidth around this resonant frequency. Therefore, the side lobes of a range of frequencies are superimposed. Each frequency produces zeroes at slightly different locations, and the net superimposed effect is not zero.

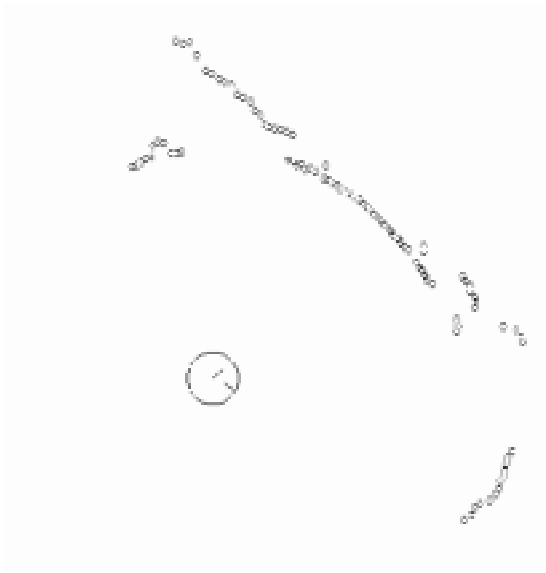

Figure 5. Sonar scan on a flat and rough surface

Figure 5 shows a typical response to a flat, rough surface. It can be understood if we consider that a rough surface is made of numerous small asperities of dimension close to the sound wavelength. Thus, the primary lobe always picks a small patch normal to its axis, and return the corresponding distance. This is often the only case where the sonar scan bears a strong resemblance with the actual map of the room.

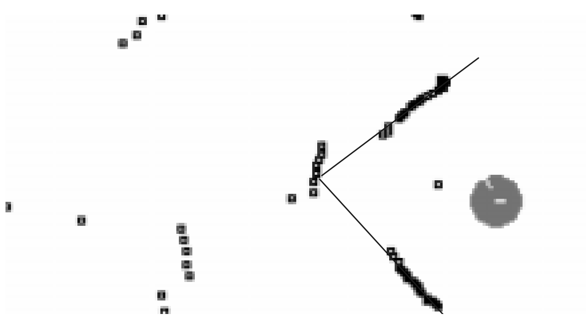

Figure 6. Sonar scan on a corner

Figure 6 show a typical response to a smooth corner. It comes from a double specular reflection at the corner (one from each surface). We also have two neighboring arcs that we can attribute to the secondary lobes. The leftmost and rightmost arcs come from specular reflection on the corner's sides. One interesting point is that the corner's side reflections could also give secondary lobe arcs, if the sonar was a bit farther from the corner. In the present case, it happens to be that these secondary lobe arcs actually come from the corner, as we verified by unfolding it (then the arcs disappeared).

Note that when the sonar is close to the corner it is difficult to tell where the returned echo is actually coming from. This is because there is competition between a weak, but specular echo (the secondary lobe on the corner side), and a strong, but distant echo (the main lobe on the corner). Additionally, there may be multiple echo phenomena that can create additional error, depending on whether the first echo to trigger the threshold circuit comes from a single-hit echo or from multiple reflections on the corner sides.

For more information on programming with this sensor, please refer to the *"Software Manual"*.

Infrared Proximity Sensors

The Sensus 350 is composed of two rings of 24 infrared proximity sensors. Infrared proximity sensors provide range information to closeby objects (typically less than 30 to 50 centimeters away). They determine range by emitting infrared energy using high-current LEDs and sensing the amount of returned energy with infrared photodiodes. The returned energy is inversely proportional to the distance to the closeby object -- thus, these sensors are used as distance or proximity sensors.

The returned energy is also a function of the object's reflectivity. High reflectivity objects return large amounts of IR energy and low reflectivity objects return proportionally lower amounts of IR energy. The difference in reflectivity between objects can cause errors in range measurements if not taken into account.

Theory of Operation

Each sensor is composed of two SIEMENS SFH 34-3 GaAs infrared emitters and a SIEMENS SFH 2030F Silicon Pin Photodiode enclosed in a delrin housing. The two emitters and the receiver are mounted colinearly with the photodiode between the two emitters.

To obtain reflected energy, one reading of IR energy is made with the emitters off and one reading is made with the emitters on. The difference between the two readings is proportional to the IR energy reflected from a nearby object and largely independent of the ambient IR energy.

Factors influencing the measurements

The factors that influence the measurement obtained from the sensors are the following:

- Geometry

  The farther the object, the weaker the reflected light coming back to the receiver will be. This is the underlying principle of the sensor. Additionally, the angle of the reflecting object also plays an important role. When illuminated, part of the incoming energy is reflected, and part of it is diffracted. If the illuminated plane is normal, or close to normal to the receiver's axis, most of the reflected light will be directed back to it. On the contrary, if the illuminated plane is close to parallel to the emitter's axis, then only the diffracted light will reach the sensor. Distance and angle are then the two most important characteristics that affect the readings.

  Additionally, the geometry of the object has an influence. If the object is small, the reading will be dependent on the illuminated area, which is a function of the size of the object. Second, if the object is not planar, then the light reflected back to the sensor will be a complex combination of the reflected / diffracted energy coming from all the illuminated parts of the object.

  Figure 7 shows the raw energy level measured at distances from 0 to 90 cm, for angles from 0 to 75°. Measurements were done in the dark, with a white dull target (regular copy paper)

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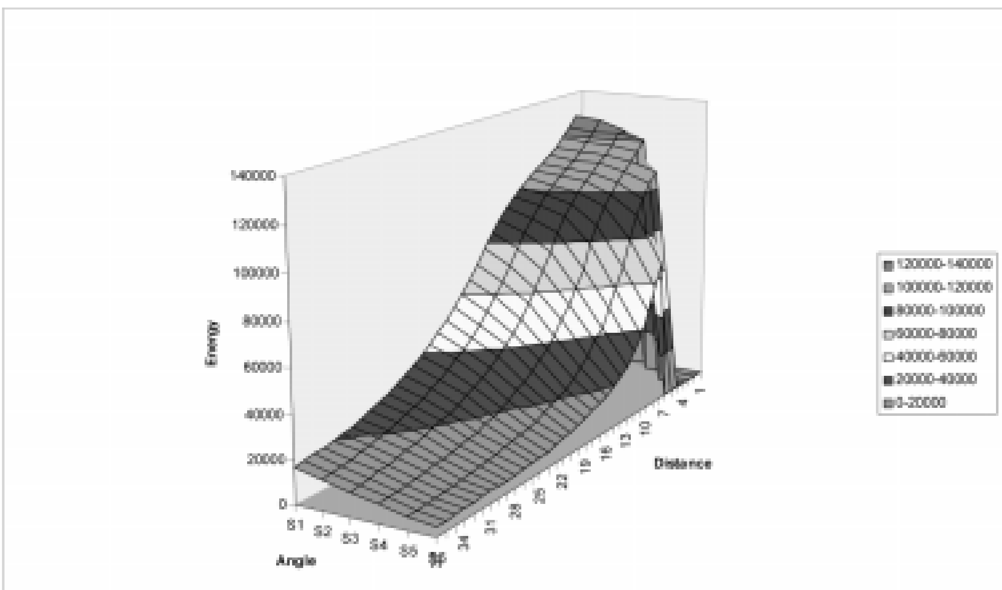


Figure 7. Energy vs. Angle and Distance: white dull surface in dark.

- Lighting

  The sensor computes the difference between the light received with emitter off, then on. If the ambient light has a lot of energy in the infrared range, then sensor may saturate and result in a difference that is small (weak contrast). This results in less sensitivity. The data of Figure 8 was recorded in fluorescent light; the data of Figure 9 was recorded in incandescent light. Compare this with Figure 7. Since fluorescent light contains very little infrared, the energy values are hardly affected.

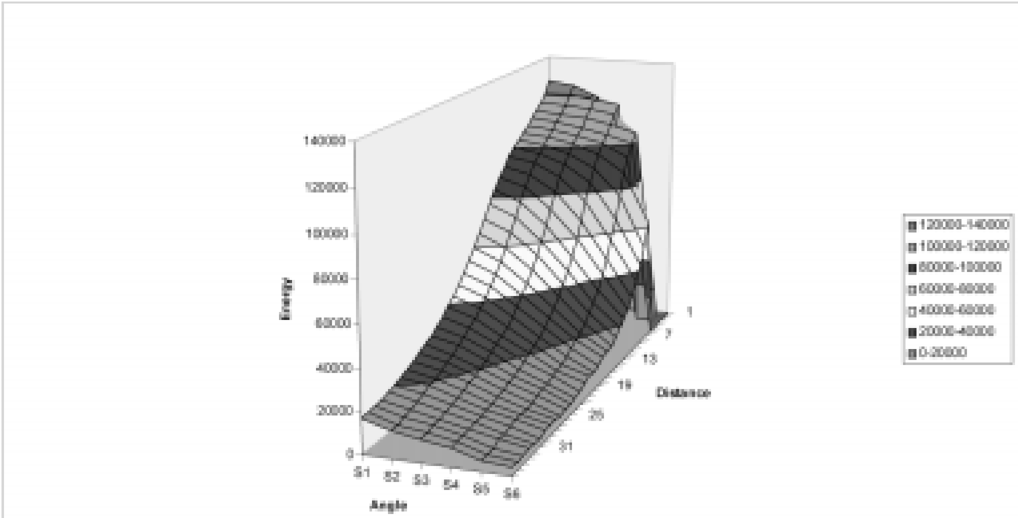


Figure 8. Energy vs. Angle and Distance: white dull surface in fluorescent light.

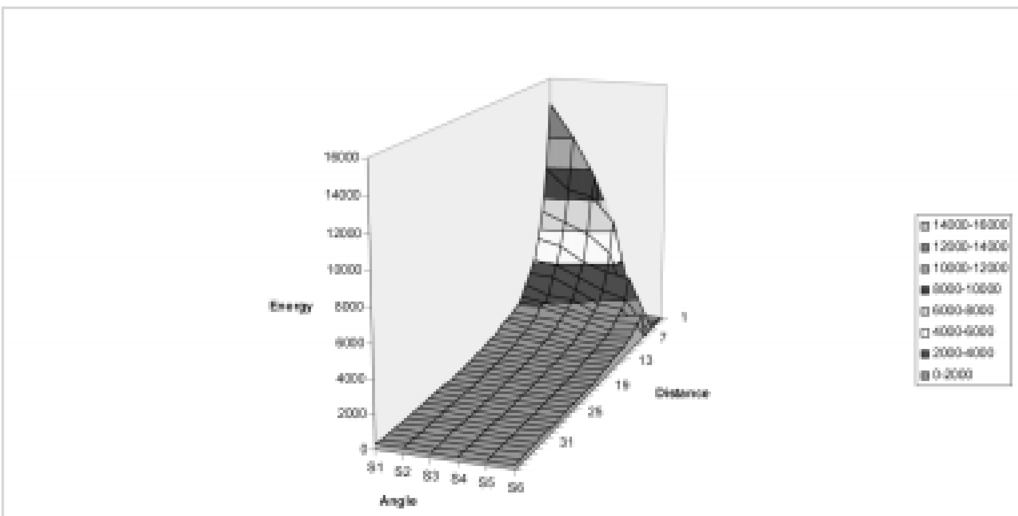


Figure 9. Energy vs. angle and distance: white dull surface in incandescent light

- Color and surface

The color (or more precisely the reflectivity in the infrared range) of the objects have an influence on the readings. The surface also has to be taken into account: glossy surfaces will show a peak in intensity for angles close to the normal to the receiver's axis, because they behave like mirrors. Surfaces like concrete or fabric will absorb more. The chart of Figure 11 shows the energy measured at 0 degrees (the object surface normal to the sensor's axis), for a black, glossy cabinet, a piece of black, dull fabric, a white, glossy board, and a sheet of dull white paper. Additionally, objects sometimes reflect differently in infrared and visible light. Objects that absorb visible light (black objects) will not necessarily absorb IR light and vice versa.

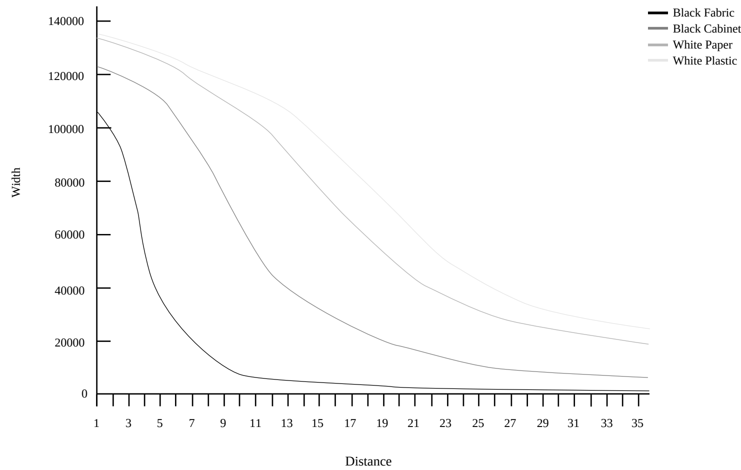


Figure 10. Energy vs. Distance at Angle 0: black/white, dull/glossy.

For more information on programming with this sensor, please refer to the *"Software Manual"*.

CHAPTER 4: HARDWARE OPTIONS

THE SENSUS 450 AND SENSUS 460 PCI VISION SYSTEMS

The Sensus 450 and Sensus 460 are complete vision systems including camera and PCI video capture card. The Sensus 450 is a monochrome RS-170 system and the Sensus 460 is an NTSC color composite system.

These systems overcome the throughput issues of ISA bus frame grabber designs, which are constrained by 2 Mbytes / second data transfer rates. Taking advantage of the higher speed of the PCI bus (45 Mbytes / second), these systems transfer frames across the bus at full framerates. This makes them ideal for visual servoing, motion analysis, or other robotic applications that require real-time performance. These systems also use the PC's onboard memory, which make them very cost-effective.

Additionally, these systems can be used with a dedicated auxiliary processor that communicates to the primary processor via MemNET™. Hence, the primary processor is free to handle other robotic tasks.

Installation

Robots purchased with this system come with the software and PCI card pre-installed. The camera, however, is located in the accessory box. All that should be required is to attach the lens and hook up the power and video cables found on top of the robot to the camera.

Sensus 450 Monochrome Vision

Running a demo

If your robot is equipped with an auxiliary processor, the vision system is installed on the auxiliary processor. Plug a keyboard and VGA monitor into the "Keyboard2" and "VGA2" ports to run the demo. If your robot has a single processor, plug a keyboard and VGA monitor into the "Keyboard1" and "VGA1" ports to run the demo.

Through the VGA monitor and keyboard, change directories into `/usr/local/robot-devices/dt3155/examples/video` and run `video`. This program will switch video modes on the monitor and display a grayscale image at about 15 frames per second. *Note that the iris of the camera may be closed, resulting in little or no image.*

If your robot is equipped with two Sensus 450's, run the video program with command line arguments 0 and 1 to see video from the different systems, for example:

`video 0`

for the first device, and

`video 1`

for the second device.

Sensus 460 Color Vision

Running a demo

If your robot is equipped with an auxiliary processor, the vision system is installed on the auxiliary processor. Plug a keyboard and VGA monitor into the "Keyboard2" and "VGA2" ports to run the demo. If your robot has a single processor, plug a keyboard and VGA monitor into the "Keyboard1" and "VGA1" ports to run the demo.

Through the VGA monitor and keyboard, change directories to `/usr/local/robot-devices/meteor/examples/video` and run `video` to see continuous color video images. You should see a color image at about 5 frames / second. *Note that the iris of the camera may be closed, resulting in little or no image.*

If your robot is equipped with two cameras, but one Meteor card, run the video program with the command line arguments 0 and 1 to see video from the different cameras, for example:

`video 0`

for the first camera, and

`video 1`

for the second camera.

If your robot is equipped with two Meteor cards, run the video program with two command line arguments, for example: `video 1 0` for second card, first camera, `video 1 1` for second card, second camera, and `video 0` for first card, first camera.

THE SENSUS 550 SICK LMS LASER SYSTEM

The Sensus 550 is a "time of flight" laser rangefinding system based on the Sick Electro-optic LMS-200 sensor. It provides 180 degrees of distance information in a plane at 0.5 degree increments (for 360 total distance measurements.) Additionally, its scanning rate for each 180 degree scan is 20 Hz.

Testing Operation

For systems without a high-speed SICK capture card, i.e. for systems with the sensor hooked to the primary CPU via RS-232 serial COM port 1, run the demonstration program in `/usr/local/xrdev/examples/sick_display`. This program will print the SICK sensor values to the screen periodically (approximately 2 Hz). For more information on programming with this sensor, please refer to the *"Software Manual"*.

THE SENSUS 600 COMPASS SYSTEM

The Sensus 600 is a digital fluxgate compass based on the KVH C100. Communication with the sensor is accomplished through an RS-232 serial port. Please refer to your shipping documentation to determine which serial COM port is dedicated to the Sensus 600.

The compass is configured by Nomadic to power up at 9600,8,1,N. It is possible to communicate with the compass for testing purposes with a text terminal such as minicom.

Please refer to the supplied KVH documentation for commands and protocols to and from the compass, or you can visit KVH's web site for more information: **http://www.kvh.com/C100/C100.html**.

THE SENSUS 700 HIGH SPEED VISION SYSTEM

The Sensus 700 is a modular, expandable, high-performance onboard image acquisition and processing system. It is capable of capturing RGB, composite, or three RS-170 camera signals while simultaneously processing images by employing multiple parallel TMS320C44 DSP's.

Fully integrated software is also included consisting of image processing routines, development libraries, and drivers that all run under Linux.

Hardware

The core system consists of an ISA "carrier card" that can accommodate up to three industry-standard TIM-40 modules and is optimized for low-power mobile robotics applications. Plugged into the carrier card is an RGB or composite digitizer module that includes a 50 MHz 'C44 DSP for image processing. The 'C44 is capable of delivering up to 50 MFLOPS of performance and is specially suited for high-speed communication with additional 'C44 processors to facilitate parallel processing. The remaining TIM-40 slots on the carrier card are intended for additional 'C44 processing or digitizing modules, which are available. A system configured with two digitizer modules is ideal for stereo vision applications.

The Sensus 700 is an "embedded processing" card. It differs from traditional frame-grabbers in that it has processing onboard for performing image-processing tasks. The resulting processed data is typically the only thing that is exchanged between the host computer and the vision system. This leaves the host processor free to do other things. That is, the host processor has other things to do such as avoid obstacles, build maps, etc. This means that an application that uses the Sensus 700 is comprised of two programs that run simultaneously: one that runs on the host processor and one that runs on the vision system. These two programs communicate through the device driver. Typically the host processor is controlling what the vision system does by making specific requests such as "Where in the image is a particular beacon?" or "Do you see a coke can?" Once the host processor makes the request, it can do other things until the result comes back. This computational model resembles a client-server type system.

The Remote Procedure Call (RPC) library makes designing such systems intuitive and easy. For example, the host makes an RPC request to the vision system that results in a procedure being called on the vision system. The vision system runs the code in the procedure and returns the result to the host processor. The host processor receives the result much like it receives data from a procedure that it calls locally, except this time, the procedure was executed onboard the vision system. Thus, the RPC library allows both the exchange of data and control of execution.

Please refer to the *"Software Manual"* for more details on using the Sensus 700 system.

RADIO ETHERNET SYSTEM

The Radio Ethernet System allows communication with your robot without using an Ethernet cable. The user can use standard network utilities and mechanisms (e.g. ftp, telnet, TCP / IP sockets) as if the robot were another workstation on the network.

Installing and Configuring the Ethernet system

To communicate with the robot using radio Ethernet, you first need to have the Access Point Bridge installed on your network. This device comes with its own installation manual. Make sure that the Access Point is properly installed before proceeding. Secondly, you will need to edit the network configuration files. This process requires information that is likely to be known only by your network administrator. Please have netmask, network, broadcast, and gateway addresses as well as a unique IP address for each computer on your robot available for the following steps:

1 Plug in a keyboard and monitor into the Keyboard1 and VGA1 connectors on the control panel. This is the "lower" computer in a multiple CPU system.

2 After the boot sequence completes, you will see a"`login:`"prompt. Log into the robot's console as "root". By default, there is no password.

3 Change to the directory `/etc/sysconfig/network-scripts`.

4 Using an editor such as vi or emacs, load the file `ifcfg-eth0`. If you are unfamiliar with UNIX-style editors, contact your network administrator for help (to exit vi, type: q! and press enter; to exit emacs, hold down the Ctrl key and press the X and C keys). Inside this file, you should see the following text (or similar):

```
#!/bin/sh #>>>Device type: RangeLAN2
#>>>Variable declarations:
DEVICE=eth0
ONBOOT=yes
IPADDR=128.1.1.128
NETMASK=255.255.0.0
BROADCAST=128.1.255.255
NETWORK=128.1.0.0
GATEWAY=none
#>>>End variable declarations
```

5 Change the IPADDR, NETMASK, BROADCAST, NETWORK, and GATEWAY values to the correct values for your network. Contact your network administrator to get these values or have values assigned to you if you don't have them already. (GATEWAY should be set to none or an IP address of your router, whichever is appropriate.) Save the file when done.

6 If you have a MemNET system (a system with more than one processor), repeat steps 4 and 5 with `ifcfg-eth1` on the lower computer (which is named lower) and `ifcfg-eth0` on the upper (which, of course, is named upper). You can connect your keyboard and monitor to KEYBOARD 2 and VGA 2 or you can simply telnet to "upper". Set IPADDR to the IP address for that computer and POINTOPOINT to the IP address for the other one. That is, for the lower computer set the POINTOPOINT address to the upper computer's IP address, and the upper computer set the POINTOPOINT address to the lower computer's IP address. Additionally, the upper computer will need the GATEWAY set to the IP address of the lower computer.

7 Also, if you are using MemNET, you may need to set the MAC address of the RangeLAN2 card on the lower computer. To do this, type the "`ifconfig`" command on the lower computer and press enter. On the eth0 line, there will be an entry named HWaddr. That entry will contain a value starting with 00:20:a6. Copy this value to paper. Next, edit the `ifcfg-eth0` file and look for the entry starting with ARP. It should also contain a number starting with 00:20:a6. Edit the remainder of the entry to match the value you copied down.

8 Change to the `/etc/sysconfig` directory.

9 Bring the file `network` into the editor.

10 Change the entry for HOSTNAME to your host and domain name (e.g. rosie.robots.com) Save the file when done.

11 Bring the file `/etc/hosts` into the editor. You should see the following (or similar):

128.1.1.128 robot0 robot0.robots.com

12 Change the IP address and name on the entries to correspond to the robot's onboard computers 14) Reboot your robot (by holding down Ctrl and Alt while pressing Del) to allow the changes to take effect. Your Nomad's networking should now be properly configured.

Nomadic Technologies, Inc. uses wireless radio Ethernet products from Proxim and Lucent. For more details on the hardware, please consult the included manuals or their web pages:

- Proxim's RangeLAN2 Access point and ISA cards:

  Access Point
  http://www.proxim.com/proxim/products/rnglan2/ap2.htm

  ISA Card
  http://www.proxim.com/proxim/products/rnglan2/isabus.htm

- Lucent's WaveLAN Access point and ISA cards:

  WavePoint
  http://www.wavelan.com/products/wpoint.htm

  WaveLAN / ISA Card
  http://www.wavelan.com/products/wl_isa.htm

PAN TILT UNIT

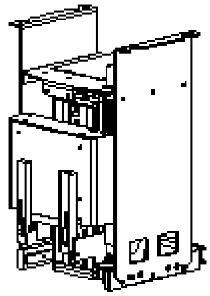
The Directed Perception pan tilt unit (model PTU-46-17.5) is controlled through a standard RS-232 serial port. Please consult the configuration document that came with your robot to determine which computer and which COM serial port is dedicated to the unit.

Example software for the unit is included in the `/usr/local/robot-devices/dp_pantilt directory`. For additional information on operating the pan-tilt unit, please consult the included product manual or the web site:

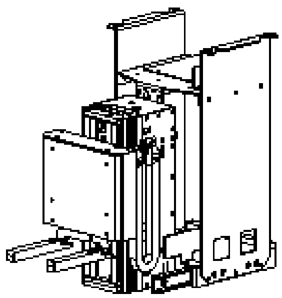
http://www.dperception.com/ptu46_70.htm

XR4000 LIFT MECHANISM

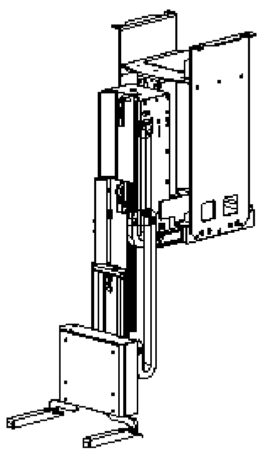
The Nomad XR4000 Lift Mechanism is a unique three stage telescoping mechanism that mounts in the back of the XR4000 mobile robot. The Lift Mechanism has a servo-controlled deploy axis and can automatically retract and be stored inside the base when not in use. With its gripper, this system can be used to perform mobile manipulation tasks. The Lift Mechanism provides motion in the Z direction and utilizes the drive system of the base to provide X, Y, and Rotation degrees of freedom. Although this system does not use brakes, it will hold its position when the robot is shutdown.



Lift Mechanism retracted



Lift Mechanism deployed



Lift Mechanism down

The Lift mechanism consists of two controllable axes and the Deploy axis:

1 The Lift Axis, which moves the gripper up and down (normal to the floor). It can move the gripper to within 3 cm of the floor and to a height of 940 cm above the floor.

2 The Grip axis, moves the fork-like “fingers” of the gripper to a fully closed position and to an open position of 20 cm between fingers.

3 The Deploy axis, simply moves the entire Lift Mechanism in and out of the robot. When the Deploy axis is in the deployed position movement of the Grip and Lift axes is permitted, however the mechanism extends beyond the outside diameter of the robot. In this position, it is possible for the mechanism to collide with obstacles and damage the mechanism and/or the environment. This makes path-planning and obstacle avoidance more difficult. When the Deploy axis is in the retracted position, the mechanism does not extend beyond the outside diameter of the robot. This protects the mechanism from potential damage and simplifies path-planning and obstacle avoidance. Please refer to the Software Manual for details on how to control the Lift Mechanism.

Lift Mechanism Calibration

The Lift Mechanism has certain mechanical parameters that vary from mechanism to mechanism and that may change during its lifetime. Thus the Lift Mechanism may need to be recalibrated occasionally. The Lift Mechanism comes from the factory calibrated with calibration parameters in `/usr/local/xrdev/etc/xrlift.cfg`. A Lift Mechanism needs to be calibrated if:

1 Upon retracting, the Lift Mechanism will sometimes or always contact the rectangular holes in the doors preventing full retraction.

2 The Lift axis will sometimes or always trigger the positive or negative limit switches when moving to its maximum or minimum limits (i.e. a calibrated Lift Mechanism will never trigger the Lift axis limit switches after zeroing.)

If either or both of these conditions is true, the Lift-Mechanism needs to be recalibrated.

Recalibrating entails killing the Nrobot process and running the `xrlcalibrate` program in the `/usr/local/xrdev/bin` directory.

That is, execute the following commands while logged in with root privileges:

```
killall Nrobot
xrlcalibrate new.cfg
```

Run the xrlcalibrate program with an output calibration filename, (e.g. `new.cfg`) as shown above. The calibration program will zero the Lift Mechanism and measure the limit switch locations by moving the Lift and Grip axes to the maximum and minimum positions. After it has completed this, it will ask the user to center the Lift axis such that it fits into the rectangular holes in the doors. The following text will be displayed:

Lift centering calibration: please use the following keys to center the lift axis so it can be retracted.

‘u’ to move the lift up

‘d’ to move the lift down

‘x’ to exit when the lift axis is centered.

Press the “u” key to move the lift up and the “d” key to move the lift down such that it is centered and ready to be retracted. The Lift axis is centered when all of the telescoping stages are flush with each other. When you are satisfied with the centering, press the “x” key and the Lift mechanism will zero again and proceed to retract. If it has problems retracting such that the Lift Mechanism makes contact with the doors, the calibration program may need to be executed again and the Lift axis recentered.

When the calibration program exits successfully, copy the outputted calibration program to the `/usr/local/xrdev/etc/xrlift.cfg` file:

```
cp new.cfg /usr/local/xrdev/etc/
xrlift.cfg
```

For the new calibration parameters to take effect, the robot must be rebooted.

PUMA 260/560 MANIPULATOR

The PUMA 260 / 560 manipulator arms provide 6 DOF manipulation capability. The PUMA 260 can handle a 0.9 Kg payload with 0.457 m reach, while the PUMA 560 is larger with a 2.3 Kg payload and 0.914 m reach. This type of arm should be mounted vertically on the top of the XR4000. The arm is controlled using a Servo-To-Go ISA board to read the encoders and write voltages to the amplifiers. Additional information about the controller card can be found at **http://www.servo-togo.com**.

MHI PA-10 MANIPULATOR

The Mitsubishi Heavy Industries PA-10 manipulator arm provides 7 DOF manipulation capability with a 10 Kg payload and 1.030 m reach. The arm can be mounted vertically, horizontally, or at an angle on top of the XR4000. It is controlled via an Arcnet network connection to the MHI embedded controller.

More information about the PA-10 manipulator can be found at **http://www.sdia.or.jp/mhikobe/products/mechatronic/index-e.html**

CHAPTER 5: THE POWER SYSTEM

POWER MODES

The XR4000 has two different power modes ("On" and "Standby") depending on the functionality the user wants.

On Mode

This power mode is used the most often because it powers all systems on the XR4000 including the onboard PC computer(s). While in this mode, hooking AC power to the AC receptacle causes the batteries to be charged and power to be delivered to the onboard electronics.

The XR4000 can be put in On Mode at any time by pressing the **On** button on the control panel.

Turning the XR4000 off from this mode should be accomplished with a "clean shutdown".

Standby Mode

This mode is used as a power-saving mode, or as a mode that charges the batteries without supplying power to the onboard PC computers. While in this mode, hooking AC power to the AC receptacle causes the batteries to be charged and power to be delivered to the onboard electronics. Since this mode does not supply power the PC computers, a significant amount of energy is saved and the user does not have to wait for a "clean shutdown" to turn the XR4000 off.

The XR4000 can be put in Standby mode from an off state by pressing the **Standby** button on the control panel. If the robot is in On Mode, pressing the **Standby** button will initiate a clean shutdown.

Turning off the XR4000

Clean Shutdown (recommended)

Clean shutdown ensures that the onboard computer(s) are shutdown cleanly (filesystems unmounted, etc). It can only be accomplished after the onboard computer(s) have finished booting.

Begin by pressing the red **Off** button on the control panel momentarily. The control panel will then ask for confirmation. Press the **Off** button again to confirm. The robot software will then initiate a clean shutdown of the onboard computers. After about 20 seconds the robot will turn off.

Similarly, the robot can be put in Standby Mode by pressing the **Standby** button momentarily and again to confirm. The robot software will then initiate a clean shutdown of the onboard computers and after about 20 seconds the robot will be in Standby Mode.

Dirty Shutdown

This type of shutdown will force the XR4000 to turn off at any time. It is recommended that this mode be used only when necessary, as it does not ensure that the onboard computer(s) are shutdown cleanly. It is accomplished by holding the red **Off** button on the control panel in a depressed state for more than 10 seconds.

Auto Shutdown

When any of the battery voltages falls below 10.8 Volts, the XR4000 will warn the user of a low battery condition by emitting a high-pitched tone. Upon hearing this, it is then recommended that the robot be shutdown or plugged into an AC power source for charging. If the user fails to do either, the power system will attempt to do a clean shutdown after five minutes of a low battery condition. If a clean shutdown fails, it will wait two additional minutes and do a dirty shutdown.

PRIMARY POWER CONTROLLER (PPC)

At the heart of the XR4000 Power System is the Primary Power controller or PPC. It can be viewed by removing one of the batteries and looking inside the base of the XR4000. The printed circuit board above the connector that engages with the battery is the PPC assembly. It accomplishes the following power management tasks:

- Controls main power and emergency stop switches
- Accepts and regulates AC power
- Controls battery charging
- Measures battery voltages
- Measures current into and out of batteries

- Measures nine important voltages for diagnostics

PPC Fuses

Please refer to "*Appendix D: Fuse Replacement*" for a complete list of fuses in the PPC.

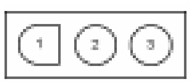
POWER DISTRIBUTION BOARD (PDB)

The Power Distribution Board or PDB converts "raw" voltages from the PPC (between 45 and 60 volts) to clean, regulated voltages for the onboard computers, sensors, and peripherals. The PDB also distributes these voltages where needed. The PDB is located behind the CPU cardcage and can be accessed easily by opening the two side doors of the XR4000.

PDB Power Connectors

Many of the connectors on the PDB are intended for optional devices or user-added devices. The following is a description of the power connectors intended for possible user expansion.

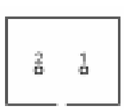
Module Connectors



J6, J8, J10, J11, J22, J23

Pin	Signal
1	+12V
2	+5V
3	GND_CLEAN (referenced to computer supply)

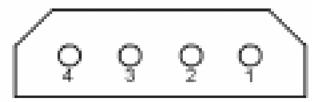
Camera Connectors



J12, J14, J28, J29

Pin	Signal
1	+12V
2	GND_CLEAN (referenced to computer supply)

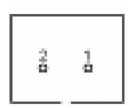
Disk Drive Connectors



J13, J15, J17, J20

Pin	Signal
1	+12V
2	GND_CLEAN (referenced to computer supply)
3	GND_CLEAN (referenced to computer supply)
4	+5V

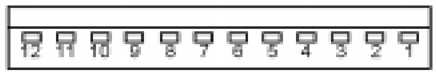
Fan Connectors



J16, J18, J19, J21

Pin	Signal
1	+12V
2	GND_CLEAN (referenced to computer supply)

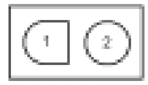
Computer Power Connectors



J2, J3, J4

Pin	Signal
1	NC
2	+5V
3	+12V
4	-12V
5	GND_CLEAN
6	GND_CLEAN
7	GND_CLEAN
8	GND_CLEAN
9	5V
10	+5V
11	+5V
12	+5V

Main Power Connector



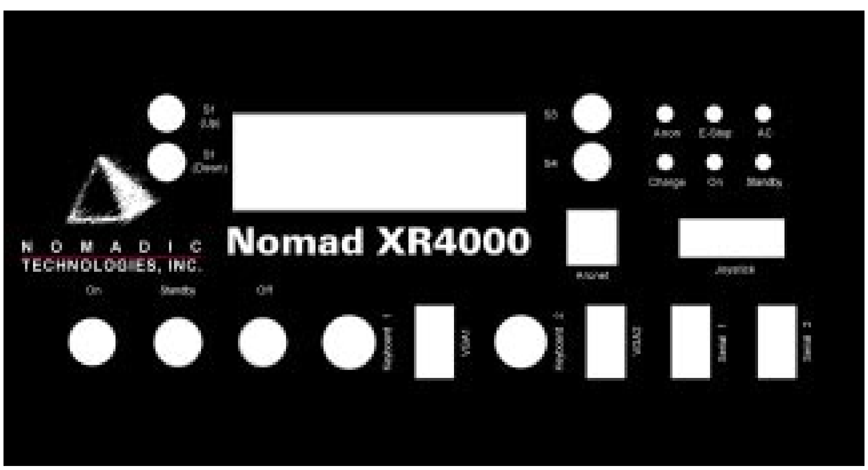
J9

Pin	Signal
1	+45V to +60V unregulated
2	GND (referenced to batteries)

PDB Fuses

Please refer to "*Appendix D: Fuse Replacement*" for a complete list of fuses in the PDB.

THE CONTROL PANEL



The Control Panel is located on the right side door of the XR4000. It provides many different types of information and many ways in which to interface to the XR4000. Contained in the control panel are the following:

Connectors

VGA1, **VGA2**, **Keyboard1**, **Keyboard2**

These connectors allow a VGA monitor and keyboard to be hooked up to the Primary Computer (**VGA1**, **Keyboard1**) and Auxiliary Computer (**VGA2**, **Keyboard2**).

Serial1, Serial2

These connectors, depending on the configuration and availability, are hooked to serial ports on the onboard PC computers.

Power Buttons

These allow the user to change the power mode and / or turn the robot off. See *"Chapter 5: The Power System"*.

Status Console

This consists of a small text display and four buttons (**S1**, **S2**, **S3**, **S4**). It is used to convey status information and is helpful when diagnosing problems with the robot. By default, the Status Console displays "Log File" information. This information conveys events during the current boot cycle of the robot such as charging, initialization, power mode changes, etc. While in this mode, **S1** and **S2** can be used to scroll up and down to view the entire contents of the Log File.

Pressing **S4** brings up the Status Console Menu. You can use **S1** and **S2** to scroll the selection to the desired choice followed by pressing **S3** to select. Of the menu items that are available:

- `About`: displays information about the robot.
- `Log File`: returns to displaying the Log File information. While in this mode, **S1** and **S2** can be used to scroll up and down to view the entire contents of the Log File.
- `Power Diagnostics`: displays information about the power system including battery voltages, charge / discharge currents, fuse voltages, and other diagnostic voltages. While in this mode, **S1** and **S2** can be used to scroll up and down to view the entire contents of the Power Diagnostics.

Status LEDs

These LEDs show current status information.

- **Anon**: this LED is currently not used.
- **Estop**: this LED illuminates when either of the E-stop buttons is down.
- **AC**: this LED illuminates when the robot is receiving AC power through its AC receptacle.
- **Charge**: this LED illuminates when the batteries are being charged. This only happens when the robot is receiving AC power.
- **On**: this LED illuminates only when the robot is in On Mode. See *"Chapter 5: The Power System"*.
- **Standby**: this LED illuminates when the robot is in Standby Mode or in On Mode. This LED turns off only when the robot is fully powered off.

CHAPTER 6: ROBOT MAINTENANCE

BATTERY MAINTENANCE

This section describes the proper use, charging and storage for the batteries used with your Nomad XR4000 system. Correct maintenance will ensure proper operation of your Nomad robot as well as lengthen the life of your batteries.

It is important to divide your batteries into their appropriate “sets” that are indicated on the top of each battery. A set is comprised of the four batteries that are used at any one time by the robot. It is important to use and charge batteries together and not mix sets. This prevents a discharged battery from being connected in series to a charged battery, which can cause damage to both batteries.

Thus, batteries of the same set should be used together AND charged together.

Charging

Charging the robot’s batteries can be accomplished by plugging the robot into a wall socket with the supplied UIC power cord (robots are pre-configured for the power grid used in the country they will be operating) while the robot is in either On or Standby Mode. The robot will not charge if it is off even though the fan in the AC / DC supply can be heard. The UIC cord plugs into the side of the XR4000 through a small square cutout between the front and left door. While the power cord is attached and the robot is turned on, the robot will simultaneously charge and receive power from the AC power cord. Thus, it is recommended that when the robot is in use, yet stationary, that the AC power cord is attached.

Usage

When the robot is loaded and running with a set of charged batteries, you should expect between six to eight hours of operating time. This estimate assumes a Nomad XR4000 that has standard equipment installed in it. The power system has a low-voltage alarm system connected to it. Whenever the voltage of any of the four batteries drops below 10.8 V, a high pitched an alarm will sound. When the alarm is heard, the robot should be plugged in or the batteries should be removed from the robot as soon as possible to avoid over-discharging them. The XR4000 will shut itself down automatically to prevent damage. Once the batteries have been overly discharged they are permanently damaged.

Removing the batteries

Make sure the robot is turned off. Open all of the doors. Lift the metal latch on the left side of each battery. Grab the hole in the circuit board on top of the battery and pull gently towards you until the battery slides out. **Do not remove any of the batteries while the robot is on and/or plugged into AC.**

Storage

When the Nomad is not in use, the batteries should be disconnected from the robot. If the batteries will not be used for an extended period of time, it is best to charge them every six months.

Battery Lifetime

When the batteries are maintained according to the above specifications, they should yield approximately 200 charge / discharge cycles. When they begin to discharge very quickly, or will not hold a charge at all, it is time to buy a new set.

Summary

- Proper maintenance and use of your batteries will ensure the proper operation of your XR4000 and lengthen the life of your batteries.
- To ensure that the batteries are exercised and recharged together; divide them into sets and do not to mix up the sets.
- The sets must be charged together and will require between 4-6 hours to be fully charged.
- A high-pitched low voltage alarm will sound if any of the battery voltages become too low. The robot should be plugged in or the batteries should be removed from operation as soon as possible after the alarm sounds.
- If not used for an extended period of time, the batteries should be charged every 6 months.

- When used properly, the batteries should yield approximately 200 charge / discharge cycles.

REMOVING THE DOORS

Open the door part way. Unplug the red / black power cable from the microprocessor board mounted to the door. Unplug the Arcnet cable(s), (they resemble phone cables) from the microprocessor board mounted to the door. Unplug the grounding strap that is located below the door hinge. Grab the top of the door near the hinge edge. Carefully lift straight up to remove the door.

MOUNTING THE DOORS

While holding the top of the door near the hinge with one hand and holding the hinge in the other hand, line the hinge up with the bracket on the robot base. Be sure to lower the door onto both hinge pins. Plug in the power and Arcnet cable(s) to the microprocessor board on the inside of the door. For doors with two arcnet cables, it does not matter which cable plugs into which modular connector. Plug the grounding strap into the door below the hinge. Close the door.

APPENDIX A: MEMORY MAP, IRQ USAGE

Here is the computer configuration of the Nomad XR4000, concerning the memory map and IRQ usage:

Board	I/O	Memory	IRQ
ARCNET	2E0-2E7	-	-
Sensus 450/460	-	-	-
Sensus 500	-	-	-
Sensus 550	COM port	-	-
Motor Controller	-	D2000	7
Radio Ethernet	270-277	-	15
Speech Synthesis	29E-29F	-	-
Compass	COM port		-
COM1	3F8-3FF	-	4
COM2	2F8-2FF	-	3
COM3 (optional)	3E8-3EF	-	4 (?)
COM4 (optional)	2E8-2EF	-	3 (?)
LPT1	378-37F	-	5 (reserved)
MemNET	-	D6000-D7FFF	9

APPENDIX B: ADDING ADDITIONAL CARDS TO THE XR4000

- Please note that adding cards incorrectly will void your warranty if the system is damaged. Follow the following steps when adding a card to the robot control system:
- Turn off the robot.
- Unplug the robot and all external equipment from their power outlets.
- Open the robot and locate an empty slot to add the card.
- Select an expansion slot, remove the slot cover and save the screw.
- Discharge any static build-up by touching the metal case of the robot.
- Insert the card into the expansion slot using the groove in the card cage to properly align the card in the slot. When the bottom of the board contacts the bus connector, gently press down on the board until it clicks into place. Do not force the card into place. When you feel resistance during insertion, pull out and try again.
- Gently lift the card to determine if it has been properly installed. If the card stays in place, it is installed correctly. Otherwise, press down firmly on the card to ensure it is seated.
- Secure the card in place at the rear panel of the card cage using the screw removed from the slot cover.

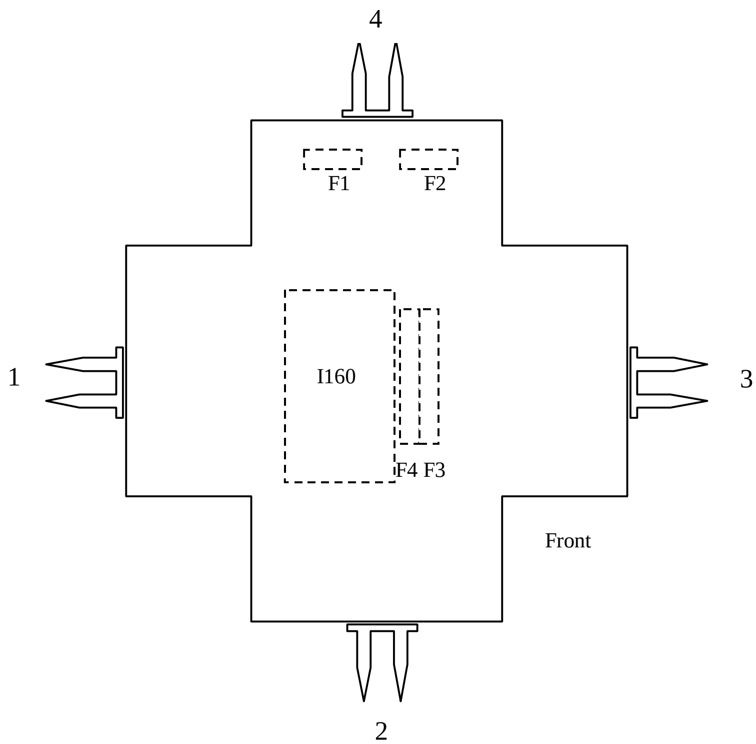
APPENDIX C: FUSE REPLACEMENT

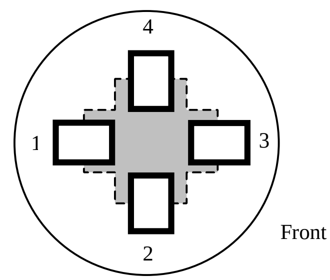
Two boards carry fuses on the XR4000: the Primary Power Controller (PPC), located in the base just above the batteries, into which the batteries connect, and the Power Distribution Board (PDB), located behind the CPU card cage.

Additionally, there is a fuse located inside the AC receptacle plug. This fuse is rated for 10 A at 250 V.

PPC FUSES

The PPC board has 4 fuses. The fuse positions are given in the sketch below (this sketch is a top view looking through the PPC). The fuses are located on the bottom side of the board and can be accessed by removing the batteries 3 and 4 as illustrated. Fuses F3 and F4 belong to a fuse block that can be removed by pulling downward on their handles.





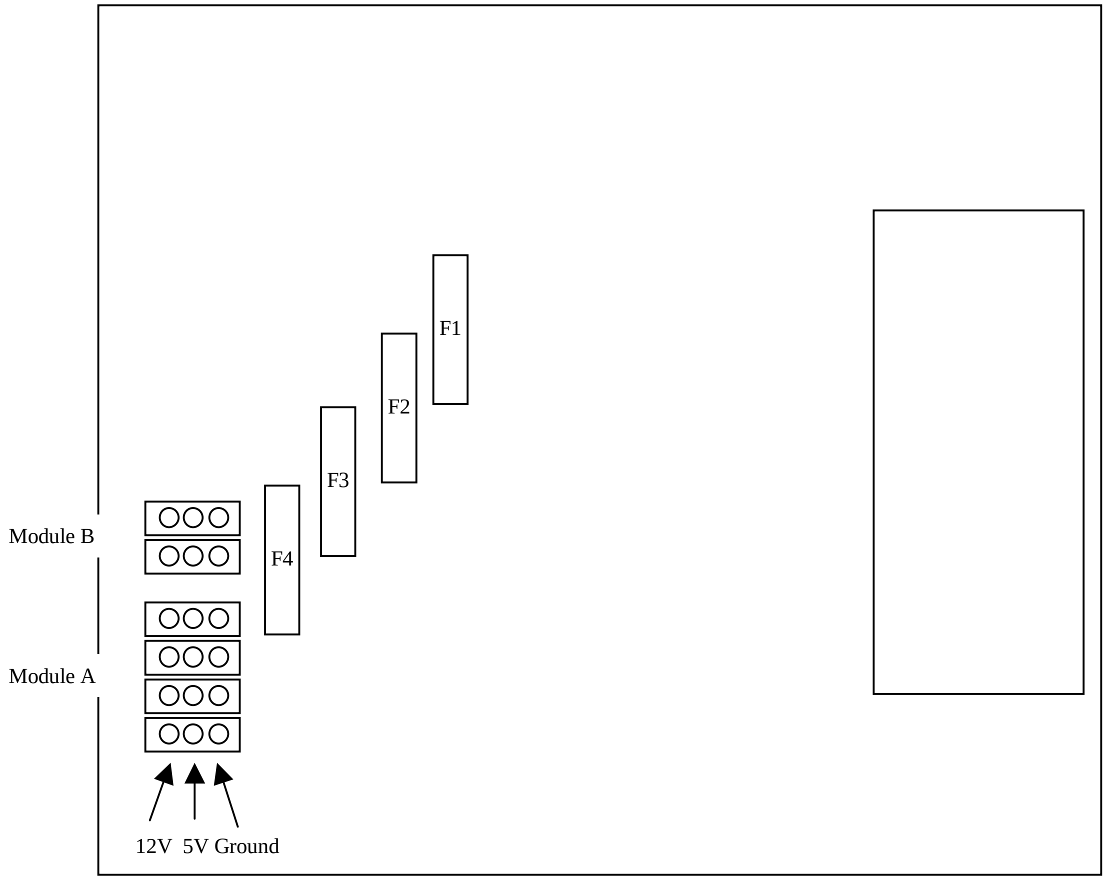
Note: The dashed line indicates that the object cannot be seen from top view.

The specifications of these fuses are as follows:

Name	Specifications	Function
F1	3AG - 5A	Standby Fuse
F2	3AG - 15 A	CPU Fuse
F3	CCMR LittelFuse-20A	Motor Fuse
F4	CCMR LittelFuse-30A	Main System Fuse

PDB Fuses

This board is located behind the CPU card cage and carries 4 fuses. The fuses can be accessed by opening the robot's left door.



The specifications of these fuses are as follows:

Name	Specifications	Function
F1	3AG - 5A	Module B 12 V
F2	3AG - 5 A	Module B 5 V
F3	3AG - 5 A	Module A 12 V
F4	3AG - 5 A	Module A 5V

APPENDIX D: TECHNICAL SUPPORT REPORT FORM

Thank you for reporting bugs, malfunctions and suggested improvements regarding this robot. Please e-mail the following information to support@robots.com. This information will help us to solve your problem faster.

INFORMATION ABOUT YOURSELF

- Your Name
- Your Organization
- Your e-mail address
- Your robot(s) serial number(s)
- The date of this report Information About Your Environment
- Your machine type (example: Sparc10)
- Your operating system (example: SunOS)
- The program and version you are using (example: Nrobot version 1.0)
- Description of Your Problem
- What were you doing when the problem occurred?
- Is the problem reproducible?
- Does the problem occur on the robot and / or the simulator?
- Additional Information
- A copy of the setup files
- The core file, if there is one
- The smallest sample of code the reproduces the problem.