Modeling of Skid –Steered Wheeled Vehicle

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Abstract— **Robotic autonomous navigation tasks in outdoor environment can be effectively performed by skid steering vehicles. Such wheeled robots called skid-steering mobile robots (SSMRs) are considered as all-terrain vehicles because of the robust nature of the mechanical structure. They can work in hard environmental conditions and can be used, e.g., to explore space. The skid steered wheeled vehicle mainly includes two sections, a handheld device and a vehicle section. The handheld device is to deliver the commands to the vehicle section while the vehicle acts accordingly. The hand- held device uses its keypad to enter the various commands to control the vehicle. The vehicle act according to the commands received through the receiver with its controller. The main feature of the skid steered wheeled vehicle is its modes of operation. The vehicle is made to operate in two different modes. First mode, manual mode, is a normal manual mode in which a vehicle is completely controlled by the user while in the second one, auto mode, the vehicle is operated in a predefined path set by the user. The predefined path includes direction, distance and the ultrasonic range. Thus the skid steered wheeled vehicle can be accessed to all different terrains and can be used with or without the aid of the user.**

Index Terms—**Accelerometer, Dynamic Modeling, Skid-steering mechanism, Ultrasonic Sensor.**

I. INTRODUCTION

In recent years, there has been observed a growing interest in the mobile robotics area. A lot of research concentrates on the description of kinematic models of mobile robots and designing feedback control laws for non holonomic systems. Researchers typically consider wheeled platforms with non holonomic constraints while assuming perfect rolling[1].

Robotic autonomous navigation tasks in outdoor environment can be effectively performed by skid steering vehicles. Such wheeled robots called skid-steering mobile robots (SSMRs) are considered as all-terrain vehicles because of the robust nature of the mechanical structure. They can work in hard environmental conditions and can be used, e.g., to explore space.

Dynamic models of autonomous ground vehicles are needed to enable realistic motion planning[2] in unstructured, outdoor environments that have substantial changes in elevation, consist of a variety of terrain surfaces, and/or require frequent accelerations and decelerations. At least four different motion planning tasks can be accomplished using appropriate dynamic models.
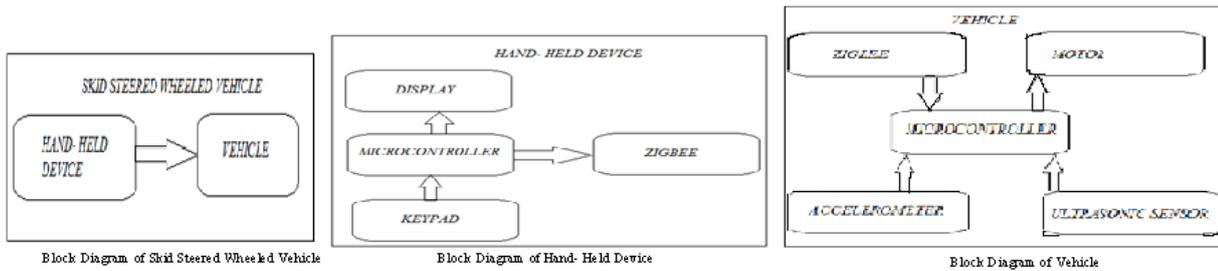
1) *Time optimal motion planning:* A dynamic model can yield good predictions of a vehicle's velocity as it traverses a hill or gulley of a particular terrain, including the maximum climbing velocity of a given hill, the estimation of the needed entry velocities to climb steep hills, and the prediction of whether a vehicle is even capable of climbing a hill. These predictions are key to computing the time-optimal trajectories, and hence, the dynamic model is important for motion planning in an undulating environment.

2) *Energy efficient motion planning:* This type of planning is important, since finite energy availability is a critical constraint that must be taken into account when planning motion for vehicles. A dynamic model provides predictions of torque and velocity and, hence, the power and energy consumption. Related capabilities are the ability to predict whether a given task can be completed with the vehicle's current energy supply and estimations of when to refuel or recharge.

3) *Reduction in the frequency of replanning:* One of the primary reasons that replanning is necessary is due to discrepancies between the predicted and actual vehicle motion. Since a dynamic model can lead to more accurate motion predictions in planning, it can reduce the frequency of replanning.

4) *Planning in the presence of a fault, such as flat tire or faulty motor:* A dynamic model includes the motor properties, and the tire and ground interaction. Common vehicle faults are faulty motors or flat tires. Their influence on vehicle motion can be captured by the dynamic model utilized to plan the vehicle trajectories. The dynamic model will enable more efficient mobility in the presence of these faults.

Ackerman steering, differential steering and skid steering are the most widely used steering mechanisms for wheeled and tracked vehicles. Ackerman steering has the advantages of good lateral stability when turning at high speeds, good controllability[6] and lower power consumption[3], but has the disadvantages of low maneuverability and need of an explicit mechanical steering subsystem. Differential steering is popular because it provides high maneuverability with a zero turning radius and has a simple steering configuration. However, it does not have strong traction and mobility over rough and loose terrain and, hence, is seldom used for outdoor terrains. Other disadvantages are that the motion tends to be energy inefficient and difficult to control, and for wheeled vehicles, the tires tend to wear out faster. Like differential steering, skid steering leads to high maneuverability and faster response and has a simple and robust mechanical structure[16]. In contrast, it also leads to strong traction and high mobility, which makes it suitable for all terrain traversal.

Block Diagram of Skid Steered Wheeled Vehicle

Block Diagram of Hand- Held Device

Block Diagram of Vehicle

A skid-steered vehicle can be characterized by two features[6]. First, the vehicle steering depends on controlling the relative velocities of the left and right side wheels or tracks. Second, all wheels or tracks remain parallel to the longitudinal axis of the vehicle, and vehicle turning requires slippage of the wheels or tracks. Due to identical steering mechanisms, wheeled and tracked skid-steered vehicles share many properties. Many of the difficulties associated with modeling and operating both classes of skid-steered vehicles arise from the complex wheel (or track) and terrain interaction[4].

II. SKID – STEERED WHEELED VEHICLE

A skid-steered vehicle does not have axles connecting the left and right wheels. Instead, all wheels on one side are connected via chains or other such mechanisms[17]. The wheels on one side can be rotated independent of the other side. The vehicle may be turned by making the wheels on one side rotate faster than those on the other side. The difference in rotation causes the vehicle to skid and turn in the direction of the slow wheels; hence the term "skid-steer."

A skid steered wheeled vehicle[1] is designed and is coded to operate such that it can be controlled by a handheld device. The hardware of skid steered wheeled vehicle mainly includes two sections, a handheld device and a vehicle section. The handheld device is to deliver the commands to the vehicle section while the vehicle acts accordingly. The main block diagram of the skid steered wheeled vehicle includes a vehicle and a handheld device.

The hand- held device consist various subsections for its working. These subsections include a microcontroller that controls its entire activities, a zigbee which is the transmitter of the commands, a display which is a LCD display and a matrix keypad to enter the commands.

The vehicle includes a microcontroller to control the activities, a zigbee which is the receiver of the commands, an ultrasonic sensor to detect the obstacle, an accelerometer for the speed control of the vehicle and a motor to run the vehicle.

The components needed are placed in schematic capture software by selecting each one from the library. Various components are available with various powers and wattage specifications. The appropriate component is selected from component list. The connections are made between the components so that area is reduced so much. The designing software helps to create the PCB so that efficient utilization of area can be maintained. The simulation can be observed in this schematic capture aid tool. There are various options to view the simulation, like virtual terminal, oscilloscope, CRO.

The designed schematic is then captured for the PCB designing. The design rules are achieved at this stage. The placement and routing of the components are done according to deign layout rules so that minimum area maximum utilization goal is achieved.

A. Working of Skid – Steered Wheeled Vehicle

The microcontroller used is a PIC 16F877A which is a low power, high speed 8 bit microcontroller. The microcontroller is coded to control the entire activities of the vehicle. The hand- held device uses its keypad to enter the various commands to control the vehicle. These commands include vehicle turn on command, mode selection command, and various direction commands like forward, backward, right and left, speed control commands for both motors, individual speed control of each motors and range setting for the ultrasonic sensor. The controller displays these commands and sent them to the transmitter. The vehicle act according to the commands received through the receiver with its controller. A DC motor drives the vehicle through a DC motor driver. The accelerometer is used to control the speed of the vehicle for various terrains[4]. The sensor detects the obstacles in the path and controller makes the vehicle to take a path deviation.

The main feature of the skid steered wheeled vehicle is its modes of operation. The vehicle is made to operate in two different modes. First mode, manual mode, is a normal manual mode in which a vehicle is completely controlled by the user while in the second one, auto mode, the vehicle is operated in a predefined path set by the user. The predefined path includes direction, distance and the ultrasonic range. Considering the various components connected to the controller, ports of the controller is used effectively. The PIC16F877A has four ports having multiple functions. The zigbee is connected to the port C pins P6 and P7. The matrix keypad is connected to the port B pins P0-P4 and port C pins P1-P3. The LCD display data port is connected the port D while its control pins are connected to the port C pins P4 and P5. The DC motor driver is connected the port B pins P0-P3. The accelerometer is connected to three of the ADC pins that is port A pins P0-P2 of the controller so that the corresponding ADC value can be controlled efficiently. The accelerometer Y direction is utilized for the vehicle and therefore it is connected to the P0. The ultrasonic sensor is connected to port B pin P4.

The sensor emits the waves and if any obstacle appears in its path, it stops the vehicle. If the vehicle is in the manual mode the user has to take the path deviation while it is in the auto mode the vehicle waits due to the obstacle and informs the user to take the path deviation. The ultrasonic sensor used

2911

has an efficient range of 30cm. This maximum range can be set by the user through keypad.

The accelerometer Y direction is utilized in the vehicle. Its default value resides at 65. If the vehicle takes a climbing direction the value can vary from 65 to 52 while for a downward motion it takes value up to 80 from 65. The speed control is done accordingly from the ADC value through the scaling principle.

Thus the modeling of skid steered wheeled vehicle is done so that it can be accessed to all different terrains and can be used with or without the aid of the user.

B. Coding of Skid – Steered Wheeled Vehicle

The modeling of skid steered wheeled vehicle is done with the aid of various softwares. The coding is done in MPLAB IDE. The language opted for the coding is Embedded C which is an efficient language for an embedded project. The hand- held device is coded to control the vehicle and vehicle is coded so that it responds to the commands of hand- held device.

The simulation is done in PROTEUS Design Suite which provides tool for schematic capture and PCB designing. The tool is user friendly and can be used with an ease. The schematic capture is done by the ISIS Schematic Capture. ISIS has the schematics of all components with different packages and specifications. It enables the designer to capture the schematics with an ease and utilization of time. The PCB designing is done using ARES PCB Designer. The net list is generated by the tool it has the special option of auto- routing also.

The PIC microcontrollers have the ability of In-Circuit Programming, and the fusing of the controller is done in PICKIT2 with the connector and the debugger/ programmer.

The zigbee is configured by the software intended for zigbee, X-CTU. The zigbee at the hand- held device is configured as the transmitter while that at the vehicle is configured as the receiver.

C. Algorithm for Hand- Held Device

The algorithm for the coding for the skid steered wheeled vehicle hand-held device is as follows:
Step 1: Start
Step 2: Setting the ports of controller and initializing the LCD Display and Serial Communication.
Step 3: Turn on the device by pressing the first button and mode-manual (2nd button) or auto (3rd button) is selected accordingly. For manual mode, first character for command is '*' and for auto mode it is '@'and range setting it is '$'.
Step 4: If manual mode is selected, the direction (button 13-16 gives forward, backward, right and left, and to indicate direction A as second character), speed control (button 4 / 8, and to indicate speed B as second character), control of each motor (button 5, 6, and to indicate motor 1 C / motor 2 D as second character) and range for ultrasonic sensor (button 3) is entered. The values are entered using button 1 and 7. Corresponding command codes are generated for each button.
Step 5: If auto mode is selected, the predefined path is set by setting the direction (button 13-16 gives forward, backward, right and left), time limit (button 4 / 8) , range is entered. The button 5 enables transmission of this path. Corresponding

command codes are transmitted to vehicle with '#' at the end of path.
Step 6: Stop

D. Algorithm for Vehicle

The algorithm for the coding for the skid steered wheeled vehicle is as follows:
Step 1: Start
Step 2: Setting the ports of controller and initializing the Serial Communication.
Step 3: Observe the first character received. If first character is '*' then it is manual mode and if '@' at starting and '#' at end then it is auto mode and if '$' at starting then it is range setting.
Step 4: If manual mode is selected, the motor conditions are set according to suite the direction and speed.
Step 5: If auto mode is selected, the predefined path is received and vehicle follows the direction and runs for the time specified. If any obstacle is detected, the vehicle waits and informs the user and continues the path.
Step 6: If the vehicle undergoes an upward tilt it increases its speed and decreases speed for a downward tilt in auto mode.
Step 7: Stop.

III. BRIEF HARDWARE DESCRIPTION

A. PIC 16F877A

PIC 16F877A[7] is a low power, high speed Flash/EEPROM 8- bit microcontroller with a wide operating voltage range and commercial and industrial temperature ranges and having low power consumption. It has 3 Timers-two 8-bit and one 16- bit timer, PWM module of about 10-bit, Universal Synchronous Asynchronous Receiver Transmitter (USART) with 9-bit address detection,10-bit, up to 8-channel Analogue-to-Digital Converter (A/D),Brown-out Reset (BOR), Flash program memory ,Self-reprogrammable under software control, In-Circuit Serial Programming via two pins, Single-supply 5V In-Circuit Serial Programming, Watchdog Timer (WDT) with its own on-chip RC oscillator for reliable operation, Programmable code protection, Power saving Sleep mode, Selectable oscillator options, In-Circuit Debug (ICD) via two pins.

B. Matrix Keypad

Tact switches[15] are widely used as digital input devices. Normally one tact switch requires one digital I/P pin of a microcontroller but if one want to interface a matrix of such switches (say a 16 digit keypad), assigning a digital I/O pin for each key won't be a good idea. So to minimize the required number of digital I/O pins of microcontroller a very popular method is a keypad matrix where the keys are arranged into rows and columns so that a 4×4 (16) tact switches can be interfaced to a microcontroller using only 4+4 = 8 I/O pins. The rows R0 to R3 are connected to Input lines of Microcontroller. The i/o pins where they are connected are made Input. This is done by setting the proper DDR Register in AVR and TRIS Register in PIC. The column C0 to C3 is also connected to MCUs i/o line. These

are kept at High Impedance State (AKA input), in high z | state (z= impedance) state these pins are neither HIGH nor

PIC 16F877A   Matrix Keypad   Zigbee   L298
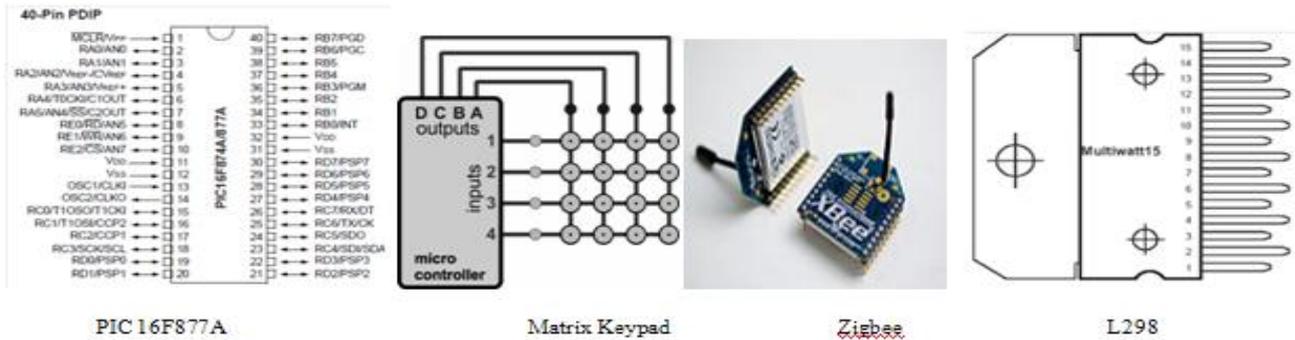
LOW they are in TRISTATE. And in their PORT value we set them all as low, so as soon as we change their DDR bit to 1 they become output with value LOW.

C. LCD Display

A liquid-crystal display (LCD)[15] is a flat panel display, electronic visual display, or video display that uses the light modulating properties of liquid crystals. Liquid crystals do not emit light directly. LCDs are available to display arbitrary images or fixed images which can be displayed or hidden, such as preset words, digits, and 7-segment displays as in a digital clock. LCDs are used in a wide range of applications including computer monitors, televisions, instrument panels, aircraft cockpit displays, and signage.. They are available in a wider range of screen sizes than CRT and plasma displays, and since they do not use phosphors, they do not suffer image burn-in. LCDs are, however, susceptible to image persistence.

The LCD used is 16 X 2 with address 80-8F and C0-CF. A **16x2 LCD** means it can display 16 characters per line and there are 2 such lines. In this LCD each character is displayed in 5x7 pixel matrix. This LCD has two registers, namely, Command and Data. The command register stores the command instructions given to the LCD. A command is an instruction given to LCD to do a predefined task like initializing it, clearing its screen, setting the cursor position, controlling display etc. The data register stores the data to be displayed on the LCD. The data is the ASCII value of the character to be displayed on the LCD. It has 2 modes – command mode to perform various commands to make LCD functioning and data mode to enter the data. The mode selection is done by the RS bit .If RS=0, then command mode otherwise data mode. A high to low signal enables the LCD.

D. Zigbee Transmitter and Receiver

ZigBee[8] is a specification for a suite of high level communication protocols used to create personal area networks built from small, low-power digital radios. ZigBee is based on an IEEE 802.15 standard. Though low-powered, ZigBee devices often transmit data over longer distances by passing data through intermediate devices to reach more distant ones, creating a mesh network; i.e., a network with no centralized control or high-power transmitter/receiver able to reach all of the networked devices. ZigBee is used in applications that require a low data rate, long battery life, and secure networking. ZigBee has a defined rate of 250 Kbit/s, best suited for periodic or intermittent data or a single signal transmission from a sensor or input device. Applications include wireless light switches, electrical meters with in-home-displays, traffic management systems, and other consumer and industrial equipment that requires short-range wireless transfer of data at relatively low rates. The technology defined by the ZigBee specification is intended to be simpler and less expensive than other WPANs, such as Bluetooth or Wi-Fi. Typical application areas include: Home Entertainment and Control, Wireless sensor networks, Industrial control, Embedded sensing, Medical data collection, Smoke and intruder warning.

XBee is the brand name from Digi International for a family of form factor compatible radio modules. The first XBee radios were introduced under the MaxStream brand in 2005 and were based on the 802.15.4-2003 standard designed for point-to-point and star communications at over-the-air baud rates of 250 Kbit/s. Two models were initially introduced—a lower cost 1 mW XBee and the higher power 100 mW XBee-PRO. Since the initial introduction, a number of new XBee radios have been introduced and all XBees are now marketed and sold under the Digi brand.The XBee radios can all be used with the minimum four numbers of connections – power (3.3 V), ground, data in and data out (UART), with other recommended lines being Reset and Sleep. Additionally, most XBee families have some other flow control, I/O, A/D and indicator lines built in. A version of the XBees called the programmable XBee has an additional onboard processor for user's code.

E. DC Motor

A DC Motor[15] in simple words is a device that converts direct current (electrical energy) into mechanical energy. It has vital importance for the industry today. The **operating principle of dc motor** is Fleming's left hand rule. A DC motor is a mechanically commutated electric motor powered from direct current (DC). The stator is stationary in space by definition and therefore its current. The current in the rotor is switched by the commutator to also be stationary in space. This is how the relative angle between the stator and rotor magnetic flux is maintained near 90 degrees, which generates the maximum torque. DC motors have a rotating armature winding (winding in which a voltage is induced) but non-rotating armature magnetic field and a static field winding (winding that produce the main magnetic flux) or permanent magnet. Different connections of the field and armature winding provide different inherent speed/torque regulation characteristics. The speed of a DC motor can be

controlled by changing the voltage applied to the armature or by changing the field current. The introduction of variable resistance in the armature circuit or field circuit allowed speed control. Modern DC motors are often controlled by power electronics systems called DC drives. The DC motors can operate directly from rechargeable batteries, providing the motive power for the first electric vehicles. DC motors are still found in applications as small as toys and disk drives, or in large sizes to operate steel rolling mills and paper machines.

F. Motor Driver

The motor driver used is L298[10]. The L298 is an integrated monolithic circuit in a 15- lead Multi watt and PowerSO20 packages. It is a high voltage, high current dual full-bridge driver designed to

accept standard TTL logic levels and drive inductive loads such as relays, solenoids, DC and stepping motors. Two enable inputs are provided to enable or disable the device independently of the input signals. The emitters of the lower transistors of each bridge are connected together and the corresponding external terminal can be used for the connection of an external sensing resistor. An additional supply input is provided. The main features include operating supply voltage up to 46V, total dc current up to 4A, low saturation voltage, over temperature protection, high noise immunity.

G. Accelerometer

Accelerometer[15] is a device that measures proper acceleration. It can be used to measure vehicle acceleration. Accelerometer used is GY61.It is small size, low power consumption, three axis accelerometer, providing the voltage output of signal disposal, it can measure $\pm3g$ magnetic field full-scale acceleration minimum. It can measure the tilt-sensing applications in the static acceleration of gravity, and movement, shock or vibration due to dynamic acceleration. User CX, CY and CZ pin capacitance X OUT, Y OUT and Z OUT choose the bandwidth of the accelerometer. Select the appropriate bandwidth depending on the application, X-axis and Y-axis bandwidth of 0.5 Hz to 1600 Hz, Z-axis of the bandwidth of 0.5 Hz to 550 Hz. The applications include Cost sensitive, low power, motion- and tilt-sensing applications, mobile devices, gaming systems, disk drive protection, image stabilization, sports and health devices.

H. Ultrasonic Sensor

The ultrasonic sensor used is TS601 ultrasonic electric telemeter module can measure a distance within 0.03-3m effectively. And transform the data into impulse with different width. The characteristics of product include high sensitivity, narrow fade zone and quick response. The principle of measurement is Ultrasonic detect. Typical application includes distance measurement. The range of measurement is $0.03 \sim 3$ M and the precision of measurement is $\pm2cm$.Mean of output is Impulse width. The working voltage is 5 VDC and working current ≤15 mA, frequency of sensor is 40 KHz, continual response time 5ms and working temperature is $0 \circ C \sim 70 \circ C$. The host offers

the TS601 module with a impulse through SIG, the trailing edge springs, and transmits a string of ultrasonic signal of 40KHz when the module receives it. Then the electrical level of SIG stitch will be risen. The duration of high level T3 will be ensured by the distance between the object and the telemeter. After 19.5ms, the high level descends, when no object is in a distance of 3M. The host computes the distance though the impulse width input by the electronic eye module: $S = (V*T3)/2$ where S indicates displacement, V denotes voltage of the signal and the pulse width is indicated by T3.

IV. BRIEF SOFTWARE DESCRIPTION

A. MPLAB IDE v 8.56

MPLAB IDE[11] is a Windows Operating System (OS) software program that runs on a PC to develop applications for Microchip microcontrollers and digital signal controllers. It is called an Integrated Development Environment, or IDE, because it provides a single integrated "environment" to develop code for embedded microcontrollers. MPLAB IDE is a "wrapper" that coordinates all the tools from a single graphical user interface, usually automatically. The project manager organizes the files to be edited and other associated files so they can be sent to the language tools for assembly or compilation, and ultimately to a linker. The linkers has the task of placing the object code fragments from the assembler, compiler and libraries into the proper memory areas of the embedded controller, and ensures that the modules function with each other (or are "linked"). This entire operation from assembly and compilation through the link process is called a project "build". The source files are text files that are written conforming to the rules of the assembler or compiler. The assembler and compiler convert them into intermediate modules of machine code and placeholders for references to functions and data storage. The linker resolves these placeholders and combines all the modules into a file of executable machine code. The linker also produces a debug file which allows MPLAB IDE to relate the executing machine codes back to the source files. A text editor is used to write the code. It is not a normal text editor, but an editor specifically designed for writing code for Microchip MCUs. MPLAB IDE is designed to work with many Microchip and third party language tools. The **HI-TECH Universal Tool suite** is used.
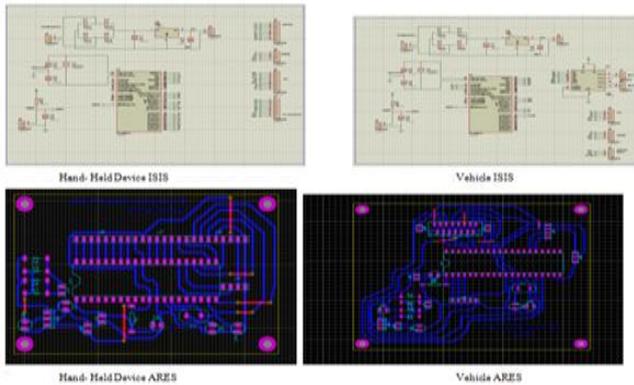
B. PROTEUS

Proteus[12] is software for microprocessor simulation, schematic capture, and printed circuit board (PCB) design. It is developed by Labcenter Electronics.

Proteus is one of the most famous simulators. It can be uses to simulate almost every circuit on electrical fields. It is easy to use because of the GUI interface that is very similar to the real Prototype board. Moreover, it can be used to design Print Circuit Board (PCB). Proteus combines circuit simulation, animated components and microprocessor models to co-simulate the complete microcontroller based designs. This is the perfect tool for engineers to test their microcontroller designs before constructing a physical prototype in real time.

a. PROTEUS ISIS

ISIS lies at the heart of the Proteus system, and is far more

than just another schematics package. It combines a powerful design environment with the ability to define most aspects of the drawing appearance. Whether your requirement is the rapid entry of complex designs for simulation and PCB layout, or the creation of attractive schematics for publication, ISIS is the tool for the job. Proteus ISIS is integrated with real time simulation of the electronic circuit ant test whether desired circuit is working properly or not. In this software one can test your test code by loading the hex file in the circuit and test the circuit proper functioning. Proteus ISIS is use to capture the schematic and do the electrical simulation. All Proteus PCB design products include an integrated shape based auto router and a basic SPICE simulation capability as standard.

Hand- Held Device ISIS   Vehicle ISIS

Hand- Held Device ARES   Vehicle ARES

b. *PROTEUS ARES*

ARES is good software for beginner because it is simple and not too complex. This is the application where the final layout will be made. Once the layout is made, the work on the software will be finished.

C. PIC KIT 2

PICkit 2[13] is a development tool to emulate and debug firmware on a target board. The PICkit 2 Development Programmer/Debugger is a low-cost development programmer. It is capable of programming most of Microchip's Flash microcontrollers and serial EEPROM devices. The PICkit 2 is intended for development programming. The PICkit 2 Programmer application allows to program all supported devices listed in the PICkit 2 Readme file.

D. X-CTU

X-CTU[14] is a Windows-based application provided by Digi. This program was designed to interact with the firmware files found on Digi's RF products and to provide a simple-to-use graphical user interface to them. X-CTU is designed to function with all Windows-based computers running Microsoft Windows 98 SE and above.
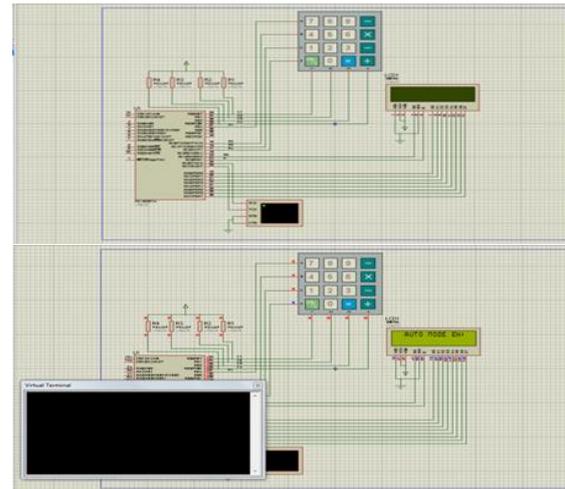
V. SIMULATION RESULT

The PROTEUS ISIS screen gives the simulation result with the help of virtual terminal option and digital oscilloscope inbuilt in it.
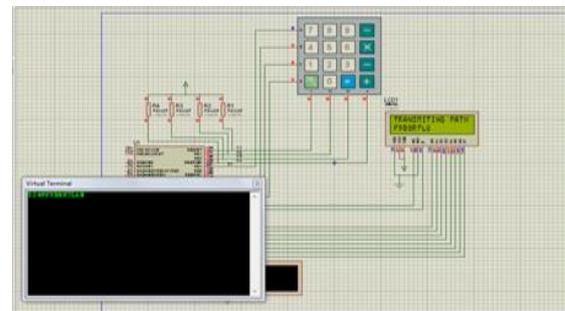
A. Hand – Held Device

The schematic capture for the hand held device is shown together with displaying mode after the project name is
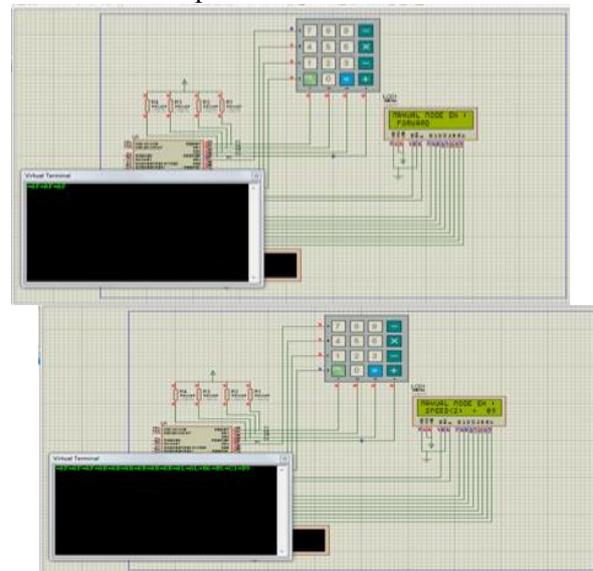
shown.

The instructions are entered and the result is showing the path transmission in auto mode.
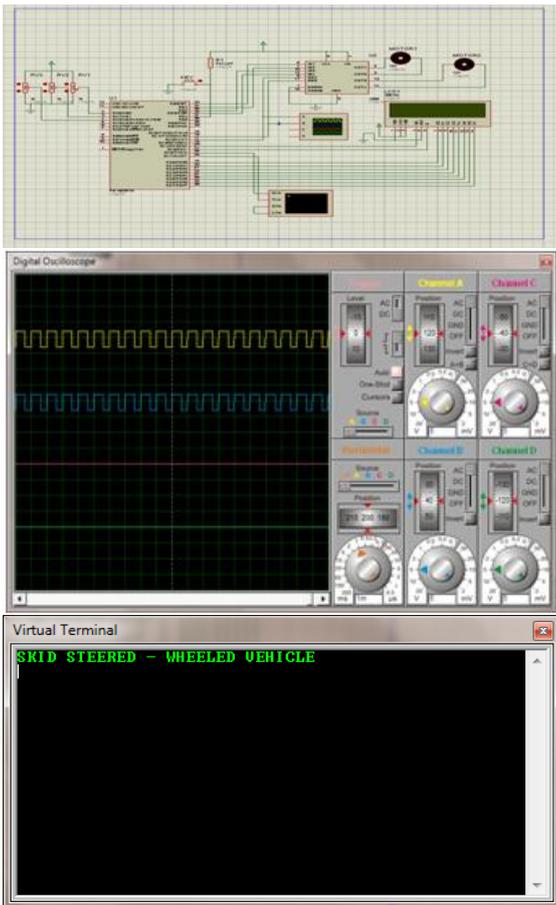

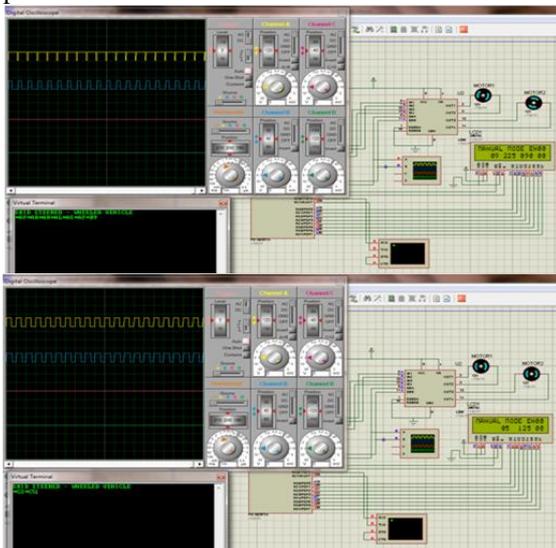The manual mode instances are considered.The direction control and speed control are shown as results.
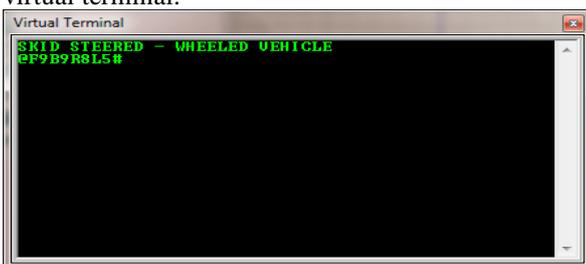

B. VEHICLE

The ISIS of vehicle is described. The digital oscilloscope shows the speed of the vehicle. The virtual terminal displays the various commands acting.

2915

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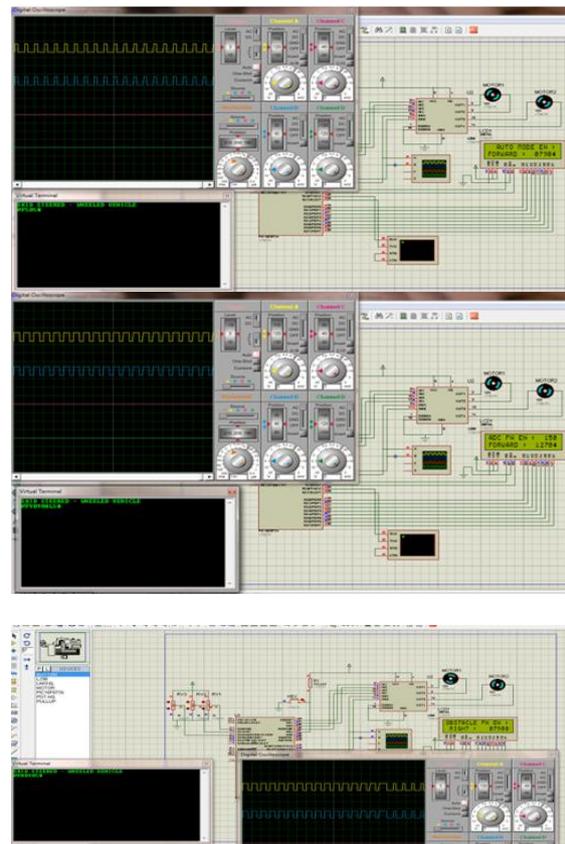*Volume 2 Issue 11, November 2013*

The various modes of operations performed by the vehicle is pictured.

The message displayed and path following is illustrated in virtual terminal.

The speed control by considering the ADC is pictured.

VI. CONCLUSION

This paper presented a wheeled vehicle which can be accessed by user and by some predefined algorithms. Using the mobile robot with an unprecedented capacity to predict the consequences of its own actions and to take corrective actions in relatively challenging environments, we can expect intelligent behaviors from it. Performance in real applications is of course subject to the fidelity of the models.

Current and future work includes the use of this algorithm in multiple contexts. First, it is being applied in the generation of corrective manoeuvres in rough terrain path following applications. Second, it is being used to generate well-separated trajectory sets for obstacle avoidance computations on rough terrain vehicles. In addition, it is being evaluated and refined as the search space generation component of a larger scale non holonomic motion planner.

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[9] Datasheet of TS601

[10] Datasheet of L298

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[12] Userguide of PROTEUS

[13] Userguide of PICKIT 2

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