A PROJECT REPORT

On

“Swarm Robotics and Its Applications”

Submitted by,

Chinmay Mahabal (B120453089)
Rutvij Pathak (B120453113)
Pratik Shende (B120453140)

UNDER THE GUIDANCE OF

Prof. Disha Parkhi (Internal Guide)

IN FULFILMENT OF
B.E.(ELECTRONICS & TELECOMMUNICATION)
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MARATHWADA MITRA MANDAL’S COLLEGE OF ENGINEERING, PUNE-52
DEPARTMENT OF ELECTRONICS AND TELECOMMUNICATION

MARATHWADA MITRA MANDAL'S
COLLEGE OF ENGINEERING, PUNE

CERTIFICATE

This is to certify that the project report entitled

"Swarm Robotics and Its applications"

Submitted by

Chinmay Mahabal	Exam No:-B120453089
Rutvij Pathak	Exam No:-B120453113
Pratik Shende	Exam No:-B120453140

is bonafide work carried out by them under the supervision of Prof. Mrs. Disha Parkhi and it is approved for the partial fulfillment of requirement of Savitribai Phule Pune University for award of the degree of Bachelor of Engineering (Electronics and Telecommunication).

This project report has not been earlier submitted to any other Institute or University for the award of any degree or diploma.

Prof. Mrs. Disha Parkhi	Prof. Mrs. P. S. Sawant	Dr. S. M. Deshpande
Project Guide	Head of Department	Principal
Department of E&TC	Department of E&TC	

External Examiner Name:

Signature:

ACKNOWLEDGEMENT

"Ability and ambition alone are not enough for success. Many able persons have failed to achieve anything worthwhile because of lack of guidance and direction. Success of any project depends greatly on the support, guidance and encouragement received from the guide." We have been fortunate to have more than one pillar of strength in our humble effort to make this project successful.

It gives us great pleasure to express our deep sense of gratitude to our college project guide Mrs. Disha Parkhi for her resourceful & able guidance which lead to timely completion of this seminar report. It was really her insight and obsession for innovative ideas that motivated us to consider our idea seriously.

We managed to learn quite few things from her which will definitely help us in the future. We sincerely thank her for this kind co-operation and extreme patience that she has shown.

They are the teachers who stayed by our side from the incorporation of necessary features into the project to the final documentation part. We are really thankful to Mrs. A. A. Kunte who has given us loads of valuable tips about what the industry actually requires and helped us choose between the necessary and additional features to be incorporated in the project.

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ABBREVIATIONS

1. PCB: Printed Circuit Board
2. LED: Light Emitting Diode
3. IR: Infra Red

ABSTRACT

In nature we observe that many insects like bees and ants work in unison .Their efficiency is observed to be higher than any individual. In similar way, swarm of robots is efficient than a single robot, due to less hardware and small size. Swarm robotics is an emerging branch which is interdisciplinary. It covers area such as mechatronics, communication and artificial intelligence. The projects aim to implement collective action of robots to accomplish small tasks. A decentralized approach has been used. A suitable algorithm has been designed which implements these collective actions. Heart of a swarm agent is an Atmega328p micro-controller. To implement the inter-agent communication, IR medium of communication is used with NEC protocol. In manual mode of operation, the user can relay command to a single robot using Zig-Bee communication. The three basic tasks are implemented on the prototype of swarm robots. They are namely; ***follow the leader*** in which agents follow the behaviour of a designated agent, ***cluster formation*** in which all agents form a predefined shape or pattern. These tasks are supplemented by localization in their environment i.e. ***mapping*** of their immediate surrounding environment.

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Nature has always been the source of inspiration for mankind. No matter how much progress we make, its always insignificant when compared with the natures intelligence. By keeping this in mind, the field of robotics has started its journey on a new emerging field where there is union of biology and many other branches. Swarm robotics is such a branch. Ant colonies, bee swarms and school of fish are the few examples which demonstrate the power of swarm. In the same way, a group of robots is much more effective than a single agent.

The tasks performed by the robot may not always be the same. Hence, there is always variance in the efficiency of the system. However, in swarm, only the necessary agents are called to accomplish a task thus resulting in maximum efficiency of the system.

The various advantages of swarm robotics which make this field an interesting one are scalability, robustness, cost effective, energy efficient and the most important one is intelligence.

1. Scalability

As seen in nature, the colony size of ants may vary but their functions remain unchanged. In the same way, once a swarm of robots has been developed, the number of agents can be varied in any number. The intelligently designed algorithms are completely independent of the number of agents. The swarm gets only more effective when the number of agents is sufficiently high.

2. Robustness

The efficient working of any system is completely dependent on the successful execution of tasks by every sub system embedded in it. So a mal function of any of the part results in the collapse of the entire system. However, in swarms, the working of system is independent of every agent. In case if an agent fails, the communication is bypassed and the system remains intact.

3. Cost effective.

The agents in swam are optimized in terms of size, power and features. This results in an extremely simple design in terms of hardware electronics. The sheer intelligence is the result of algorithms and protocols. The inter bot communication is carried out by Infrared LED which also the main reason why the Swarm Robotics becomes cost effective.

1.2 INTRODUCTION TO SWARM INTELLIGENCE

A. Decentralized System

The complete swarm works in a decentralized way. There exists no concept such as a head or origin. The complete information of a task is equally shared by all and executed in the same way. Hence the system as a whole becomes intelligent. The execution speed is increased without any tradeoffs with the accuracy. Especially in homogeneous swarms the agents are completely identical in terms of electronics and algorithms.

B. Inter robot Communication

As previously stated, the system works in decentralized way. So a continuous communication between the agents plays an important role. Every single agent is constantly aware of the current status of the task and also the status of the system. The success and failure reports are constantly hopped through the entire system. The communication is carried out with the help of IR sensors. Though the line of sight is a crucial problem for IR, the system can be configured to overcome it. Any robot if positioned out of the line of sight, a message is passed across the system. Also the robot moves out of that area to previous location to join the communication grid.

C. Use of agent Identity

Every robot in the swarm is configured with a special robot id or agent id. The transmitted signals carry encrypted robot identity, that helps to improve the intelligence.

The receivers mask the robot identity from the signals thus generating a map of the current locations of the robots in the surroundings.

CHAPTER 2

LITERATURE SURVEY

2.1 REVIEW OF THE RELATED LITERATURE:

1. **Kilobots**: Kilobot was originally developed by the Harvard University. Currently it is produced and distributed the K-team. The basic aim of the Kilobots is to study the collective behavior of robots. It is a best platform to study AI algorithms on hardware platform. Kilobots are very economic in cost. The design is highly simple which makes the software more complex. The locomotion is done using vibrator motors.
2. **Jasmine**: Cheap and reliable open source swarm robot platform made by students of the University Of Stuttgart, Germany. Capable of handling high level tasks such as implementing of basic Artificial Intelligence in agents. It has ability of auto docking and colour sensors
3. **Colias:** Colias design made to meet the bio-inspired mechanisms of swarm robots .The Colias design have following criteria: low-cost design, long-term autonomy, long-range communication, bearing, distance and obstacle detection, neighboring robot detection, fast motion, a small size and an open-source design. The design of Colias was considered due to its small size and fast motion and time-effectively in a small working area.

2.2 PRESENT SCENARIOS:

Currently swarm is in very initial stages of development. Many challenges are being faced right from wireless communication up to swarm behaviors. These research projects are being undertaken in only some universities in USA. The artificial intelligence algorithms are studied only in simulation software and it lacks the problems and drawbacks of practical implementations. Currently swarm robotics is used only in laboratories for research purposes, but its application areas include Artificial Intelligence, search and rescue robotics .Swarm robots are also considered as a precursor to self-assembling robots.

Various top universities are working on swarm robotics like Harvard University developed "Kilobots" which consisted of a swarm of 1000 robots which communicated using IR and moved with the help of vibrator motors. Massachusetts Institute of Technology has developed self-assembling prototype robots known as "M blocks " which have no external moving parts ,but house of motor inside which is attached to a flywheel ,capable of achieving speeds of 20,000 rpm . When they are suddenly braked it imparts angular momentum to the robot .University of Lincoln , United Kingdom has developed the "Colias Project " which is well known for its "Bee clust " Algorithm where the robots assemble in the highest lit area in the environment .

2.3 SELECTION CRITERIA FOR PROJECTS

Swarm Robotics being an emerging field various research projects are being undertaken. Every project has its own unique aim. We admit that comparing all the projects is a complex task further increasing the ambiguity in the concepts, hence certain selection criteria were established to choose the projects.

1. Simplicity of hardware

2. Simplicity of software platforms

3. Generalized application domain

The main aim of this project is to predict the flow of research in this field and thus provide a base for further development. Thus, after an in depth study of the current projects the practical realization of the prototypes of swarm robots can be achieved without industry level precision.

2.4 SELECTION CRITERIA OF THE FEATURES:

1. Simplicity of hardware

Swarm robots have its power in mere optimization. To achieve this target, many projects have worked on MEMs and Nano technology. Being in miniature size, the hardware like motors, controllers are very different and unique from the general applications. To design a fundamental swarm robot, the simplicity in hardware is a crucial criterion. It is a trade off for the projects which aim to be a platform for collective behavior and Artificial Intelligence algorithms.

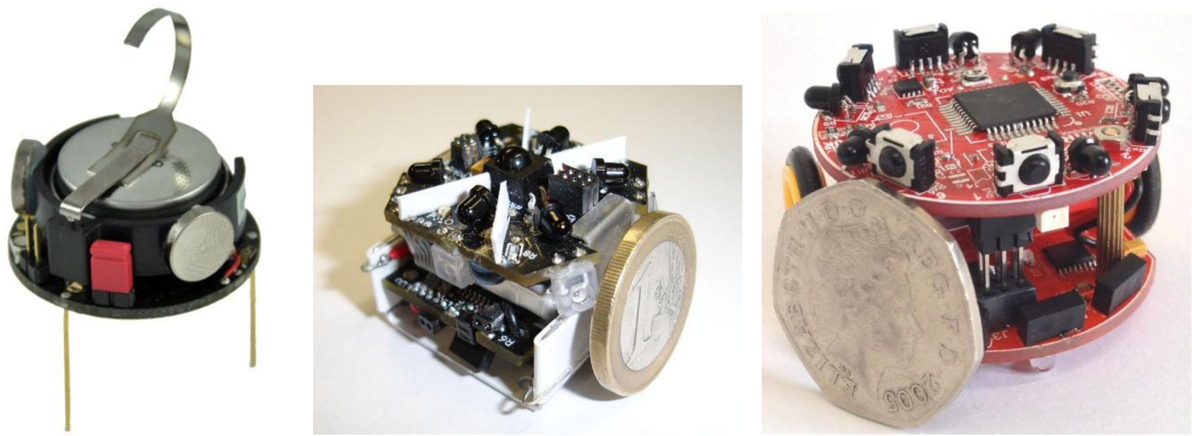
2. Simplicity in Software

Though it is claimed that Swarms are highly intelligent and the power is in their intelligent communication and co-ordination skills, the software platforms must be simple. Here, we claim that we mean only the platforms and not algorithms of the tasks. Many projects use Linux based systems. However, to generate a fundamental swarm robot, an available micro controller with a C platform has been given an edge.

3. Generalized application domain

Swarm robots have a varied application ranging from defense areas to physiotherapy, from construction to industry automation. However, the projects aimed for higher applications are no doubt complex in nature. So to provide a fundamental base, this paper has considered projects with basic applications like cluster formation and follow-the-leader.

However, in some cases, these basic projects can also undertake great challenges merely on the strengths of Artificial Intelligence and protocol



(1) (2) (3)

Figure 1: Selected references for this project

(1) Kilobot

(2)Jasmine Swarm Project

(3)Colias Project

Parameters	Selection Criteria for Swarm Projects		
	Hardware Simplicity	***Software Simplicity***	***Special Application***
Alice		✓	
AMiR		✓	
Colias [6]	✓	✓	BEECLUST
E-Puck			
Jasmine [2]	✓	✓	Docking
Ko-Bot			
Kilobot [3]	✓	✓	OHC
R-one	✓		
Swarmbot	✓		

Table 1: Selection Criteria of project

Parameters	Comparison of Swarm Projects		
	Kilobots	***Jasmine***	***Colias***
Cost	$14	116.01$	36$
Utility	Distance, light	Distance, light, bearing	Distance, light, bearing
Proximity	0	Min 4, Max 6	3
Motor name	Vibrator motors,3	GM 15	GM 15,2
Rpm	12000	920	300
Speed	1 cm/s	10cm/s	35 cm/s
Power	Li Ion 3.7 V	Li Po 3.7V	Li Po 3.7V
Communication	1 IR	IR	IR
Controller	Atmega 328p	Atmega 168/ Atmega 88	Atmega 168/ Atmega 644
Algorithm	S-Dash		BEECLUST
Size	3.3cm	3 cm	4 cm

Table 2 :Selection Criteria of features

CHAPTER 3

SYSTEM DESCIPTION

3.1 Agent block diagram

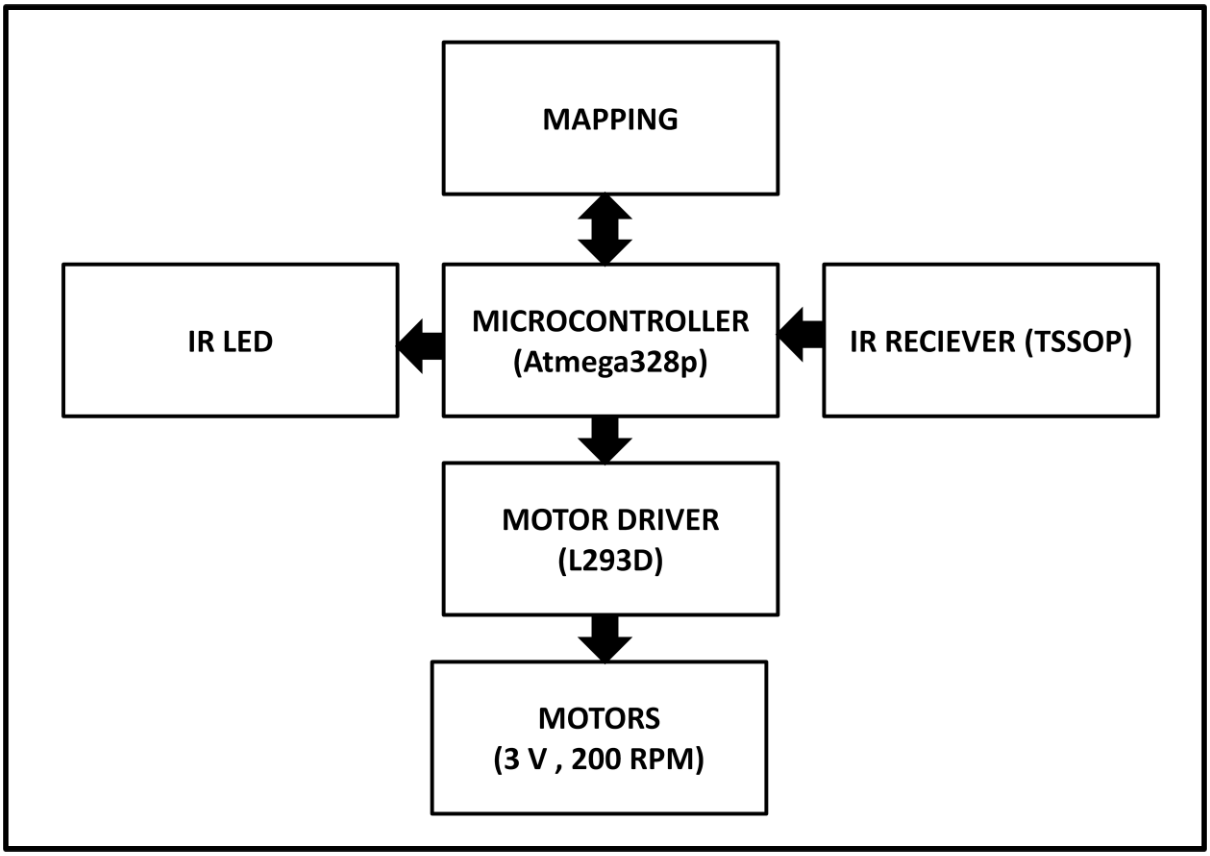


Figure 2 : Block diagram of an agent

3.2 System block diagram

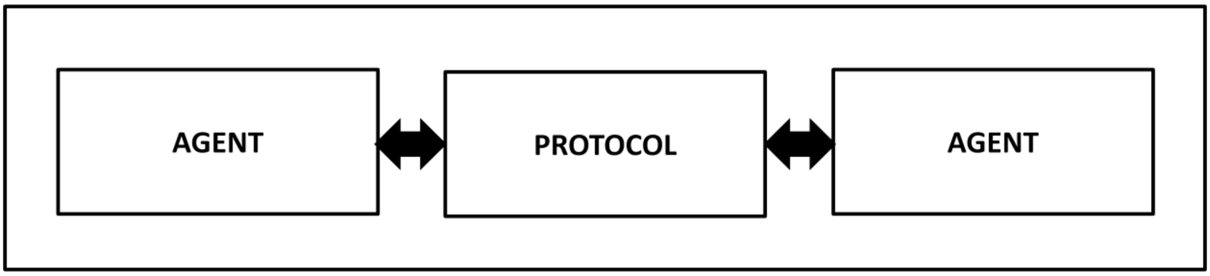


Figure 3 : Block diagram of Swarm

CHAPTER 4

HARDWARE DESIGN DESCRIPTION

4.1 Microcontroller ATMEGA 328p:

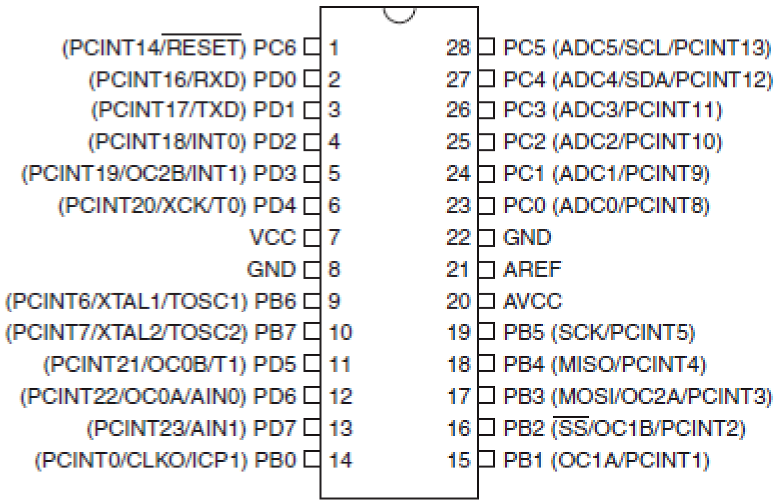


Figure 4: Pin out diagram of ATMEGA 328p

Features of ATMEGA 328p

- High Performance, Low Power AVR® 8-Bit Microcontroller
- Advanced RISC Architecture
- 131 Powerful Instructions – Most Single Clock Cycle Execution
- 32 x 8 General Purpose Working Registers
- Fully Static Operation
- Up to 20 MIPS Throughput at 20 MHz
- On-chip 2-cycle Multiplier
- High Endurance Non-volatile Memory Segments
- 4/8/16/32K Bytes of In-System Self-Programmable Flash progam memory
- (ATmega48PA/88PA/168PA/328P)
- 256/512/512/1K Bytes EEPROM (ATmega48PA/88PA/168PA/328P)
- 512/1K/1K/2K Bytes Internal SRAM (ATmega48PA/88PA/168PA/328P)
- Write/Erase Cycles: 10,000 Flash/100,000 EEPROM
- Data retention: 20 years at 85° C/100 years at 25° C(1)

- Optional Boot Code Section with Independent Lock Bits
- In-System Programming by On-chip Boot Program
- True Read-While-Write Operation
- Programming Lock for Software Security
- Peripheral Features
- Two 8-bit Timer/Counters with Separate Prescaler and Compare Mode
- One 16-bit Timer/Counter with Separate Prescaler, Compare Mode, and Capture

4.2 Infrared Communication:

For every Communication system, there is a need of transmitter and receiver. While considering the Infrared Communication, the IR LED acts a transmitter. It receives the data signals from the microcontroller. The receiver is the TSSOP phototransistor. It has a band pass filter of 38 KHz and receives the IR signal

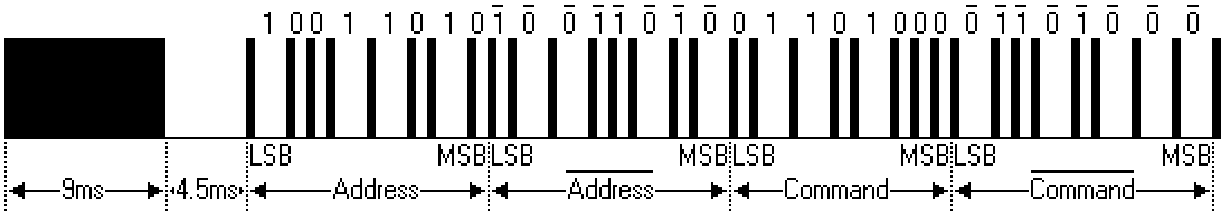


Figure 5: NEC protocol

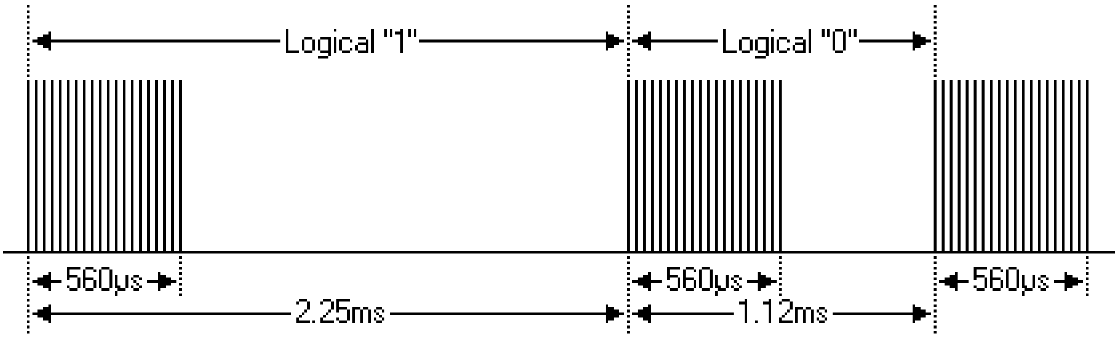


Figure 6 : NEC protocol (Logical 1 and Logical 0 timing diagram)

4.2.1 Infrared LED (Transmitter):

Figure 7 : IR LEDs

The IR LED operates in the Infrared band of frequency. Depending on the incoming signals, these LEDs turn on and off thus transmitting the signal in binary form. As the receiver is set at 38 KHz, the LEDs are also operated at same frequency

4.2.2 Infrared TSOP (Receiver):

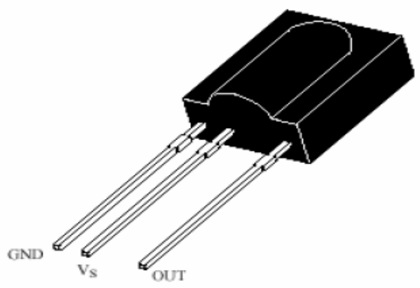


Figure 8 : TSOP HS 1738

The TSSOP operates at a frequency range of 38 KHz. It has a band pass filter, hence it allows only the signals in that range. It has three pins, namely Ground, VCC and Data. The supply is given to be 5V. The data pin is connected to the Microcontroller. It takes input from IR transmitter module and accordingly gives signals to microcontroller.

TSOP 1738 (IC2) is used as an infrared receiver. It's a 3 pin module with active low output. When no key is pressed on remote, it shows high output. Figure shows the pin diagram of TSOP.

4.3 Transistor:

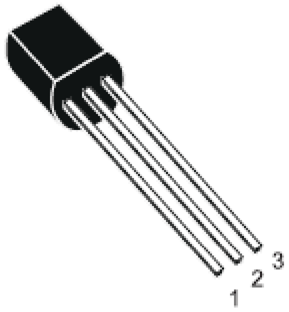


Figure 9 : Transistor 2N3906

For the communication purpose, the microcontroller has to drive four IR LEDS. To optimize the pins, all LEDs have to be driven from same pin. As the sourcing capacity of microcontroller is not sufficient, a transistor 2N3906 has been used. Its base has been connected to the microcontroller. It is a NPN transistor. The load is driven from the emitter terminal. The collector terminal is given the VCC.

Thus the transistor helps to drive four LEDs using just one pin from microcontroller. As per the project application, the transistor should switch at 38 KHz. Hence if there is delay in the rise or fall time, it would affect the data to be transmitted. Hence the rise and fall time of transistor have also been practically verified.

SWITCHING CHARACTERISTICS					
t_d	Delay Time	V_{CC} = -3.0 V, V_{BE} = -0.5 V I_C = -10 mA, I_{B1} = -1.0 mA		35	ns
t_r	Rise Time			35	ns
t_s	Storage Time	V_{CC} = -3.0 V, I_C = -10 mA, I_{B1} = I_{B2} = -1.0 mA		225	ns
t_f	Fall Time			75	ns

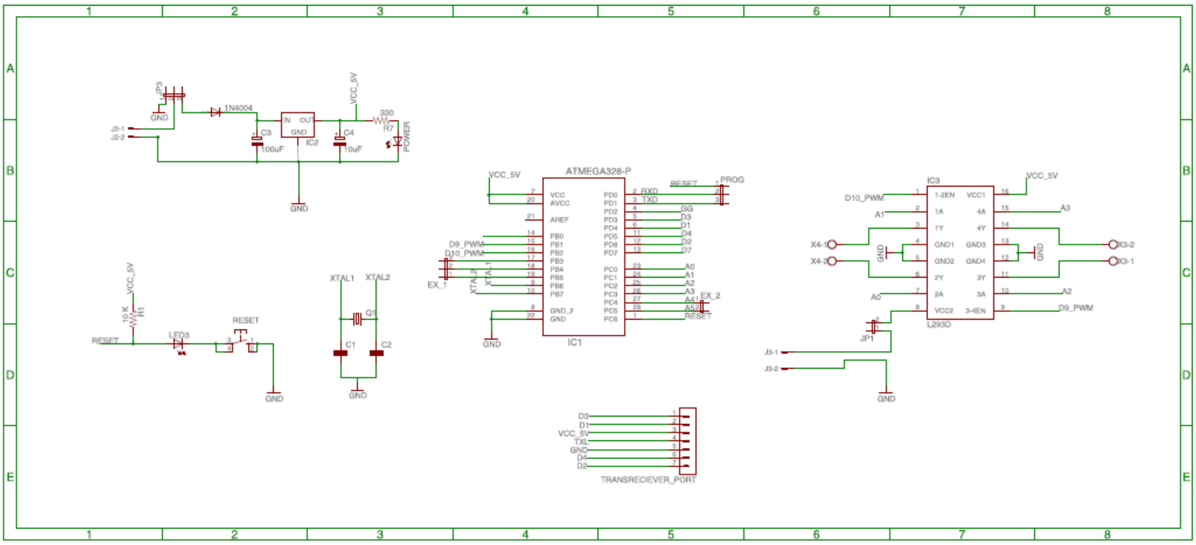
Table 3: rise and fall times of the transistor

4.3 Motor

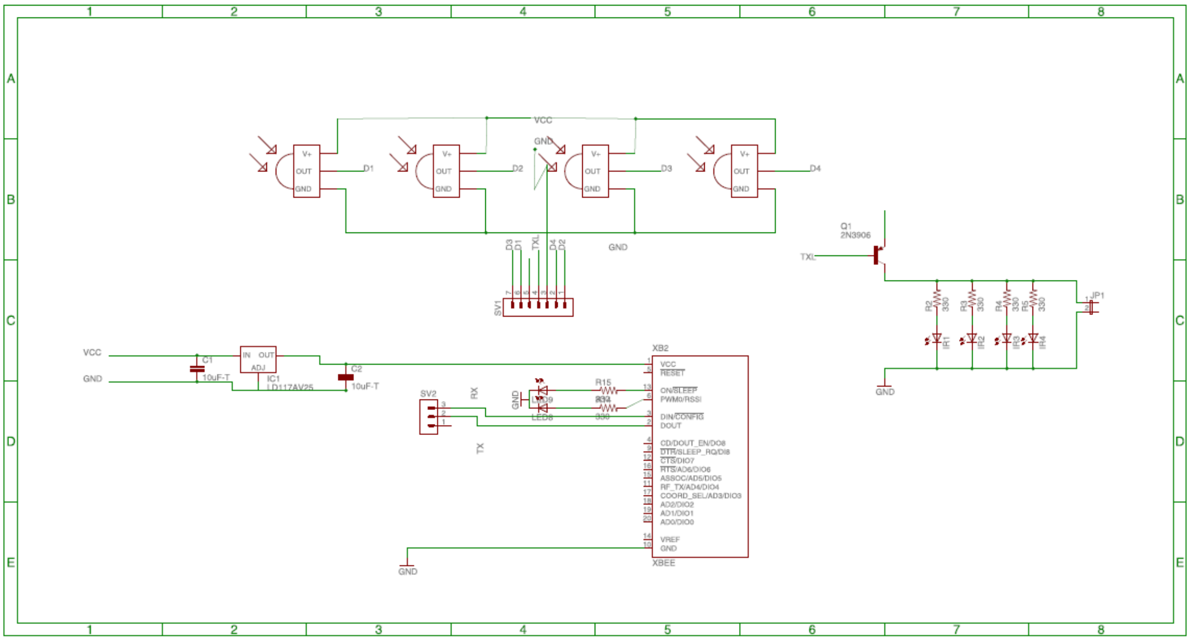
Figure 10 : Motor

The motors are used for the locomotion of the robot. By taking into the consideration the weight of the robot and the speed required, the motors have been selected .Motors runs of a 3V DC. The speed of the motors is 60±10 rpm .Motor at no load status is 260 mA (350mA). Torque is 120nM.m

4.4 Schematic of the agent



Schematic of the main board



Schematic of the upper board

4.5 PCB LAYOUT OF THE AGENT

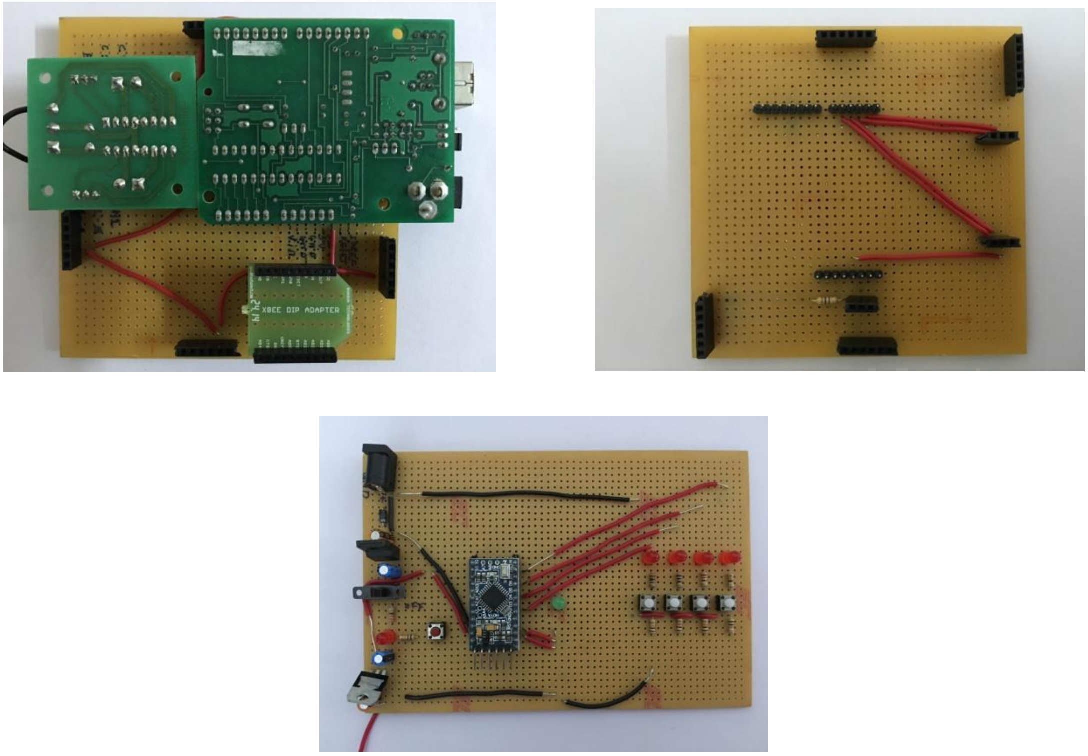


Figure 11 : Version 1 of the PCB

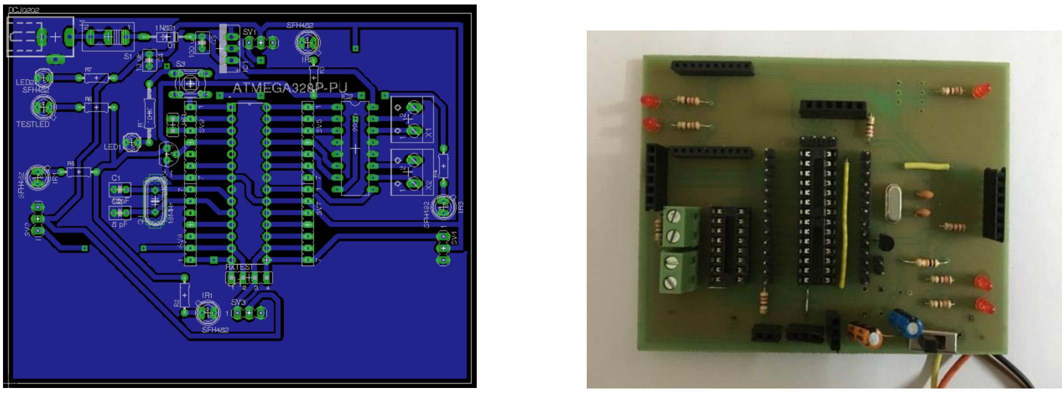
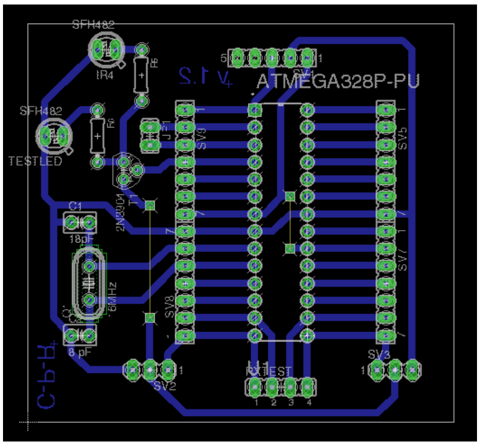


Figure 12 : Layout of Version 2 .1 of the PCB



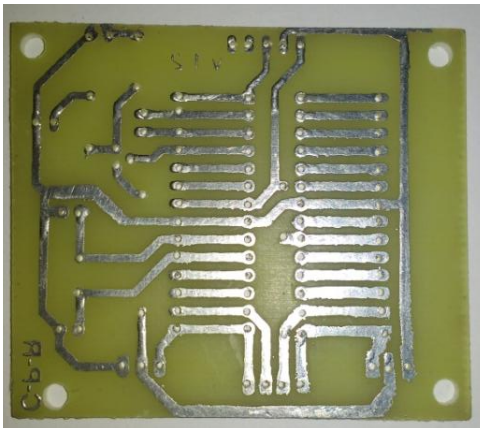
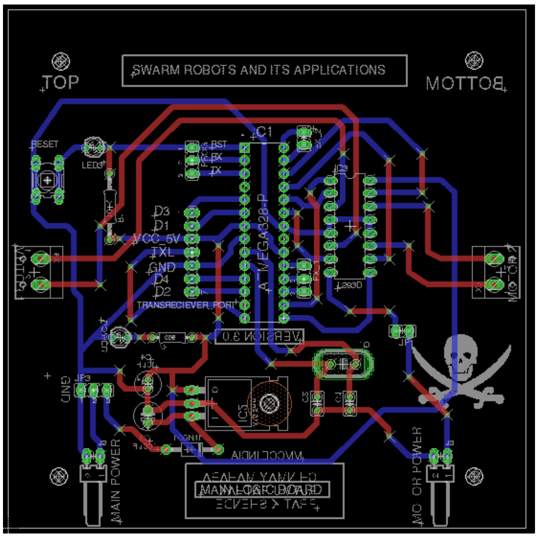


Figure 13 : Layout of Version 2.2 of the PCB



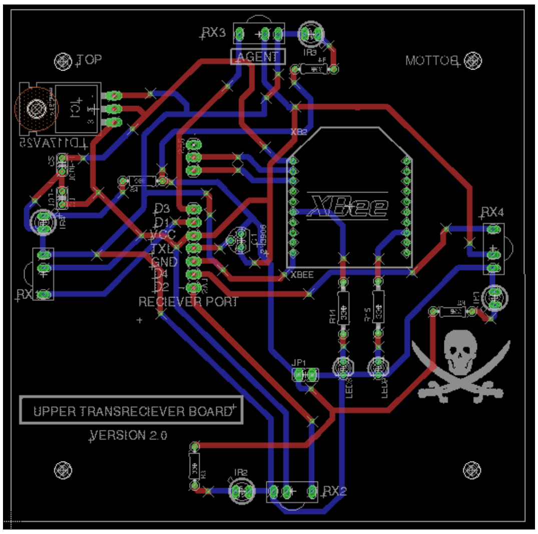


Figure 14 : Final version 3.0 of the PCB

4.6 Proposed agent prototype

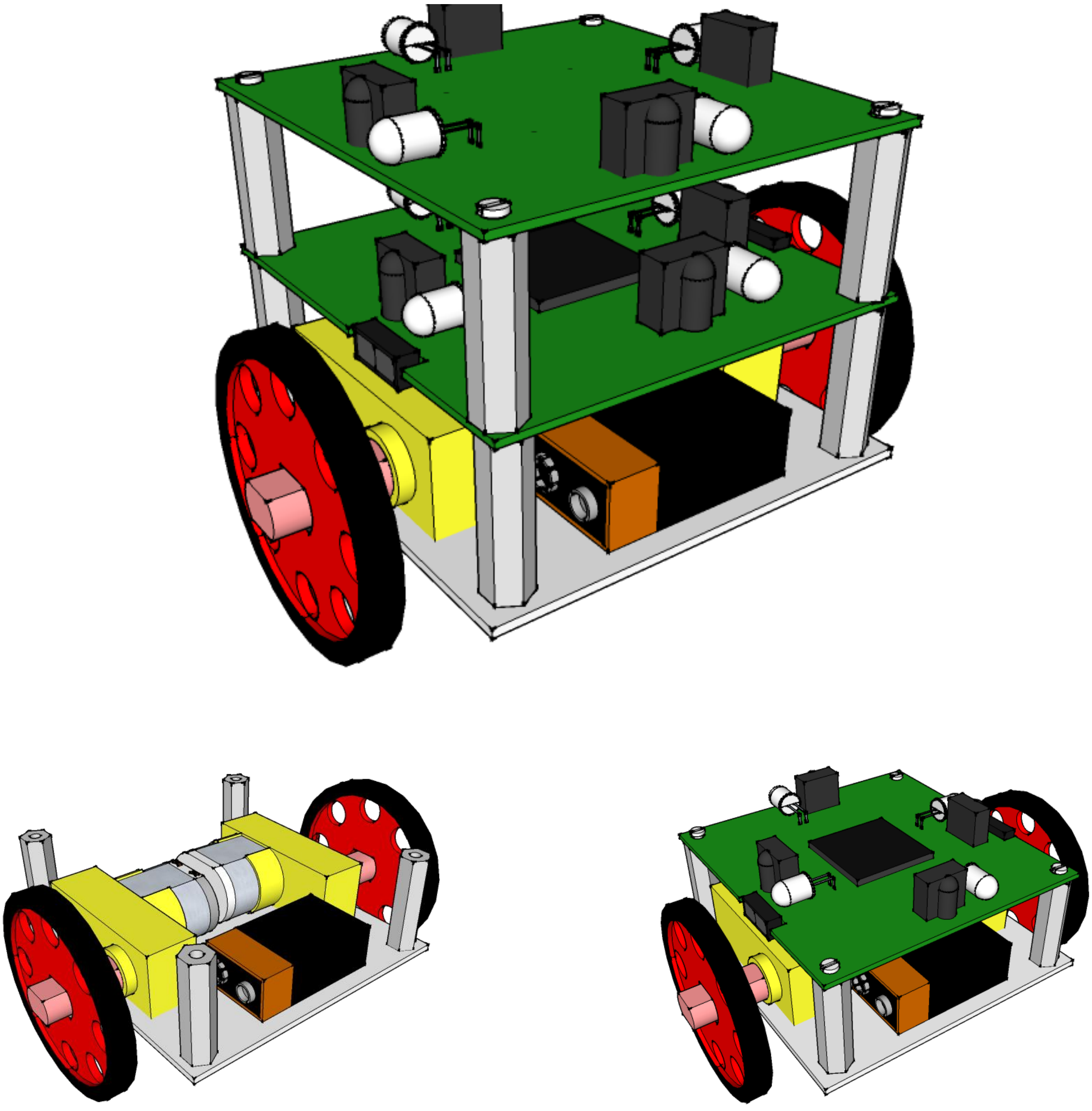


Figure 15 : Prototype design of Swarm agents

4.7 Photographs of the finished agent

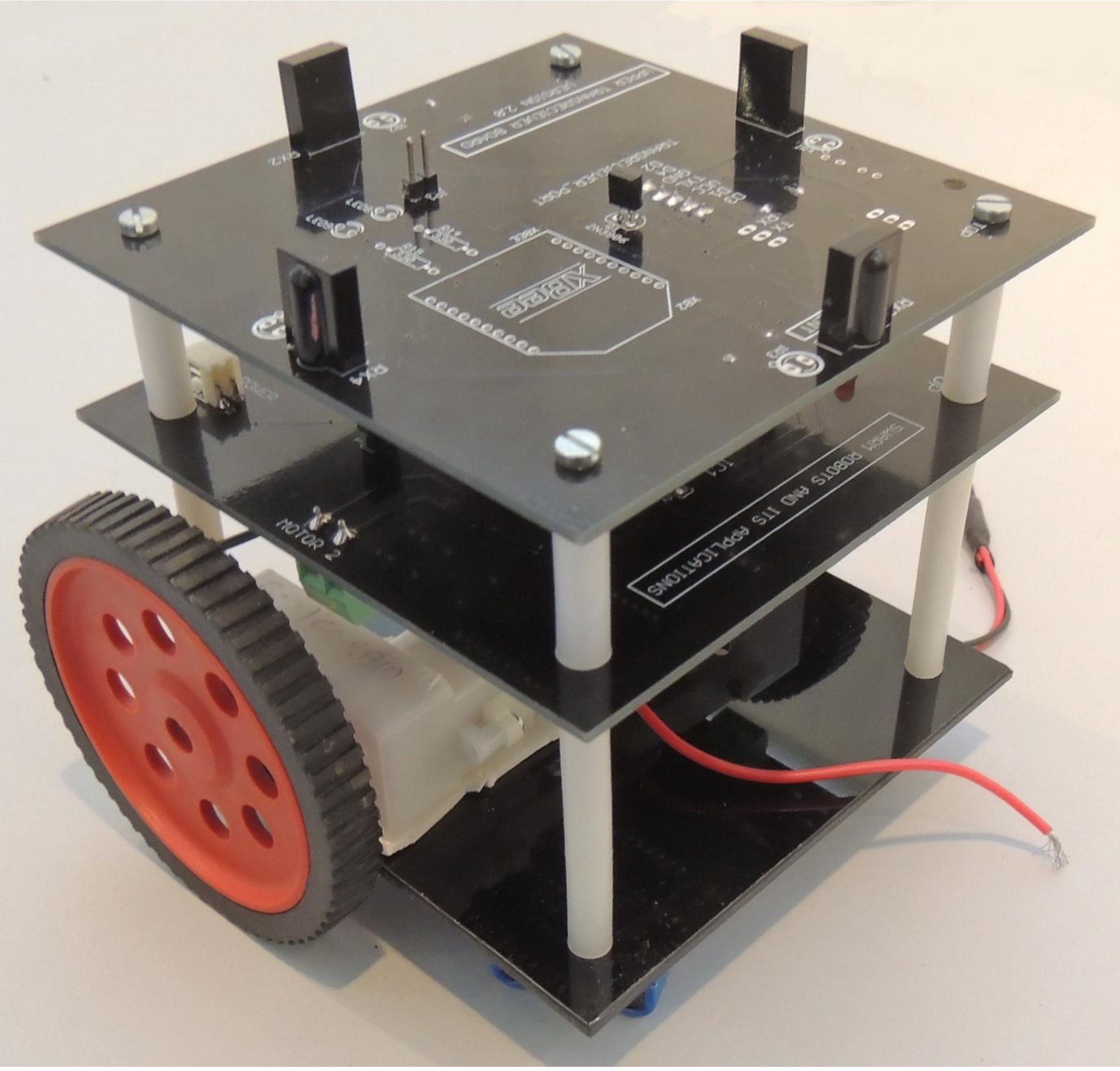


Figure 16 : Final photographs of the constructed agent

CHAPTER 5

SOFTWARE DESIGN DESCRIPTION

5.1 Software used:

The software used in the process is as follows:

5.1.1 Arduino

Arduino is a term for a software company, project, and user community that designs and manufactures computer open-source hardware, open-source software, and microcontroller-based kits for building digital devices and interactive objects that can sense and control physical devices.

Arduino in this project was used for quick prototyping of various high level algorithms .Arduino offers a quick and simple IDE which increases the productivity further.

Versions used (1.6.8)

5.1.2 Multisim

NI Multisim (formerly MultiSIM) is an electronic schematic capture and simulation program which is part of a suite of circuit design programs, along with NI Ultiboard. Multisim is one of the few circuit design programs to employ the original Berkeley SPICE based software simulation. Multisim was originally created by a company named Electronics Workbench, which is now a division of National Instruments. Multisim includes microcontroller simulation (formerly known as MultiMCU), as well as integrated import and export features to the Printed Circuit Board layout software in the suite, NI Ultiboard. Multisim is widely used in academia and industry for circuits' education, electronic schematic design and SPICE simulation.

Versions used (11.0)

5.1.3 Sketch up Pro 2016

SketchUp (formerly Google SketchUp) is a 3D modeling computer program for a wide range of drawing applications such as architectural, interior design, civil and mechanical engineering, film, and video game design—and available in a freeware version, SketchUp Make, and a paid version with additional functionality, SketchUp Pro.

SketchUp is currently owned by Trimble Navigation, a mapping, surveying, and navigation equipment company. The program's authors describe it as easy to use There is an online open source library of free model assemblies (e.g. windows, doors, automobiles), 3D Warehouse, to which users may contribute models. The program includes drawing layout functionality, allows surface rendering in variable "styles", supports third-party "plug-in" programs hosted on a site called Extension Warehouse to provide other capabilities (e.g. near photo-realistic rendering), and enables placement of its models within Google Earth.

SketchUpPro2016 was used in this project to quickly visualize and prototype the agent chassis designs.

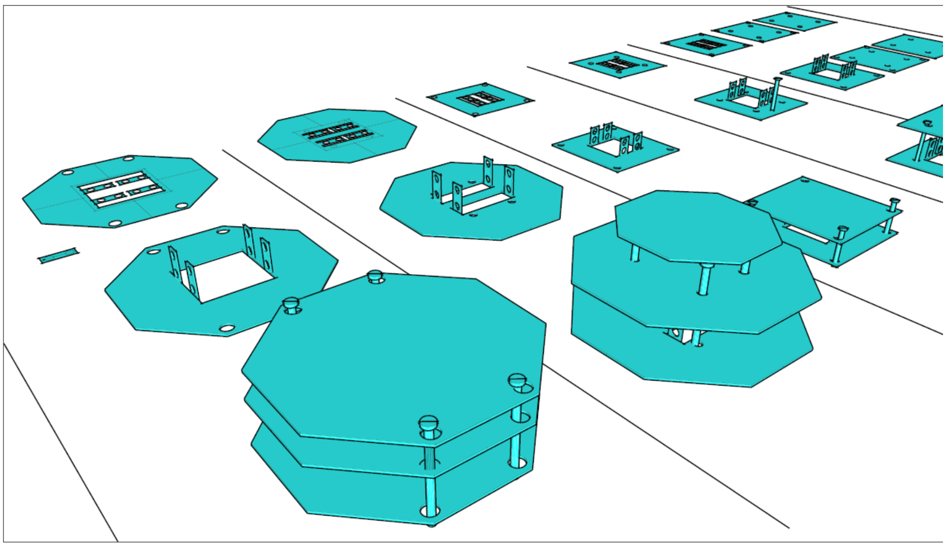


Figure 17 : Multiple iterations of chassis of agents

5.1.4 Eagle

EAGLE stands for, Easily Applicable Graphical Layout Editor in English. It is designed and developed by CadSoft Computer GmbH and is a flexible, expandable and scriptable, electronic design automation (EDA) application with schematic capture editor, printed circuit board (PCB) layout editor, auto-router and computer-aided manufacturing (CAM) and bill of materials (BOM) tools. Premier Farnell bought EAGLE in 2008.

Eagle was used in designing PCB's for the project.

Version used (7.4)

5.2 Algorithm used:

The project software is divided in two main types, the communication part and the actual realization of task

5.2.1 Communication.

The protocol has been designed specially for the swarm communication. To optimize the system only 6 bits are used out of 32 bits.

- 2 bits for data.
- Acknowledge bit.
- Start bit.
- Tx and Rx bit.
- Stop bit

The algorithm is designed as follows.

1. The sender will transmit tx bit.
2. On receiving, the receiver will transmit ack bit.
3. Then the sender will transmit the data, until the stop bit is high.

5.2.2 Locomotion Algorithm

Algorithm for "follow the leader"

1. Send the task number.
2. The leader bot will transmit the command.
3. The receiver will send the acknowledgement.
4. The bot will move cerain distance and wait till the bot arrives.
5. The mode will stop once received the stop command.

Algorithm for cluster formation.

1. Send the task number.
2. Send the command
3. Verify the positions using TSOP sensors.
4. Adjust the position using feedback
5. send stop bit

Algorithm for mapping

1. Send the task number.
2. Send the command.
3. Resend the data of co-ordinates of area to the leader bot
4. The leader bot will transmit the data to PC
5. The PC will map the coordinates using MATLAB.

5.3 FLOW CHART

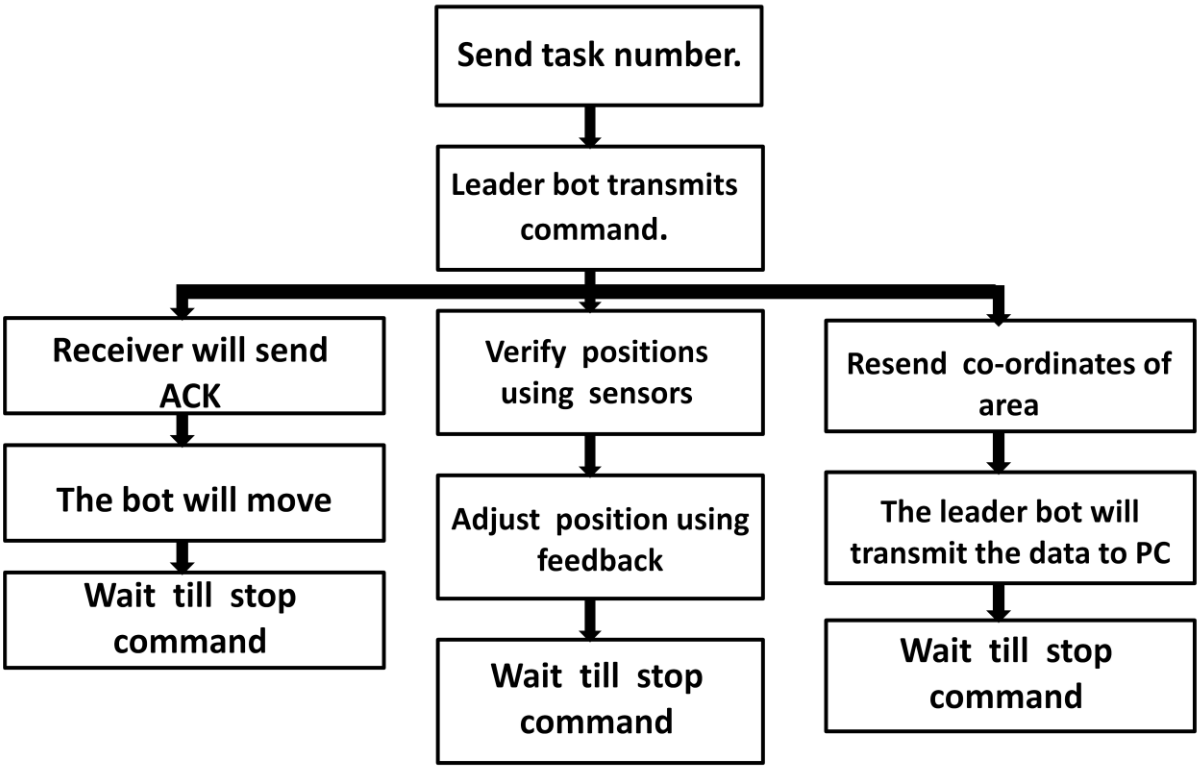


Figure 18 : Flowchart illustrating flow of the algorithm

CHAPTER 6

IMPLEMANTATION

6.1 Setup:

The implementation of project requires setup for communication and actual robot assembly.

6.1.1 Setup for Communication between robots:

1. Connect a pair transmitter and receiver in front of each other.
2. Send the data from sender and verify it on serial monitor.
3. Verify the received data serially.
4. Send the acknowledgement.

6.1.2 Setup for Communication between robots:

1. Connect communication, motors and motor.
2. Test the motors depending on the received signals.
3. Verify with the RGB LEDs if data is sent and received.

6.2 Results:

6.2.1 Cone angle for IR transmission.

For transmission of signals, 4 IR LEDs have been used. To verify if there is interference between the adjacent .The transmitter cone angle was determined to be 120^{o}. The receiver angle was determined to be 18 ^{o}.

6.2.2 Distance limitation for IR transmission.

The data transmitted through IR LED and received on TSOP. We gradually increased the distance while simultaneously sending the data. The distance was limited until there were error bits introduced in the signal. After experiment, the data was successfully sent over a distance of 6 m

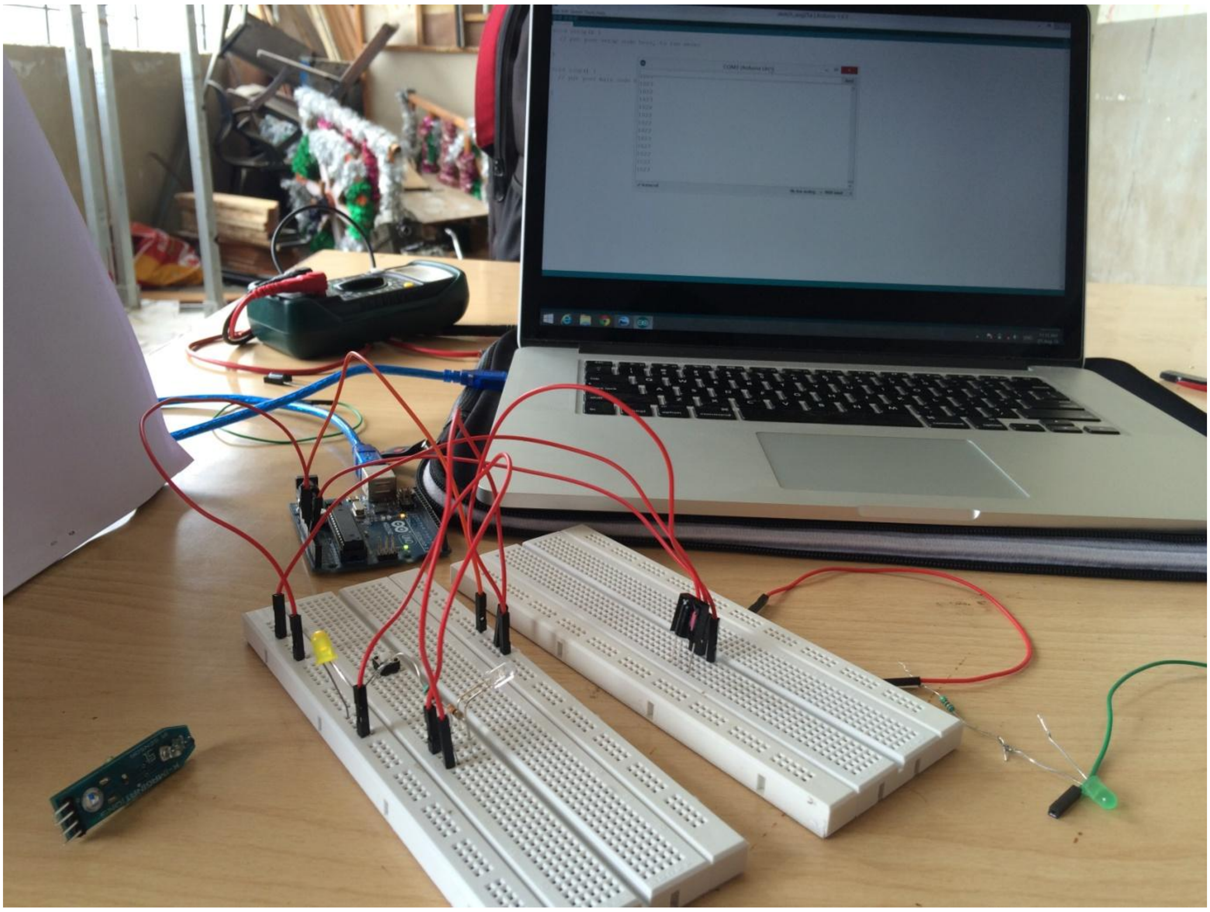


Figure 19 : Setup for testing cone angle and distance for IR LED

6.2.3 Use of transistor to drive 4 LEDs.

The requirement of the project was to drive four LEDs using on a single pin on transistor. However, considering the sourcing capacity of microcontroller, it not possible. So the data was given to base of transistor, and the LED were driven from the emitter of transistor.

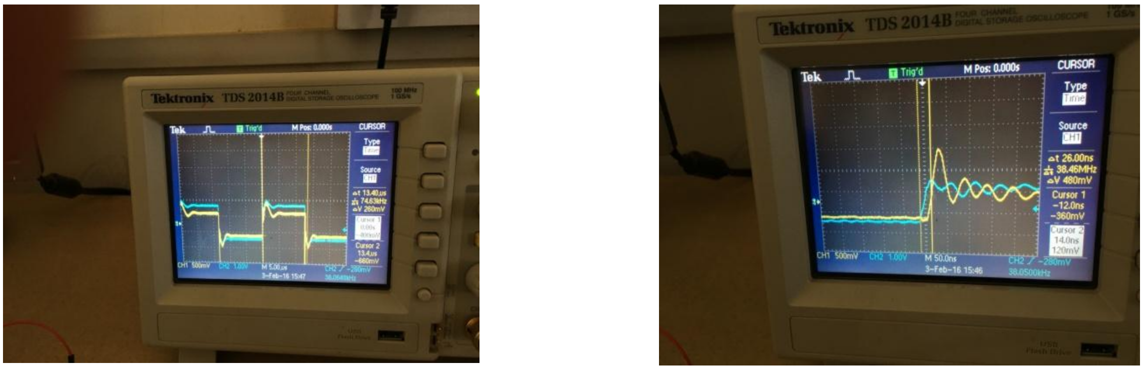


Figure 20 : Input Output Waveform & Rise time waveform

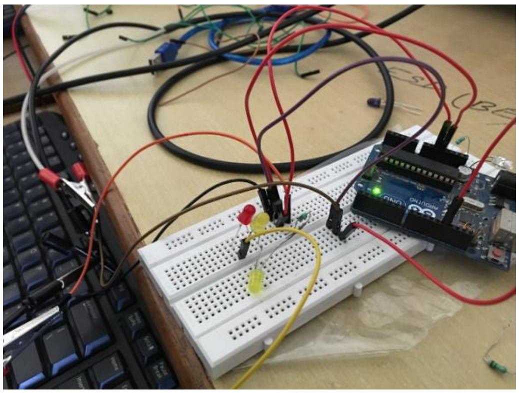


Figure 21: Setup for driving LEDs

6.2.4 Selection of number of bits for transmission.

As the NEC protocol is being used, the transmission of data takes place using 32 bits. However, we noticed that it increases redundancy. Hence, depending on the requirement of communication information, only six bots of data is used for communication

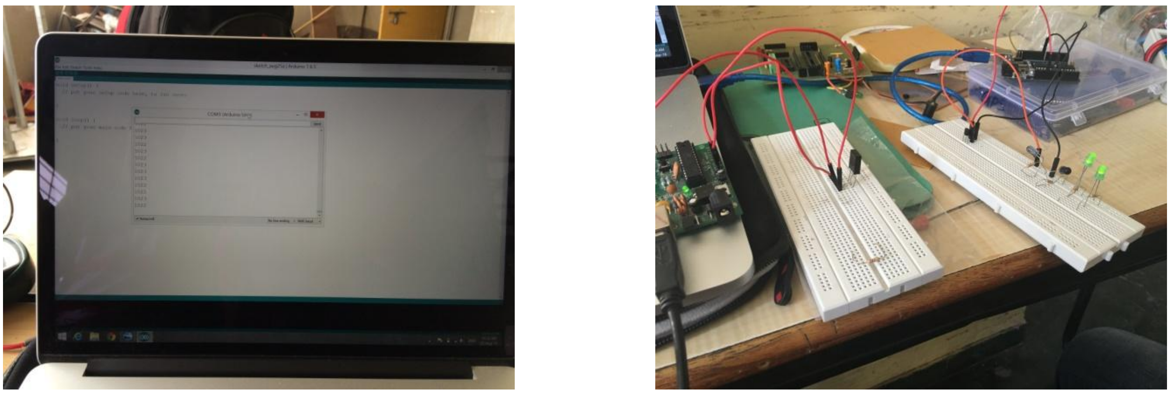


Figure 22: Setup for selection of number of bits

CHAPTER 7

APPLICATIONS AND CONCLUSIONS

7.1 Applications

- Swarm agents are used in search and rescue operations.
- Agents are used in mapping huge portions of land.
- Swarm robotics are the precursor to self-assembly approach in robotics where small individual units come together to form a definite structure.
  (M – Blocks, MIT, USA).

7.2 Limitation

The system is limited by the actual physical size and construction of the agents. The terrain in which the agents will operate is defined by the design . Main limitation of the agents is the power requirements which can either be satisfied by onboard battery or a rechargeable battery

7.3 Conclusion

In this project, we have successfully created a simple, low cost platform for exploring swarm robotics. This platform is easy to use and can be made with easily available hardware. We have simplified the platform further by adding a high performance which is easy to code. Three milestones tasks in swarm robotics have been implemented. These 3 basic tasks help in implementation of other high complexity.

7.4 References:

7.4.1 Journal papers:

[1] Serge Kernbach, Ronald Thenius, Olga Kernbach, Thomas Schmickl
Re-embodiment of Honeybee Aggregation Behavior in an Artificial Micro-Robotic System Copyright ,"© 2009 International Society for Adaptive Behavior" (2009)".

[2] Rubenstein, Michael, Christian Ahler, Radhika Nagpalv, "Kilobot: A Low Cost Scalable Robot System for Collective Behaviors," In Proceedings of 2012 IEEE International Conference on Robotics and Automation (IRCA 2012): May 14-18, Saint Paul, Minnesota. 3293-3298. Washington, D.C.: Computer Society Press of the IEEE.

[3] www.eecs.harvard.edu/ssr/projects/progSA/**kilobot**.html

[4] S. Kornienko, S. Kornienko ,"IR based Communication and Perception in Microbotic Swarms", IROS 2005.

[5] Farshad Arvin and Shigang Yue," Colias-Φ: An Autonomous Micro Robot for Artificial Pheromone Communication", Manuscript received April 1, 2015; revised September 1, 2015.

[6] Farshad Arvin, John Murray, Chun Zhang and Shigang Yue," Colias: An Autonomous Micro Robot for Swarm Robotic Applications", IJARC Nov 2013.

[7] Manual of Kilobots by K-Team.

[8] Swarm Intelligence and Algorithm by Yuhui Shi.

[9] Muhammad Ali Mazidi, "AVR Microcontroller and Embedded Systems", 14 Aug 2011. 1st Edition.

[10] www.swarmrobot.org

7.4.2 Book references:

1. Artificial Intelligence: A Modern Approach - Stuart J. Russell and Peter Norvig.

7.5 APPENDIX