DESIGN AND DEVELOPMENT OF MOBILE ROBOTIC PLATFORM FOR COLLECTION AND STORAGE OF PINE NEEDLES IN A MULTI TERRAIN AREA

By

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THESIS COMPLETION CERTIFICATE

This is to certify that the thesis on "**Design and Development of Mobile Robotic Platform for Collection and Storage of Pine Needles in a Multi Terrain Area**" by **Shival Dubey** in Partial completion of the requirements for the award of the Degree of Doctor of Philosophy (Engineering) is an original work carried out by him under our joint supervision and guidance.

It is certified that the work has not been submitted anywhere else for the award of any other diploma or degree of this or any other University.

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Shival Dubey
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February 2016

DEDICATED

TO

MY MOTHER

&

(Late.) Dr. APJ ABDUL KALAM

DECLARATION

I do hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person, nor material which has been accepted or the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgement has been made in the text.

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NOMENCLATURE

S. No.		Abbreviations
1.	PiNCoR	Pine Needle Collector Robot
2.	CHT	Circular Hough Transform
3.	MRF	Markov Random Field
4.	RGB	Red Blue Green
5.	SLAM	Simultaneous Localization and Mapping
6.	LiDAR	Light Detection and Ranging
7.	AFPM	Automated Fruit Picker Machine
8.	EKF	Extended Kalman Filter
9.	MRI	Magnetic Resonance Image
10.	RBPF	Rao-Blackwellised particle filter
11.	ARM	32 bit processor
12.	IDE	Integrated Development Environment
13.	TTE	Total Tractive Effort
14.	GR	Grade Resistance
15.	FA	Acceleration Force
16.	GVW	Gross Vehicle Weight
17.	C_{rr}	Surface Friction Coefficient
18.	T_w	Total Wheel Torque
19.	GPS	Global Positioning System
20.	IMU	Inertial Measurement Unit
21.	BLDC	Brushless Direct Current (Motor)
22.	RAM	Random Access Memory

LIST OF SYMBOLS

S. No.	Symbol	Description
1.	$\psi_1 - \psi_2$	Joint Angle Between the Small and Main Rocker
2.	$\beta_1 - \beta_2$	Left and Right Bogie Angles
3.	ζ_i	Wheel Rotation
4.	O	Reference Point (Robot Frame Coordinate)
5.	D	Differential Joint
6.	A_i	Axes of all Wheels
7.	ϑ	Rotation Between z – axis
8.	d	Distance along z – axis between joints
9.	a	Distance along x – axis between joints
10.	α	Angle between z – axis of joints
11.	$T_{j,I}$	Transformation Matrix from i to j
12.	C_i	Wheel contact frame
13.	M_i	Wheel motion frame
14.	R_w	Wheel Radius
15.	η_i	Wheel rotational slip
16.	γ_1	Left rocker angle
17.	γ_2	Right rocker angle
18.	J	Jacobian Matrix
19.	$\dot{\varphi}_d$	Angular Rate of rover
20.	$\dot{x}_d$	Forward Velocity
21.	h	Increase in vertical height per second

EXECUTIVE SUMMARY

The robot is usually an electro – mechanical machine controlled by a computer or an electronic circuitry. Robots are generally designed to work the repetitive tasks, in the environment that can be dangerous for the human being, at the places where the reach of the human cannot be possible such as the bottom of the sea or outer spaces. Other than the industries, the robots are of significant use in agriculture too. These robots are termed as Agricultural Robots or Agribots. The robots are generally deployed at the harvesting stage for the product from the field or the forest. The main focus of research in this area is to design a machine that can traverse through the field or forests for the harvesting without any human intervention. The design of the locomotion and control of the robot for the environment is a challenging task and is a core concern.

This thesis deals with the different aspects of Design and Modelling of an Agribot that can be used for the harvesting on different terrains

CHAPTER 1

INTRODUCTION

One of the main reasons for moving towards biofuels as an alternate source of energy has to do with conservation of fossil fuels. In 2010 worldwide biofuel production reached 105 billion liters (28 billion gallons US), up 17% from 2009, and biofuels provided 2.7% of the world's fuels for road transport, a contribution largely made up of ethanol and biodiesel. As we are having an abundance raw source of bio fuels we can judiciously use it.

The global energy needs have increased significantly in the past several decades and are predicted to rise more than 50% by 2030 [1]. At present the energy needs are met mostly from the conventional sources of energy like coal, gas and oil, which are exploited in an unsuitable manner resulting in exhausting global reserves of fossil fuels in the near future.

Biomass from the industry, agricultural & forest residues such as straw, firewood, wood flour, rice husks, coconut shell, groundnut shell, pine needles, bamboo etc. had been traditionally used as direct fuel as well as for their gasification into producer gas to cater to the rural energy needs.

Pine Needles because of having high resin content can be used as a good source of fuel in rural areas also these pine needles are the major cause of the forest fires in the middle altitude of the Himalayan region. Apart from these Pine Needles have several other uses viz. Decorative purposes in the garden landscape, check dams, bailing and briquetting and many more [2]. The major issue with the use of pine needles is the method of harvesting it from the forest floors as the dry needles

This present research proposes to design a robotic mobile platform that can collect pine needles. This design will be useful in harvesting at the hilly areas where the human interference is less. The harvesting is done by a suction mechanism attached to a robotic platform and the needles will be stored on board at the back of the platform using a fabric bag. The locomotion of the platform will be equipped with rubber tracks that will support the vehicle in hilly condition of the hills.

An efficient robotic device can service such large scale forest for collecting leaves and built-in auto monitoring, when compared to human crews and current hardware alternatives. This autonomous robotic vehicle will carry out task that would be conventionally difficult for human intervene. The robot, capable of multi – terrain operation, can be used for many applications such as terrain mapping, collection of forest products therefore the common components such as motor drivers, sensors will be designed in such a way that any addition in future will be allowed without much modifications.

1.1 RESEARCH MOTIVATION

Reviews show that there is no such method of harvesting pine straw/needles from the forests except manually, also the climatic conditions of hilly areas are very unpredictable, which can affect the productivity of the human labors, hence the need of a machine that can collect/harvest pine straw/needles for the forest with least human interference is identified that can serve on the hilly forests ensuring safety and higher productivity.

1.2 PROBLEM STATEMENT

Pine, being the most available conifer in the higher altitudes, serves the purpose of fuel (due to its high calorific value), medicine and adds to generate economy to the local rural households which in turn saves valuable resources, time and money. Although the pine needle collection from the hilly forest isn't an easy task, it is usually collected manually by employing labors and mechanical balers to roll the collected pine needles.

The collection of those pine needles is a challenging task till now. There are till now few agricultural mechanized methods known with very limited applications and uses on the flat fields not on the hills. Development of a new mechanism can be helpful in the collection of these needles from the hilly forests and certainly will add an advantage to the lives of the local rural people.

1.3 OBJECTIVES

The research aims at developing a mobile robotic platform for the collection and storage of pine needles in a multi terrain area:

- ❖ To develop the mathematical model of mobile robotic base.
- ❖ Design and development of structure of pine needle collecting robot.
- ❖ Development of the operating technique for control and collection.

1.4 RESEARCH METHODOLOGY

The following research methodology will be incorporated:

- ❖ The mechanism will be designed which can climb the gradient and sweep through the uneven terrain without tipping through various available locomotion and suspension mechanisms.
- ❖ The pattern recognition and machine vision technique will be developed to recognize the pine needles in the forest.
- ❖ In order to move through the woods path planning and path restoration with the help of various sensors will be developed.

- ❖ The design will be optimized based upon the output of the analytical software tool.
- ❖ Testing will be done on different terrains to optimize the design through a collected data set of observations.

1.5 THESIS CHAPTER SCHEME

Chapter 1 is the introductory part includes motivation of the research, Statement of the problem, Objectives and proposed methodology of the research

Chapter 2 discusses in detail about the Literature survey done of the present mechanism and the system scheme of different control & pattern recognition methods.

Chapter 3 discusses in detail about the experimental development of the PiNCoR and why its collection is an area of concern. The mechanism, approach of collection and few control strategy of the locomotion, pattern recognition and collection schema also been detailed. The kinematic and structural analysis has been done of the rocker arm and bogie parts for the safe designing of the robot structure.

Chapter 4 discusses in detail about various results and observations taken during the testing phase of the structure in-house and outhouse environment. The data has been concluded in the tabular based on the observation of the 3 weeks run of the mobile robotic structure on various gradients.

Chapter 5 deals with the conclusion and future scope of the research project references used during the documentation of this thesis.

CHAPTER 2

LITERATURE REVIEW

2.1 OVERVIEW OF FOREST RESIDUE/BIOMASS

2.1.1 History

Domestication of plants, i.e. Agriculture, has been started way back about 11500 years ago, since then the human being is dependent on the plants, trees of farms and forests for the daily food and other stuffs such as wood, hay, medicines, etc. In the rural areas forests provide a number of products like timber, fruits, biomass and fuel to the households for daily use. Biomass is a n important source of energy in most of the rural areas till now. Many households use wood, dried leaves, charcoal and other forest residue to meet their household fuel requirements [3]. Forest residues and wood wastes are a potential source of daily energy production and needs. Until 19th century the biomass contributes nearly 70% of the global energy needs and with the recent advancments in the need supply of the enegy through coal, gas and other fossil fuels, the share of biomass decreased upto 14% but its importance can still be experience in rural and higher altitude areas [4].

With the advancement in the biomass energy conversion and production technologies including planting, cultivation techniques and improved harvesting techniques significantly contributed in lowering down the production of the biomass energy [5]. Biomass and forest residue is the main source of energy at higher altitudes and mountain rural regions and more than half of the energy generated is consumed for cooking food apart from fodder and feed [6]. The forest biomass can be divided into four major forest categories viz. hardwood, spruce-fir, pine and bamboo by Forest Survey of India.

2.1.2 Pinus Roxburghii, A Himalayan Conifer

Pinus Roxburghii commonly khnown as Pine or Chirr Pine, a type of conifers, are very important in the Himalayan Region across India, Pakistan, Nepal and southern part of Tibet between the elevation of 600 – 2300 m [7]. Pine has many uses in rural and mountain areas ranging from home decorating to medicinal uses. The resin extracted from the pines have been used for repair broken pottery, cure cough, plaster for fractured bone, reduce scar tissues etc. Also it is also a good fuel with high calorific value than other forest fuels such as wheat husk, olive husk, corncob [8] and hence pine has been used as widely used for fuels by the hilly and rural households because of its easy availability. As compared to other trees of the category Chir Pine shed their needle type leaves in the dry months starting from April to June and usually cover the whole grassland of the forest. Being very dominated pine needles fallen on the ground doesn’t alow any other plant to grow and being hig in calorific value, it also leads to several forest fires.

2.2. INDUSTRIAL ROBOTS

- **Automation Center for Research and Education (ACRO) – Robotic Apple Picker [9]**

The ACRO automated fruit-picking machine (AFPM) harvester uses a unique vacuum-gripper design to pick the fruit and ease coordination between the vision system and robot controller. Mounted behind a common agricultural tractor, the AFPM platform supports a Panasonic industrial robot to "pick" the fruit.

To pick one apple, the robot has to determine the distance between the camera and the apple and the path to get there. The camera measures this distance by triangulation. The measuring is done in several steps. The camera first acquires an image, and then the camera is turned so that the apple is situated in the center.

Fig. 2.1: ACRO Apple Picker

- **Boston Dynamics – BigDog [10]**

It is based on feet, with vacuum technology, BigDog is a rough-terrain robot that walks, runs, climbs and carries heavy loads. BigDog is powered by an engine that drives a hydraulic actuation system. BigDog's on-board computer controls locomotion, processes sensors and handles communications with the user. The big Dog's control system keeps it balanced, manages locomotion on a wide variety of terrains and does navigation. Sensors for locomotion include joint position, joint force, ground contact, ground load, a gyroscope, LIDAR and a stereo vision system.

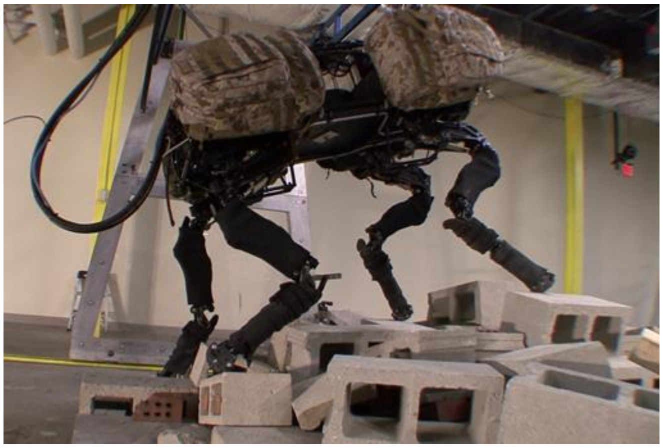


Fig. 2.2: Boston Dynamics – BigDog

- **Manual Raking and Mechanical Baling [11, 12]**

Collection of Pine straw is done manually and baled mechanically either by using hydraulic balers attached to tractor' s hydraulic system or simple hand powered box balers. The cost of the entire bailing process goes to $250 per acre without labor charges. The optimum row spacing depends upon the size and shape of the equipment used for raking and baling. The old style equipment requires 12 to 16 feet between rows for equipment access. However, newer, specialized equipment requires only 6 to 8 feet between rows to move the equipment.

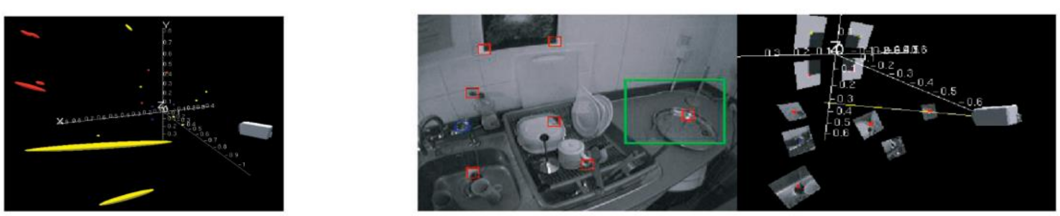
Fig. 2.3: Mini Star Roll Baler

Fig. 2.4: Simple Hand Powered Box Balers

2.3. MACHINE VISION AND IMAGE PROCESSING TECHNIQUES

Michael et.al [13] has discussed the performance of FastSLAM over the EKF (Extended Kalman Filter) technique in the open environment for the data association. FastSLAM, an approach uses Rao-Blackwellized Particle Filter, shown to scale logarithmic number of landmarks on the map [14]. Simultaneous Localization And Mapping (SLAM) is used to building a map of unknown environment with a moving robot. SLAM is an additional feature in the autonomous robots working in environment where accurate maps are not available [15, 16].

Davison A.J et.al [17] in their paper has worked on a real time algorithm which can retrieve the movement of a freely moving camera as an only data source. In MonoSLAM the main assumption are probabilistic mapping, motion modeling & active measurement and mapping of a sparse map of high quality feature. The efficiency is ensured by the active feature search resulting in no waste of image processing effort. The algorithm, with its experimental result, has an impact on advance robotics, wearable technology and user interface. The work majorly deals with the high frame rate real time performance (~30 Hz). As localization and mapping is an extremely inter-related issue and requires attention on both to solve the problems, hence the author worked on localization as their main output of the interest.



(a) (b)

Fig. 2.5: (a) A snap shot of probabilistic 3D Map showing camera position estimate and feature position uncertainly ellipsoids (b) visually salient feature detected.

Hussin R. et.al [18] in the paper discussed about an algorithm that can be used to detect/recognize object from intricate environment by using edge detection, color processing and mathematical morphology. Author in his experiment detects the shape of Mangoes from the mango tree using CHT (Circular Hough Transform) [19] with the help of MATLAB program. The CHT algorithm detects the object (Mango) by detecting the circular pattern with the help of joining maximum voting points around the given radius. It prepares the image of the object then the image RGB adjustment is done which is followed by the detection of the color of each pixel to compare the object and the background and finally the deleting the unwanted region by changing RGB pixel value to 0.

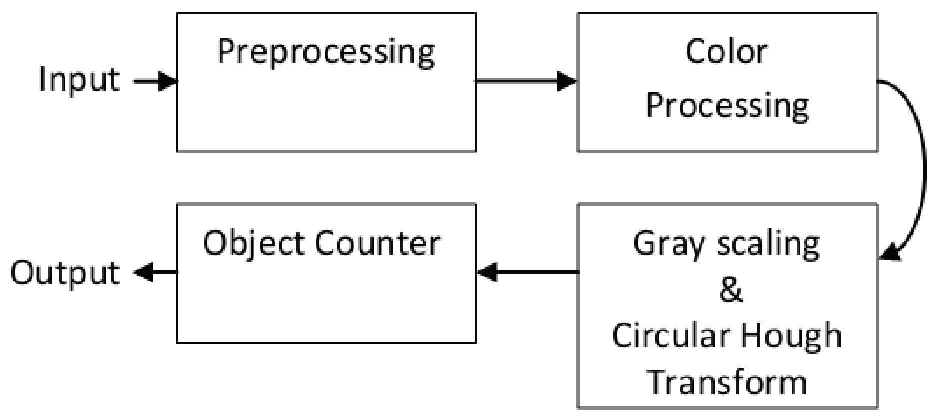


Fig. 2.8: Object Recognition Block Diagram using CHT

Pal Nikhil R & Pal Sankar K [20] has analytically discussed and summarized different image segmentation techniques such as Gray Level histogram, Spatial Details, fuzzy sets, Thresholding, Edge detection, Clustering, Markov Random Field (MRF) and compared the results obtained. For different types of images viz. light intensity (visual), range image, nuclear magnetic resonance image (MRI), thermal images, there is no single segmentation technique that can hold good for all the images. Author also tried to survey on the fuzzy sets and neural network based model algorithms which generate accurate output in real time as these methods are robust enough to process magnetic resonance images (MRI) [21].

The paper concluded with the finding of objective evaluation of segmentation results.

Robert Sim, James J. Little [22] addressed the issue of navigation of robot in an unknown environment with the help of Rao-Blackwellised particle filter (RBPF) which has an added advantages over active range-finding devices such as laser or sonic transducers. Author clarified autonomous exploring and mapping issue with stereo camera and an odometry sensor and trot out a consistent, convergent simultaneous localization and mapping solution with the generation of accurate localization and collision free navigation. The paper determines a system which holds a capability of accurate mapping a large and complex environment, can analyze and navigate fully autonomously using exact localization (visual landmarks).

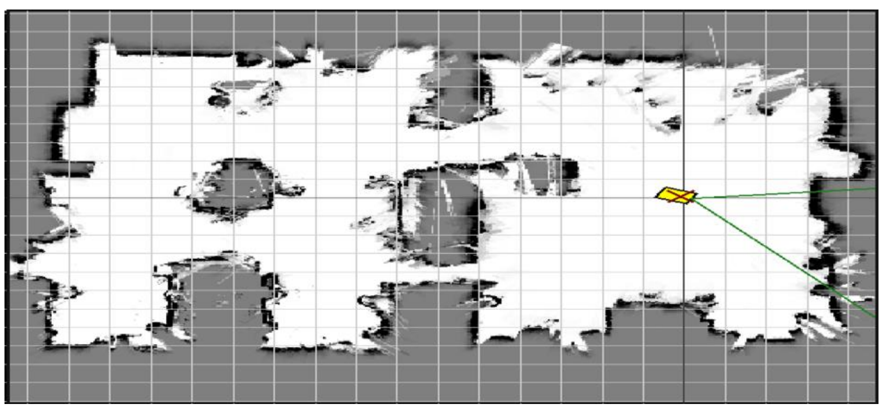


Fig. 2.9: Map captures environment features

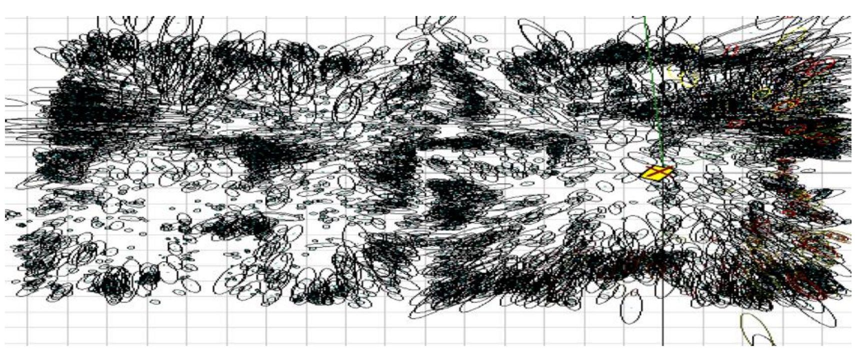


Fig.2.10: Landmark map constructed at the end

Ahmad Z. A et. al [23] has proposed an advanced distributed computing technology for Image processing applications. This technology uses an integrated multi-processing unit that work together to execute the task simultaneously [24] where the size of the data of processing is huge such as Image Processing Applications. The experiment was done using ARM processor connected to another processor using RS 232 cable and a DB 9 sub connectors using shortest cable length in order to avoid any signal loss. The firmware was C ARM language using Kiel uVision3 Integrated Development Environment (IDE).In this experiment author has used 8 bit data bus whereas ARM processor has 32 bit [25] data line by implying a 32 bit data bus the speed can be further improved up to 4 times theoretically.

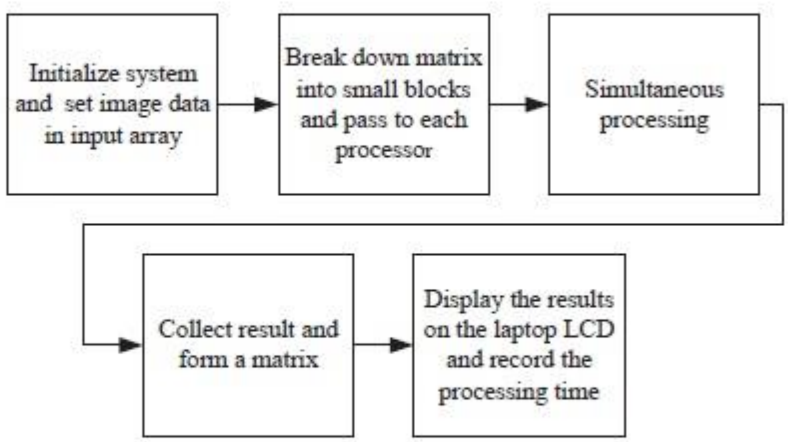


Fig. 2.11: General Process Flow

Kazuhiro Fukui and Osamu Yamaguch [26] has proposed a novel technique of pattern matching which is fast and extract exact feature in order to provide accurate results. The facial point extraction majorly affects the template matching based face recognition methods. The proposed method combines shape information and pattern information to root out the conventional pattern information method issues. It basically determines the feature points which are based on the shape information and authenticate it the pattern matching information to produce high position accuracy, robust to feature point shape variations and brightness. It also reduces the volume of the computation as the pattern matching will be done only for the objects which are sorted by the separability filter and hence increases the speed.

2.4 PATH PLANNING TECHNIQUES

Lumelsky et. al [27] discussed the path planning problem of a mobile robot which is working in an environment filled with obstacles of unknown shape and position. In the algorithm used, the motion palnning has been done dynamically, based on the automaton's current position and feedback.

Emilio Frazzoli et. al [28] proposed a randomized path planning architecture for dynamical systems. The architecture is closed loop which enables the vehicle guidance from any point/state to any configuration at rest and motion in presence of obstacles. After starting the from the initial conditions, the algorithm incrementally builds a tree of feasible trajectories and adds a new branch and a noode to the tree. The randomized motion-planning algorithm based on obstacle-free guidance systems in probabilistic roadmap framework was presented which is having a main advantage of its capability to address in an efficient and natural fashion the dynamics of the system.

Giebrecht J [29] in his paper discussed the global path planning method for unmanned ground vehicles which gives an overview of high-level planning methods used in mobile robotis espacialy in outdoor planning. The survey was done on all portion of the path planning process and investigated the recently developed and popular algorithms such as Potential Fields, Wavefront Planning, Probablistic Roadmaps etc.

Vu T Minh et. al [30] discussed the feasible path planning of nonholonomic vehicles subjected to real vehicle dynamic constraints. The paper presents the performance of the path planning methods along with the simulations and comparison for evaluation of more realistic and smoother generated trajectories. The system automatically generates a optimal path and control and track the vehicle exactly on the path from any given start to destination points from the map restricting vehicle physical constraints on obstacles, speed, steering anlges etc. The paper concludes the analysis which shows the symmetric polynomial algorithm will have the smoothest trajectory.

2.5 SUMMARY OF LITERATURE REVIEW

The literature review has shown that the Pine Straw can be an important forest residue and source of energy available in plenty at higher altitudes where the transportation and the availability of the conventional fuels will be a challenging task at times. It can also be noted from the literature review that the methods for harvesting pine straw from the hilly forests is limited to manual harvesting only, whereas the raking and baling can be done with the help of mechanical balers. Some agricultural advances shows human machine interference for rowing, ploughing, cultivating and harvesting crops with advanced computing, artificial neural schemes and image recognition and processing techniques of field but still limited to flat terrains. All these experiments have their advantages, disadvantages and limitation over another. The lack of optimal solutions for these agricultural problems is a challenge due to various reasons such as non-uniform pattern, capacity of tackling the unknown environment, environmental impact, territorial & geographical impact.

Current systems are limited to the manual harvesting of the forest products. There is no system available in the market that can serve the purpose on uneven terrains and dangerous zones for humans to reach.

It’s a new technology for collection of leaves/fruits autonomously operating machine to reduce the manual labor for the collection in rough and heavy forests in all the seasons of the year. Till date most of the advanced R&D centers are working for the machine. So far we are collecting it manually covering a limited area in a day and hence increasing the cost. In order to address this limitation, we have designed a wireless system for collection of the leaves/fruits in various rough terrains.

A brief comparison of the technologies is briefed as under: -

Table 2.1 - Comparison between different techniques used for Pine Needle/Straw Harvesting

Technology	**Method**	**Merits/Demerits**
Human Effort	With Hand raking devices and Mini hydraulic balers	• Costly, harvesting cost goes up to 40,000/- • Time taken, more effort is needed
Proposed harvester robot	Uses suction system to harvest and automatically stores in a storage area on board.	• Can be used multi terrain • Human intervention is less • The performance area is more

The proposed system will override the limitation of the current system with its advanced sensor fusion with the hardware and allow harvesting the products (Pine needles) without human intervention.

CHAPTER 3
EXPERIMENTAL PROCEDURE

3.1 DESIGN CONSIDERATION AND CONSTRAINTS

3.1.1 Consideration of Geographical Conditions

The pine needle/straw (in various species) has been available in abundance in the hilly forest areas, generally in temperate and subtropical regions around the earth. In India the pine (commonly *Pinus roxburghii)* forests majorly spread over the northern hilly region across Jammu and Kashmir, Punjab, Himachal Pradesh, Uttarakhand and Sikkim to Nepal and Bhutan. Pine forests are evergreen tall trees with each every part is important of it as discussed in the literature review section.

3.1.2 Constraints for the design of PiNCoR

In order to sweep the hilly forest area, the robotic machine should have:

i. Flexible locomotion system to maneuver over the rough terrains, pots and holes.
ii. Obstacle avoidance mechanism to avoid hitting the tress on the way.
iii. System to recognize pine straw/needles.
iv. Mechanism to pick pine straw from the ground.
v. Power backup to run the machine and its accessories.
vi. Sensory system to operate and control the machine function and avoid hazards.

Hence, according to the requirements a robotic multi terrain prototype has to be designed and fabricated which has features such as:

a. Rocker Bogie Locomotion and Suspension Mechanism equipped with variable ground clearance, which enables the rover to maneuver through the terrain.

b. Path Planning and Path restoration algorithm needs to be developed for Obstacle Avoidance while maneuvering through forest.
c. An advance needle/straw suction mechanism with retractable facility.
d. DC high torque geared motors to facilitate the rover to move uphill and downhill without slippage.
e. 10Ah DC rechargeable power bank to fuel up the rover power requirement throughout the run continuously without fail,
f. Smart sensory circuit of six sensors which helps in avoiding the obstacle while negotiating the path through woods.

3.2 MECHANICAL AND CONTROL ASPECT

The approach has been divided into two parts as follows:

Table 3.1- Mechanical and Control Aspect of PiNCoR Design

S. No.	Mechanical Aspect
1.	Mobile base for Terrain Locomotion
	➢ Design of Mobile Vehicle for rough terrain and leaf collection.
	➢ Stress, Strain Analysis
	➢ Incorporating of ultrasonic sensor in mobile vehicle for navigation.

S. No.	Control Aspect
1.	Control System design
	➢ Study of DC Geared Motor
	➢ Study of bidirectional Encoders and Interrupts
	➢ Study of DC Servo Motor

2.	Robot manipulator and Vacuum System Design		➢ Driving and exchanging data wirelessly of microcontrollers in SPI mode
	➢ Design of high suction vacuums with less complexity		➢ Study and Testing of Ultrasonic sensor
	➢ Separate Stress , Strain Analysis of Robotics Base		➢ Incorporating of ultrasonic sensor in rail guide system for navigation.
	➢ Selection of material.		➢ Interfacing of LCD
	➢ Fabrication of Robotic Mobile Platform		➢ Study and testing of SLAM
3.	Fabrication of Mobile Vehicle Locomotion.		➢ Pattern Recognition logarithm testing and analysis
4.	Study and integration of Laser Distance Mapping Sensor.		➢ Analysis of all parameters, block diagram and transfer function design.
5.	Integration of mechanical and control aspects.		
6.	Testing of the system on different terrains for troubleshooting		
7.	Comparative study of performance and efficiency of Manual and Robotic Collection System and the present possible system architecture		
8.	Data analysis for the development of design perspective, identification and efficiency analysis.		

3.3 MECHANICAL DESIGNING OF PINCOR

The design of mobile platform [31-34] of a multi terrain robot requires several considerations such as height, length, width, weight, ease of accessibility of parts assembled along, load capacity which draws the attention to choose the material which has strength to carry the load of components, drive system and power station unit plus stiffness to take the off road dynamic load from the locomotion system.

In the designing of mobile platform cum storage box of PiNCoR, preference has been given to the dimensions of the box so that every component such as a suction pump, controlling and driving unit plus storage will not interfere with each other also has minimum effect on the center of gravity. Since the central platform cum storage box houses all the electronic circuitry, battery pack and chopped needles, hence in order to safeguard it must be heat and water resistant also it must be lightweight so that the overall power requirement will be lowered down for longer run operations.

After going through the properties, machining constraints and availability of various materials, it has been found out that the Aluminum will be the right material for the design of central platform cum storage box as it is readily available, machinable, heat and water resistance and above all very light weighted as compared to other materials in the same dimensions. General properties of Aluminum 6063 – T5 have been tabulated as under:

Table 3.2 - Mechanical properties of Aluminium -6063-T5

Property	**Value**	**Units**
Elastic Modulus	6.9×10^{10}	N/m^2
Shear Modulus	2.58×10^{10}	N/m^2
Density	2700	Kg/m^3

Tensile Strength	1.45×10^8	N/m^2
Compressive Strength	5.72165×10^8	N/m^2

Since PiNCoR has to work off road all the time, hence special attention has been paid while designing its locomotion cum suspension unit. After going through number of locomotion systems [35] such as tracked, wheeled, vacuum etc. it has been found that Rocker Bogie mechanism has more advantages over any other locomotion techniques. This type of locomotion design has continuously been used in so many off roads & multi terrain activities, inter terrestrial operations such as Mars Rover [36] by the National Aeronautics and Space Administration (NASA) for findings on the Mars and so on.

Rocker Bogie locomotion unit is generally link mechanism that consists of number of rigid elements connected through joints of some number of Degree of Freedom (DoF) helping the structure to move through rough terrain without tilt or losing ground contact [37].

Stress, Strain and displacement analysis of the rocker and bogie were done in Solidworks software of Dassault Systems. From the figure 4.1 it is apparent that the maximum stress is induced at the juncture where there is a provision provided for motor fitting on both ends of the bogie. This is due to the maximum amount of strain occurs at that position. The junction is a drilled space and hence the maximum amount of stress is concentrated at this point. The graph besides the diagram shows the maximum and minimum stress strain ranges. This analysis gives us a clear idea that we need to release the stress from the specified location. It can be either done by heat treating the component to make bring it to a specified strength or using the same material for welding as the base material to maintain the uniformity of the properties. Hence welding was done using electric arc welding only.

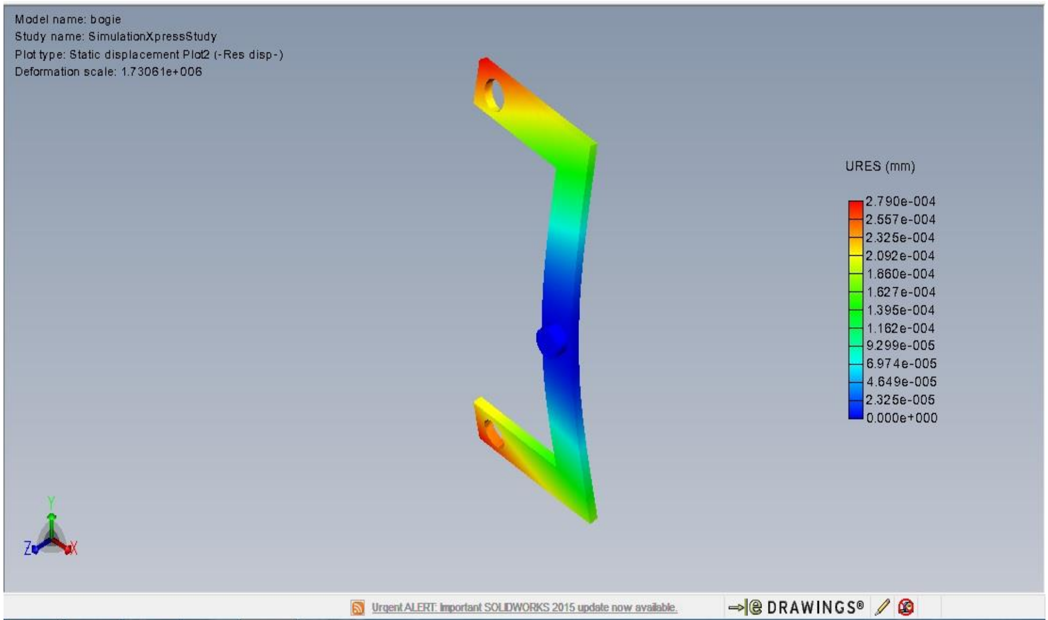


Fig. 3.1: Static Displacement of the Bogie

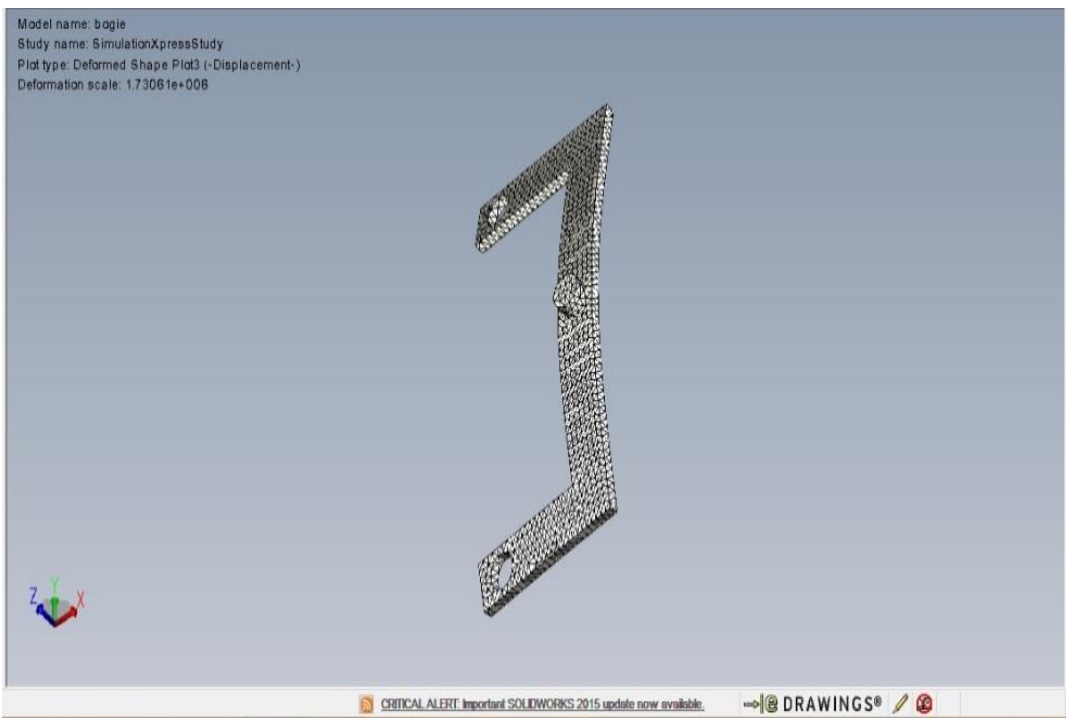


Fig. 3.2: Deformation of the Bogie

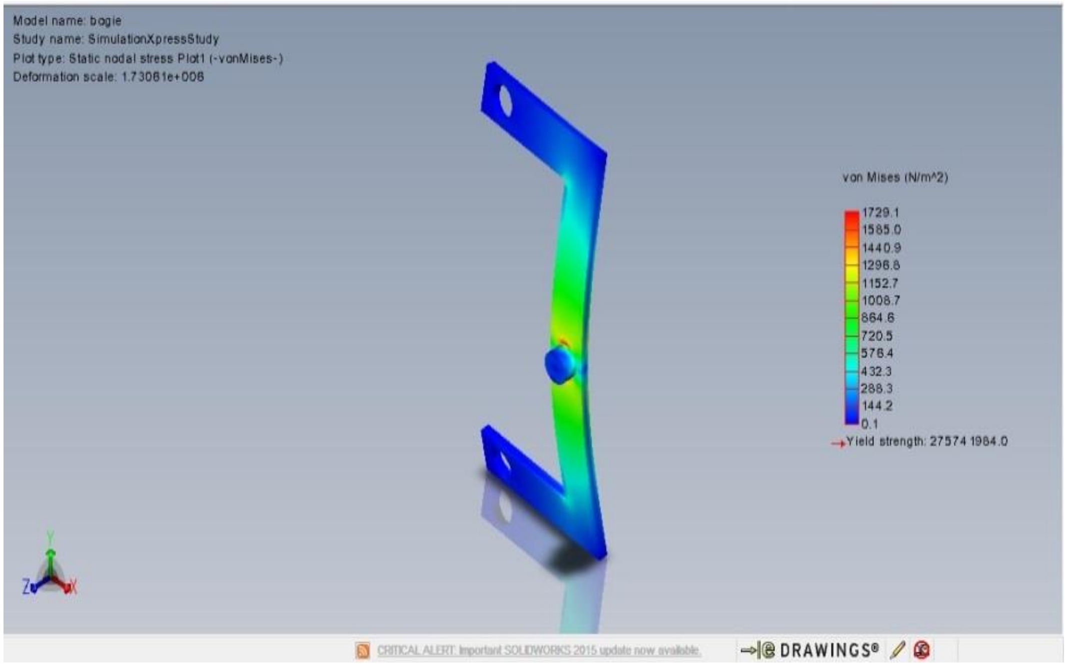


Fig. 3.3: Von Mises Static Nodal Stress of the Bogie

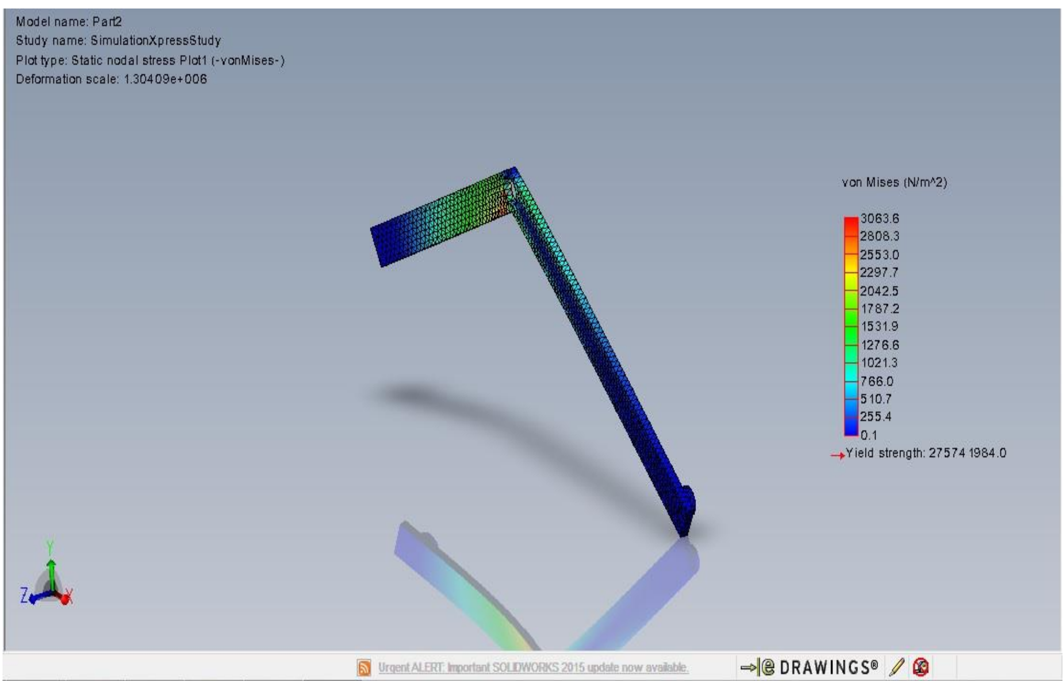


Fig. 3.4: Von Mises Static Nodal Stress of the Rocker

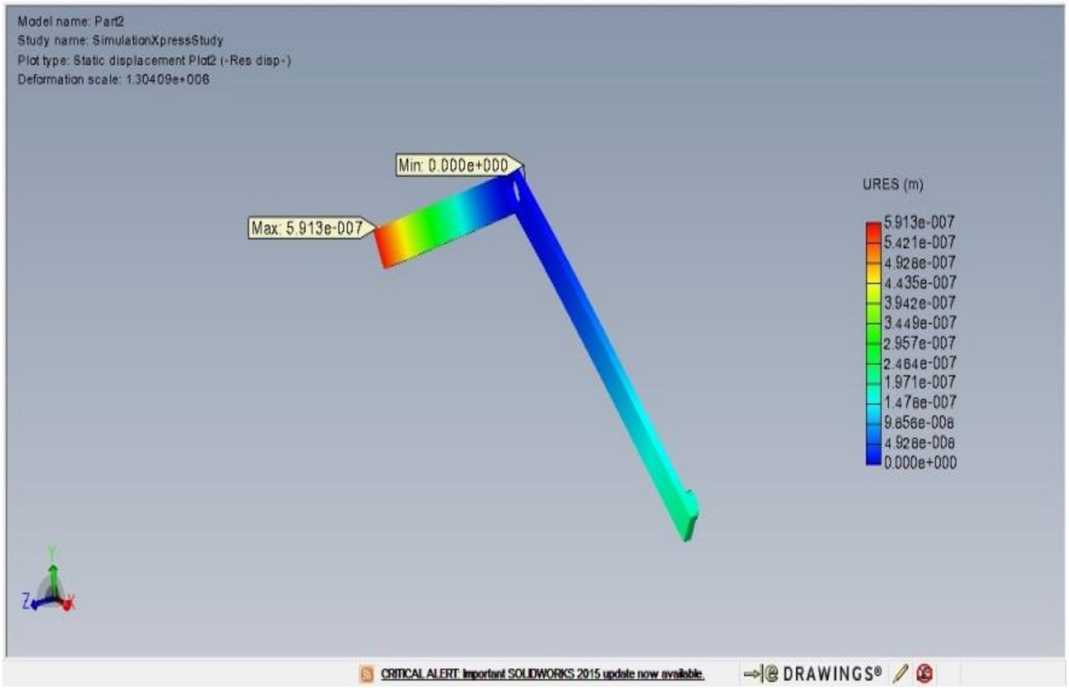


Fig. 3.5: Static Displacement of the Rocker

Fig. 3.6: Deformation of the Rocker

The above images show the results produced by the load analysis on the rocker and bogie of the structure. Fig 4.1 shows the static displacement of the bogie ranges from 0.0 mm (min) to $2.79X10^{-4}$ mm (max). Fig 4.2, shows the mesh diagram of the deformation of the bogie which sustains the reaction from the ground as well as the load of the structure coming on to the bogie.

Fig 4.3 shows the Von Misses stress analysis of the bogie. The values of the stress range from 0.1 (minimum) to 1729.1 (maximum) N/m^2. The von Mises yield criterion suggests that the yielding of materials begins when the second deviatory stress invariant J_2reaches a critical value. For this reason, it is sometimes called the J_2-plasticity or J_2flow theory. It is part of a plasticity theory that applies best to ductile materials, such as metals. Prior to yield, material response is assumed to be elastic. Fig 4.5 shows the Static Displacement analysis of the rocker arm. The values of the displacement range from 0.00 mm (minimum) to $5.913X10^{-7}$ mm (maximum) under the maximum load condition. The load is assumed to be 210 N (~21 Kg) which is under the loading factor of safety of >3.

The mechanical properties of the selected material are as follows in table 4.3 and 4.4:

Table 3.2 - Mechanical properties of Cast Iron

Property	**Value**	**Units**
Elastic Modulus	6.61781×10^{10}	N/m^2
Shear Modulus	5×10^{10}	N/m^2
Density	7200	Kg/m^3
Tensile Strength	1.51658×10^{8}	N/m^2
Compressive Strength	5.72165×10^{8}	N/m^2

The suspension used in PiNCoR has symmetrical construction on both sides with each side having 3 wheels (powered) connected with each other via single link. The rocker is the main link which consists of two joints; first joint is connected to the front wheel while the second joint holds the bogie. The symmetric suspension mechanism has been connected to a central differential mechanism, the output shaft of which has been connected with suspension joint connecting the main box platform. This mechanism results in greater stability of the structure because of the following reasons:

a. The differential mechanism reduces the cornering forces on the main platform
b. The load on each wheel is approximately same
c. It can cross over the obstacle, pit holes without affecting the center of gravity of the structure by keeping other wheels constantly in ground contact.

3.3.1 Torque Calculations

There are a number of factors that affect the selection of drive motors for a mobile vehicle. The drive motors required for PiNCoR locomotion depends on the coefficient of friction of the terrain surface on which the robot will move, dimensions of the structure, weight of the vehicle and so on. In order to select the appropriate motor which produces enough torque to propel the vehicle, it is necessary to determine the total tractive effort required for the vehicle.

Total Tractive Effort (TTE) is:

TTE = Rolling Resistance (RR) + Grade Resistance (GR) + Acceleration Force (FA) [N]

These components can be derived from the following steps:

The design criteria to determine the maximum torque required for the drive motors of the PiNCoR:

- ❖ Gross Vehicle Weight: 215.74 N
- ❖ Radius of the wheel: 0.0635
- ❖ Maximum Incline angle: 55 degree
- ❖ Working Surface: Firm Mud

(1) Rolling Resistance is the force necessary to drive a vehicle on any surface. For PiNCoR the contact surface is firm mud whose surface friction coefficient C_{rr} is 0.037. For determining the Rolling Resistance (RR):

Rolling Resistance (RR) = Gross Vehicle Weight (GVW) x C_{rr}

Rolling Resistance = 215.74 x 0.037 N

RR = 7.98 N

(2) Grade Resistance is the force necessary to overcome the resistance offered during the movement of the vehicle on a Slope or Grade. The maximum grade or angle up to which the PiNCoR will move is 55^o.

Grade Resistance (GR) = Gross Vehicle Weight (GVW) x sin (α)

Grade Resistance = 215.74 x sin (55) N

GR = 176.72 N

(3) Acceleration Force (FA) is the force necessary to accelerate the vehicle from stop to maximum speed.

Acceleration Force (FA) = Gross Vehicle Weight (GVW) x V_{max}/ (32.2 x t_a)

Acceleration Force (FA) = 215.74 x 0.2/(9.81 x 2) N

FA = 2.20 N

The total tractive force (TTE) is the net horizontal force applied by the drive wheels to the ground and varies according on the number of drive wheels in the vehicle will be the sum of RR, GR and FA as discussed earlier

Total Tractive Force = 7.98 N + 176.72 N + 2.20 N

TTE = 186.91 N

Tractive force required per wheel will be, Total Tractive Force/ No. of Drive Wheels, 31.15 N (as PiNCoR has six drive wheels).

Wheel Motor Torque is the torque required per drive wheel in order to move the vehicle uphill on a gradient of 55^o:

Total Wheel Torque (T_w) = Total Tractive Effort x Wheel Radius x Resistance Factor

Total Wheel Torque (T_w) = 186.91 x 0.0635 x 1.15 N-m

T_w = 13.65 N-m

Hence, per motor torque required at each drive wheel of PiNCoR for uphill movement of 55^o (max) with a gross vehicle load of 22 kg (215 N) is **2.27 N-m**.

3.3.2 Kinematic Analysis of PiNCoR

This section describes the robot characteristics for its kinematic modelling. The robot has six wheels using a rocker bogie suspension mechanism as shown in the Fig. (1). The PiNCoR is 56.5 cms long, 31.5 cms wide and 25.5 cms high. The PiNCoR is equipped with a suction mechanism which enables the collection of pine needles from the ground. An adjustable ground clearance of 20 cm is provided which enables it to maneuver freely through pits and holes on the hills.

All the wheels in PinCoR are 17 cm in diameter and have a nominal speed of 0.2 m/sec.

The smooth operation of the PiNCoR is due to the independently actuated wheels which are attached to a rocker bogie suspension mechanism which enables its movement in low velocity and uneven terrain. The rocker bogie suspension consists of two main rockers which are joined at a central differential unit, with the main body called as Averaging Mechanism. This stabilizes the body unit and helps in preventing the toppling effect of the rover at inclinations. Each rocker has three non-steerable independently actuated wheels; one at the front and the remaining two at the small rocker end in the back portion. The joint angle between the small and main rocker is denoted by ψ_1 & ψ_2, the left and right bogie angles (main rockers via differential) are denoted by β_1 & β_2. The wheel rotation is denoted by ζ_i where i = 1 – 6. There are in total six actuators in the form of encoded motors connected to the wheels which enable independent movement of the PinCoR along the β_1, β_2, ψ_1, ψ_2 rocker bogie joints for flexibility based on the terrain.

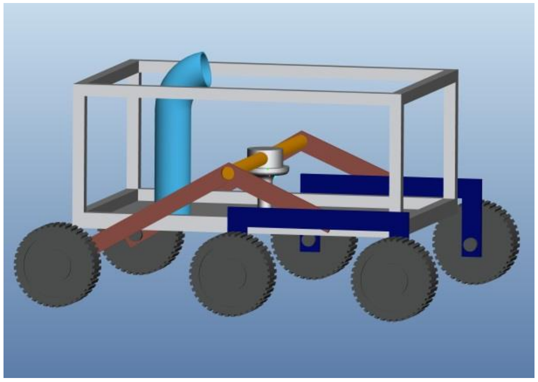


Fig.3.7: Pro – E Model of PinCoR

The encoded motors help in determining the wheel angular rotation ζ_i. The body roll, pitch and yaw was calculated with the help of accelerometer. The location of the rover in the forest was tracked using a real time GPS map at the base station and the PiNCoR equipped with battery level encoder so that it can return to base when the power reduces during its operation.

In the coming sections, the forward kinematics of the PiNCoR using wheel Jacobian matrices has been discussed followed by the inverse kinematics derivation.

3.3.2.1 Forward Kinematics

For the forward kinematic analysis of the PiNCoR, the coordinate frame system for both left and right bogies was defined as shown in the fig. (2) & (3). For the PiNCoR, a local coordinate system was defined and the origin of these coordinate system was called as 'Reference point' on the robot frame designated as '*O*', the differential joint as '*D*', the left and right bogie's as 'β_i $(i = 1, 2)$' and axes of all wheels as 'A_i $(i = 1,2,3,4,5,6)$'.

Various design angles are shown in the fig. (2) & (3).

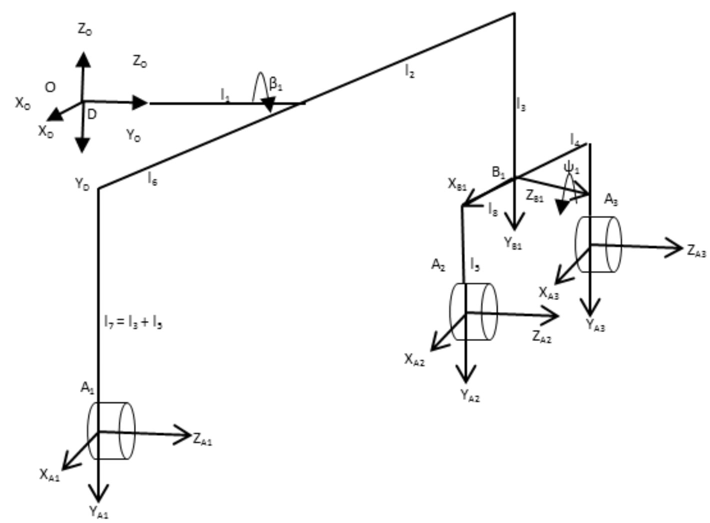


Fig. 3.8: Left Coordinate Frame

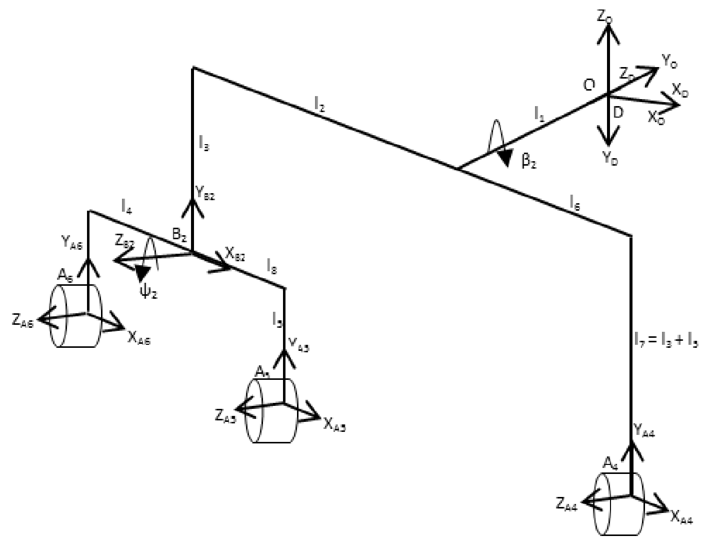


Fig. 3.9: Right Coordinate Frame

Every coordinate frame shows a step by step kinematic chain from the origin to the wheel axis e.g. the kinematic transformation from the origin (reference) to the wheel 1 axle can be represented by $O - D - A_1$. The coordinate frames was determined by the Denavit – Hertenberg notations [38] related to the various coordinates given in the Table 1. The D – H parameters define the transformations from one joint to the next joint in the kinematic chain, ***'θ'*** defines rotation between the z-axis, ***'d'*** defines the distance along the z-axis between joints, ***'a'*** defines the distance along the x-axis between joints, and ***'α'*** defines the angle between z-axes of joints. The general transformation matrix is represented below based on the coordinate frame *i* to coordinate frame *j* using a homogenous transformation matrix:

$$T_{j,i} = \begin{bmatrix} Cos\,\vartheta_j & -Sin\,\vartheta_j Cos\,\alpha_j & Sin\,\vartheta_j Sin\,\alpha_j & a_j Cos\,\vartheta_j \\ Sin\,\vartheta_j & Cos\,\vartheta_j\,Cos\,\alpha_j & -Cos\,\vartheta_j\,Sin\,\alpha_j & a_j Sin\,\vartheta_j \\ 0 & Sin\,\alpha_j & Cos\,\alpha_j & d_j \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad \text{Eqn. (3.1)}$$

Where ϑ_j, α_j, a_j, d_j are the D – H parameters for coordinate frame j. The above matrix shows the transformation of coordinate frame j in terms of coordinate frame i. The transformations from the robot reference frame *'0'* to the wheel axle *'A_1'* was obtained by cascading each transformation.

$$\mathbf{T}_{O,\,A1} = \mathbf{T}_{O,\,D}\,\mathbf{T}_{D,\,B1}\,\mathbf{T}_{B1,\,A1}$$

Table 3.4- D – H Parameters

Joint Axis	ϑ (deg)	α (deg)	d (cm)	a (cm)
O – D	0	-90	0	0
D – A_1	β_1	0	15	44
D – B_1	β_1	0	15	-19
B_1 – A_2	Ψ_1	0	0	20
B_1 – A_3	Ψ_1	0	0	-20
D – A_2	β_2	180	-15	44
D – B_2	β_2	90	-15	-19
B_2 – A_2	Ψ_2	0	0	20
B_2 – A_3	Ψ_2	0	0	-20

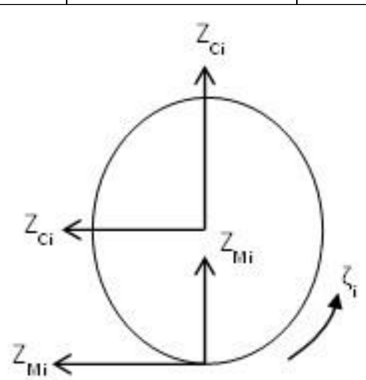


Fig: 3.10: Wheel Motion frame

To capture the wheel motion, there is an additional requirement of coordinate frames i.e. wheel contact frame C_i and wheel motion frame M_i. To obtain $C_{i,}$ the wheel axis A_i was rotated about the Z – axis until the X – axis became parallel to the ground which was later rotated by an angle of 90 degrees.

The derivation of the transformation matrices of contact frame C_i was done using Euler angle Z-X-Y as given below.

$$\mathbf{T_{Ai,Ci}} = \begin{bmatrix} Cos\,p_i Cos\,r_i - Sin\,p_i Sin q_i Sin r_i & Cos\,r_i Sin\,p_i + Cos\,p_i Sin\,q_i Sin\,r_i & -Cos\,q_i Sin\,r_i & 0 \\ -Cos\,q_i\,Sin\,p_i & Cos\,p_i Cos\,q_i & Sin\,q_i & 0 \\ Cos\,r_i Sin\,p_i Sin\,q_i + Cos\,p_i\,Cos\,r_i & -Cos\,p_i\,Cos\,r_i\,Sin\,q_i + Sin\,p_i\,Sin\,r_i & Cos\,q_i Cos\,r_i & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Eqn. (3.2)

Where p_i, q_i, & r_i are the rotation angle about X, Y and Z respectively.

Also, in order to obtain the wheel motion frame, it was translated along the negative Z – axis by wheel radius (R_w) and translating along the X – axis for wheel roll ($R_w \zeta_i$).

Hence the transformation matrices, for all frames, can be shown as below:

$$\boldsymbol{T_{OM1} = T_{OD}, T_{DA1}, T_{A1C1}, T_{C1M1}} \qquad \text{Eqn. (3.3)}$$

$$\boldsymbol{T_{OM2} = T_{OD}, T_{DB1}, T_{B1A2}, T_{A2C2}, T_{C2M2}} \qquad \text{Eqn. (3.4)}$$

$$\boldsymbol{T_{OM3} = T_{OD}, T_{DB1}, T_{B1A3}, T_{A3C3}, T_{C3M3}} \qquad \text{Eqn. (3.5)}$$

$$\boldsymbol{T_{OM3} = T_{OD}, T_{DA4}, T_{A4C4}, T_{C4M4}} \qquad \text{Eqn. (3.6)}$$

$$\boldsymbol{T_{OM4} = T_{OD}, T_{DB2}, T_{B2A5}, T_{A5C5}, T_{C5M5}} \qquad \text{Eqn. (3.7)}$$

$$\boldsymbol{T_{OM6} = T_{OD}, T_{DB2}, T_{B2A6}, T_{A6C6}, T_{C6M6}} \qquad \text{Eqn. (3.8)}$$

To obtain the wheel Jacobian matrix, the motion of the robot must be expressed as wheel motion by applying the derivative of instantaneous transformation from the origin '***O***' to the wheel motion '***M_i***' $\dot{T}_{\hat{O},\widehat{M_i}}$ as shown below

$$\dot{T}_{\hat{O},R} = \dot{T}_{\hat{O},\widehat{M_i}}\, \dot{T}_{(M_i),(O)} \qquad i = 1, 2, 3, 4, 5, 6 \qquad \text{Eqn. (3.9)}$$

where the derivative of the transformation matrices and instantaneous matrices was discussed in [39]. Using Euler angles, Yaw φ (rotation about Z – axis), Roll r (rotation about X – axis) and Pitch p (rotation about Y – axis) can be derived. From the eq. (9), the derivative of the robot coordinate frame $\dot{T}_{\hat{O},\widehat{M_i}}$ was as following

$$\dot{T}_{\hat{O},\widehat{M_i}} = \begin{bmatrix} 0 & -\dot{\varphi} & \dot{p} & \dot{x} \\ \dot{\varphi} & 0 & -\dot{r} & \dot{y} \\ -\dot{p} & \dot{r} & 0 & \dot{z} \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad \text{Eqn. (3.10)}$$

The transformations in eq. (10) can be derived by solving equations (3 – 9) for each wheel in addition to the table 1 consisting of the D – H Parameters. Once the derivative is obtained for each wheel, it gives an equation set for robot's motion to the joint angular rates in vector form $[\dot{x} \quad \dot{y} \quad \dot{z} \quad \dot{\varphi} \quad \dot{p} \quad \dot{r}]^T$.

The resultants for wheel 1 and 4 (left & right front) were

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \\ \dot{\varphi} \\ \dot{p} \\ \dot{r} \end{bmatrix} = \begin{bmatrix} R_w Cos\,\beta & 0 & b_i d_{s1} \cos\beta \\ R_w & 0 & a_{s1} \\ b_i R_w \sin\beta & 0 & d_1 Sin\,\beta \\ 0 & 0 & -\cos\beta \\ 0 & b_i & 0 \\ 0 & 0 & -b_i \sin\beta \end{bmatrix} \begin{bmatrix} \dot{\zeta_i} \\ \dot{\beta} \\ \eta_i \end{bmatrix} \text{ for } i = 1, 4 \qquad \text{Eqn. (3.11)}$$

Where b_1 = -1 and b_2 = 1, a_{s1} and d_{s1} are kinematic parameters defined in D – H parameters of Table 1, and R_w is Wheel Radius. Though the wheels are non – steerable, the rotational slip must be considered. Hence η_i is the wheel rotational slip for (1-6) wheels. The middle wheels 2 and 3 have same kinematic equations as shown below

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \\ \dot{\varphi} \\ \dot{p} \\ \dot{r} \end{bmatrix} = \begin{bmatrix} R_w Cos\ 〚(\sigma〛_1) & 0 & -a_{\gamma 1}\sin〚(\vartheta〛_{\gamma 1}) & -d_{s1}\cos〚(\sigma〛_1) \\ 0 & 0 & 0 & K_i \\ -R_w\sin(\sigma_1) & 0 & -a_{\gamma 1}\cos(\vartheta_{\gamma 1}) & d_{s1}\sin(\sigma_1) \\ 0 & 0 & 0 & -\cos(\sigma_1) \\ 0 & -1 & -1 & 0 \\ 0 & 0 & 0 & -\sin(\sigma_1) \end{bmatrix} \begin{bmatrix} \dot{\zeta}_\iota \\ \dot{\beta} \\ \dot{\gamma}_1 \\ \eta_i \end{bmatrix} \text{for } i = 2, 3$$

Eqn. (3.12)

Where $\sigma_1 = \gamma_1 + \beta$, γ_1 is the left rocker angle, $K_i = a_{Ai}\cos(\vartheta_{ci}) + a_{\gamma 1}\cos(\vartheta_{ci} + \vartheta_{Ai})$; i = 2, 3, d_{s1}, a_{A3}, ϑ_{ci}, $a_{\gamma i}$ and γ_{Ai} are the kinematic parameter provided in the table 1

The back wheels 5 and 6 have similar kinematic equations as equation number (3.12):

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \\ \dot{\varphi} \\ \dot{p} \\ \dot{r} \end{bmatrix} = \begin{bmatrix} R_w Cos\ 〚(\sigma〛_2) & 0 & -a_{\gamma 1}\sin〚(\vartheta〛_{\gamma 2}) & -d_{s1}\cos〚(\sigma〛_2) \\ 0 & 0 & 0 & K_i \\ -R_w\sin(\sigma_2) & 0 & -a_{\gamma 1}\cos(\vartheta_{\gamma 2}) & d_{s1}\sin(\sigma_2) \\ 0 & 0 & 0 & -\cos(\sigma_2) \\ 0 & -1 & -1 & 0 \\ 0 & 0 & 0 & -\sin(\sigma_1) \end{bmatrix} \begin{bmatrix} \dot{\zeta}_\iota \\ \dot{\beta} \\ \dot{\gamma}_2 \\ \eta_i \end{bmatrix} \text{for } i = 5, 6$$

Eqn. (3.13)

Where $\sigma_2 = \gamma_2 - \beta$, γ_2 is the right rocker angle, $K_i = a_{Ai}\cos(\vartheta_{ci}) + a_{\gamma 2}\cos(\vartheta_{ci} + \vartheta_{Ai})$; i = 5, 6

The general form of the set of equations from (3.11 – 3.13) is $\dot{u} = J_i \dot{q}_\iota$ i = 1 – 6; where J is the Jacobian matrix of the wheel *i*, and $\dot{q}$ is the Joint angular rate vector.

3.3.2.2 Inverse Kinematics

Inverse kinematic model is required to determine the velocity of individual wheel in order to accomplish desired rover motion. The motion of the robot will be given by the forward velocity. Since there is no steering, there will be no turning rate or rotational slip. The actuation velocity of all the wheels of PinCoR was developed. Since there is no steering in any of the wheel, the wheel rolling velocity of the robot has been discussed below.

Wheel Rolling Velocities

Let us assume that the desired forward velocity and the angular rate of the rover are $\dot{x}_d$ and $\dot{\varphi}_d$ respectively. The equation set by solving Eqn. (3.11) would be:

$\dot{x}_d = R_w \cos(\beta)\, \dot{\zeta}_i + b_y\, d_{s1} \cos(\beta)\, \dot{\eta}_i$

$\dot{\varphi}_d = -\cos(\beta)\, \dot{\eta}_i$ $i = 1, 2$ Eqn. (3.14)

Equation (3.14) would then give the wheel rolling velocity of wheel 1 and 2 by solving the two equations :

$\dot{\zeta}_1 = \frac{\dot{x}_d - \dot{d}_{s1}\dot{\varphi}_d}{R_w Cos\, \beta}$ $i = 1, 2$ Eqn. (3.15)

In the same way, the rolling velocities of wheel 3 and 5 was derived using Eqn. (3.12)

$\dot{x}_d = R_w \cos(\beta)\, \dot{\zeta}_i - a_{\gamma 1} \sin(\vartheta_{\gamma 1})\gamma_1 - d_{s1} \cos(\sigma_1)\, \dot{\eta}_i$

$\dot{\varphi}_d = -\cos(\sigma_1)\, \dot{\eta}_i$ $i = 3, 5$ Eqn. (3.16)

Equation (3. 16) will provide the rolling velocities of wheel 3 and 5;

$\dot{\zeta}_1 = \frac{\dot{x}_d - d_{s1}\dot{\varphi}_d + a_{\gamma 1} \sin(\dot{\vartheta}_{\gamma 1})\dot{\gamma}_1}{R_w Cos\, \sigma_1}$ $i = 3, 5$ Eqn. (3.17)

Finally the rolling velocity of wheel 4 and 6 from equation number (3.13) can be written as:

$$\dot{\zeta}_1 = \frac{\dot{x_d} + d_{s1}\dot{\varphi_d} + a_{\gamma 1}\sin(\vartheta_{\gamma 2})\gamma_2}{R_w Cos\ \sigma_2} \qquad i = 4, 6 \qquad \text{Eqn. (3.18)}$$

These wheel rolling velocities equations are relatively simple and do not require any complex matrix operations as in forward kinematics. Further the solution of the Eqn. (3.15, 3.17 and 3.18) can be defined by the operating range of kinematic parameters such as β, σ_1 and σ_2.

3.4 CONFIGURATION OF PINCOR

PiNCoR has been designed to navigate through rough, hilly forest areas, hence the most important component become the locomotion system which with the help of motor actuators can negotiate tough terrains easily. Hence, as per the requirement, the electric motor can be chosen over and has been many advantages [40]. DC Geared Motors being low weighted, low power consumption ease of use and commercial availability has overcome its many disadvantages.

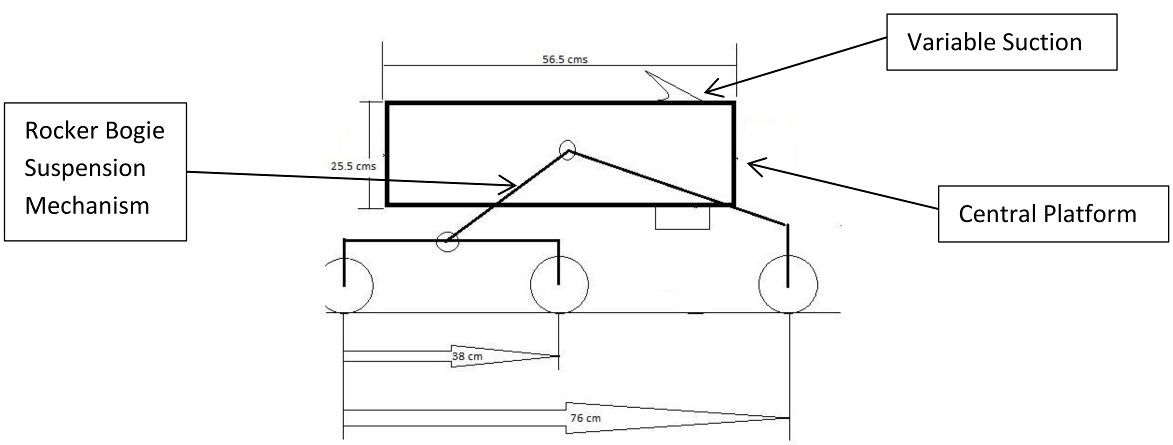


Fig. 3.11: PiNCoR Detailed Structure

PiNCoR is a robotic machine having a box type structure mounted on a six wheeled rocker bogie locomotion and suspension mechanism. The locomotion has been achieved by using six high torque 300 rpm 12V DC geared motors all together on each side of the rocker bogie arms. The DC Geared motor controlled with motor driver with a peak current overflow of 30A. The assembly has been connected with a differential averaging mechanism which helps in maintaining the balance, tilt and rolling of the robot. PiNCoR is powered by on-board power bank of 60 Ah Ni-MH rechargeable batteries with backup capacity of 3 hours with full load.

The navigation through the woods is achieved employing ultrasonic sensors on the corner of the centrally mounted control cum storage box along with laser range finder placed at the top. The directional and tilt stability of the robot has been controlled by 3-axis accelerometer, GPS and IMU unit placed inside the box.

The collection of the pine straw/needle has been done by a retractable suction mechanism placed at the front of the robot. A 5000 rpm 12V BLDC motor has been placed inside a cylindrical section which with the help of two side shaft DC motors on diametrically opposite to each other outside the cylindrical section unit. The side shaft motors will help in up down motion of the suction unit as and when required.

3.4.1 Component Specification

1. Power and drive mechanism

- 6 Ni - MH (10 Ah) rechargeable dry batteries for longer and continuous run.
- 4.3 N-m DC geared motor with 20 Amps dual dc motor driver (override control).

2. Collection mechanism

- Variable vacuum suction with 500 rpm BLDC motor with rotatory cutting blades

3. Control mechanism

- 32 bit multi core propeller microcontroller with 512 kb RAM with two sub microcontroller system to provide precise navigation and path restoration.

4. Dimensions

- Length – 56.5 cms, Breadth – 31.5 cms, Height – 25.5cms, Ground clearance –adjustable up to 19 cms, Forward link length – 12 cms, Wheel radius – 2.5 inch

5. Sensor system

- 4 Ping Ultrasonic Sensors for obstacle avoidance,
- 3-axis Accelerometer, Laser Range Finders, GPS and IMU

Table 3.5 - Specifications of PiNCoR

#	COMPONENT	SPECIFICATION	DESCRIPTION
1.	ROBOTIC BASE	(ALUMINIUM 6063-T5)	• LIGHT WEIGHT AND HIGH STRENGTH
	DIFFERENTIAL AVERAGING MECHANISM	BEVEL GEARS CONNECTED TO ROCKER, SUN GEAR HAS FREE MOVEMENT TO AVERAGE THE TILT	• CORNERING BALANCING AT TURNS • TILT STABILITY OF CENTRAL BODY AT HIGHER GRADIENT • REDUCES TOPPLING EFFECT ALONG Y AXIS (ANTI ROLL)

	SIDE SHAFT BI DIRECTIONAL ENCODED MOTOR	OPERATING VOLTAGE: 12 V STALL CURRENT: 4.8 A NOMINAL POWER: 50 W NO LOAD SPEED: 30 RPM LOAD SPEED: 30 RPM WEIGHT: 320 g	• BI DIRECTIONAL ENCODER FOR THE LOCOMOTION, FORWARD AND REVERSE. • PWM BASED SPEED CONTROL • INDIVIDUAL DRIVE FOR EFFICIENT TRANSMISSION
	MOTOR DRIVER	OPERATING VOLTAGE: 6- 16 V CONTINUOUS O/P CURRENT: 8 A PEAK CURRENT: 30 A CURRENT SENSE: 0.13 V PER A. DIMENSION: 51.3 X 27.7 mm^2	AS PER BATTERY RATING AND SPCRA CURRENT CONSUMPTION. OVER VOLTAGE AND UNDER VOLTAGE SHUTDOWN THERMAL SHUTDOWN MOTOR FAULT DIAGNOSTICS OUTPUTS FOR OVER TEMPERATURE OR SHORT CIRCUIT
2.	AUTOMATED SUCTION PUMP MECHANISM (VARIABLE GROUND CLEARANCE)		

	SUCTION HOUSING	CYLINDERICAL SHEET METAL OF 16 CM DIAMTER	• FOR CUTTING BLADE HOUSING AND SUCTION ROUTING • LIGHT WEIGHT • UP AND DOWN MOTION CONTROLLED BY SIDE SHAFT DC MOTOR
	SIDE SHAFT DC MOTOR	OPERATING VOLTAGE: 12/24 V NO LOAD CURRENT: 0.7 A LOAD CURRENT: 1.8 A NOMINAL POWER: 50 W NO LOAD SPEED: 85 RPM WEIGHT: 320 g	• HIGH TORQUE • UP DOWN MOTION WITH LIMIT SWITCHES TO ACCOMODTE VARIABLE GROUND CLEARANCE • MIN – 0.5 CM • MAX – 20 CM
	BLDC MOTOR	OPERATING VOLTAGE 12 V MAX 5000 RPM	PROVIDES SUCTION UPTO 18 l/s

	CUTTING BLADES	SHARP METAL BALDES WITH ANTI RUST COATING	• MOUNTED ON BLDC SHAFT • WORKS FOR BOTH SUCTION AND CHOOPING THE NEEDLES FOR HIGHER STACKING VOLUME • ROTATES AT HIGH RPM FOR CUTTING
3.	CONTROLLER		
	ATMEGA 16		SPEED CONTROL BY PWM (OCR PINS) 16 KB OF FLASH MEMORY FOR STORING CODE. 1 KB OF RAM FOR PERMANENT STORAGE DATA RETENTION RATE OF 20 YRS. (85 DEG. C) 10 BIT ADC WRITE / ERASE CYCLES: 10K FLASH

3.5 Fabrication Process

After all the analysis, market research and components availability, the fabrication of the PiNCoR has been done with the components specified in Table 3.5. The rocker bogie suspension cum locomotion unit has been made with the cast iron square tubular section to reduce weight & enhanced capacity to carry the twisting torque and hence welded specified angle with the motors fixed with bolts along with the wheels at the end of the axle. The aluminum central box has been fixed on the axles attached with the differential averaging mechanism, also it is accommodated with the suction mechanism with up/down motion, controlling unit which includes micro-controller, motor driver and storage section. The obstacle avoidance sensors have been placed on the outer corner of the central box. A picture of actual structure has been shown below:

Fig. 3.12: Actual Structure of PiNCoR

3.6 Path Planning

In order to cover the maximum area of the Pine Needle forest, serpentine path planning has been setup and tested on the PiNCoR, the process is as follows:

- Initially PiNCoR will come to its home position P0 shown in figure 9. works in serpentine pattern
- From its home position, it will go to its position P1 which will be determined via encoded motors.
- During its course the camera in front will analyze the frame captured of the needles..

❖ The PiNCoR will stop as soon as it detects pine needle and the suction will start to stack in the box on board

❖ After traversing through Row1, PiNCoR will move 90 degree and moves from P1 to P2 and proceed further

❖ On reaching Pn it will straight come back to P0, its home position.

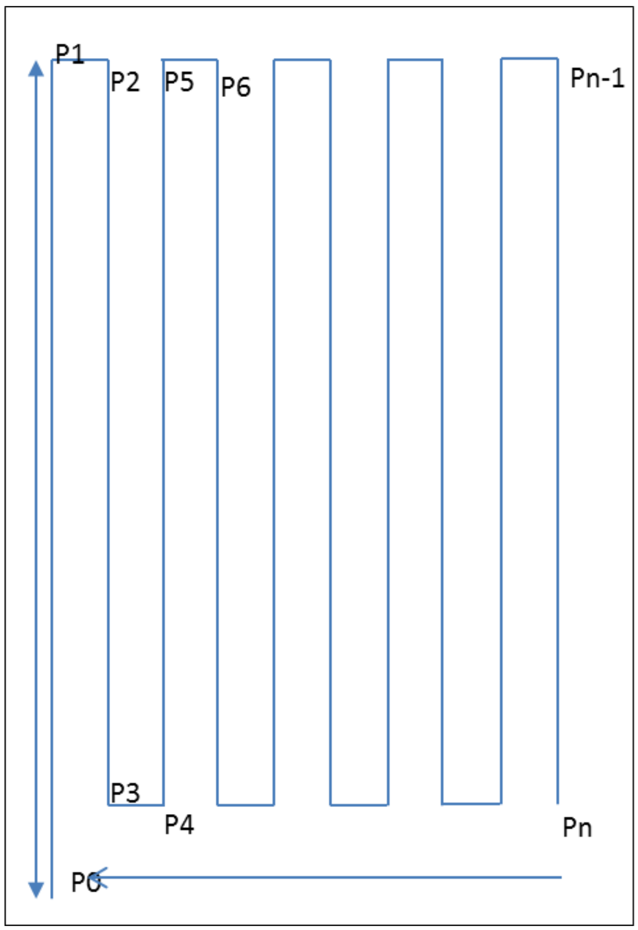


Fig. 3.13: Path Planning of PiNCoR

3.7 Block Diagram

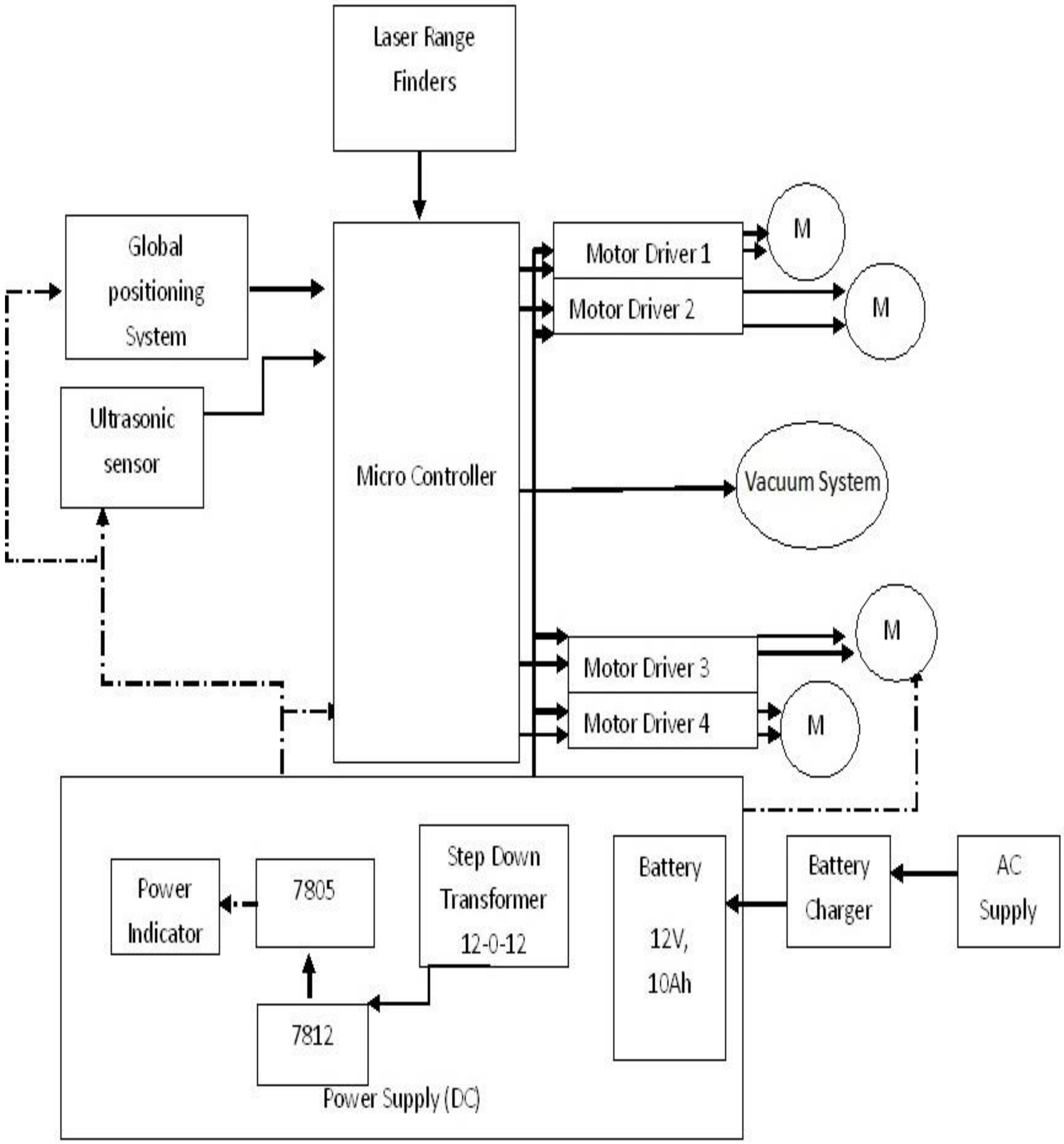


Fig.3.14: Block Diagram of PiNCoR

3.8 Circuit Diagram

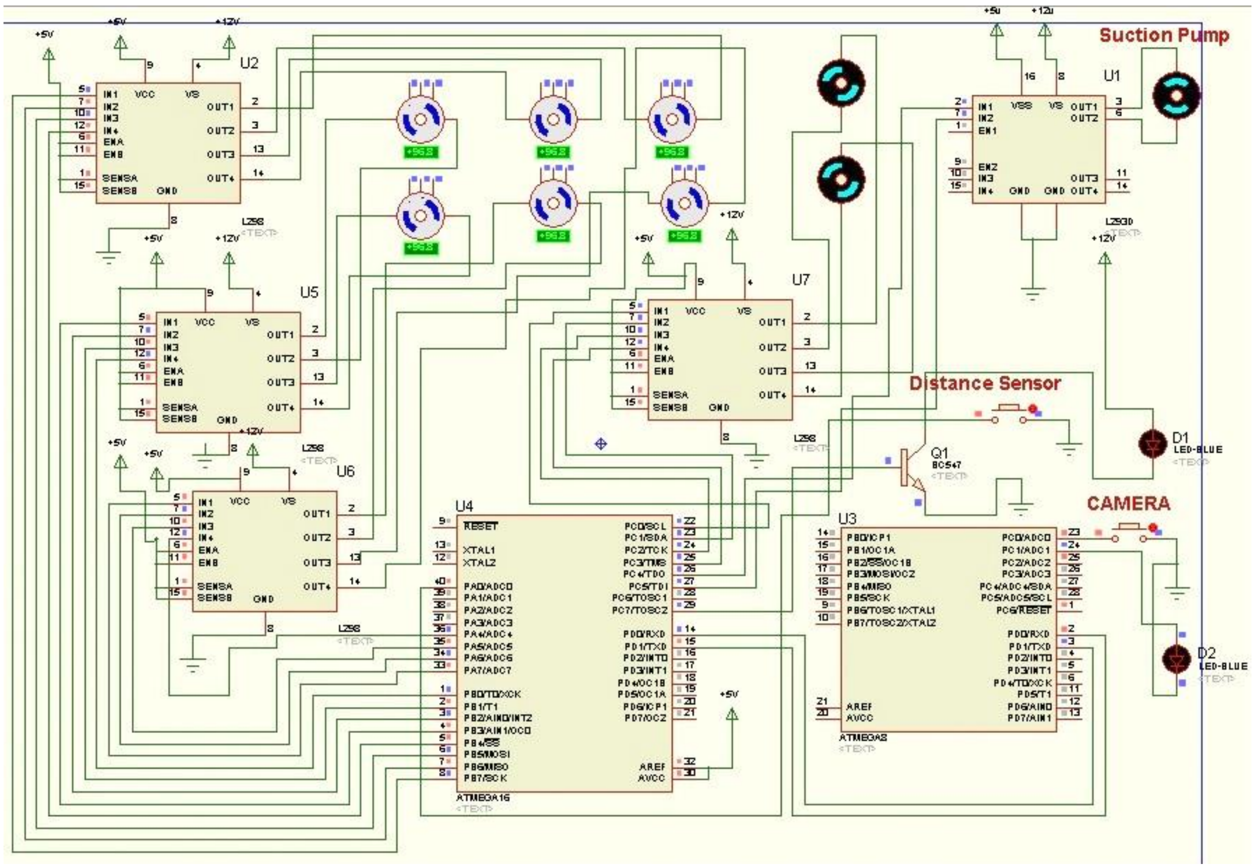


Fig. 3.15: Circuit Diagram of PiNCoR

3.9 ALGORITHM

Few algorithms have been followed for the working of PiNCoR:

- Main Loop
  - i. Status Check Loops
    - a. Obstacle Detection
    - b. Battery Indicator
  - ii. Forward Motion Algorithm
  - iii. Image Processing Algorithm
  - iv. Suction Algorithm

3.9.1 Main Loop

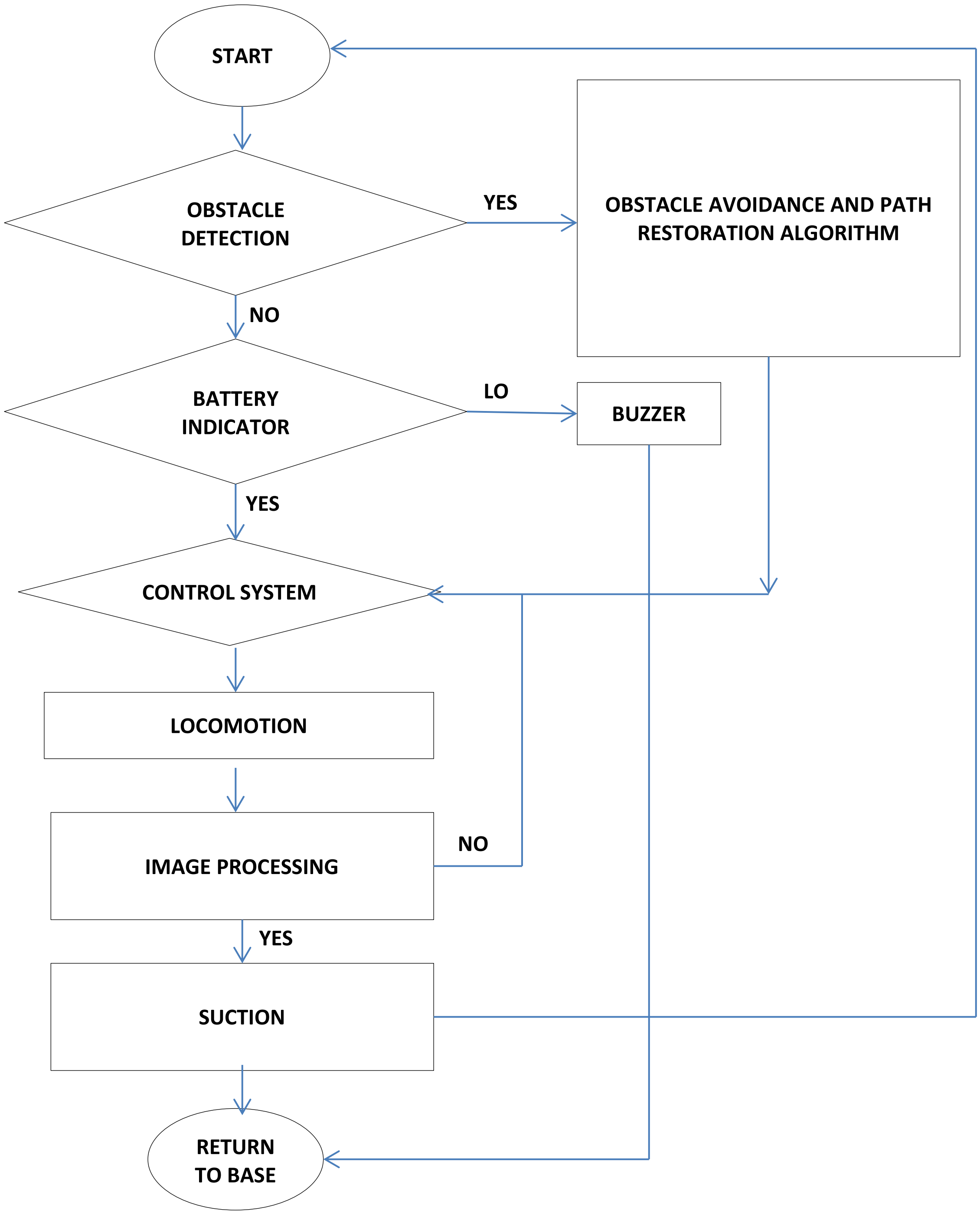


Fig. 3.16: Main Loop

3.9.2 Obstacle Detection and Path Restoration Algorithm

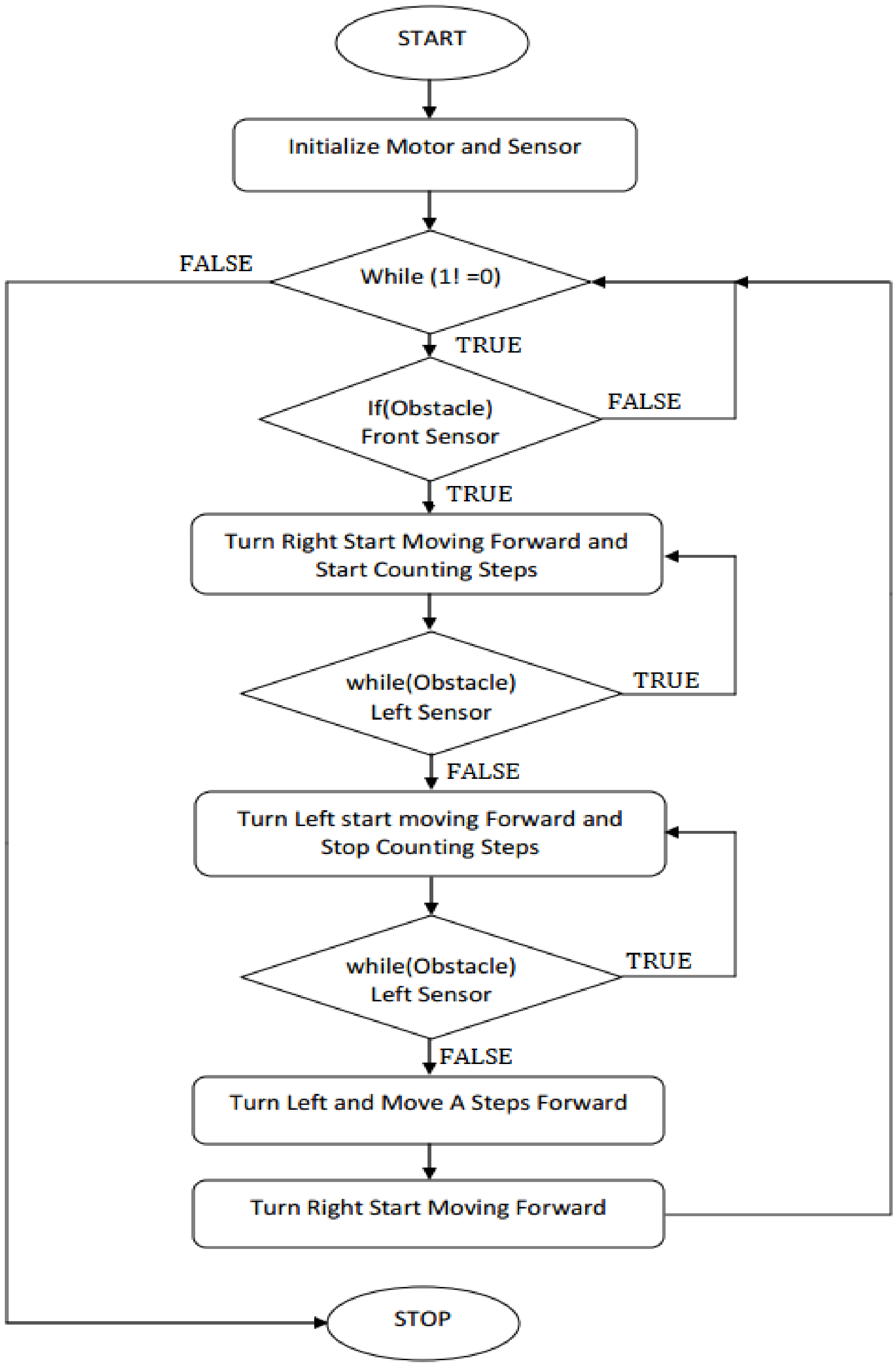


Fig. 3.17: Obstacle Detection and Path Restoration Algorithm

3.9.3 Main Controller

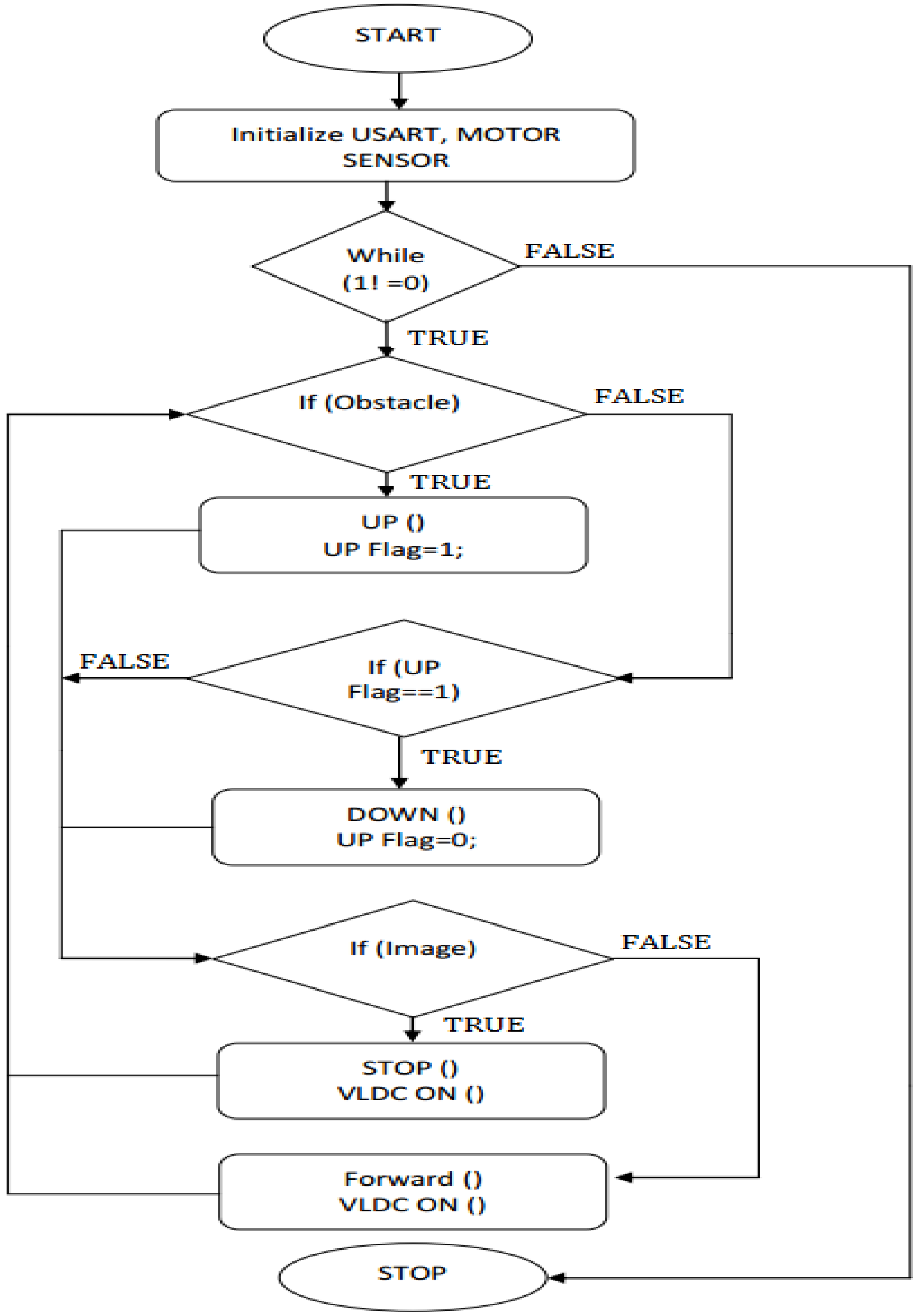


Fig. 3.18: Main Controller

3.9.4 Image Processing Algorithm

3.9.4.1 Camera Controller

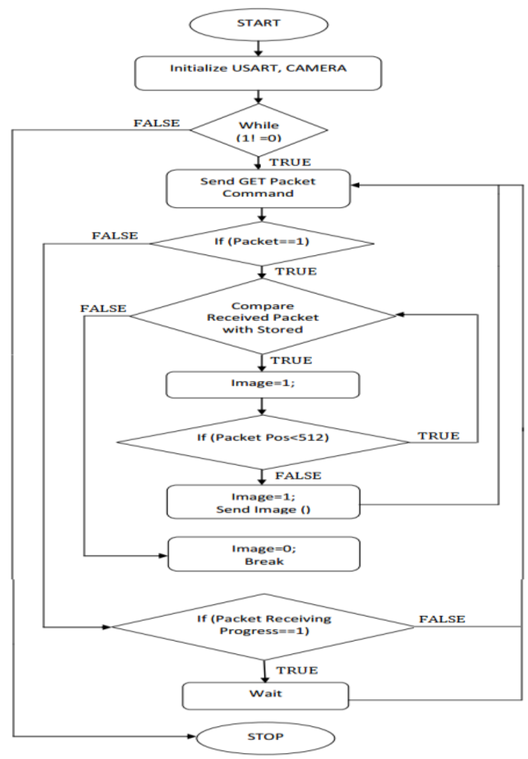


Fig. 3.19: Camera Controller

3.9.4.2 Camera Controller Transmitting Side

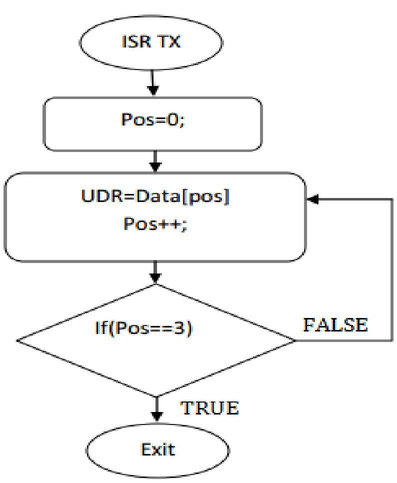


Fig. 3.20: Camera Controller TX

3.9.4.3 Camera Controller Receiving Side

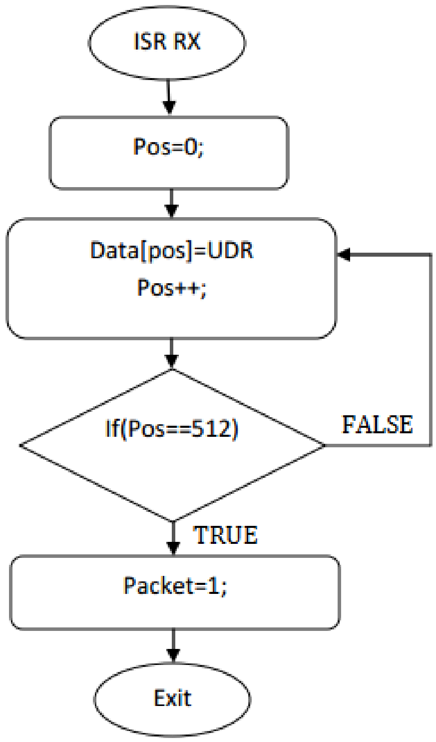


Fig. 3.21: Camera Controller Rx

3.9.5 Battery Level Indicator

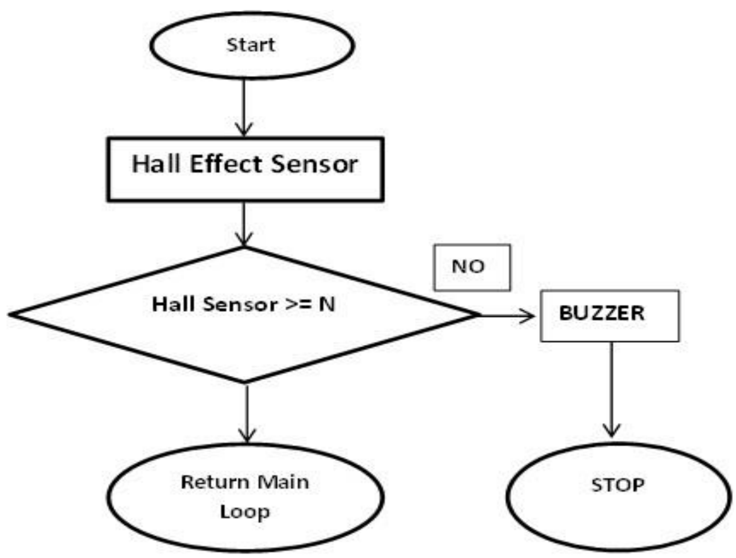


Fig. 3.22: Battery Level Indicator

3.9.6 Suction Algorithm

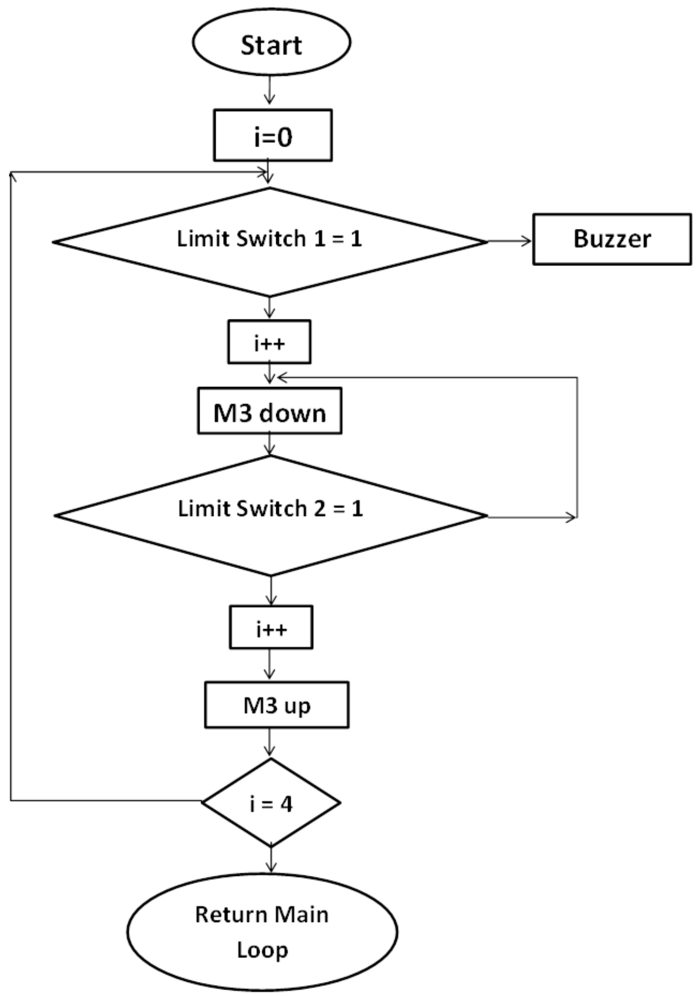


Fig. 3.23: Suction Algorithm

3.10 Field Testing

After the successful fabrication of PiNCoR, it has been tested at three different sites of different gradient of approximately 45^0, 50^0, 55^0 for seven days randomly for three hours continuously randomly between 1000 hrs to 1600 hrs. The observations have been taken for the run time, needle collection and listed for each day in a table form. Detailed results have been discussed in the next chapter.

CHAPTER 4

RESULTS AND DISCUSSIONS

The Pine Needle Collector Robot (PiNCoR) has been initially tested at the University of Petroleum and Energy Studies for its hill holding capacity, uneven terrain locomotion, obstacle avoidance and path planning at a gradient of 38 degrees. The specification of the PiNCoR is:

Table 4.1 - Specifications of PiNCoR

Specifications	
Locomotion	Rocker bogie suspended powered by 6 individual motors
Suction area	0.201 sq. m
Traversing duration/ distance	3 hr / 1.5 km
Stacking capacity	8 liters
Unladen weight	22.65 kg
Laden weight	24.8 kg
Operating voltage	12 V

4.1 RESULTS

Monitoring of the test rig, data collection, performance analysis and reporting were shown below. Data was collected for a period of three weeks from morning 1000 hrs to evening 1700 hrs randomly taken over an interval of 3 hours continuous run. Data were being collected full three hour operation of the machine on different elevations the area covered by serpentine path planning and pine needle collected by weight and the following observations are made:

Table 4.2 - Weekly observed performance table of PiNCoR

Week	**Angle of elevation**	**The area covered by pincer (7 hours/ week)**	**Net weight of pine needles**
1	45 DEGREE	98800 SQ FT	160.8 KG
2	50 DEGREE	86700 SQ FT	158.3 KG
3	55 DEGREE	56905 SQ FT	139.8 KG

Power Consumption by PiNCoR

Table 4.3 - Current Consumption of PiNCoR

CURRENT RATINGS IN DIFFERENT CONDITIONS		
PART OF PiNCoR	UPHILL	DOWNHILL
BASE MOTOR (AT)		
45 DEGREE	2.15 A	2.7 A
50 DEGREE	2.8 A	3.2 A
55 DEGREE	3.3 A	3.6 A
SUCTION MOTOR	UP	DOWN
	0.15 A - 0.18 A	0.1 A – 0.12 A

For entire one time collection operation (which includes moving along the serpentine path, image and pattern analysis, suction operation) for one time running operation.

The power requirement for PiNCoR is different for each degree of change in altitude. For the altitude under observation i.e. 45^o, 50^o, 55^o, the power requirement will be as follows

To ascent a slope at 100% efficiency, power consumption will be
Power = [(Mass × height change)/second] × 10W
Where, Mass in kg, *h* is increase in vertical height per second.

The mass of the PinCoR is 22 kg & *h* is 0.027 (for 45^o of altitude) Power required is 5.87 W per motor, hence total power required is 35.22 W

Similarly for 50^o, the power required is 42 W, and for 55^o, the power required is 50.34 W

The battery power bank is 12V 10Ah which is equivalent to 120 W

4.2 DISCUSSIONS

The observations taken as shown in Table 5.2, on the basis of seven day trials taken at each location for three hours on each day. The start point was randomly generated while the robot followed the serpentine path planning. The used serpentine path planning method has been compared with conventional path planning method while avoiding obstacle and path restoration. The applied path planning algorithm has covered the maximum within the stipulated time frame before the draining of the battery power bank.

The decrement pattern shown by the in the collection of pine needles and area covered by the PiNCoR with the increment in the angle of elevation of terrain is because of the power consumed by the motor during the uphill and downhill movement of the structure with the stored pine needle and load of the structure. This dimensional constraint in the built structure has the limitation, which can be improved by using low power high torque motor and battery power bank of enhanced capacity.

Table 5.3 shows the power consumption by the various component of the PiNCoR, which affects the run performance and recharging time of the battery power bank. The power supply in the robot is achieved by using six dry Ni-MH batteries of 10000 mAh (10Ah) capacity, which provides uninterrupted power supply to the structure for three hours of continuous operation.

CHAPTER 5

CONCLUSIONS AND FUTURE SCOPE OF WORK

5.1 CONCLUSIONS

The objective of the design of pine needle collection robot with on board storage mechanism on a mobile robotic platform is successfully achieved.

The conclusions can be derived as:

- One supervisor is enough to carry out the task all day.
- The operational cost involved is only of charging the battery packs.
- The electronic circuitry & components remain unaffected at even 50^{oC} of heat.
- Inbuilt function of cutting and chopping of needles results in large collections of Pine Needles.
- The per hectare cost of harvesting through PiNCoR is comparatively lower than the manual collection in the hilly areas.
- No raking through PiNCoR, hence no harmful effects.
- Mechanical pine needle collection robot proves flexible in operation, cost effective, time effective and requires no/minimum human intervention in its operation.

5.2 FUTURE SCOPE OF WORK

With the enhacement of technology day by day, there is lot of scope of work in multi terrain robotic platform with advanced sensors, computing platforms and sensor fusion technologies:

- Autonomous operation can be made more flexible through by wireless communicating with the machine.
- Laser Mapping Devices can be used to map the area on the base station for records/area exploration.
- Nonlinear path restoration can be done.
- Artificial intelligence can be incorporated for filtration of Pine from garbage.
- Machine based navigation mechanism for smoother movement through the woods.

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APPENDIX A

CALCULATIONS FOR VEHICLE UP SLOPE FORCE

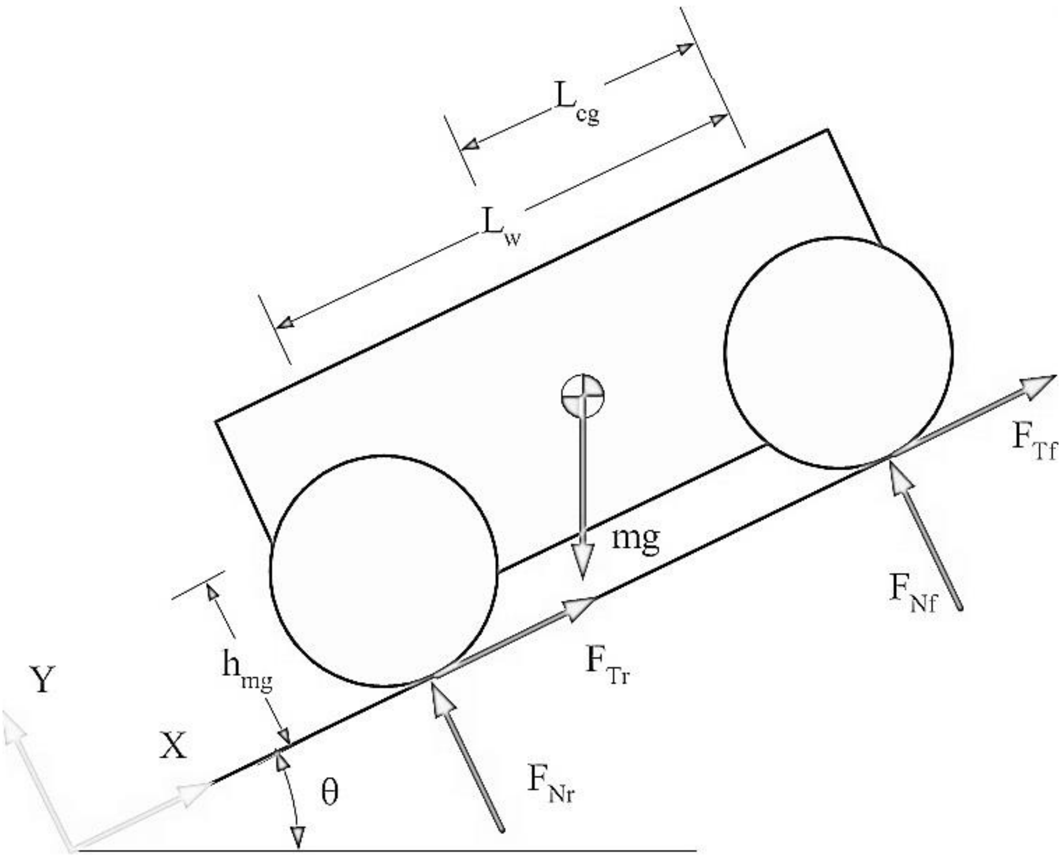

Fig. A1.1: Various Forces on Vehicle at an angle of inclination ϑ

$\sum Fx = \mu\gamma_r F_{Nr} + \mu\gamma_f F_{Nf} - mg \sin\theta = 0$ Eqn. (A1.1)

$\sum Fy = F_{Nr} + F_{Nf} - mg \cos\theta = 0$ Eqn. (A1.2)

$\sum M = F_{Nr} L_w - mg \left(L_{cg}\cos\theta + h_{mg}\sin\theta\right) = 0$ Eqn. (A1.3)

From Eqn. (A1.2, A1.3) the value of F_{Nf} and F_{Nr} is

$$F_{Nr} = \frac{mg\left(L_{cg}\cos\theta + h_{mg}\sin\theta\right)}{L_w} \quad \text{Eqn. (A1.4)}$$

$$F_{Nf} = \frac{mg\left(\left(L_w - L_{cg}\right)\cos\theta - h_{mg}\sin\theta\right)}{L_w} \quad \text{Eqn. (A1.5)}$$

$$\mu \geq \frac{L_w \sin\theta}{(\gamma_r - \gamma_f)\,(h_{mg}\sin\theta + L_{cg}\cos\theta) + (\gamma_f\, L_w \cos\theta)} \quad \text{Eqn. (A1.6)}$$

Tipping over backward angle $\theta = \tan^{-1}\frac{(L_w - L_{cg})}{h_{mg}}$

where,

F_x = Summation of all forces in X axis

F_y = Summation of all forces in Y axis

μ = Coefficient of Friction between the surface and the wheel

F_{Nf} = Normal Reaction Force at the front driving wheels

F_{Nr} = Normal Reaction Force at the rear driving wheels

L_w = Distance between the wheels

L_{cg} = Distance of front wheels from the center of gravity

h_{mg} =Distcne of Center of gravity from the ground

ϑ = Angle of Inclination of the surface

FWD $\gamma_f = 1$, $\gamma_r = 0$; RWD $\gamma_f = 0$, $\gamma_r = 1$; AWD $\gamma_f = 1$, $\gamma_r = 1$

APPENDIX B

CALCULATION OF SLOPE, RISE AND RUN

Slope, tilt or inclination can be expressed in three ways:

1) As a *ratio* of the rise to the run (for example 1 in 20)
2) As an *angle* (almost always in degrees)
3) As a *percentage* called the "*grade*" which is the *(rise ÷ run) * 100*

Typical calculations in order to calculate grade, rise and run

1. Calculating the angle and grade from ratio (rise/run)

angle A = arctangent (rise ÷ run)
grade = (rise ÷ run) * 100

2. Calculating ratio and grade from angle

ratio = 1 in (1 ÷ tan (A))
grade = (rise ÷ run) * 100

3. Calculating angle and ratio from grade

angle A = arctangent (rise ÷ run)
ratio = 1 in (1 ÷ tan(A))

Table (B2.1) - Slopes at different angle of inclination and %

Angle	% rise / run	% rise / hyp	%Diff
10	17.63270	17.36482	101.5427
15	26.79492	25.88190	103.5276
20	36.39702	34.20201	106.4178
25	46.63077	42.26183	110.3378
30	57.73503	50.00000	115.4701
35	70.02075	57.35764	122.0775
40	83.90996	64.27876	130.5407
45	100.00000	70.71068	141.4214
50	119.17536	76.60444	155.5724
55	142.81480	81.91520	174.3447

PUBLICATIONS

PhD Publications

S. No.	Details
1	Shival Dubey, Manish Prateek and Mukesh Saxena,**“Kinematic Modelling of Multi Terrain Pine Needle Collecting Robot (PiNCoR) for Hilly areas of Uttarakhand**”, IAES International Journal of Robotics and Automation ISSN 2089 – 4856 Volume 4 Number 3 September 2015.
2	Shival Dubey, Manish Prateek, Mukesh Saxena “**Robot Locomotion – A Review**” International Journal of Applied Engineering Research (IJAER) ISSN 0973-4562 Volume 10 Number 3 (pp) 7357 – 7369 June 5, 2015
3	Shanky Bhatnagar, Anant Wadhwa, Shival Dubey, **“Detecting Specified Object from a Cluttered Data in a Live Video Using Rotation Invariant Detector and Descriptor”** International Journal of Advanced Research in Computer Science and Software Engineering in December 2013 Volume 3 Issue 12.
4	Shival Dubey, Abdul Wahid Ansari, **“Design and Development of Vehicle Anti-collision Device using Ultrasonic Sensors”** International Conference of Mechanical and Industrial Engineering (ICMIE) at Bhubaneswar in January 2013.

Other Publications

S. No.	
1	Shival Dubey, Anant Wadhwa **“Agent-Less Hardware Monitoring Tool for Cluster Management”** International Journal of Advanced Research in Computer Science and Software Engineering in September 2013 Volume 3 Issue 9.
2	Shival Dubey, Abhishek Sharma, Amit Kumar Mondal, **“Integration of Solidwaorks on MATLAB (SimMechanics)”.** IEEE Robotics and Automation Magazie **(Under Review)**

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	(b)	State whether you belong to Scheduled Caste/Tribe/Backward class	NO
07.	Present Post held with Designation & Name of the Organization where employed		Doctoral Research Fellow at University of Petroleum and Energy Studies, Dehradun, Uttarakhand
08.	Present Salary with pay scale		

Pay Scale	Basic Pay	D.A	H.R.A	Any Other Allowance	Total Rs.
28000				5000	33000

10.	Were you at any time declared medically unfit, asked to submit your resignation, discharged or dismissed from Government or private services?	NO

11. ACADEMIC QUALIFICATION, Give Details in chronological order, starting with the highest degree

Degree	Year	College/University	Division	% Marks/CGPA	Remarks
PhD		University of Petroleum and Energy Studies			Thesis Submitted
M.Tech	2012	University of Petroleum and Energy Studies	I	3.2/4	
B.Tech	2010	Oriental Institute of Science and Technology/Rajiv Gandhi Technical University	I	74.88	
12^{th}	2005	M.P Board	I	73.33	
10^{th}	2003	M.P Board	I	80.8	

12. Teaching and Professional Experience

Position Held	Name of Orgnization	Period		Pay	Nature of Work
		To	From		

Doctoral Research Fellow	University of Petroleum and Energy Studies	May 21st, 2012	Till Date		Research Activites and Administrative Functioning
Course Coordinator	University of Petroleum and Energy Studies	July 1st 2014	Till Date		Coordination of Departmental activites for students

13. Courses Taught (Give details in chronological order starting with present)

Name of the Course	Level UG/PG	Year in which Taught	Class Strength
Robotics	UG	2016	58
Vehicle Body Engineering	UG	2016	58
Workshop Technology	UG	2013, 2014, 2015, 2016	76
Engineering Mechanics	UG	2015	65
Strength of Materials	UG	2014	30
Introduction to Robotics	PG	2012	20

14. Research Experience

Sponsored Research Projects (Including in-house industrial projects)				
Year of Funding	Sponsoring Organization	Title of the Project	Amount of Grant (in Lacs	Co-investigators

2014	Incubation Funding – University of Petroluem and Energy Studies	Automatic Air Filling System for 4 Wheelers	1.98	Yes
2013	DST-SERB	Pipeline Surveiilance Parachute Aerial Vehicle (PAV) (Mechanical Part only)	6.00	Yes
2012	Internal Seed Fund – R&D University of Petroleum and Energy Studies	Design and Development of Autonomous Pine Needle Collector Robot	4.00	No

15. Publications

S. No.	Details
01.	Shival Dubey, Abdul Wahid Ansari, “Design and Development of Vehicle Anti-collision Device using Ultrasonic Sensors” presented at International Conference of Mechanical and Industrial Engineering (ICMIE) at Bhubaneswar in January 2013.
02.	Sival Dubey, Manish Prateek, Mukesh Saxena, “Kinematic Modelling of Multi Terrain Pine Needle Collecting Robot (PiNCoR) for Hilly areas of Uttarakhand” published in the IAES International Journal of Robotics and Automation ISSN 2089 – 4856 Volume 4 Number 3 September 2015.
03.	Sival Dubey, Manish Prateek, Mukesh Saxena, “Robot Locomotion – A Review” published in International Journal of Applied Engineering Research (IJAER) ISSN 0973-4562 Volume 10 Number 3 (pp) 7357 – 7369 June 5, 2015
04	Shanky Bhatnagar, Anant Wadha, Shival Dubey, “Detecting Specified Object from a Cluttered Data in a Live Video Using Rotation Invariant Detector and Descriptor” published in International Journal of Advanced Research in Computer Science and Software Engineering in December 2013 Volume 3 Issue 12.

05.	Shival Dubey, Anant Wadhwa, "Agent-Less Hardware Monitoring Tool for Cluster Management" published in International Journal of Advanced Research in Computer Science and Software Engineering in September 2013 Volume 3 Issue 9.

16. `Patents

S. No.	Author(s)	Year of Award	Title of Patent	Patent Number	International/ Indian
1.	Om Prakash, Amit Kr. Mondal, Shival Dubey et. al.	Filed	A system for Monitoring and Maintaining Air Pressure in Vehicles	1205/DEL/2014A	Indian
2.	Anant Wadhwa, Amit Kumar Mondal, Shival Dubey et.al	Filed	A System for Preventing Fuel Theft from Vehicle	365/DEL/2014A	Indian
3.	Rajesh Singh. Shival Dubey et. al	Filed	Method and apparatus to adjust Dish positioning system with RF remote	TEMP/E-1/33169/2014-DEL	Indian

17. Projects

S. No.	Company Name	Title of the Project	Duration
1.	Bhilai Steel Plant, Bhilai, C.G	**Observation of the Plant and Maintenance System**	2 weeks
2.	Mahindra and Mahindra ltd. Kandivali, M.H	**Work Content reduction, Cost Reduction and Quality Concern in Transmission Production Unit**	1 Month

3.	Tata Motors Ltd. Ahmedabad, Guj.	**Sequencing and Palletizing of Engines at Dressing Line Loading Station**	2 Months
4.	In-house at Oriental Institute of Science and Technology, Bhopal, M.P	**Design and Fabrication of ATV (All Terrain Vehicle)**	8 Months

18. Administrative Experience

S. No.	Period	Organization	Designation	Nature of Responsibility
01.	November 1st, 2012 – Till Date	University of Petroleum and Energy Studies	Technical Assistant to Dean	Research Activites and administrative functioning for Dean College of Engineering
02.	July 1st, 2014 – Till Date	University of Petroleum and Energy Studies	Course Cordinator	Coordination of Departmental Actiities for Students and maintaining a channel between the students and Departmental Management
03.	July 1st, 2015 – Till Date	University of Petroleum and Energy Studies	Placement and Internship Coordinator of B.Tech ADE	Reponsible for Students Internship , Industrial Tour & Placement Activities Arrangement in coordination with Placement Cell.

19. Awards, Honor's and Recognitions

S. No.	Year	Name of the Award/Recogntion	Awarding Institute/Organization

1.	2015	PhD Project selected in Top 10 Innovative Projects in India and Demonstarted to Dr. APJ Abdul Kalam at IIM Ahmedabad	National Innovation Foundation
2.	2015	R&D C^3 Research ublication Award Presented by Dr. CNR Rao, FRS	University of Petroleum and Energy Studies
3.	2014	R&D C^3 Patent Filling Award, Presented by Dr. Rajendra Dobhal (Director – UCOST)	University of Petroleum and Energy Studies
4.	2014	2nd In Startup Weekend	University of Petroleum and Energy Studies
5.	2013	Demonstrated PhD Project " Design and Dvelopment of Autonomous Pine Needle Colledtor Robot" to Honorable President of India Dr. Pranab Mukherjee	Exhibition Center, University of Petroleum and Energy Studies

20. H – Factor:

Google H – Factor	1
Google Citations	9

24. Any other Information

Organizing Committee Member of 10th Uttarakhand State Science and Technology Congress organized by Uttarakhand Council of Science and Technology (UCOST) and University of Petroleum of Energy Studies (UPES)

25. References

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Declaration:

I hereby declare that the mentioned details are true to the best of my knowledge.

Shival Dubey