GAIA-2 mobile robot with Harmonic arm

This unmanned ground robotic system comprises two main components: i) a GAIA-2 mobile robot base and ii) a 5DOF Harmonic arm. The robot (base and arm) is in mint condition (practically it is a new system). The original cost of the base is CA$26,440 while the arm's original cost is CA$26,000 making the original cost of the complete system CA$52,440 (CA = Canadian Dollars). This complete robot (base + harmonic arm) is now being sold by the current owner at a great price.

GAIA-2 Robot

GAIA-2 platform (from AAI Canada Inc) is designed for outdoor intelligent robot research and development using behavior-based, as well as conventional mobile robot technology. Waterproofing applied to the bottom and axles of the rugged robot allows it to run in water or mud up to 10cm deep. GAIA-2 can climb over obstacles up to 15cm high. Independent and differential drive on all 4 wheels provide a zero turning radius. GAIA-2 also offers waterproof ultrasonic sensors for obstacles avoidance.

Software access to the processor, sensors, and drive motors is easily achieved through standard interface. This interface is also used for accessing GAIA-2 options (e.g., vision system, additional sensors, actuators).

PC/104 is the default processor and additional processors such as the Motorola 68332 processor (Vesta board), or XSCALE PXA-255 processor (Korebot board) can be added. GAIA-2 can be operated by remote control from a PC, notebook computer, or a workstation providing the user creates the required interfaces. Or to make GAIA-2 robot fully autonomous, a program can be downloaded directly to GAIA-2. GAIA-2 robot has a wide variety of options such as people following/avoidance, light following/avoidance, and various data/video communication devices. With the included harmonic arm, which holds a camera vision system, vision-based maneuvering and landmark navigation can be implemented.

❖ **SPECIFICATIONS:**

Processor:	PC/104 processor Optional (user can add/replace) Motorola MC68332, 32-bit microcontroller Optional (user can add/replace) XSCALE PXA-255 processor Optional (user can add/replace) MC6811 and/or PIC for peripheral processing
Sensors:	7 ultrasonic sensors that emit 40 Khz carrier wave with 20 Hz modulation to detect the strength of reflection.
Standard I/O:	Serial port for remote control and program download. 2 additional serial ports 6 digital inputs 7 digital outputs
Size:	width: 53 cm (21 in) length: 49 cm (19 in) height: 26.5 cm (11 in)
Weight:	40 kg (88 lbs) approximately
Payload:	20 kg (44 lbs) maximum
Top Speed:	80 cm/s (3.6 km/h). Speed can be adjusted continuously.
Run Time:	5 hours (with zero payload)
Motor Output:	140w (x4)

Harmonic Arm

Harmonic Arm™, by Neurobonics, is a high-quality 5DOF (including the open/close of the gripper) programmable robot arm with fully integrated electronics and sensors.

❖ **FEATURES:**

- Manipulator with different Sensors
- Intelligent Control
- Can be used stand-alone or on a mobile robot

- High Precision
- Harmonic Drive - minimizes backlash
- Quick movement: averaging 90 degrees/second
- Degree of freedom: 5 (including a gripper)
- Controller: Built inside of the cylinder
- Interface: serial and SPI
- Power: 12 V DC, maximum 3.5 A

❖ APPLICATIONS:

- Research and education mainly in intelligent pick-and-place
- Industrial handling of objects up to a weight of 500 g

❖ ENVIRONMENT:

- Stand-alone, on a linear axis or on a mobile robot
- Direct control via a serial interface by a PC or a Programmable Logic Controller (PLC), or by a special interface of a mobile robot

❖ SPECIFICATIONS:

	Harmonic Arm 5M
Motors	DC-Motors with integrated digital position encoders
Precision	+-0.1 mm (repetition accuracy)
Base Height	188 mm
Degrees of Freedom	5 (5 Motors)
Working Radius	60 cm
Construction	Anodized Aluminum
Weight	4.1 kg
Payload	500 g
Power	12V 3.5A
Velocity	Average 90 degrees in 1 second (all joints move in parallel)

❖ COMMUNICATION INTERFACES:

<u>Basic Protocol</u>

- The host sends a packet consisting of:
  - in some cases an address to distinguish several Harmonic Arms
  - a command code
  - Parameters/data
  - in some cases a checksum
- Then, an answer packet will be returned by Harmonic Arm

<u>Interface Variants</u>

At each Harmonic Arm, the following interfaces are available (no need to change software):

Asynchronous Serial

- **Asynchronous Serial:** 5V logic level, Default settings 57600 bps , 1 start, 1 stop, 8 data bits, no parity. Requires CMOS-RS232 converter to connect to host computer
  Needed on Host: a bidirectional asynchronous port. If this works on RS-232 logic levels (?12 V), a small converter is plugged in between

Synchronous Serial

- **Standard SPI (Serial Peripheral Interface):** two data lines, clock line, select line, synchronous, 5 V logic level, (no addressing, individual select lines used to enable communication)
  Needed on Host: an SPI port, can be emulated by software. Multiple arms can share data and clock lines, but need separate select lines

- **Modified SPI (K-Net):** two data lines, a clock and some control lines, synchronous, 5 V logic level, (SPI extended with addressing)
  Needed on Host: an SPI port, can be emulated by software, with additional digital I/O (total incl. data and clock: 4 out, 2 in). One of the digital inputs must be able to detect short pulses, so it should be latched or trigger an interrupt

❖ **GRIPPERS AND EXTENSIONS:**

Interface Arm - Gripper

- Fast mechanical connection
- Coupling for force transfer from the fifth motor to the gripper
- Power supply and data bus
- Free electric connection to the arm base, e.g. for a video signal of a miniature video camera above the gripper

Universal Gripper

- Two-finger gripper with miscellaneous sensors:
  - Infrared reflex sensors inside and outside, e.g., for object detection
  - Local force sensors inside the fingers
  - The sensor values can be read out as digital numbers
  - Gripper is able to grasp small objects with frontmost part and larger ones in the middle part of the gripper

Overall Mobile Manipulator System

A complete manual with detailed information about the robot base and the arm will be provided with the robot. In the following section a small part of such manual is provided as general information.

1. Introduction

1.1 Main Characteristics

GAIA-2 (small size, High payload Autonomous Platform)

Size	Length: 490 mm Width: 530 mm Height: 355 mm
Weight	46 Kg
Maximum Payload	20 Kg
Maximum Speed	0.8 m/s
Run Time	6 Hours (with zero payload) 4 Hours (with 20 Kg payload)
Battery	140 W sealed lead-acid battery (2x12V 26Ah)
Motor Output	140 W(x4)
Processor	Digital Logic PC/104 processor (SmartCore) Other processors can be used (Motorola MC68332, MC68376) as the board allows for additions (stackable – Fig 1.0)
Basic Sensors	7 Ultrasonic sensors User can add front and rear bumper with touch detection sensors

1.2 Applications

- Mobile robot experiments
- Development of intelligent conveyance vehicles
- Research on multiple intelligence and collaboration of multiple robots
- Research and development of cleaning robots
- Research on evolutionary mobile robots
- Experiments on evolutionary robots and artificial life
- Development of entertainment robots
- R&D on Autonomous Ground Vehicles for factory/warehouses

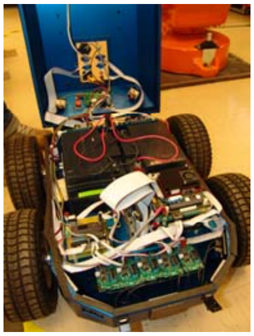


Figure 1.0 Robot electronic components inside the chassis

1.3 System Overview

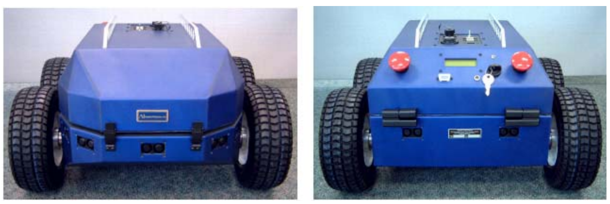
This document provides basic information needed to begin working with GAIA-2 (GAIA-2's mechanical, electrical and signal structure, Basic procedures for using and programming the robot and the main components and procedures for using the robot vision system).

1.4 About GAIA-2

GAIA-2 (Figure 1.1) is a small-size, high-payload intelligent robot platform for indoor/outdoor use. It is 490 mm in length, 530 mm wide, and 355 mm in height. It weighs about 46 kg and can be used for a variety of research purposes. GAIA-2 is designed with a flat top to which users may attach equipment of their own for diverse purposes. The top panel is made of aluminum with a thickness of 1.6 mm. The maximum payload is 20 kg. With its two-wheel differential drive, GAIA-2 can turn with virtually zero turning radius.
GAIA-2 is equipped with ultrasonic (US) obstacle detection sensors (see Figure 1.2. With behaviour-based AI technology, GAIA-2 can run autonomously and continuously in complex environments.

Research on high-speed obstacle avoidance in free space using color can be conducted with GAIA-2's vision system.
Users can use any of three processors (as well as other possibilities) to meet their needs. All the processing to control the robot is executed on-board.

Figure 1.1 Overview of GAIA-2



(a) front view (b) back view

Figure 1.2 Two views of GAIA-2

1.5 PC/104

GAIA-2 is equipped with a PC/104 computer by Digital Logic, Inc. (Figure 1.3), as its main computer. This board contains a Pentium 700 MHz processor and 128MB of RAM. In this document, this computer is called a PC/104. Management of the sensor input, motor output, and user interface (buttons, LCD, etc.) is handled by this basic processor. If the behaviour based AI approach is used for your application, all the processing can be executed by this computer. Basic behaviours (e.g., obstacle avoidance) to correspond with the basic sensors are already installed so that a user can add any necessary behaviours during research. Usually, the robot is programmed in 'C' and all example code is written in 'C'.

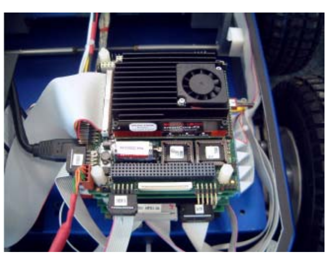


Figure 1.3 PC/104 computer by Digital Logic

1.6 GAIA-2 and Accessories

GAIA-2

- Robot body
- On-board computer
- 7 Ultrasonic (US) sensors (composed of 7 sensors, 5 at front, 2 at back)
- Optional bumpers (can be added by the user)
- 4 motors

Software

- GNU C Cross-Compiler
- Sample Program
- Sensor, motor, and serial related functions stored in ROM

1.7 Other Options that can be implemented

1.7.1 Behavior-based Vision System

Using active vision, this system can detect free space ahead of GAIA-2 while it is moving at high speed.

- • Camera Base: Turning base with 2 degrees of freedom (pan tilt) using a FUTABA S9303 servo motor
- • Frame grapper with 720x480 YUV or RBG
- • CCD color camera
- • Navigation software for the detection of free space

This system efficiently processes the input from the CCD camera and sends the signals required for GAIA-2 to move within its environment at high speed. It is equipped with high-speed navigation control software based on behaviour-based vision theory. It detects obstacles up to 10 meters ahead to generate avoidance behaviour.

1.7.2 People Following/Avoidance System

This option is comprised of four (two two-element) pyro sensors with two servo motors. The sensor detects changes in deep infrared (thermal radiation) emitted from the human body and the software installed on GAIA-2 uses these readings to enable following and avoidance behaviour. This software can be accessed from the on-board processor using C language function calls.

1.7.3 Light Following/Avoidance System

Six high-sensitivity light sensors are installed on GAIA-2 to enable light following and avoidance behaviours. The software to make GAIA-2 follow or avoid a light is already installed and can be accessed using C language function calls.

1.7.4 Wireless Transmitter and Program Interface

The package makes possible a smooth manual override for a GAIA-2 that is running autonomously, using a remote controller. The sample program for the remote controller is in the "avoid.c" program (included in the robot).

1.7.5 Video Signal Transmitter

User can add a color camera with a transmitter and a servo-driven platform with two degrees of freedom (pan and tilt). Images can be transmitted from GAIA-2 in NTSC format. Images can be received within a range of 20 to 30 meters.

1.7.6 Additional Sensor Platform

GAIA-2 is equipped with the hardware harness required for additions, such as additional sensors, that a user may require.

2 Mechanical Interface

2.1 GAIA-2 System Overview

GAIA-2 was developed as a fully autonomous mobile robot for laboratory research or application development (see Figure 2.2)

2.2 GAIA-2 Body

The length of GAIA-2 is 490 mm, its width is 530 mm, and its height is 355 mm. GAIA-2's body is made of T6 50/52 aluminum. The weight of GAIA-2, including the battery, is approximately 46 kg.

2.3 Processor

The computer stack is located at the front of the body. The LCD display and the switches on the control panel are connected to the I/O board.

2.4 Sensors, Motors, and Batteries

GAIA-2 has 7 ultrasonic sensors: five at the front, and two at the back. Each wheel is controlled by its own motor. GAIA-2 uses differential drive, giving it a zero turning radius.
Two sealed, lead-acid batteries are located in the center of the robot's body (Figure 2.1). The two batteries provide a total capacity of 624 Wh. Special attention to electric discharge still needs to be taken. Since the batteries are sealed, however, the circuit will not be damaged by gas emission, and the batteries are very easy to maintain.

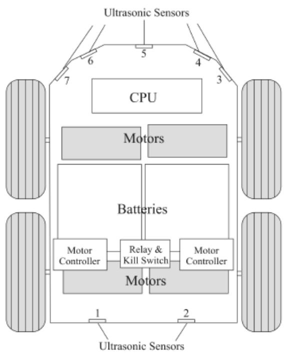


Figure 2.1 Battery location in GAIA-2

2.5 Accessories

The top panel of GAIA-2 is equipped with two aluminum rails (Figure 2.3) so that accessories can be mounted as needed. GAIA-2 also has four serial, IEEE 1394 (firewire), and ethernet ports available for communication with peripheral devices. The maximum payload is 20 kg.
To add an accessory, make holes in the top panel to attach the accessory using the necessary metal fittings. The bottom of an accessory can be fixed directly to the top panel. GAIA-2's body is made of aluminum, and the thickness of its body is 1.6 mm.

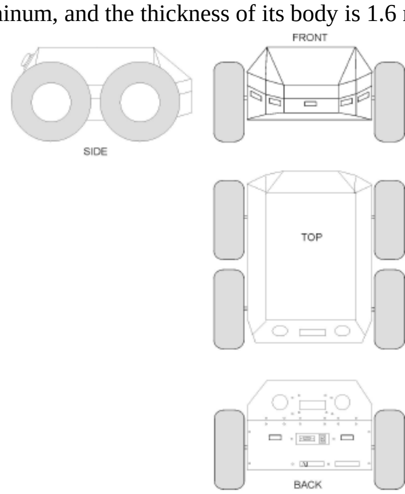


Figure 2.2 Top panel of GAIA-2

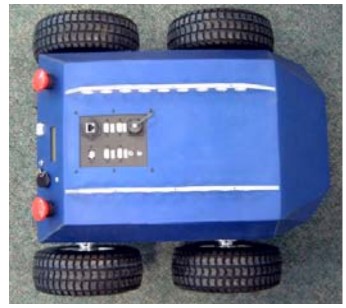


Figure 2.3 View of top panel of GAIA-2

3 Electrical Interface

3.1 Control Panel

The control panel is located at the back of GAIA-2 as shown in Figure 3.1. The control panel has an power switch, two control buttons, an LCD display, and an power indicator. A DB-9 female serial port connector and indicators are also present on most robots.

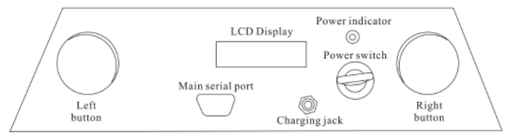


Figure 3.1 Control panel for GAIA-2

There is a battery charging jack on the control panel at the back of the robot. GAIA-2 can be charged through this connector using the cable included with the robot. The robot must be turned off while charging.

3.2 Power

3.2.1 Battery

To charge the batteries: GAIA-2 uses 2 x 12V sealed lead-acid batteries wired in series for a total of 24V. Fully charged batteries should last 4 hours– 6 hours under normal operating conditions.

- Plug the cable of the battery charger into an AC outlet. A green LED light will appear on the battery charger.
- Insert the charger plug into GAIA-2's charging jack. Figure 3.3 shows the polarity of the power plug for GAIA-2. If there is any doubt, check with a multimeter or tester. The charging current should not exceed 2 Amp. An orange LED light will remain on for the duration of the charge and will go off when the charging is complete.
- Charging may take from four to 16 hours depending on the battery use. Once the battery is fully charged, the charger will automatically stop charging the battery.

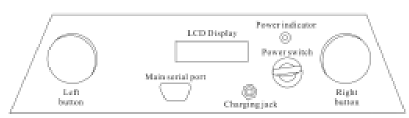


Figure 3.2 Main Power Switch for GAIA-2

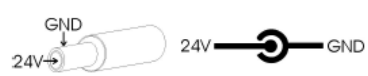


Figure 3.3 Power Jack for GAIA-2

3.2.2 PC/104 Power Supply

When connecting any peripherals, user must make sure an appropriate fuse is used to protect the circuitry. Power can be supplied to accessories in two ways (see Figure 3.4): 24V unregulated power directly from the battery, or 12V regulated power from the DC-DC converter. The DC-DC converter can supply up to a total of 2A (including PC/104 requirements) at 12V. Both the 12V regulated and 24V unregulated supplies are available through the extra power connector on the top panel. The DC-DC converter provides a regulated +12V supply. This power is controlled by the main power (key) switch at the back of the robot. The 24V power is controlled by the switch on the top panel. The main on/off switch is located on the control panel at the back of GAIA-2. This switch controls power to all of the internal systems of GAIA-2 including sensors and motor controllers. The motor power is controlled by the CPU's controller board.

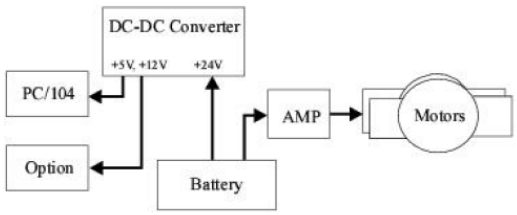


Figure 3.4 Power supply for GAIA-2 PC/104

3.3 Motor Control and Amplifier

The control signals from the interface board include Pulse-Width Modulation (PWM), Brake and Dir for each motor. Those signals control an H-bridge on the amplifier board. On the motor controller connector, PWM is referred to as Speed. The PWM signal is amplified by the motor controller board, and this is what controls the amount of power to the motors. The Direction signal controls which way the motors turn, and the Brake signal can be used to disable the motor at any time. Figure 3.5 shows a block diagram of the motor control for GAIA-2.

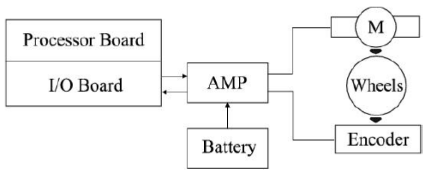


Figure 3.5 Motor control block diagram

4 Signal Interface

4.1 Extension Bus

This 8-bit data bus is connected directly to the internal bus on the I/O board. All peripherals except those connected to the serial port are memory mapped. The extension bus allows extra peripherals to be connected to the data bus. The chip selects and address lines determine where the peripherals appear in the memory map. The R/W (Read/Write) signal controls whether the processor is reading from the bus, or writing to it.

Table 4.1: Extension Bus

Signal Name	Mnemonic	In/Out	Active State
Ground	GND	Out	-
Power Supply (5V)	Vcc	Out	-
Address Bus bit (3:0)†	A(3:0)	Out	-
Data Bus bit (7:0)	D(7:0)	In/Out	-
Read/Write	R/W	Out	High/Low
Chip Select (2,3,4,7)	CS2,3,4,7	Out	Low
Interrupt Req.	IRQ2	Input	Low

†Only A0 is available on PC/104 based robots.

4.1.1 PC/104 Extension Bus

The 8-bit bi-directional data bus (extension bus) can be accessed using chip select CS2, CS3, CS4, and CS7 and an address bit A0. The chip select signals on the connector correspond to the internal signals CS12, CS13, CS14, and CS15 respectively. The interrupt request signal, IRQ2, is not used on the PC/104 I/O board.

4.2 Motor Control

Table 4.2 is a summary of the motor controller signals. These signals are grouped into control and feedback signals.

Table 4.2: Vesta and PC/104 Motor Control

Signal Name	Mnemonic	In/Out	Active State
Ground	GND	Out	-
Power Supply (5V)	Vcc	Out	-
Brake	$\overline{\text{Brake}}$	Out	Low
PWM Output	PWM	Out	High
Direction	Dir (F/$\overline{\text{B}}$)	Out	High/Low
Speed (Encoder Output)	Speed	In	-
Actual Direction	D	In	-
Over-current (Analog)	SENS	In	-

Control signals to the Motor Controller: The motor control signals are Brake, PWM, and Dir. The Brake signal disables the motor when it is low. This signal overrides the PWM and Dir signals. The PWM controls the speed of the motor. When the PWM signal is high, power is applied to the motor. When PWM is low, the motor is disconnected from the power. Varying the ratio between high and low time of the PWM signal (ie. the duty cycle) allows the motor controller to change the average power applied to the motor. The Dir signal controls the direction of the motor. A high Dir signal causes the wheel to turn forward when power is applied. Similarly, the wheel will turn backward if the Dir signal is low when power is applied.

Feedback signals from Motor Controller: The encoder pulse output signals are buffered and connected to the Speed signal. The encoder provides 100 pulses per revolution. The PC/104 interface board uses the 82C54 timer/counter to count the pulses. On the Vesta board, the TPU handles the pulse counting. On the Vesta board, the TPU only counts the pulses and the position (and speed) of each motor is calculated using the D signal to determine the direction.
SENS measures the current in H-Bridge. This is connected to the Analog-Digital Converter on the interface board, then converted to digital signals to detect overcurrent

4.3 Serial Ports

4.3.1 PC/104 Serial Ports

ttyS0 is the primary serial port and is referred to by the board's ROM-BIOS as the PC-DOS 'COM 1' device. The secondary serial port is ttyS1. It is referred to by the board's ROM- BIOS as the 'COM2' device.

Table 4.3: PC/104 Serial Port

Pin	Signal Name	Function	In/Out	DB25	DB9
1	CD	Data carrier detected	In	8	1
2	DSR	Data set ready	In	6	6
3	RXD	Receive data	In	3	2
4	RTS	Request to send	Out	4	7
5	TXD	Transmit data	Out	2	3
6	CTS	Clear to send	In	5	8
7	DTR	Data terminal-ready	Out	20	4
8	RI	Ring indicator	In	22	9
9	GND	Signal ground		7	5

4.4 Power Output

The Power port can provide power to accessories. The Vcc output is a switched 5V regulated supply, and VBat output is switched unregulated battery power (about 24V on GAIA-2). This power can be turned on or off using the switch on the LCD board.

Table 4.4: Power Output

Signal Name	Mnemonic	In/Out	Active State
Ground	GND	Out	-
Power Supply (5V)	Vcc	Out	-
Power Supply	VBat	Out	-

4.5 Input/Output Signals from Accessories

Serial communication is used for input and output of signals from the accessories.

There are three serial communication ports in the stack: one connector on GAIA-2's control panel, and two connectors on the I/O board. When the robot is equipped with ultrasonic sensors (as in this robot), one of the serial ports is used to connect to the ultrasonic controller.

4.6 Ultrasonic Sensor Input/Output Signals

The ultrasonic sensor input/output signals are converted from an electrical signal to a value at the ultrasonic controller before it is transmitted through the serial port. When an obstacle is at the minimum distance (approximately 30 cm), the value is 8. When there are no obstacles, the value is 255. Each unit in the value given is equal to approximately 3 cm. Objects within the minimum range will not register on the sensors.

5. Using GAIA-2 (PC/104)

5.1 Features of the PC/104 On-board Computer

- 700 MHz Pentium III-M CPU
- 128 Mbyte DRAM
- Size: 15 x 90 x 95 mm
- AT-IDE hard disk interface
- Floppy disk interface
- Real-time clock with CMOS-RAM (battery backed)
- 1 parallel port
- 2 RS232 serial ports
- Speaker interface
- AT-keyboard interface or PS/2-keyboard interface
- PS/2 mouse interface
- VGA/LCD video interface
- PC/104 embedded BUS
- Power management functions
- Ethernet - 10baseT/100baseTX
- Single 5 volt supply
- Watchdog
- Power-fail EEPROM for set up and configuration

5.2 Boot-up the On-board Computer

Turn on GAIA-2 by turning the power key on the control panel at the rear of the robot (see Figure 5.1) in a clockwise direction (to vertical position). A bar may first appear on the LCD display. The kernel, sensors module, motor module, serial console, and button module will be loaded. This takes about 90 seconds.

5.5 Shutting Down

To shut down GAIA-2, press down and hold the two red push buttons near the LCD display (see Figure 5.1) for about four seconds. This causes the robot to go through a proper shutdown sequence. After the corresponding sequence has completed it is safe to turn the power off by turning the key counter-clockwise.

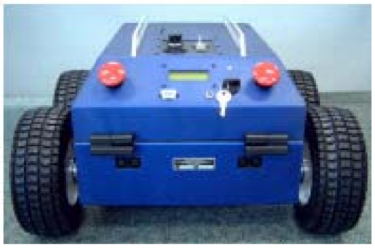


Figure 5.1 Key position at the rear of the robot

6. Vision System

6.1 GAIA-2 Vision System Overview

The vision system was developed using a powerful MSMG104+ Frame grabber and a bullet color camera 6005B. It is capable of excuting many image processing algorithms desired by machine vision research or application development. It also includes a Free Space Navigation System and an object searching application.

6.2 Features of MSMG104 Frame grabber

The MSMG104+ is a Framegrabber Module based on the BT848A / 878A controller.

- Size: PC/104plus Board
- Funct: Framegrabber PC/104-Plus
- Controller: BT848A / 878A
- Connector: 3 x Coax
- Bus: PCI
- Power Normal: 5V/100mA (typ.)
- Power Suspend: 5V/100mA (typ.)
- Operating Temp: -25C to +70C
- Weight: 80g

6.3 Features of 6005B Camera

Camera is mounted on top of the Harmonic Arm (Figure 6.1). Thus its pointing direction can be changed by setting different arm positions.

- Resolution: 380 lines
- Minimal Illumination: 1.0 LUX, f2.0
- Len Focal Lenth: Fixed 3.6mm
- Power Consumption: DC 8.5-15V/300ma
- TV system EIA, CCIR
- No. of Pixel for EIA: 512X492
- No. of Pixel for CCIR: 512X582
- Video Output 1.0-1.1 VP-P 75
- S/N Ratio: More than 48db

6.4 Free Space Navigation System

The Free Space Navigation System was designed to let GAIA-2 always moving to free space. It used a simple but efficient algorithm based on Ian Horswill's behavior-based visual navigation system. The source code is in the /home/robot/KNI/robotNavigation directory. To run the program, go to the directory and type command: ./robotNavigation katana5M.cfg

6.5 Object Searching Application

The object searching application on GAIA-2 with Harmonic Arm was designed to search for a red ball on the ground and approach to it (Figure 6.2). Then the robot tries to locate the ball using its vision system and the arm reaches for the ball to pick it up. The source code of object searching application is in the /home/robot/KNI/robotVISION directory.

To run the program, get to the directory and type commond:
./robotVISION katana5M.cfg

Figure 6.1 Camera position on top of the Harmonic arm

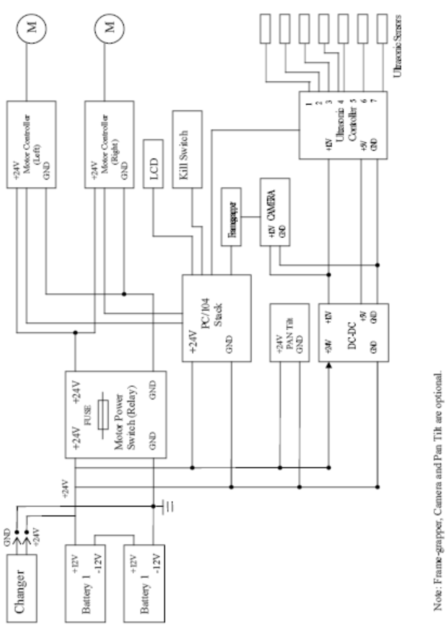
Figure 6.2 Harmonic arm scan position / object searching application

A. C Language Library for GAIA-2

In the manual provided with the robot there is a chapter that explains the C language library function included with GAIA-2. These functions are primarily used to access the main board that controls GAIA-2. They provide services such as GAIA-2's basic sensing, motor control, and serial communication. Also there are functions for periodic processing.

C. GAIA-2 Diagrams

The manual provided with the robot includes all relevant diagrams and block diagrams such as the one provided below necessary to use , assemble and add functionality to the robot as well as to explain all the functions of the robot.



D. GAIA-2 with Harmonic Arm Assembly Procedure

The manual provided with the robot includes all relevant information and pictures to connect the Harmonic Arm to the robot as illustrated below.

1. Attach the mounting plate (provided with the robot), where Harmonic Arm will be mounted) to GAIA-2.
2. Connect the front ultrasonic sensor with the sensor board on the attaching plate using the connector and cable.
3. Connect the arm serial cable with Harmonic Arm, then mount the Harmonic Arm on the mounting plate.
4. Rest the arm at start position.
5. Connect the Harmonic Arm power jack with GAIA-2 power cable.
6. Connect the serial port cable to the main serial port on GAIA-2.
7. Connect the camera power jack to GAIA-2 power cable.
8. Connect the video plug to the video-in jack on GAIA-2 panel.

Now you can turn on the arm power switch and turn on GAIA-2.

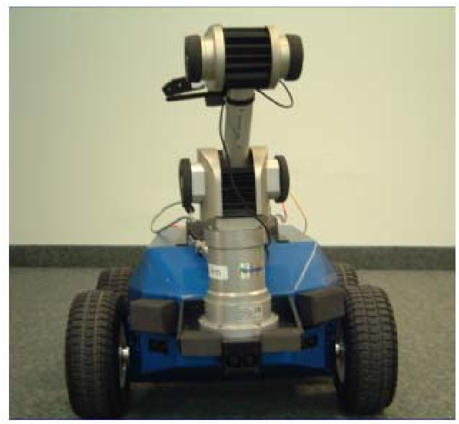


Figure D.1: Harmonic arm mounting position

Figure D.2: Start position of Harmonic Arm