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**Approved by:**

Dr. Ernest L. Hall
Dr. Ronald L. Huston
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# Remote administration of an autonomous guided vehicle through web based wireless interfaces

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# *Abstract*

Motion control is one of the most critical factors in the design of autonomous vehicles such as mobile robots. Bearcat III is an autonomous vehicle designed by the student at the Center for Robotics Research at the University of Cincinnati. The data transfer between the motion controller and the computer on Bearcat III is via serial port interface. This method is inflexible, sluggish and dated. A new motion control solution that uses a Galil DMC-2130 motion controller with a Galil ICM 1900 as the interconnect board is proposed. The new motion control system uses a DC brush less servo motor with encoders for feedback control. The choice of amplifier depends up on the choice of the motor type. This forms a closed loop feedback control system. The communication between motion controller (DMC-2130) and the central computer is achieved using Ethernet technology. This facilitates the use of Internet communication protocols and wireless communication standards to control the robot remotely. The new motion control system thus helps to control the robot via Internet and without physically present near the robot. The systems will be tested on the new robot, Bearcat cub, built by the students of the Center for Robotics Research. The significance of this work is in the increased understanding of motion control system for robot control and the synergetic combination of autonomous control of a robot and Internet and wireless communication standards in the field of defense and medicine.



**Keywords:** Mobile robot, motion control system, amplifier, encoder, motor, TCP/IP, wireless communication standards, 802.11 standards, remote desktop protocol, Windows XP, Windows 2000 server

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# Chapter 1

## *Introduction*

### 1.1 Motivation

There is a great amount of research devoted to motion control systems in mobile robot platforms and intelligent vehicles. The students of Center for Robotics Research at the University of Cincinnati has built an unmanned, autonomous guided vehicle (AGV); named Bearcat III for the Intelligent Ground Robotics Competition conducted each year by the Association for Unmanned Vehicle Systems (AUVS). Bearcat III is an intelligent autonomous vehicle. The vehicle is designed to navigate autonomously within the course of two lines, while avoiding obstacles and potholes. It can also navigate to pre-determined waypoints with the help of a global positioning system as well as follow another AGV. Bearcat III uses a Galil dynamic motion control system (DMC 1000) to control the motors. The DMC sends data to the computer using a RS-232 serial port interface. The data transfer rate is slow since it uses a serial port. Special driver interface programs have to be written to get data on to the computer. Besides this motion control system is old. The only way to interact with the onboard controller on robot is using it directly. There is no remote access to the computer on the robot. This handicaps the productive efficiency of the developer who writes programs to run the robot. A new motion control system from Galil Corporation, Galil DMC-2130 was tested for the new robot design. It uses an Ethernet card for communication, which makes it easier and faster to manage. The use of Ethernet technology has opened up some opportunities to utilize the advances in the field of communication using TCP/IP (Transfer control protocol/Internet protocol) suite of protocols.

## 1.2 Objective

The objective of this work is to develop a new motion control solution and provide remote access to the onboard controller on a robot. A new and advanced motion control system from Galil Inc., DMC-2130 is used as the motion controller for this project. DMC-2130 can communicate with the onboard controller via Ethernet technology or via RS232 serial port interface. For this project, the Ethernet communication protocols are used. Once Ethernet technology is introduced onto the mobile-guided vehicle, numerous possibilities for controlling the vehicle remotely have opened up. With the introduction of a wireless router on the robot, and using TCP/IP, one should be able to control the robot without actually going to the robot. The application of this is of prime importance while developing and testing application outdoors. The programmer can use his own laptop and communicate with the onboard computer through the wireless router without actually going to the robot. This feature also comes handy while attending the intelligent ground vehicle competition. The robot can also be controlled through Internet using the onboard wireless router. All these methods are proposed, compared, and tested in this thesis.

## 1.3 Organization of this Thesis

The thesis is organized into six chapters, with this chapter providing the introduction, motivation, and objective for this work. Chapter 2 describes the test bed on which the proposed models were tested. Chapter 3 presents an overview of the literature on the theory of motion control systems in autonomous guided vehicle systems. Chapter 4 describes the various components that go into the suggested models. Chapter 5 presents three different models for controlling an autonomous vehicle and a discussion about each of these models. Chapter 6 presents the conclusion and the direction of future research with recommendations for improvement and areas for further improvement.

# Chapter 2

## *Test Bed - The Bearcat III*

Bearcat III is an Autonomous Guided Vehicle built at The University of Cincinnati Center for Robotics Research. The vehicle is capable of following line tracks and avoiding obstacles on the path. It also has navigational capabilities using a global positioning system (GPS). The specifications and performance of the vehicle is explained in table 2.1 below.

| | Task | Predicted Performance |
|---|---|---|
| 1 | Line Following | Tracks lines with an accuracy of 0.3 inches |
| 2 | Obstacle Avoidance | Detects obstacles 8 inches and higher in a range of 24 feet |
| 3 | Pothole Detection | Detects simulated potholes across the 10 feet track and a distance of 4 feet |
| 4 | Waypoint Detection | Navigates waypoints with an accuracy of 5 feet |
| 5 | Emergency Stop | Has a remote controlled emergency stop that can be activated from a distance of 65 feet |
| 6 | Dead End Detection | Detects dead ends and avoids traps by backing up and following alternative route |
| 7 | Turning Radius | Vehicle has a zero turning radius |
| 8 | Maximum Speed | 5 miles per hour |
| 9 | Ramp Climbing Ability | Can climb inclines up to 10 % |
| 10 | Braking Distance | Vehicle comes to a dead stop as soon as the power is cut off |

**Table 2.1 The predicted performance of the Bearcat III**

## 2.1 Major systems and components of Bearcat III

Figure 2.1 shows the major subsystems of the Bearcat III According to the functionality Bearcat III has been categorized into the following major units as –

a. Vision system

b. Motion control system

c. Sonar system

d. Laser scanner system

e. Mechanical system

f. Navigation system

g. Electrical system

h. Health and Safety systems

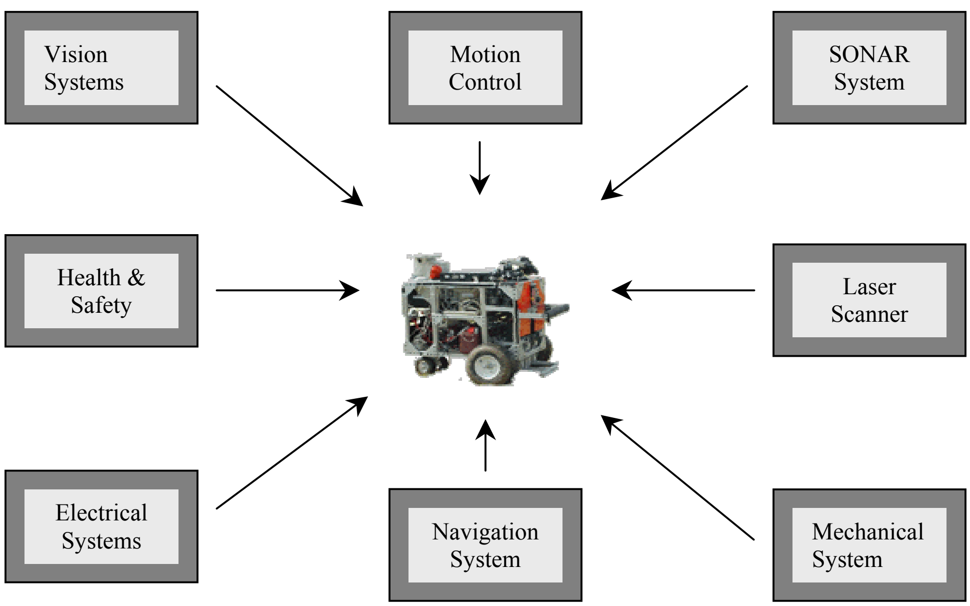


**Figure 2.1 The major subsystems of the bearcat**

## 2.2 Vision System

The Bearcat III was designed to negotiate around an outdoor obstacle course in a prescribed time while staying within a 5 mph speed limit and avoiding the obstacles on the track. The Bearcat's vision system for the autonomous challenge comprises three cameras, two for line following and one for pothole detection. The vision system for line following uses two charge-coupled device (CCD) cameras and an image tracking device (ISCAN ®)[1] for the front end processing of the image captured by the cameras. The ISCAN tracker is used to process the image of the line. The tracker finds the centroid of the brightest or darkest region in a captured image. The three dimensional world co-ordinates are reduced to two dimensional image coordinates using transformations between the ground plane and the image plane. A novel four-point calibration system was designed to transform the image co-ordinates back to world co-ordinates for navigation purposes. Camera calibration is a process to determine the relationship between a given 3-dimensional coordinate system (world coordinates) and the 2-dimensional image plane a camera perceives (image coordinates). The objective of the vision system is to make the robot follow a line using a camera. At any given instant, the Bearcat tracks only one line, either right or left. If the track is lost from one side, then the central controller through a video switch changes to the other camera. In order to obtain accurate information about the position of the line with respect to the centroid of the robot, the distance and the angle of the line with respect to the centroid of the robot has to be known. When the robot is run in its auto-mode, two Iscan windows are formed at the top and bottom of the image

[1] ISCAN® is a registered trademark of ISCAN, Inc. http://www.iscaninc.com/

screen as shown in Figure 2.2. The Iscan tracker returns the centroids of the line segments. These are shown as points (x1, y1) and (x2, y2) in Figure 2.2. These data-points are used to determine the angle and distance of the line to the robot as shown in Figure 2.3. The calculated distance and angle are used as inputs for the motion control system.

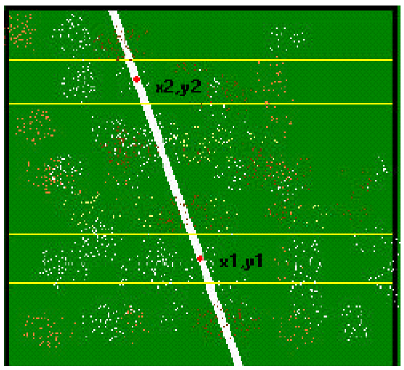


**Fig 2.2 Two windows are used to capture two points on the boundary line.**

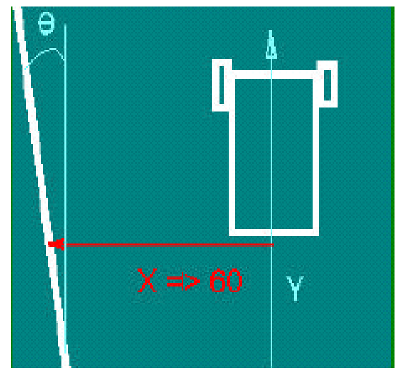


**Fig 2.3 Robot in relation to the line**

## 2.3 Motion Control System

The motion control system shown in the Figure 2.4 enables the vehicle to move along a path parallel to the track and to negotiate obstacles.  Steering is achieved by applying differential speeds to the left and right wheels. Manipulating the sum and difference of the speed of the right wheels, the velocity and orientation of the vehicle can be controlled at any instant. Two motors power the gear trains. The motor torque is increased by a factor of 40 using a worm gear train. The power to each motor is delivered through an amplifier that amplifies the signal from the Galil®[2] DMC motion controller. The data

[2] Galil Motion control http://www.galilmc.com

from the vision and obstacle avoidance systems work as an input to the central controller to give commands to the motion control system to drive the vehicle.

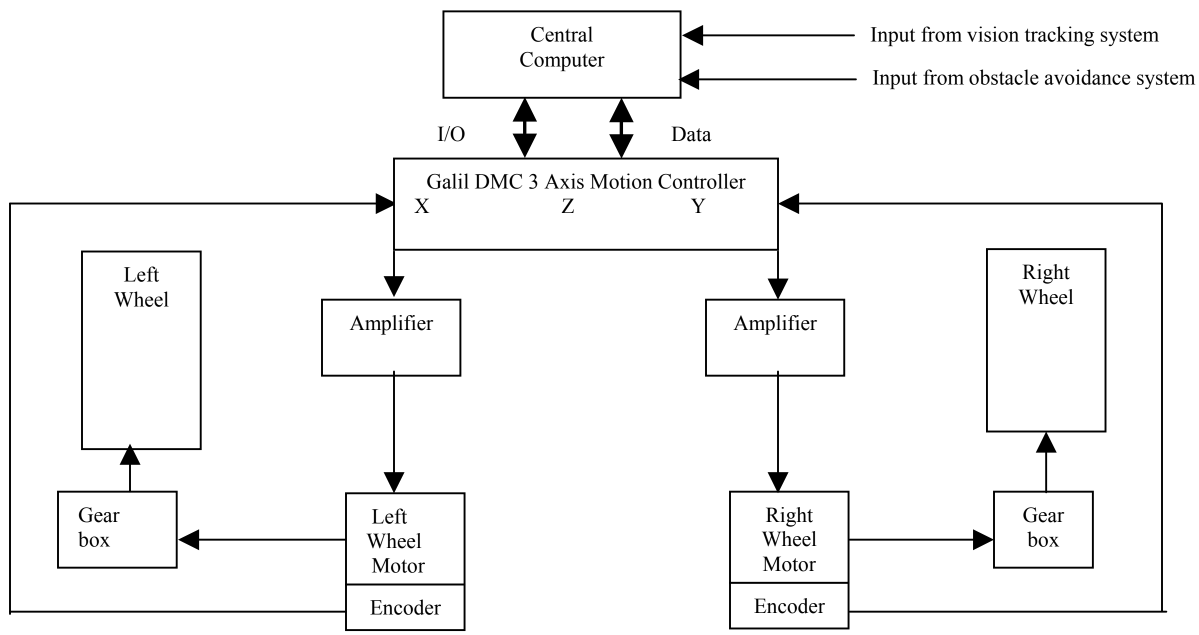


**Figure 2.4 Motion control system block diagram**

## 2.4 Sonar System

The two main components of the ultrasonic ranging system are the transducers and the drive motor. A 12 Volts DC, 0.5 Amps unit powers the sonar system. A “time of flight” approach is used to compute the distance from any obstacle. The sonar transmits sound waves towards the target, detects an echo, and measures the elapsed time between the start of the transmit pulse and the reception of the echo pulse. The transducer sweep is achieved using a motor and Galil motion control system. Adjusting the Polaroid system parameters and synchronizing them with the motion of the motor permits measuring distance values at known angles with respect to the centroid of the vehicle. The distance value is returned through an RS232 serial port to the central controller. The central controller uses this input to drive the motion control system. The range of this system is 40 feet.

## 2.5 Laser Scanner System

The Bearcat uses the SICK®[3] laser scanner (LMS 200) for sensing obstacles in the path. The power supply to the unit is through a 24Volt, 1.8 Amp adapter. The unit communicates with the central computer using a RS422 serial interface card. The maximum range of the scanner is 32 meters. For the practical purpose, a range of 8 meters with a resolution of $1^{o}$ has been selected. The scanner data is used to get information about the distance of the obstacle from the robot. This can be used to calculate the size of the obstacle. The scanner is mounted at a height of 8 inches above the ground to facilitate the detection of short as well as tall objects. The central controller performs the logic for obstacle avoidance and the integration of this system with the line following and the motion control systems.

## 2.6 Waypoint Navigation

Bearcat-III is designed to autonomously travel from a starting point to a number of target destinations and return to home base, avoiding obstacles in the course, knowing the coordinates of those targets. The waypoint navigation is achieved by using a differential GPS as explained below.

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[3] SICK AG
http://www.sick.de/de/products/categories/auto/lasermeasurementsystemsindoor/lms200indoor/en.html

### *2.6.1 Waypoint Navigation Using Global Positioning System*

The methodology behind the Bearcat navigational challenge problem was to select a commercially available GPS unit and utilize the built in features of the unit to provide a solution to the GPS navigational problem. This approach relies on the GPS unit's navigational processing features and reduces the computational load that the robot CPU must perform to navigate the course. The basic criteria used in the selection of the GPS unit are WAAS (Wide Area Augmentation System) capability, RS-232 serial port input/output ability, external antenna, external power capability, and embedded navigation features. Based on these selection criteria the Garmin[4] GPS 76 was chosen as the unit to provide GPS navigational ability to the robot. The major navigational features of the GPS unit used in the solution of the GPS navigational problem are the ability to input/output NMEA (National Marine Electronics Association) messages, set target waypoints, and calculate bearing/range information to the target waypoint.

## 2.7 Mechanical System

The mechanical system as a whole serves as steering control for the robot. Bearcat III is an outdoor vehicle designed to carry a payload of 100 pounds. The frame of the vehicle has been designed keeping in mind the outdoor conditions. Standard design procedures were used for initial calculations. CAD software i.e. AutoCAD Release 14 and IDEAS were used for the final design process for stress and load analysis. The components include 40:1 reduction gearbox, two pairs of flexible couplings, two 36 volts servomotors

[4] Garmin Ltd. http://www.garmin.com/

and two sets of wheels with shafts, couplings and keys. The computer through Galil motion controller controls the servomotors, which supply power to the gear train for the mechanical motion transmission. Two separate gearboxes are used to individually power the wheels. Worm gears with a ratio of 40:1 are used to transmit power to the wheels through a mechanical coupling. The self-locking mechanism of the worm gears does not require the vehicle to have a separate mechanical breaking system. Power is transmitted to the front wheels. The rear wheel is a castor wheel and this gives the Bearcat a zero turning radius.

## 2.8 Power System

The Bearcat's electrical system consists of a DC battery power system that supports an AC power system through an inverter. Three 12-Volt DC, 130 Amp hours, deep-cycle marine batteries connected in series provide a total of 36 Volts DC, 4680 Amp hours for the main electrical power. A 36-Volt, DC input, 600-Watt inverter provides 60 Hz pure sine wave output at 115 Volts AC. The inverter supplies AC electrical power for all AC systems including the main computer, cameras, and auxiliary regulated DC power supplies. An uninterruptible power source (UPS) interfaces the robot main computer with the AC power system. The UPS provides 3 minutes of emergency power to the main computer during AC power system interruptions. The UPS allows the main computer to be properly shutdown or connected to an external power source if the main robot AC power system is offline. The DC system provides 36 volts unregulated DC electrical power to the motors at a maximum of 10 Amps. The total power required by the Bearcat is approximately 735 Watts for the DC systems and 411.3 Watts for the AC systems. Thus, 1146-Watts total power is required to operate the Bearcat III. A loss of 10 percent was estimated for the required power to yield 1261 Watts actually required. A 10 percent loss can also be assumed for power supplied by the batteries to yield 4212-watt hours available. Based on these estimates the Bearcat III power system has an estimated endurance of 3.34 hours at full load. A spare set of batteries is available and will be needed during the contest runs.

## 2.9 Health Monitoring System

The Bearcat III is equipped with a self-health monitoring system. A RS-232 serial port is used to take input from a digital multi meter, which can be accessed from C++ code to check the total DC voltage of the batteries. The health monitoring is implemented as a C++ class module that has methods that can monitor battery voltage and display warning messages to the computer screen. Two voltage threshold trip points can be set that will trigger a low voltage and a critical low voltage warning message. The low voltage warning indicates that the battery voltage is below the first threshold trip point and that preparations should be made to change or charge the batteries. The critical low voltage warning indicates that corrective actions must be taken immediately because robot power system shutdown is eminent. The voltmeter class can also be used in code to sound an audible alarm or activate the robot strobe light at the specified threshold point. The power system voltage display is also visible to the operator and provides a constant indication of the robot electrical voltage.

## *2.10 Safety System*

The safety system of Bearcat III consists of a manual emergency stop button on the robot and a remote controlled emergency stop.

### 2.10.1 Manual Emergency Stop

The manual emergency stop unit consists of a red manual push button located on the rear surface of the vehicle, easily accessible. When pressed, the power to the motors is cut off and the self-locking mechanism of the gearbox brings the vehicle to an instant halt. The self-locking mechanism ensures that the vehicle does not move when it is not powered, and serves as a safety measure against any undesirable motion such as rolling when parked on a slope.

### 2.10.2 Remote Controlled Emergency Stop

The remote controlled emergency stop unit can de-activate the mobile robot from a distance of no less than 50 feet. The remote controlled emergency stop consists of a Futaba transmitter, a receiver, an amplifier and a relay. The advantage of using this is that the transmitter need not be in line with the sight of the receiver. The Futaba transmitter uses a 6V DC and transmits FM signals at 72.470 MHz over a range of 65 feet. This amplified current activates the contacts of the relay that in turn activates the emergency stop solenoid and cuts power to the motors.


**Figure 2.5 Bearcat III in 2003 IGVC competition**


**Figure 2.6 UC Robotics team after winning navigational challenge**

# Chapter 3

## *Literature review*

### 3.1 Motion control in mobile robots

Motion control is one of the corner stones of industrial automation and robotics. In mobile robots motion control design is one of the most challenging modules. Almost all the mobile robots use a closed loop feedback control system to navigate the robot. In many mobile robots, steering control mechanism implementing a proportional, integral and derivative (PID) controller is used to control identical motors on both sides of the motor individually[12]. The values of the PID controller are set and adjusted with the error signal obtained from the BEI®[5] encoder system attached to the motor[9]. The loop continues to correct the signal and feed the drive train. Recent studies in motion control systems have used fuzzy enhanced adaptive control for drive using genetic algorithms[5]. This study is mainly useful if the robot uses a flexible drive system and expecting a high variance of friction. Studies to avoid wheel slippage and mechanical damage during mobile robot navigation have concentrated on the dynamic constraints on the robot[4]. The proposed solution is based on the design of a path-tracking algorithm based on the driving velocity control law and bang-bang control. Study on dynamic modeling and robust control of a differentially steered mobile robot[3] proposes a variable structure control method employed to design a tracking controller of the mobile robot.

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[5] BEI Industrial Encoder Division http://www.motion-control-info.com/index.html

## 3.2 Wireless communication and Internet protocols

Wireless communication has evolved tremendously in recent years with the third generation technology (3G) currently available in most parts of the world. The single most manifestation of wireless technology is in cell phones. Global system for mobile communication (GSM) is a globally accepted standard for digital cellular communication. It operates at 900MHz frequency. This standard is mostly used in Europe and Asia. Cellular systems began in the United States with the release of the advanced mobile phone service (AMPS) system in 1983. Throughout the evolution of cellular telecommunications, various systems have been developed without the benefit of standardized specifications. This presented many problems directly related to compatibility, especially with the development of digital radio technology. The GSM standard is intended to address these problems. New services based on GSM like General Packet Radio Service (GPRS) enabled networks offer 'always-on', higher capacity, Internet-based content and packet-based data services. This enables services such as color Internet browsing, e-mail on the move, powerful visual communications, multimedia messages and location-based services.

The biggest leap in wireless communication came when computers in a local area network (LAN) can communicate with each other without wired connection. The standard used for wireless LANs is called 802.11. 802.11 is a family of specifications for wireless local area networks (WLANs) developed by a working group of the Institute of Electrical and Electronics Engineers (IEEE). There are currently four specifications in the family: 802.11, 802.11a, 802.11b, and 802.11g. All four use the Ethernet protocol and CSMA/CA (carrier sense multiple access with collision avoidance) for path sharing.

The most recently approved standard, 802.11g, offers wireless transmission over relatively short distances at up to 54 megabits per second (Mbps) compared with the 11 megabits per second of the 802.11b standard. Like 802.11b, 802.11g operates in the 2.4 GHz range and is thus compatible with it. The biggest advantages of these standards are they use the popular Ethernet technology for LAN and the popular TCP/IP suite of Internet protocols. The 802.11b standard - often called Wi-Fi - is backward compatible with 802.11. The modulation method selected for 802.11b is known as complementary code keying (CCK). The 802.11a specification applies to wireless ATM systems and is used in access hubs. 802.11a operates at radio frequencies between 5 GHz and 6 GHz. It has data speeds as high as 54 Mbps, but most commonly, communications takes place at 6 Mbps, 12 Mbps, or 24 Mbps[23]

## 3.3 Open access to mobile robots on Internet

In the past, various attempts to bring mobile robot control to Internet have been made. Patrick Saucy et al [13] has described their efforts to use a live camera and a web server on the central computer of the mobile robot to accomplish this. The hardware and the communication system used were primarily in the nascent stage. The interaction between the web server and the programs were achieved by CGI-scripts that are cumbersome to write. On the client side Java applets were used. Java applets tend to be slow and the user experience may be compromised. RS-232 serial port interfaces were used for data communication. Earlier work on providing to universal access to remote robots can be seen in the work of Zhen et al [14]. Their approach was to standardize the interface to an existing robot and provide connectivity to Internet and provide a universal interface to remote users using browser. The operating system on the computers on robots was Linux and they used Linux shell scripts and application program interface (API) to provide access to the control programs to the remote users. Again RS-232 serial port interface was the preferred method of communication. All the computers were connected to an Ethernet LAN and the central computer communicates with the web server using AT&T/NCR's waveLAN wireless network. TCP/IP communication protocols were also used. Roning et al [16] has suggested using a virtual user interface (VUI) to communicate remotely and over the Internet to personal robots and devices in smart environments. The communication between the robot and the VUI on the control device is achieved with the help of a middleware called control for ubiquitous embedded systems (CUES). A CUE is an embedded prototype platform. When the control device wants to interact with the robot, it downloads a mobile code from the robot using the mobile protocol code and the short-range wireless communication link. The robot should contain a CUES interface program that implements CUES specific functionality and acts as a mediator between the VUI and the robot hardware. The system can interact with other devices in any smart environment as long as the device has CUES interface. The programming is done using Java applets. The disadvantage of this model is that it uses a lot of custom-built programs, which make it difficult to keep up to date with the latest advances in technology.

# Chapter 4

# *Components of the wireless remote administration system*

## 4.1 Control system

Motion control system is very critical to the effective functioning of a mobile robot. Often the motion control system in mobile robots has to interact and coordinate with other modules to achieve its purpose. The basic principle of the motion control system is based on the closed loop feedback control system. The proposed system uses a proportional, integral and derivative (PID) controller. The error signals are fed into the system to correct the signal. The components of the system are explained below. The elements of a motion control system are show below.

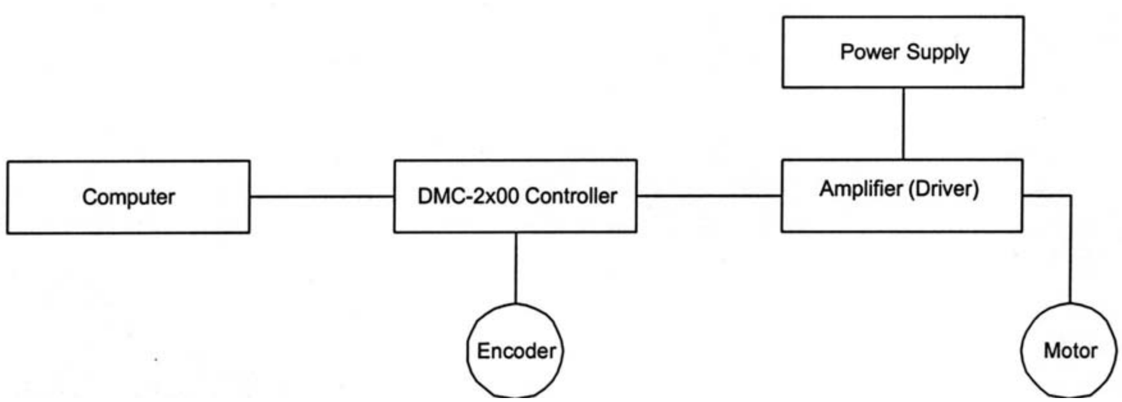


**Figure 4.1 Elements of a servo system**[11]

## 4.1.1 Dynamic motion control system

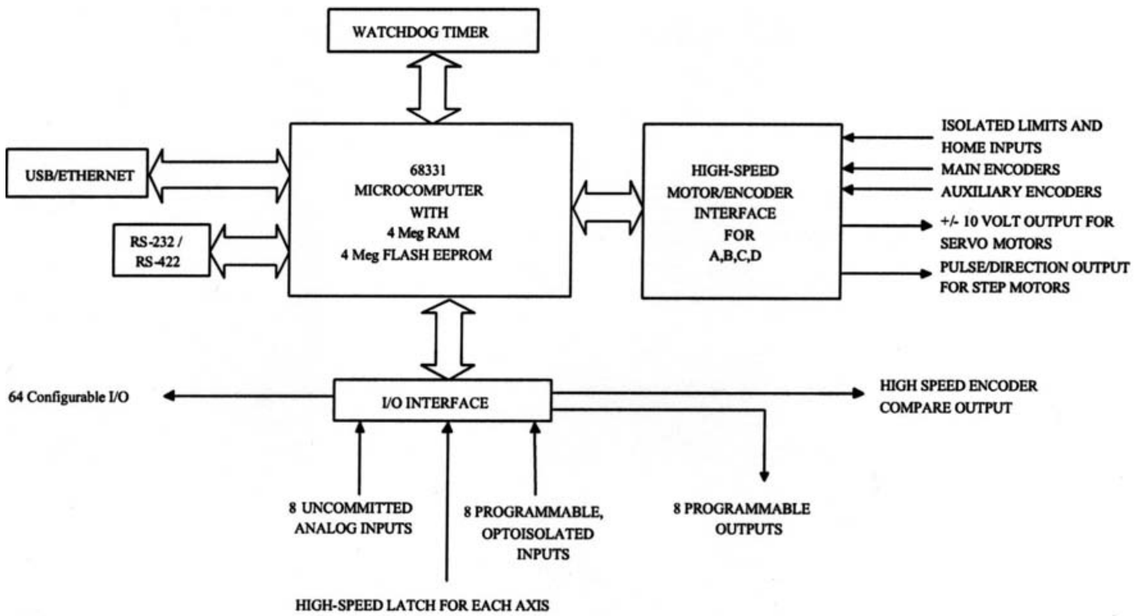


**Figure 4.2 DMC-2130 functional elements[11]**

The controller forms the brain of a motion control system. For the proposed models, Galil DMC-2130 is used as motion controller. DMC-2130 provides the interface to the central computer and to the other elements of the motion control system. It has many features including high-speed communications, non-volatile program memory, faster encoder speeds, and improved cabling for electro magnetic interference reduction. The DMC offers two communication channels: high speed RS-232 (two channels up to 115K Baud) and 10BaseT Ethernet. For this paper, 10Base T Ethernet is chosen for communicating with the central computer. DMC-2130 has three axes, which means it can control three motors. It’s designed to solve complex motion problems like jogging, point-to-point positioning, vector positioning, electronic gearing, multiple move sequences, and contouring. Commands can be sent in either Binary or ASCII. Application programs to interface with the central computer can be written in DOS, Linux, Windows 3.1, 95, 98, 2000, ME and NT.

The main processing unit of the DMC-2x00 is a specialized 32-Bit Motorola[6] 68331 Series Microcomputer with 4MB RAM and 4 MB Flash EEPROM (electrically erasable programmable read-only memory). The RAM provides memory for variables, array elements and application programs. A 4MB Flash EEPROM provides non-volatile memory for storing application programs, parameters, arrays and firmware. For motor interface, sub-micron gate array performs quadrature decoding of each encoder at up to12 MHz. For standard servo operation, the controller generates a +/-10 Volt analog signal (16 Bit DAC). For sinusoidal commutation operation, the controller uses two digital to analog converters (DAC) to generate 2 +/-10Volt analog signals. For stepper motor operation, the controller generates a step and direction signal. The DMC-2x00 provides an internal watch dog timer which checks for proper microprocessor operation. The timer toggles the Amplifier Enable Output (AMPEN), which can be used to switch the amplifiers off in the event of a serious DMC-2x00 failure. A reset is required to restore the DMC-2x00 to normal operation.

### 4.1.2 Interconnect module

The Interconnect module, ICM-1900 interconnect module, provides easy connections between the DMC-2130's controller and other system elements, such as amplifiers, encoders, and external switches. The ICM-1900 accepts the 100-pin main cable and 25-pin auxiliary cable and breaks them into screw-type terminals. Each screw terminal is

[6] Motorola, Inc. http://www.motorola.com

labeled for quick connection of system elements. An ICM-1900 is required for each set of three axes. The DMC-2130 is connected to ICM-1900 using a 112-pin connector. The DMC translates the commands from the computer and passes it on to interconnect board.

### 4.1.3 Theory of control system

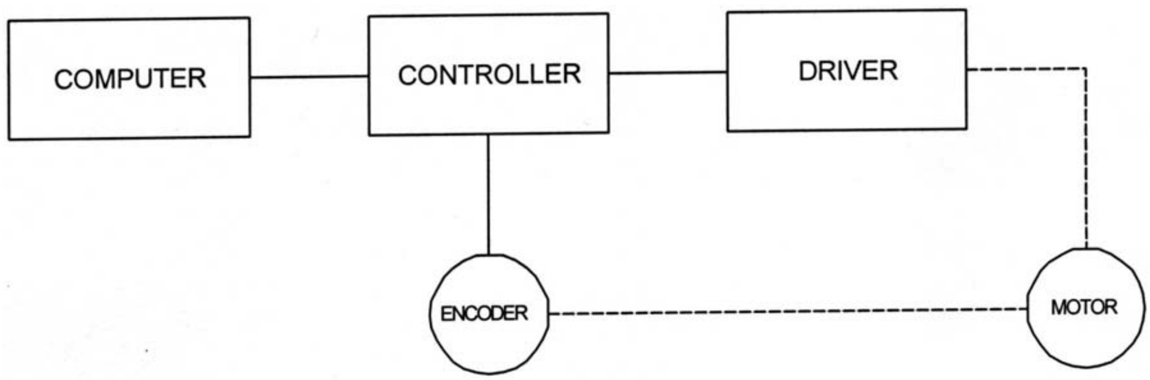


**Figure 4.3 Elements of a servo system[11]**

The operation of a motion control system can be divided into three levels: closing the loop, motion profiling and motion programming. The first level, the closing of the loop, assures that the motor follows the commanded position. Closing the position loop using a sensor does this. The operation at the basic level of closing the loop involves the subjects of modeling, analysis, and design. The motion profiling is the generation of the desired position function. This function, describes where the motor should be at every sampling period. The profiling and the closing of the loop are independent functions. The profiling function determines where the motor should be and the closing of the loop forces the motor to follow the commanded position. The highest level of control is the motion program. This can be stored in the host computer or in the controller. This program describes the tasks in terms of the motors that need to be controlled, the distances and the speed.

The operation of a servo system is achieved using a feedback signal. Depending upon the signal, a corrective action is initiated until the desired value is obtained. The over reaction of a signal can cause oscillation and it leads to instability. The delay in servo systems is between the application of the current and its effect on the position. The current must be applied long enough to cause a significant effect on the velocity, and the velocity change must last long enough to cause a position change. This delay, when coupled with high gain, causes instability. This motion controller includes a special filter, which is designed to help the stability and accuracy. Typically, such a filter produces, in addition to the proportional gain, damping and integrator. The combination of the three functions is referred to as a PID filter. The filter parameters are represented by the three constants KP, KI and KD, which correspond to the proportional, integral and derivative term respectively. The damping element of the filter acts as a predictor, thereby reducing the delay associated with the motor response. The integrator function, represented by the parameter KI, improves the system accuracy. With the KI parameter, the motor does not stop until it reaches the desired position exactly, regardless of the level of friction or opposing torque. The integrator also reduces the system stability. Therefore, it can be used only when the loop is stable and has a high gain. The output of the filter is applied to a digital-to-analog converter (DAC). The resulting output signal in the range between +10 and -10 Volts is then applied to the amplifier and the motor. The motor position, whether rotary or linear is measured by a sensor. The resulting signal, called position feedback, is returned to the controller for closing the loop.

### 4.1.4 Amplifier

An amplifier is an electronic component that boosts the voltage or power level of a signal that is a linear replica of the input signal, but with greater power or voltage level, and sometimes with an impedance transformation. The output may also be a nonlinear analog function of the input signal, as in a signal compression device. The amplifiers chosen should be suitable for the motor and may be linear or pulse-width-modulated. For each axis, the power amplifier converts a +/-10 Volt signal from the controller into current to drive the motor. An amplifier may have current feedback, voltage feedback or velocity feedback. Amplifiers in current mode should accept an analog command signal in the +/-10 Volt range. The amplifier gain should be set such that a +10V command will generate the maximum required current. For velocity mode amplifiers, a command signal of 10 Volts should run the motor at the maximum required speed. The velocity gain should be set such that an input signal of 10V runs the motor at the maximum required speed. For step motors, the amplifiers should accept step and direction signals.

Current mode is generally used for positioning involving a digital motion controller and encoder feedback. Velocity mode is typically used where four-quadrant speed control is needed, such as an inclined conveyor with an overhauling load. For this project a DC brushless servomotor is selected and the current mode of amplifier is set. For this project, an amplifier (Copley Controls Xenus CANopen Digital Servo Amplifier, 12 Arms, 85-264 VAC powered) from Copely controls corporation[7] is used

[7] Copley Controls Corp. http://www.copleycontrols.com/motion/downloads/pdf/CANopenBrochure.pdf

### 4.1.5 Motor

The common motors used are servo or stepper in nature. For this project, standard DC servomotor (PMA series brushless servomotor with commutating encoder 1024 lines/rev) from Pacific Scientific[8] is used. The DMC-2130 can control the following type of motors: Standard servo motors with +/- 10 volt command signals, brushless servo motors with sinusoidal commutation, AC or DC brushless servo motor, step motors with step and direction signals, and other actuators such as hydraulics. To control a standard DC servo motor the DMC uses a 16-bit motor command output DAC and a sophisticated PID filter that features velocity and acceleration feed forward, an extra pole filter and integration limits. The PID filter has three parameters: the damping, KD; the proportional gain, KP; and the integrator, KI. The parameters should be selected in this order. The DMC can control stepper motors. In this mode, the controller provides two signals to connect to the stepper motor: step and direction. For stepper motor operation, the controller does not require an encoder and operates the stepper motor in an open loop fashion.

### 4.1.6 Encoder

An encoder translates motion into electrical pulses, which are fed back into the controller. The DMC-2130 accepts feedback from either a rotary or linear encoder. Typical encoders provide two channels in quadrature, known as CHA and CHB. This type of encoder is known as a quadrature encoder. Quadrature encoders may be either single-ended (CHA and CHB) or differential (CHA, CHA- and CHB, CHB-). The DMC-2130 decodes either

[8] Pacific Scientific http://www.pacsci.com

type into quadrature states or four times the number of cycles. Encoders may also have a third channel (or index) for synchronization. For this project, the encoder that comes as a built-in unit with the motor is used. The encoder uses a single –ended channel with no channel for synchronization. For stepper motors, the DMC-2x00 can also interface to encoders with pulse and direction signals.

## 4.2 Wireless system

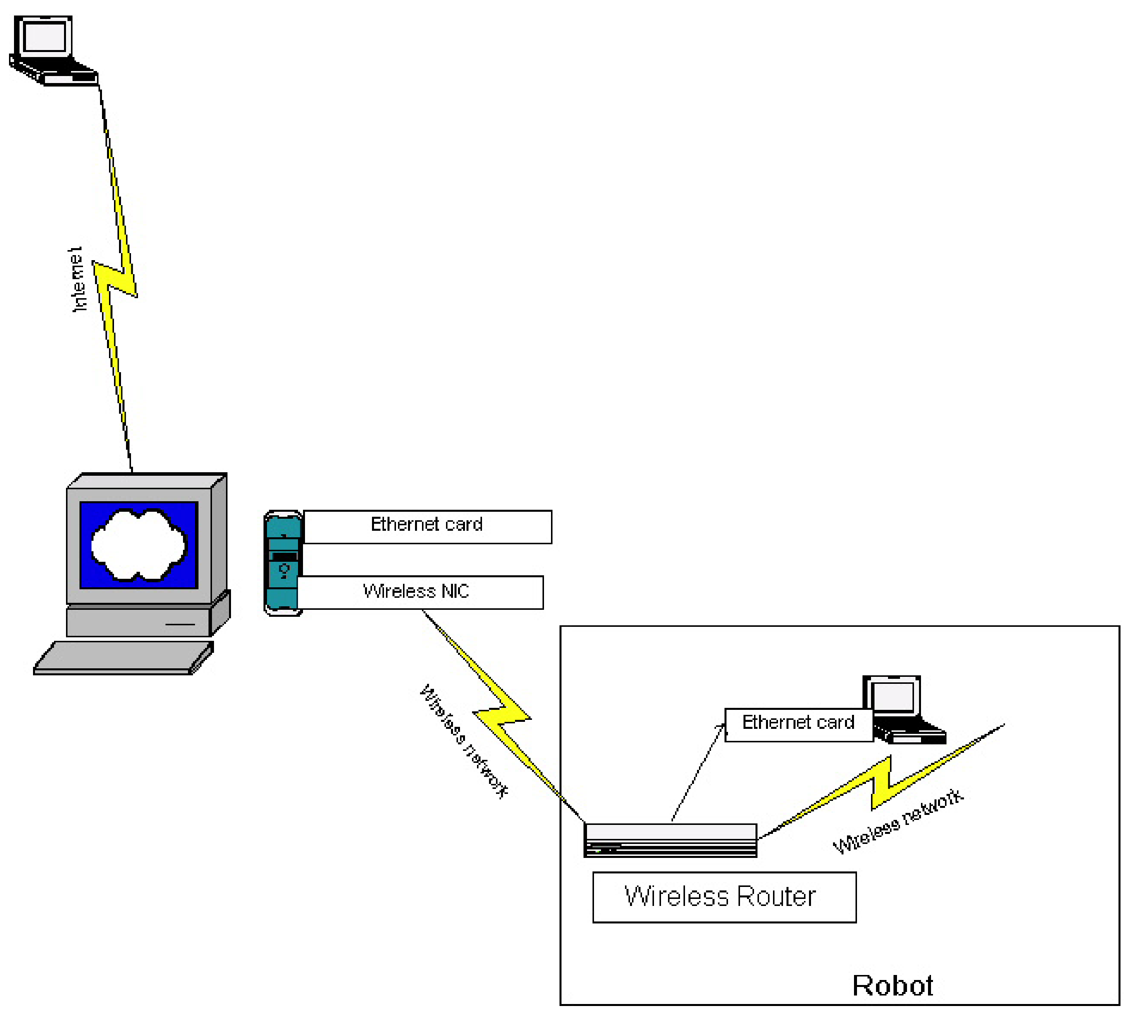


**Figure 4.4 Elements of wireless system**

The wireless system consists of a wireless router and wireless network interface card (NIC) as shown in Figure 4.4. The objective is to create wireless local area network (WLAN) using these components on the robot. A wireless LAN (WLAN) is a data transmission system designed to provide location-independent network access between computing devices by using radio waves rather than a cable infrastructure. The wireless router acts as a gateway to this WLAN. The external computer will have two network interface cards. One a traditional Ethernet network interface card that is connected to the Internet and the other a wireless NIC. The wireless network around the robot facilities communication with the Internet.

### 4.2.1 Transfer Control Protocol/Internet Protocol (TCP/IP)

The Internet protocol suite, TCP/IP, was developed by the Defense Advanced Research Projects Agency (DARPA) in the mid 1970s, with the architecture and protocols taking their current form around 1977-79. The technique selected for multiplexing was packet switching, as the applications which should be supported were naturally served by the packet switching paradigm, and the networks which were to be integrated together were packet switched networks. The TCP/IP or Internet Protocol suite consists of several protocols. The more common ones are: TCP,UDP, ICMP,IP, ARP, and RARP. These protocols are explained below.

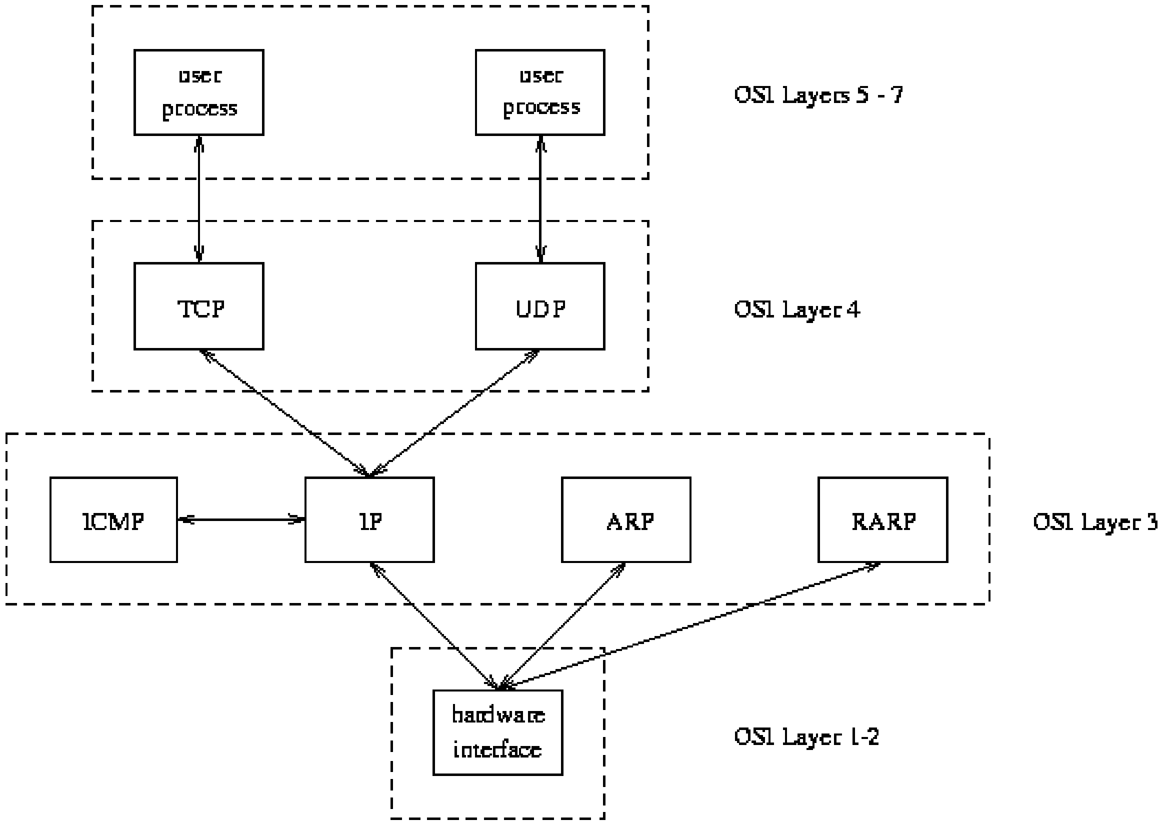


**Figure 4.5 The components of the Internet protocol suite[21]**

**TCP**: The *Transmission Control Protocol* is a connection-oriented protocol which provides a reliable, full-duplex byte stream. It uses the Internet Protocol to transfer data. TCP is the most used protocol for user processes. This is the reason why the Internet Protocol suite is often called TCP/IP.

**UDP**: The *User Datagram Protocol* is an unreliable connectionless protocol for user processes.

**ICMP**: The *Internet Control Message Protocol* is used for handling error and control information. It uses the Internet Protocol to exchange data. User processes normally do not need access to ICMP, as ICMP messages are generated and processed by the TCP/IP networking software.

**IP**: The *Internet Protocol* is the basic protocol that provides a best effort packet delivery service for UDP, TCP, and ICMP. User processes normally use only TCP or UDP, the direct use of IP is seldom.

**ARP**: The *Address Resolution Protocol* maps an Internet address to a hardware address. Only some networks need it.

**RARP:** The *Reverse Address Resolution Protocol* maps a hardware address into an Internet address.

Open systems interconnect (OSI) model, developed by International standards organization (ISO) in 1978, is a model for network architecture and a suite of protocols (a protocol stack) and act as a framework for international standards in heterogeneous computer network architecture. The OSI architecture is split between seven layers, from lowest to highest: 1 physical layer, 2 data link layer, 3 network layer, 4 transport layer, 5 session layer, 6 presentation layer, and 7 application layer. Each layer uses the layer immediately below it and provides a service to the layer above. In some implementations a layer may itself be composed of sub-layers. The ISO/OSI protocol with seven layers is the usual reference model. Since TCP/IP was designed before the ISO model was developed it has five layers; however the differences between the two are mostly minor. Table 4.1 is a comparison of the TCP/IP and OSI protocol stacks.

OSI seven-layers Model TCP-IP Reference Model

| | | | | |
|---|---|---|---|---|
| It is the totality of all applications and their relating protocols that use networks and have not yet been represented by the lower layers. | Application Layer | | TCP/IP Application | Like OSI Model, it contains all the higher-level protocols. |
| Here are the standards necessary for unambiguously representing data and more generally, a syntax of messages to be transmitted (simple text, executable code, pictures...). | Presentation Layer | | | Because no need for them was perceived, Presentation and Session layers are not included in the TCP/IP Model |
| It establishes a connection with another node and manages the data flow from the higher layers to the lower ones by managing the timing of data transmission and the memory buffer managing, when several applications try to transmit data at the same time. | Session Layer | | | |
| It handles the transmission, reception and error checking of the data. TCP and UPD are the main protocols. | Transport Layer | | Transport Layer | The same as OSI Model |
| It is concerned with the physical transmission of the data from computer to computer. There is one further level of software to be considered, the network level. It routes the packages across a particular network. | Network layer | | Internet protocol | It is the linchpin that holds the whole architecture together: it permits to send and receive packets, even if they are in random order. |
| It handles the transmission of a framed set of data (usually a sequence of bits) from one point in a network (node) to another one. This layer also represents the boundary between hardware (e.g. CRC) and software implementation (e.g. physical addressing). | Data link Layer | | Data link Layer | The TCP/IP reference model does not really say much about what happens here, except to point out that the host has to |
| The physical medium used to transmit the information. To specify this layer, it is necessary to define the physical properties of the connection, such as mechanical properties, electrical/optical properties, functional aspects of the data | Physical Layer | | Physical Layer | connect to the network using some protocol so it can send IP packets over it. This protocol is |

| | | | | |
|---|---|---|---|---|
| transmission (modulation/demodulation for example) and procedural aspects of data transmission (e.g. bit stuffing to ensure that special signals are unequivocal). | | | | not defined and varies from host to host and network to network. |

**Table 4.1 OSI Model versus TCP/IP protocol[22]**

# 4.2.2 802.11b wireless protocol

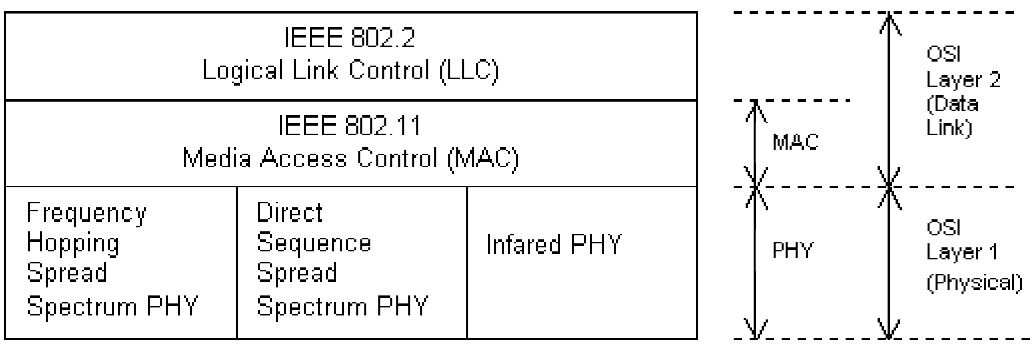


**Figure 4.6: IEEE 802.11 standards mapped to the OSI reference model[7]**

In 1997 the IEEE (Institute of Electrical and Electronics Engineers, Inc.) adopted IEEE Std. 802.11-1997, the first wireless LAN (WLAN) standard. This standard defines the media access control (MAC) and physical (PHY) layers for a LAN with wireless connectivity. It addresses local area networking where the connected devices communicate over the air to other devices that are within close proximity to each other. Specifically, the 802.11 standard addresses:

- Functions required for an 802.11 compliant device to operate either in a peer-to-peer fashion or integrated with an existing wired LAN

- Operation of the 802.11 device within possibly overlapping 802.11 wireless LANs and the mobility of this device between multiple wireless LANs
- MAC level access control and data delivery services to allow upper layers of the 802.11 network
- Several physical layer signaling techniques and interfaces
- Privacy and security of user data being transferred over the wireless media

The 802.11 architecture is comprised of several components and services that interact to provide station mobility transparent to the higher layers of the network stack. The proposed models in this work use 802.11b protocols. The transmission speed is 11Mbs (Megabits per second). The reason for selecting this protocol is the easy commercial availability of the compliant equipments for implementation. IEEE 802.11b "High Rate" standard wireless local area network (WLAN) operates in the 2.4GHz (2.4 to 2.483 GHz) unlicensed Radio Frequency (RF) band and can transmit up to 11Mbps. It was released in September 1999 after the Institute of Electronic and Electrical Engineers had released IEEE 802.11 in June 1997. IEEE 802.11b standard defines only two bottom levels of OSI (Open Systems Interconnection) reference model, the Physical Layer (PHY) and the Data Link Layer (Medium Access Control, MAC sub layer).

**Operation Modes**

IEEE 802.11b defines two pieces of equipment, a wireless station, which is usually a PC or a Laptop with a wireless network interface card (NIC), and an Access Point (AP), which acts as a bridge between the wireless stations and Distribution System (DS) or wired networks. There are two operation modes in IEEE 802.11b, Infrastructure Mode and Ad-Hoc Mode.

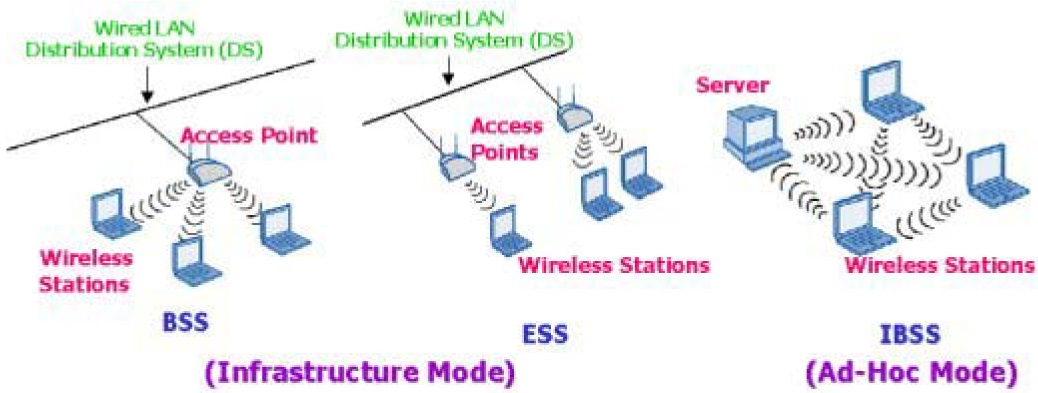


**Figure: 4.7 Wireless operation modes**

**Infrastructure Mode**

Infrastructure Mode consists of at least one Access Point connected to the Distribution System.

**Basis Service Set (BSS)**

An Access Point provides a local bridge function for the BSS. All wireless stations communicate with the Access Point and no longer communicate directly. All frames are relayed between wireless stations by the Access Point.

**Extended Service Set (ESS)**

An Extended Service Set is a set of infrastructure BSS's, where the Access Points communicate amongst themselves to forward traffic from one BSS to another to facilitate movement of wireless stations between BSS's.

**Ad Hoc Mode**

**Independent Basic Service Set (IBSS) or Peer-to-Peer**

The wireless stations communicate directly with each other. Every station may not be able to communicate with every other station due to the range limitations. There are no Access Points in an IBSS. Therefore, all stations need to be within the range of each other and they communicate directly.

The fundamental access method of 802.11 is Carrier Sense Multiple Access with Collision Avoidance or CSMA/CA. CSMA/CA works by a "listen before talk scheme". This means that a station wishing to transmit must first sense the radio channel to determine if another station is transmitting. If the medium is not busy, the transmission may proceed. The CSMA/CA scheme implements a minimum time gap between frames from a given user. Once a frame has been sent from a given transmitting station, that station must wait until the time gap is up to try to transmit again. Once the time has passed, the station selects a random amount of time (the back off interval) to wait before "listening" again to verify a clear channel on which to transmit. If the channel is still busy, another back off interval is selected that is less than the first. This process is repeated until the waiting time approaches zero and the station is allowed to transmit. This type of multiple accesses ensures judicious channel sharing while avoiding collisions.

## 4.2.3 Wireless network interface card

A network interface card (NIC) is used to connect a computer to an Ethernet network. The card (shown in Figure 4.8) provides an interface to the media. This may be either using an external transceiver (as shown) or through an internal integrated transceiver mounted on the network interface card PCB. The card usually also contains the protocol control firmware and Ethernet Controller needed to support the Medium Access Control (MAC) data link protocol used by Ethernet.

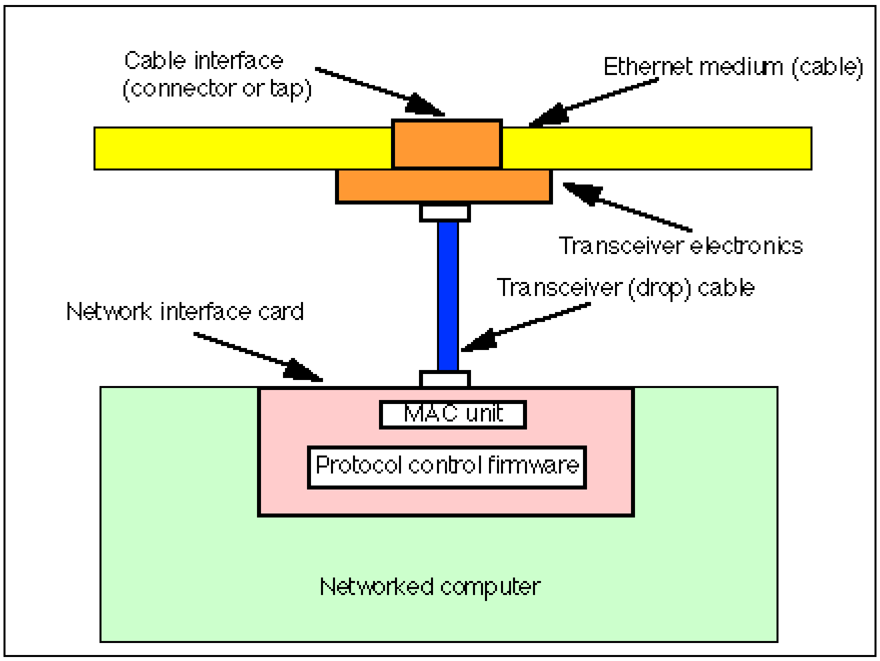


**Figure 4.8 Network interface card connection to an Ethernet network**

Wireless NIC is quite similar to a traditional Ethernet NIC, except that the wired portion is replaced by wireless. Most wireless cards come as plug and play devices. The operating system will be able to detect the card. The wireless NIC should be compatible with the media sending out the signals to function properly.

## 4.2.4 Router

Router is a networking device that controls network traffic. A router is used to connect two physically separate networks. Technically, a router is a "layer 3 gateway," meaning that it connects networks (as gateways do), and that it operates at the network layer of the OSI model. The router will forward packets between these networks. Routers sit at layer three in the OSI model. This means that they are protocol dependent. This is because with TCP/IP it is IP, which decides about the routing to be done. It can route the IP data gram packets to the appropriate destination. At minimum, it is a collection of network interfaces, some sort of bus or connection fabric connecting those interfaces, and some software or logic that determines how to route packets among those interfaces. Before a host will send an IP data gram the IP address is studied. The net id of the destination IP address is compared to the local net id. If they are the same then IP knows that no routing is required and that the data gram can be sent using the direct routing method where Address resolution protocol (ARP) will find the physical address of the destination host. The proposed model uses a TCP/IP router with wireless capabilities. The wireless router is at the center of the proposed private network around the robot. It can interact with the onboard computer on the robot as well as the controlling computer.

## 4.2.5 Ethernet technology & local area networks

Local area network (LAN) is a computer network that spans a relatively small area. Most LANs are confined to a single building or group of buildings. However, one LAN can be connected to other LANs over any distance via telephone lines and radio waves. A system of LANs connected in this way is called a wide-area network (WAN). Most LANs connect workstations and personal computers. Each node (individual computer) in a LAN has its own CPU with which it executes programs, but it also is able to access data and devices anywhere on the LAN. This means that many users can share expensive devices, such as laser printers, as well as data. Users can also use the LAN to communicate with each other, by sending e-mail or engaging in chat sessions. There are many different types of LANs Ethernets being the most common for PCs.

The following characteristics differentiate one LAN from another:

**Topology:** The geometric arrangement of devices on the network. For example, devices can be arranged in a ring or in a straight line.

**Protocols:** The rules and encoding specifications for sending data. The protocols also determine whether the network uses peer-to-peer or client/server architecture.

**Media:** Devices can be connected by twisted-pair wire, coaxial cables, or fiber optic cables. Some networks do without connecting media altogether, communicating instead via radio waves.

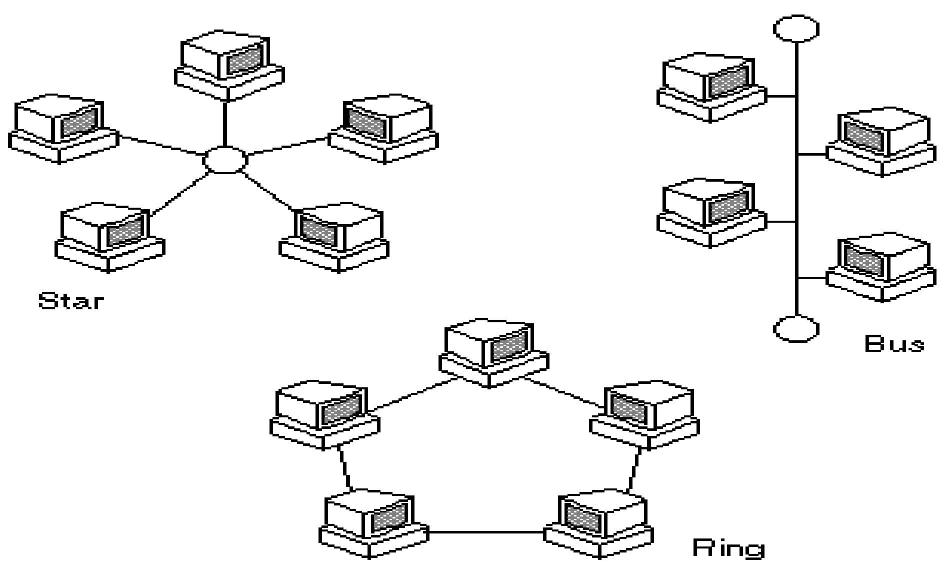


**Figure 4.9 Ethernet topologies**

Ethernet uses a bus or star topology and supports data transfer rates of 10 Mbps. The latest Ethernet specification is IEEE 802.3 standard, which specifies the physical and lower software layers. Ethernet uses the CSMA/CD access method to handle simultaneous demands. It is one of the most widely implemented LAN standards. A newer version of Ethernet, called 100Base-T (or Fast Ethernet), supports data transfer rates of 100 Mbps. And the newest version, Gigabit Ethernet supports data rates of 1 gigabit (1,000 megabits) per second

Topology is the shape of a LAN or other communications system. Topologies are either physical or logical. There are four principal topologies used in LANs.

**Bus topology:** All devices are connected to a central cable, called the bus or backbone. Bus networks are relatively inexpensive and easy to install for small networks. Ethernet systems use a bus topology.

**Ring topology:** All devices are connected to one another in the shape of a closed loop, so that each device is connected directly to two other devices, one on either side of it. Ring topologies are relatively expensive and difficult to install, but they offer high bandwidth and can span large distances.

**Star topology:** All devices are connected to a central hub. Star networks are relatively easy to install and manage, but bottlenecks can occur because all data must pass through the hub.

**Tree topology:** A tree topology combines characteristics of linear bus and star topologies. It consists of groups of star-configured workstations connected to a linear bus backbone cable.

These topologies can also be mixed. For example, a bus-star network consists of a high-bandwidth bus, called the backbone, which connects collections of slower-bandwidth star segments.

# 4.2.6 Private networks and IP addressing

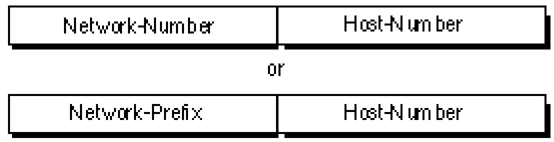


**Figure 4.10 Two-level Internet address structure**[23]

When IP (Internet protocol) was first standardized in September 1981, the specification required that each system attached to an IP-based Internet be assigned a unique, 32-bit Internet address value. Some systems, such as routers, which have interfaces to more than one network, must be assigned a unique IP address for each network interface. The first part of an Internet address identifies the network on which the host resides, while the second part identifies the particular host on the given network. This created the two-level addressing hierarchy, which is illustrated in Figure 4.10. In recent years, the network-number field has been referred to as the "network-prefix" because the leading portion of each IP address identifies the network number. All hosts on a given network share the same network-prefix but must have a unique host-number. Similarly, any two hosts on different networks must have different network-prefixes but may have the same host-number.

**Primary Address Classes**

In order to provide the flexibility required to support different size networks, the designers decided that the IP address space should be divided into three different address classes - Class A, Class B, and Class C. This is often referred to as "classful" addressing because the address space is split into three predefined classes, groupings, or categories.

Each class fixes the boundary between the network-prefix and the host-number at a different point within the 32-bit address. The formats of the fundamental address classes are illustrated in the following figure.

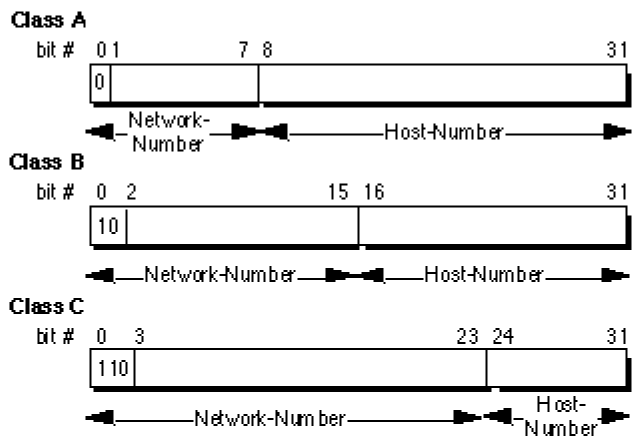


**Figure 4.11 Principle IP address formats**[23]

One of the fundamental features of classful IP addressing is that each address contains a self-encoding key that identifies the dividing point between the network-prefix and the host-number. For example, if the first two bits of an IP address are 1-0, the dividing point falls between the 15th and 16th bits. This simplified the routing system during the early years of the Internet because the original routing protocols did not supply a "deciphering key" or "mask" with each route to identify the length of the network-prefix.

There are five forms of IP addresses:

Class A: 126 networks, each can have up to (16M-2) nodes. (1.0.0.0 - 126.0.0.0)

Class B: (16K-2) networks, each can have up to (64K-2) nodes (127.0.0.0 - 191.255.0.0)

Class C: (2M-2) networks, each can have up to 254 nodes. (192.0.0.0 - 223.255.255.0)

Class D: multicast address. (224.0.0.0 - 240.0.0.0)

Class E: reserved for future use. (241.0.0.0 - 248.0.0.0)

Class C is generally accepted as a private IP address. These IP addresses won't be allocated to computers directly connected to Internet. Only the nodes in a private network are allocated these IP addresses. For the proposed model, Class C IP addresses are used.

## 4.2.7 Virtual private networks

Virtual private networks (VPN) are secured private network connections, built on top of publicly accessible infrastructure, such as the Internet or the public telephone network. VPNs typically employ some combination of encryption, digital certificates, strong user authentication and access control to provide security to the traffic they carry. They usually provide connectivity to many machines behind a gateway or firewall.

Four different protocols have been suggested for creating VPNs over the Internet: point-to-point tunneling protocol (PPTP), layer-2 forwarding (L2F), layer-2 tunneling protocol (L2TP), and IP security protocol (IPSec). PPTP, L2F, and L2TP are largely aimed at dial-up VPNs, while IPSec's main focus has been LAN–to–LAN solutions. The most commonly used protocol for remote access to the Internet is point-to-point protocol (PPP). PPTP builds on the functionality of PPP to provide remote access that can be tunneled through the Internet to a destination site. As currently implemented, PPTP encapsulates PPP packets using a modified version of the generic routing encapsulation (GRE) protocol, which gives PPTP the flexibility of handling protocols other than IP, such as Internet packet exchange (IPX) and network basic input/output system extended user interface. Aside from the relative simplicity of client support for PPTP, one of the protocol's main advantages is that PPTP is designed to run at open systems interconnection (OSI) Layer two, or the link layer, as opposed to IPSec, which runs at Layer three. By supporting data communications at Layer two, PPTP can transmit protocols other than IP over its tunnels.

In the proposed models, users can log onto the University of Cincinnati network using Internet via a VPN connection. Users have to download the VPN client and install it on their machines. Once they are connected via VPN, the users are virtually in the UC network and can perform any action they could as if they were inside UC network. VPN connection provides a secure access to private networks. So a developer sitting at home should be able to develop applications over the Internet without compromising security.

## 4.3 Computer system

The main component of the computer system on the robot is a laptop with Windows XP as the operating system. There is also a Windows 2000 server in the Center for Robotics Research, which is connected to the Internet and acts as the client for the network created by the wireless router on the robot. This is accomplished by virtue of two network interface cards (NIC) on the Windows 2000 server. The desktop of the Windows XP client on the robot can be viewed from the Windows 2000 server using the remote desktop protocol. Extending this logic further, using a VPN connection via Internet to the Windows 2000 server, one should be able to interact with the onboard computer from anywhere in the world. All the computers will have Ethernet compatible NIC and uses TCP/IP as the communication protocol.

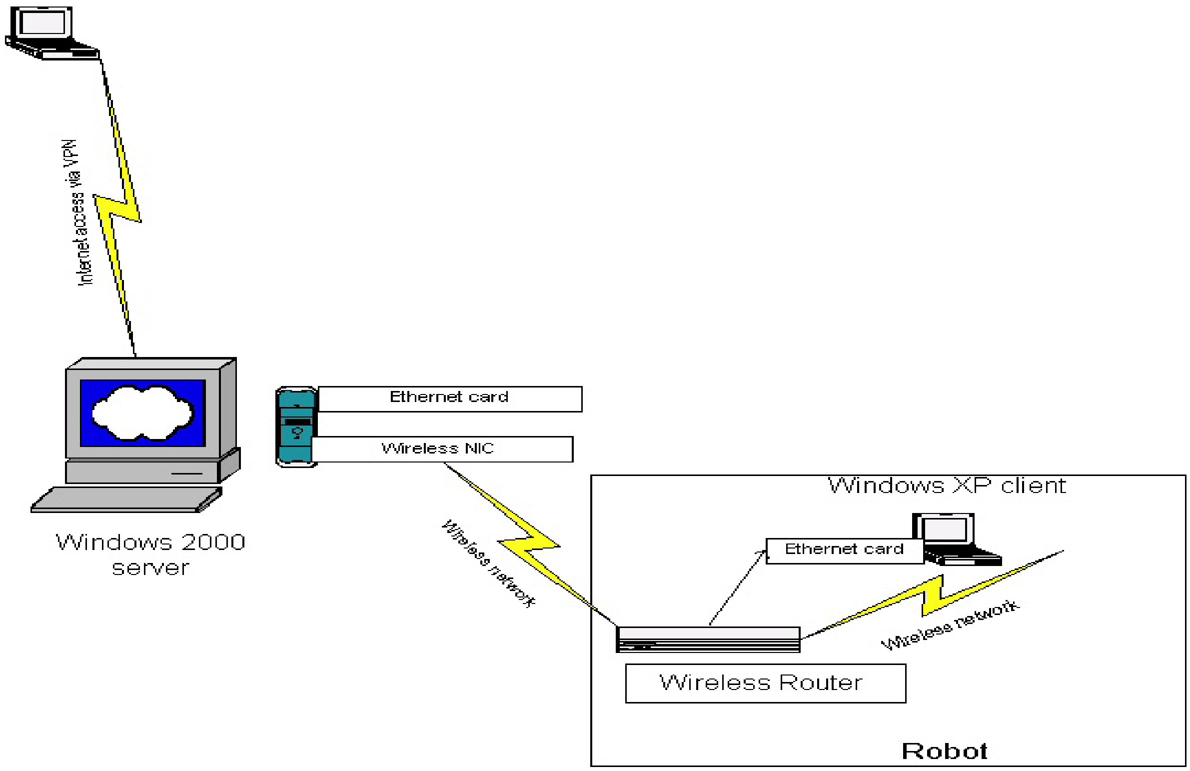


**Figure 4.12 Elements of the proposed computer system**

## 4.3.1 Windows XP client on Bearcat

Windows XP™[9] is the latest 32-bit client operating system from Microsoft Corporation. For the project, we are using the professional edition of Windows XP. The operating system comes with built-in support for wireless networking with IEEE 802.1x, remote desktop protocol, Internet information services, .Net framework and many other enhancements. The operating system supports plug and play of peripheral devices and has remote assistance for users. The user accounts can be managed based on policies thus enhancing the security of the system. It has greater application and device compatibility,

[9] Windows XP is a registered trademark of Microsoft Corporation http://www.microsoft.com

improved networking and communications features, better manageability, and native support for 32-bit applications and future support for even 64-bit applications.

### 4.3.2 Windows 2000 server

Windows 2000 server™[10] edition is a multi-purpose network operating system from Microsoft Corporation. Although Microsoft will be coming out shortly with Windows 2003 server™, the project uses Windows 2000 server. The network operating system supports file and print services, networking services, Internet information services (web server hosting), directory service called the active directory service, terminal services for remote access and administration, and a host of other services. It's a true 32-bit architecture operating system with a reasonably high amount of scalability. The security features of the operating system are quite good and it has better manageability functions. The terminal service allows remote logon to a computer and brings the desktop of that computer to the local machine. This feature allows administrators to access machines remotely as if they were sitting at the console of the remote machine.

### 4.3.3 Remote desktop protocol

Remote Desktop Protocol (RDP) brings the desktop of a remote machine on to the local machine. Windows 2000 server has native support for this protocol through terminal services. Windows XP also provides native support to it. The advantage of RDP is that user does not have to physically go to a computer to log on to it. RDP is based on, and an

[10] Windows 2000 server and Windows 2003 server are registered trademarks of Microsoft Corporation

extension of, the existing ITU (International Telecommunication Union) T.120 family of protocols. RDP is a multiple-channel capable protocol that allows for separate virtual channels for carrying device communication and presentation data from the server, as well as encrypted client mouse and keyboard data. RDP provides an extensible base and supports up to 64,000 separate channels for data transmission and provisions for multipoint transmission.

On the server, RDP uses its own video driver to render display output by constructing the rendering information into network packets using RDP protocol and sending them over the network to the client. On the client, RDP receives rendering data and interprets the packets into corresponding Microsoft Win32 graphics device interface API (application program interface) calls. For the input path, client mouse and keyboard events are redirected from the client to the server. On the server, RDP uses its own virtual keyboard and mouse driver to receive this keyboard and mouse events. Microsoft RDP includes the following features and capabilities: encryption, bandwidth reduction features, roaming disconnect, clipboard mapping, print redirection, virtual channels, remote control, and network load balancing

# Chapter 5

## *Proposed models*

This thesis proposes three models for implementing the motion control system solution. The following sections describe each of the models followed by a discussion of the model. The models range from the traditional motion control system to motion control system using wireless communication protocols and finally via Internet.

## 5.1 Control system without wireless

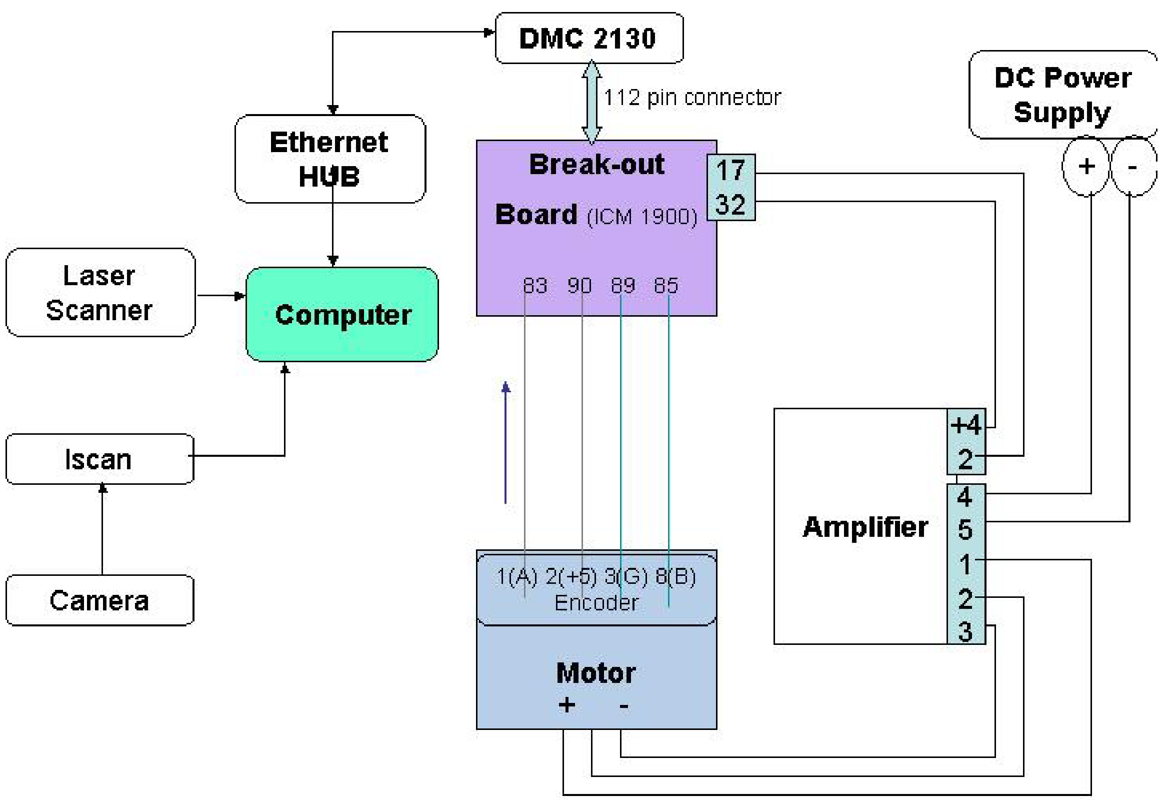


Figure 5.1 Elements of model one (without wireless system)

The proposed model is the traditional approach to motion control system solution. This is the model followed in all the robots built by students at the Center for Robotics Research. The previous solutions used RS-232 serial port interface instead of using Ethernet port for communication between the central computer and the dynamic motion control system. The computer is at the center of the model. It uses Windows XP professional as the operating system. It receives inputs about vision from the CCD cameras on the robot through the ISCAN. The CCD cameras sent the images to the ISCAN and the ISCAN processes these images into bits before transmitting to the computer. The obstacle avoidance feature is provided by SICK laser scanner. The laser scanner sends a laser beam to detect obstacles in front of it. It can generate a profile of any protruding object in the course with an accuracy of a quarter of a degree for 180 degrees.

The motion control system starts with a Galil dynamic motion controller (DMC-2130). DMC-2130 is connected to the central computer via Ethernet hub or a router. The connection from the hub or router is accomplished using a CAT 5 (category 5) or better grade cables. DMC-2130 is a three-axis motion control system, which means that it can control three motors. The DMC is connected to a break out board of the Interconnect module (Galil ICM-1900) via a 112-pin connector. This module is the workhorse of the motion control system. The DMC-2130 translates the commands and messages back and forth from the computer and feed the ICM-1900. A DC power source provides power to the amplifier. The amplifier is connected to the motor and to the ICM-1900. The selection of the motor depends upon factors like the weight of the robot, the required power and traction for the robot and other performance criterion. The motor can be stepper or servo in nature and powered by a DC or AC source. The choice of amplifier depends upon the choice of the motor. In this case, we have selected DC brush less servomotor from Pacific Scientific. The motor drives the drive train connected to the wheels. Separate motor drive each wheel. Each motor is represented by an axis on the DMC-2130. A feedback encoder is built on to each of the motors. The encoder is connected to the ICM-1900 for error correction and feedback. So the computer can control each motor and achieve direct control on the movement of each wheel of the robot.

### 5.1.1 Discussion of the model

The motion control system in Figure 5.1 can be run without a computer and DMC-2130. The DMC-2130 provides the computer interface to the motion control system. The motion control system commands can be embedded in a program, in this case the C++ program used to control the robot, and used to control the functions of the motor. Through these commands computer can control the movement of the robot. The figure also details the pin numbers of each connection. It shows only connections for X-axis. The biggest enhancement to this model over the previous motion control system solutions is the use of TCP/IP communication protocol over Ethernet network cards. Previously data transfer between central computer and motion controller was achieved via RS-232 serial port interface. The data has to be programmatically acquired from the serial port interface through special programs. But the use of TCP/IP communication protocols, via an onboard Ethernet Hub or Router, has provided the opportunity to control the robot remotely. The robot takes inputs from the laser scanner about obstacles; from ISCAN about the lines it follows and calls in appropriate routines to guide the vehicle while avoiding the obstacles and staying within the course of the line. This is a multi-tasking control.

## 5.2 Remote administration through wireless

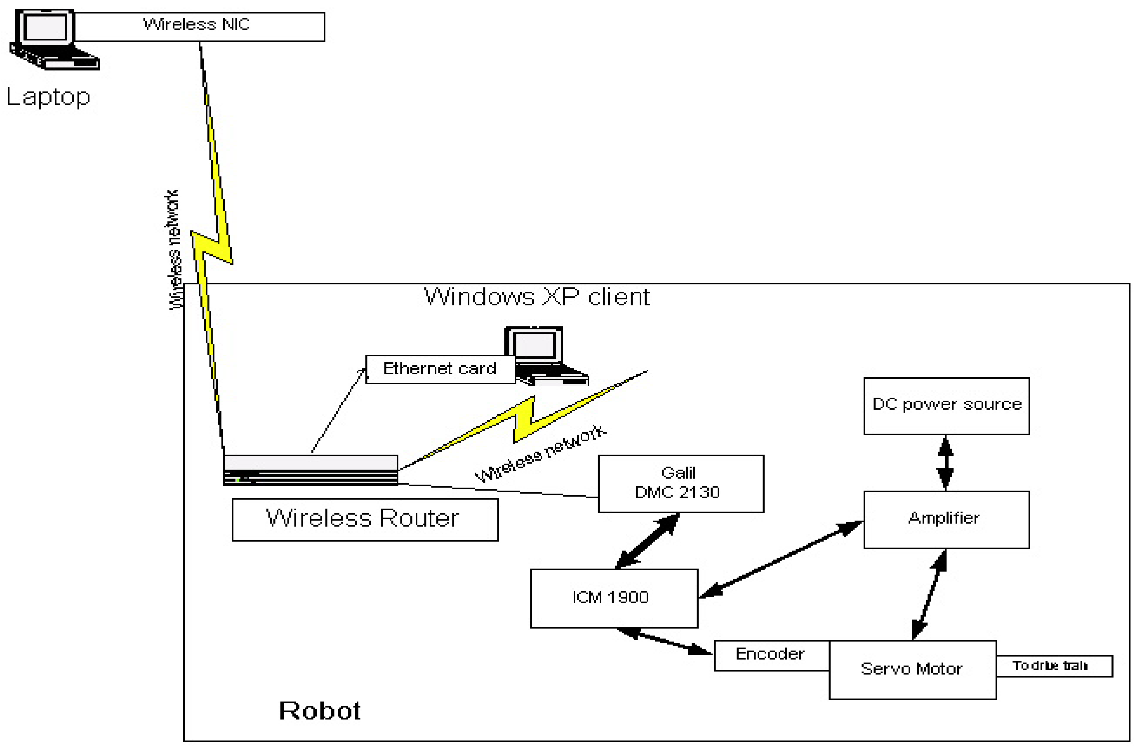


**Figure 5.2 Elements of model two**

This model is an extension of the Model one shown in Figure 5.1. While testing the robot outdoors or in maneuvering the robot in the Intelligent Ground Vehicles Competition, the developer has to go to the console of the central computer to make any change in the program. This is an arduous task while testing the robot outdoors on a warm sunny day. Since the robot requires an Ethernet hub or a router onboard to communicate between the central computer and the DMC-2130, this model proposes the use of a wireless router in its place. The wireless router can form a private network of its own.

**Figure 5.3 Linksys Wireless Access Point router with 4-point switch**[25]

**Figure 5.4 Linksys Instant Wireless PCI card**[26]

The wireless router chosen is a commercially available one for home networking from Linksys Corporation. The model is Linksys Wireless Access Point Router with 4-Port Switch - Version 2™. This is compliant with 802.11b wireless standard. It can support a data transfer rate of 10/100Mbps (Megabits per second) on an Ethernet backbone. It also has features like networking address translation and dynamic host configuration protocol setting. The latter feature allows nodes to use dynamic IP address in the network centered on this router. It also has four ports for wired Ethernet connection. The operating range of the wireless router indoors is 30m (100 ft.) @11Mbps and outdoors is 152m (500 ft.) @11Mbps. This provides a sufficient range of operation. The central computer and the DMC-2130 will be using wired Ethernet access to the router. The developer uses the laptop shown in Figure 5.2 to connect to this wireless network. The laptop should have a wireless network interface card (NIC) to achieve this. The wireless NIC chosen is

Linksys Wireless PCI card™. It's fully compliant with 802.11b wireless network standard, transferring data up to 11Mbps in the 2.4GHz radio band.

### 5.2.1 Discussion of the model

The developer uses the wireless NIC on the laptop in Figure 5.2 to connect with the private wireless network on the robot. Once the developer is on the network there are two ways of controlling the robot. The first method is to use remote desktop protocol (RDP) to connect directly to the central computer on the robot. This brings the desktop of the central computer to the laptop of the developer. The user experience is similar to physically logging on to the console of the central computer. Figure 5.5 captures the screen copy of the desktop of the developer. The outer window is the developer's desktop. The inner window is the desktop of the onboard central computer. On the developer's laptop it appears as another Windows™ application.

The second method uses web access and is preferred if the application development is complete and the developer is testing the robot. The central computer has Windows XP as the operating system. This computer can be configured to host Microsoft Internet Information server (IIS)™. The programs controlling the robot can then be accessed via port 80 (http port for Internet applications). ASP.Net™ (Active server pages) applications can be written to access these programs. This way the tester cannot make changes to the program but can execute them. This can be even used by a novice user in the demonstration of the working of the robot.

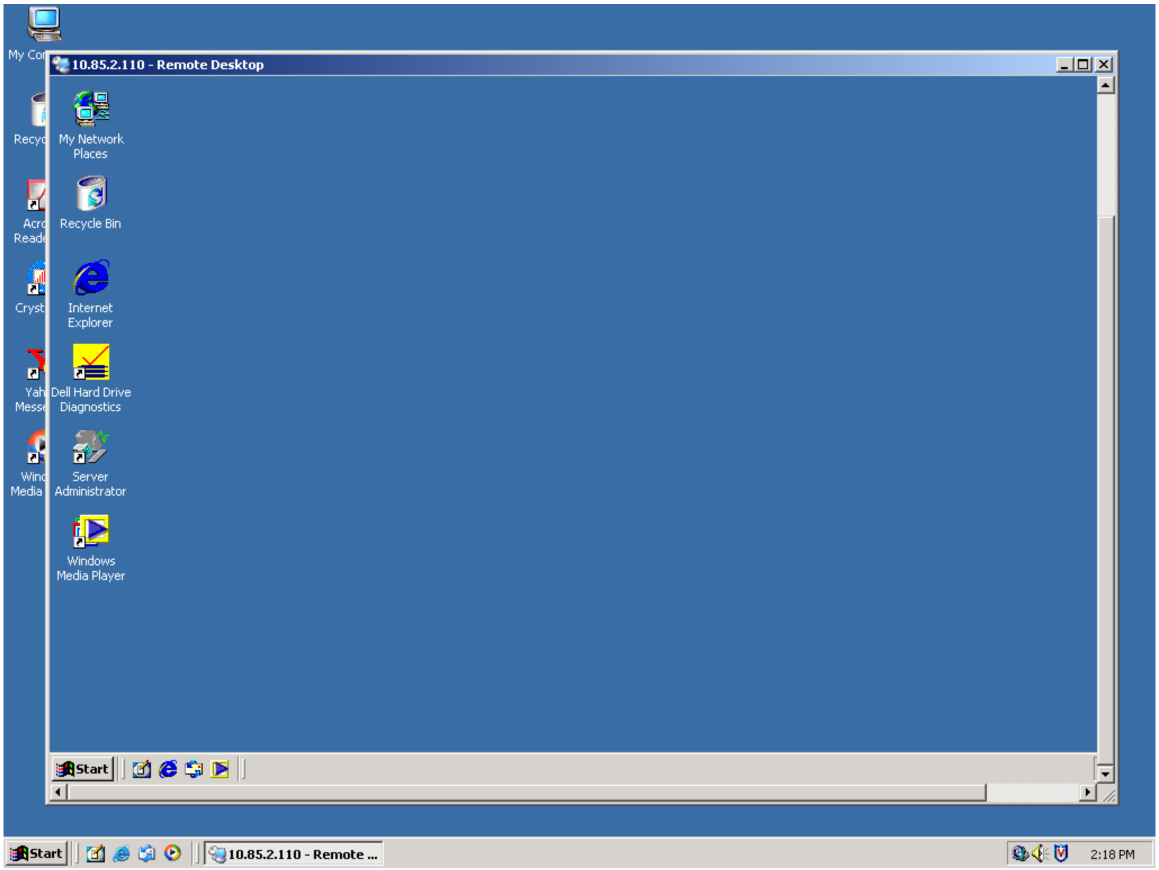


**Figure 5.5 Remote desktop window on the local machine**

## 5.3 Remote administration through Internet

This model is an extension of model two suggested earlier in Figure 5.2. The model makes use of Internet to control the robot. As shown in Figure 5.6, a user can log on to the Windows 2000 server via Internet using virtual private network (VPN) connection. VPN provides a secure access to the computer by creating a "tunnel" on the public Internet using point-to-point tunneling protocol. The Windows 2000 server is inside the Center for Robotics Research laboratory and is connected to the University of Cincinnati network. The robot will be stationed at a distance closer to this server. This server has two network interface cards: one a wired Ethernet card and the other a wireless network card. Using the wireless network card, the server can communicate with the central computer on the robot. Once the user logons to the server via a VPN connection, he/she can access the central computer on the robot the same way as described in model two in Figure 5.2, namely remote desktop connection or using http port 80. The model also proposes a CCD camera or a web camera on the robot to send real time pictures about the surroundings of the robot back to the central computer.

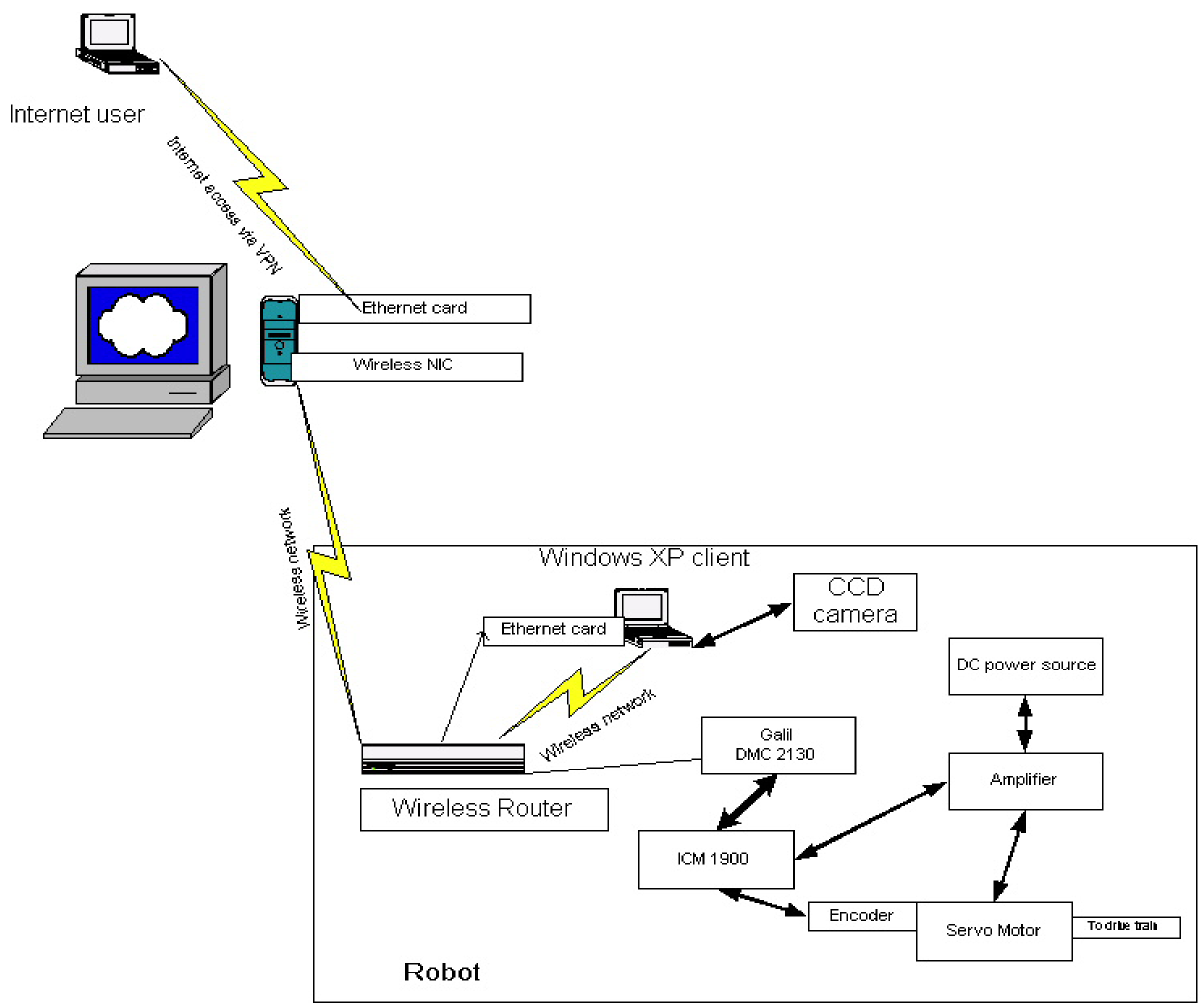


**Figure 5.6 Elements of model three**

### 5.3.1 Discussion of the model

The proposed model is useful for conducting software development activities or diagnostic activities on the robot from a remote location via Internet without having physical proximity to the robot. This creates an unprecedented amount of uptime for software development activities on the robot. Using the live pictures from the camera, one can maneuver the robot sitting at a remote location via Internet without the fear of crashing on to some obstacles. The limitation of the model is the range of the wireless router on board. The VPN provides a secure connection to the robot without the fearing of compromising security. But the wireless router with the current standards may compromise security, unless active security policies are enforced. The wired equivalent policy (WEP) feature is turned off in the factory settings. This has to be turned on for improved security. The 128-bit encryption is, in reality, a 104-bit encryption with the 24 bits of the key being standard across all manufacturers. The media access control (MAC) address filtering feature can be turned on for improved security. This feature is based on the fact each device (PC or handheld computer etc.) has a unique MAC address. This feature restricts the nodes that can access the network based on the physical (MAC) address of each node. With these added security measures, the wireless network is reasonably secure for transactions.

# Chapter 6

## *Conclusion and direction of future research*

The motion control system solutions suggested in this thesis can be used for building the new robot, Bearcat cub, designed by the students at the Center for Robotics Research. The motors, amplifiers, and the motion controller are replaceable as long as the new motion control system supports Ethernet technology for data communication. The wireless system provides the basic infrastructure for all the proposed models. New wireless standards like 802.11g are developed to improve the range and data communication rate of the systems. The new standards will be compatible with the current standards. Besides, the cost of the wireless components is declining at a steady pace. The applications of the wireless system are not limited to the proposed models. Future applications can be devised based on the needs that will arise. The proposed model two will be suitable for participating in contests that require long distances to cover especially for autonomous travel on highways.

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# Appendix – Configuring DMC-2130 Ethernet connections

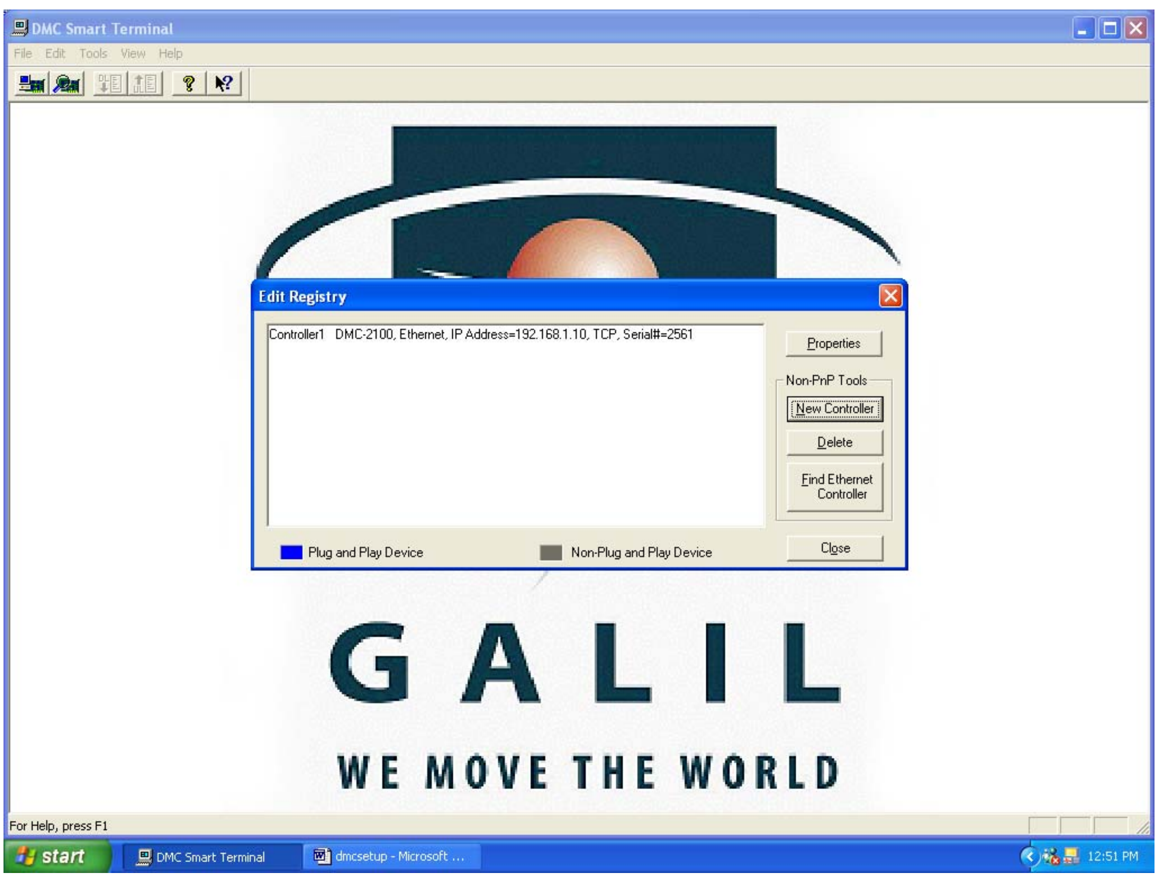
The first step in configuring Galil DMC-2130 motion controller is to configure the IP address of the computer.

Right click on My network places → Properties → double click on local area connection → click on properties→ double click on Internet protocol (TCP/IP)→ select use the following IP address and enter the following IP address

IP address: 192.168.1.4 Subnet mask: 255.255.255.0

Leave blank all other fields and click OK to save the settings

Open the DMC smart terminal program



The connection status with the Galil DMC-2130 will be shown at the bottom task bar. To configure DMC-2130, on the top menu choose Tools → click on controller registration

If a new controller is being added, click on new controller, select the model number as 2100 and connection type as Ethernet. Enter the IP address as 192.168.1.10 and click on assign IP address. On the other hand, if an existing controller is being reconfigured, select the controller from the edit registry window and click on properties. On the controller communication parameters window, click on the tab Ethernet parameters, enter the above IP address and click on assign IP address. After assigning the IP address, close the edit registry window.

The rule of thumb for both devices to communicate using TCP/IP is that both devices should be on the same class of IP address, in this case, Class C IP address. Once the IP address is assigned, on the top menu, click on Tools→ select controller. This will select the controller registered with the computer and establishes a connection between the motion controller and the computer. Notice the change of status message at the bottom left corner of the window. Make sure the caps lock is on while issuing commands to the motion controller.

If there is still difficulty in connecting, unplug the power cable of motion controller and re-plug it and repeat the above procedure.