UB Swarm Robot – Design, Implementation, and Power Managment

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***Abstract*— In this paper we described the hardware architecture of an inexpensive, heterogeneous, mobile robot swarm, designed and developed at RISC lab, University of Bridgeport. Each UB robot swarm is equipped with sensors, actuators, control and communication units, power supply, and interconnection mechanism. This article also describes the essential features and design of a dynamic power distribution and management system for a dynamically reconfigurable multi-robotic system. It further presents the empirical results of the proposed dynamic power management system collected with the real robotic platform.**

Keywords—Heterogeneous Robot Swarm; Hardware Architecture; Power Distribution in Robot Swarm.

I. INTRODUCTION

Swarm robotics is inspired from the animals that behave in a group such as insects, ants and bees. Till date, most existing swarm robot systems have been designed and implemented with homogeneous hardware. Only a few of them have heterogeneous robots, but those swarm system were limited physically and behaviorally. Due to the lack of methods and tools, swarm robot designers cannot achieve the complexity required for the real world applications [1]. The complexity of designing and physically implementing the heterogeneous robot swarm is greater when compared to the homogeneous robot swarms. There are several aspects involved in the development of robot swarm hardware, such as locomotion, actuation, navigation, size, appropriate sensors, cost, and communication [2, 3]. One of the challenges for robot swarm is its autonomy, as the robot must be aware of its battery life, self localization etc. In our review article [3], we have reviewed the hardware architecture of robot swarm with self-configurability, self-assembly, and self-replication. After reviewing existing swarm systems and studying the limitations, we decided to design and built our own robot swarm system. In this design we have considered some important factors such as its size, cost, autonomy, flexibility, robustness, power consumption, weight, etc. The main goal of our research is to build a heterogeneous robot swarm system in which each robot has distinct type of hardware compared to other robots. The proposed architecture is an autonomous, modular, heterogeneous robot swarm with self-configurability, self-assembly, and self-learning capabilities. Nowadays electronic products are cheaper, smaller, lighter in weight and easily available, which makes robot swarms more cost efficient, lighter in weight, and compact in size [4, 5].

The swarm-bot research project [6], deals with design and implementation of swarm robots (s-bots) with self organizing and self assembling capabilities, but each S-bot is physically identical (homogeneous) and uses same kind of sensors, actuators, microcontroller. S-bot can connect with other S-bots with rigid gripper and also able to lift the other S-bots to create bigger structure. Further, they extended the swarm-bots into swarmanoid project, which focused on the study, design and implementation of swarm of heterogeneous robots [1]. In this case, a swarm includes robots that can move on the ground, fly and climb on vertical surface. In swarmanoid project, robots use different colored light emitting diodes (LED) and omnidirectional camera for communicating with each other. The camera is pointed at a half spherical mirror to directly acquire images from its surroundings. The problem with swarm bot is that, the images that camera receives are further away than seen in mirror. Table I summarizes the hardware platforms implemented so far in swarm robot research experiments.

The hardware platforms given in the above Table I are homogeneous in nature and limited with capabilities and functionality. In section 2 we have explained the hardware architecture and the design goals of the UB robot swarm. Section 3 describes the sensory platform and their technical specification and working principles. Section 4 describes the locomotion and manipulation. Section 5 describes the communication and control units used on the UB robot swarm. Section 6 shows an experimental results of human rescue task using the UB robot swarm.

The power management and distribution in swarm robotics is of very high importance, which depends not only on the electronic design but also on its mechanical structure. To perform a task in an unknown environment, robots should be capable of great degree of autonomy and operate over a longer time. The autonomous mobile robots draw power from batteries carried on the chassis in order to provide the power to the onboard sensors, actuators, and communication modules. Batteries have a limited lifetime, due to which the operational time of the robots in the swarm is also limited. For successful completion of the tasks, the robot swarm must be continuously aware of the lifetime of its power source; therefore, management of power resources is necessary and vital for spending the available energy for robots swarm economically.

TABLE I HARDWARE PLATFORM SUMMARY

Sr. No	Name	Sensor	Actuation	Controller	Communication	Positioning system
1	E Puck	11 IR, Contact ring, Color camera	wheeled	dsPIC	Bluetooth	Expansion IR based
2	Alice	IR, Light Sensor, Linear Camera	Wheeled	Microchip PIC	Radio (115 kbit/s)	------
3	Jasmine	8 IR	wheeled	2 ATMega	IR	Integrated IR based
4	I-swarm	Solar cell	3 micro leg piezoelectric actuator	Not Available	Not Available	-----
5	Khepera	8 IR	wheeled	Motorola MC66831	RS232, Wired link	-----
6	Khepera III	11 IR, 5 Ultrasound	wheeled	PXA-255, Linux, dsPIC	WiFi & Bluetooth	Expansion IR based
7	S-Bot	15 Proximity, Omnidirectional Camera, Microphone, Temperature	Wheeled, 2 gripper	Xscale Linux PICs	WiFi	Camera based
8	SwarmBot	IR, Camera, Light, Contact	Wheeled	ARM and FPGA 200 kgate	IR based	Integrated IR based
9	Kobot	8 IR, Color camera	wheeled	PXA-255, PICs	ZigBee	Integrated IR based

II. HARDWARE DESIGN

The hardware design for any swarm is an interactive and an important phase; as all components and/or parts are assembled to build one robot swarm. At the hardware level, the most work has been done in collective behavior with homogeneous robots. In this project we decided to exploit reconfigurability, and modularity using heterogeneous robots with decentralized control algorithms which are influenced by ants, bees colony, and insects behaviors [7]. Swarm robots developed so far are aimed to provide a research platform and not intended for real-world applications or vise versa. In this section, we explain the hardware architecture of the UB robot swarm, design and build at RISC Lab., University of Bridgeport. This swarm of heterogeneous robots is designed for real physical world applications in order to perceive their environmental physical properties through sensors and do the manipulation and localization using actuators. UB swarm robots can be used for real life applications as well as for research purpose. This modular hardware architecture consists of independent sensory unit, actuator modules, and communication unit, that make swarm system scalable and flexible such that more sensors and/or actuators can be added without modifying the overall architecture. The fig. 1 shows an overview of the hardware design implementation.

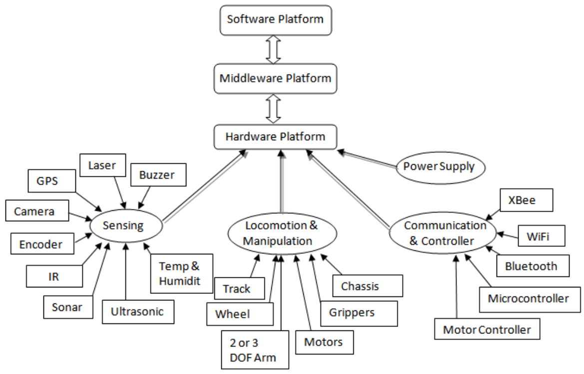

Fig. 1 Hardware Architecture Design

There are many things that have to be considered while designing and implementing the hardware platform for the heterogeneous robots. Following are the design goals for UB swarm of heterogeneous robots, such as:

- Each robot should be easily modifiable and compatible with a high performance microcontroller.
- Should consume less power.
- Should provide user friendly mobile, modular, and flexible platforms.
- They should be reconfigurable and provide easy support for the software as well as for the middleware.
- They should provide low cost wireless communication for indoor as well as outdoor applications
- They should have enough future expansion space for sensory units and actuators.
- The robot should be relatively of different size and shape with light weight, so that it can allow ease of movement and maneuverability.
- Each robot should be fully functional, and continuously coordinate and communicate with other robots.

Building of such a heterogeneous swarm of robots is a really difficult task in real life. At the time of writing this paper we have built five swarm robots, which are fully assembled and tested for mapping, obstacle avoidance, painting, and rescue application. The UB robot swarm is simple, capable of sensing, localization, and actuation based on the local information and basic rules. In the following sections, the mechanical and electronic modules of the robots are described with their working. All the parts were tested and slightly modified for the applications, and then assembled to build the physical robots swarm. The software scans for replaced or extra added sensors itself which makes robot swarms more dynamic.

III. SENSOR FUSION

Gathering an information or data about the working environment or surrounding environment of the swarm robots is everlasting job. The sensory unit is important for robot swarms to perform the tasks such as obstacle detection, obstacle avoidance, detecting its neighboring robot, and navigation [6]. Sensors are classified as five sensing elements of the robot swarm and are used to collect the information about their surrounding environment by means of electrical or electromechanical signals. In this proposed hardware design, each robot swarm is equipped with different types of sensors such as temperature sensor, humidity sensors, encoder, camera, communication devices, proximity sensors, ranger detector, GPS tracking devices, etc. There are two primary factors that affect the limitation of sensors, they are

- Range and resolution of the sensors.
- Noise that affects the output of the sensors.

The study of animal behavior shows that, the sensory skills are developed and adapted by the interpretation of signals generated from sensors. In swarm robots, this self learning capability is achieved by configuring and calibrating sensors for a given task. Using multiple sensors (known as sensor fusion) provides the most efficient and effective methods for collecting, and investigating the unknown environments. In this section we have explained all the sensors that are used in our proposed robot swarm hardware with their technical specifications.

A. *Proximity Sensors*

Distance measurement and obstacle avoidance is the fundamental element of the information gathering quest. In swarm robotics, obstacle detection and collision avoidance in real time while the robots are in motion is major constrain and difficult task. Proximity sensors sense the object or surrounding material or other moving swarm robots without any physical contact, and calculate or give very precise distance of that object [8]. This crucial component not only avoids collision, but also prevents the physical damage to the swarm robots and maintains safe distance [2, 3]. Depending on the type of technology used, proximity sensors are classified into different categories such as, inductive, capacitive, photoelectric, and ultrasonic proximity sensors.

Among these, ultrasonic proximity sensors were found to be more accurate and have more capabilities when compared to the others types of proximity sensors [3]. In proposed swarm robot model, we use ultrasonic as well as photoelectric (Infrared) proximity sensors.

1) *Ultrasonic Sensor*

Ultrasonic sensors are very commonly used to measure distance because they are inexpensive and easy to handle. They are used to avoid obstacles, to navigate, and for map building. Ultrasonic sensor emits sound waves (ultrasound) of 20 KHz frequency and uses it to find a way around the obstacle, detect the uneven surfaces, any shape and size of object in known as well as in unknown environment. This is known as Echolocation. This sensor sends outs ultrasonic waves which are then detected after they are reflected or bounced back from object and/or obstacle. The time required for sending and to receiving the ultrasonic waves is measured and further processed to calculate the distance. These sensors are very precise in measurement and used in applications that require measurement between stationary and moving objects.

In our proposed hardware architecture design, ultrasonic sensors are mounted on the sides (left and right), front and back corners of the robot. Following are the ultrasonic sensors used in UB robot swarm system with their technical specification.

- Devantech SRF02 – We use the SRF02 in Serial mode, the mode pin is connected to 0v Ground. The Rx pin is data into the SRF02 and connected to the Tx pin on PIC controller. The Tx pin is data out of the SRF02 and connected to the Rx pin on PIC controller.
- Seeedstudio Ultrasonic Range Finder – This sensor operates on 5VDC voltage, 15 mA current and the maximum measuring range is 400cm. The data pin of sensor is connected to the digital pin of microcontroller.
- Ping Ultrasonic Sensor – The output from the ping sensor is a variable-width pulse that corresponds to the distance to target. The GND pin is connected to the GND of the microcontroller, 5 VDC is connected to the 5 VDC power supply and the signal pin is connected to the analog pin of the micro controller.
- LV-MaxSonar-EZ1 MB1010 Sensor - The analog pin of the sensor is connected to the analog pin of the controller. The analog voltage pin outputs a voltage which corresponds to the distance. The distance of an object from the sensor is directly proportional to the voltage.

2) *Infrared Sensors*

The IR Range Finder works by the process of triangulation. A light pulse of wavelength range 850 nm (+/-70nm) is emitted from the sensor and then reflected back by an object or not reflected at all. When the light returns it comes back at an angle that is dependent on the distance of the reflecting object as shown in fig. 2. Triangulation works by detecting this reflected beam angle and by knowing the angle, the distance can then be determined. The performance of the IR sensor is limited by its poor tolerance to the ambient light or bright object color reflection. The IR range finder receiver has a special precision lens that transmits the reflected light onto an enclosed linear CCD array based on the triangulation angle. The CCD array then determines the angle and causes the rangefinder to then give a corresponding analog value to be read by microcontroller. The output of the IR sensors is analog, which is connected to the analog pin of the microcontroller. The Sharp IR Range Finder-GP2Y0A02YK0F and Dagu compound infrared sensor are used in UB swarm robot system.

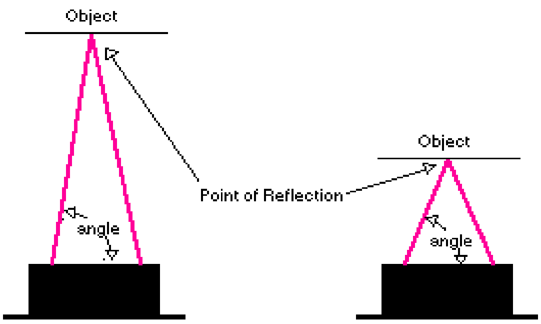

Fig. 2 IR Triangulation Method

B. Encoder

To determine the exact position or location of the robot; odometry is more reliable, very precise technique and inexpensive. Encoder counts the number of pulses for every rotation of the wheel and from that rotation of wheel, distance can be calculated. The encoder has the IR reflective sensors which read the black and white strips on the encoder wheel. The encoder wheel is attached to the shaft and the sensor unit is mounted on the chassis. When the shaft starts rotating, the encoder wheel also rotates and the sensor board starts counting the revolutions [9]. The encoder shown in fig. 3 is mounted on the chassis with micro metal gear motor. This encoder has two IR reflective sensors with a phase difference of 90 degrees and the lead – lag of the waveform will decide the forward and reverse rotation of the wheel. This encoder works on 3.3 – 5 VDC voltage and the pulse output is 48 pulses per revolution.

Fig. 3 DFRobot Encoder

C. GPS/GPRS/GSM Module

Solving a task which is beyond the capability of the single robot, requires cooperation from the other swarm robots. For such a cooperative task, robots must communicate with each other and know their relative position and orientation [10]. To achieve the heterogeneity of swarm system, one of the robot uses the GPS/GPRS/GSM module shield, while other robots use encoders, vision navigation to send its relative position to the other robots as well as to the host computer. This shield with a Quad-band GSM/GPRS engine works on frequencies EGSM 900MHz/DCS 1800MHz and GSM850 MHz/PCS 1900MHz. It also supports GPS technology for satellite navigation.

D. Camera

The camera module provides vision based localization and obstacle avoidance in the swarm system. We use Blackfin Camera with Radio/Motor Board on our robot swarm. This camera can transmit the live feed to the host computer over wireless communication. In differentiating between the obstacle and goal objects, IR sensor and ultrasonic sensor have some limitations, which can be rectified by using the camera module. We can view the images on the host computer or we can also feed them to the microcontroller with the onboard image processing unit. This camera is mounted on the SRV1 platform and DF robot rover platform.

E. Humidity and Teperature Sensor

We are using fully calibrated digital SHT1 humidity and temperature sensor mounted on small PCB, integrated with signal processing unit. The sensor uses CMOS technology which guarantees excellent reliability and long term stability. The two wire serial interface and internal voltage regulation provides easy and fast integration with any microcontroller. This sensor consumes very low power and can be triggered only when needed.

IV. LOCOMOTION AND MANIPULATION

The biggest challenges in developing the robot swarm is to make them mobile, fully autonomous and versatile so that they can move from one place to another over different types of terrains in an unknown environment. The locomotion of robot can be achieved by the motors with some gear ratio to slow down the speed of rotation and increase the torque. In manipulation, objects are moved from one place to another with the help of actuators and we also use the motors to rotate the wrist or open and close the gripper to grab the objects. In our previous work [3], the locomotion and manipulation of different robot platforms is explained in detail. In this section, we explain the type of motors used and their connection and control mechanism with microcontroller. The robot swarm uses track and wheel for locomotion and for manipulation uses robot arm which are driven by the DC motors, Geared DC motors, and Servo Motors. These motors need motor controller to control their speed of rotation and the direction. The number of rotations can be measured by the encoder to determine the exact position of the robots using odometry.

A. Motors

The drive motor is selected based on the voltage, RPM, brushed or brushless parameters. The UB swarm robots are driven by motors which are attached to the wheel. On each robot, two motor are attached to the wheels along with encoder modules. We are using DC gear motors; Solarbotics gear motors, Micro-metal gear motors, Tamiya gearbox motors. These motors are actuated and controlled using the motor controllers. The specification of motors use on UB swarm robots is given in Table III.

TABLE II SPECIFICATION OF MOTORS

Tamiya Twin-Motor	**Micro Metal Gear Motor**	**Solarbotics GM9 Gear Motor**	**Hitec HS-422 Servo Motor**
Gear ratios: 58:1	Gear ratio: 50:1	Gear ratio: 143:1	Speed: 0.16 sec/60o
Motor RPM: 12300	Motor RPM: 13000	Motor RPM: 78	Control Signal: Pulse Width Control
Voltage: 1.5-3VDC	Voltage: 6VDC	Voltage: 3-6 VDC	Voltage: 4-6 VDC

B. *Motor Controller*

We use the motor controller to drive the wheel motors in addition to the microcontroller. The fig. 4 shows the Pololu low voltage dual motor controller which is mounted on Rover 5 to control the speed and direction of the wheel motors. This low voltage dual motor controller is specially designed for the motors which require low voltage, high current to drive. The left side motor's positive terminal (Black wire) is connected to M0+ and negative terminal (Red wire) is connected to the M0- of the motor controller. The right side motor's positive terminal is connected to the M1+ and negative terminal connected to the M1- on the motor controller. The Vcc terminal of motor controller is connected to the 5 V on microcontroller. The GND of the battery, motor controller and microcontroller are connected to each other. The SER pin of the motor controller is connected to the Pin 1 – Tx pin of the microcontroller and RST on motor controller is connected to the RST pin on microcontroller. The complete wiring diagram for the motor controller and microcontroller of Rover 5 is shown in fig. 4.

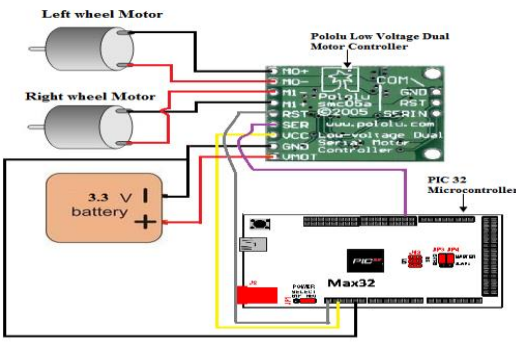

Fig. 4 Motor Controller Wiring

C. *Small Manipulator Arm with Gripper*

To add more flexibility and modularity to the robot swarms, small manipulator arms with gripper are attached on the chassis. These arms are with 2 or 3 Degree of Freedom (DOF) and were built in the UB RISC lab, using the off the shelf materials such as aluminum plates, plastic materials, nut, screws etc. In theory, advanced modularity and versatility is easy to explain, but at the hardware level it's really difficult to achieve and implement. The fig. 5 shows images of the small arm with gripper mounted on robot rovers and actuated using Hitec HS-422 Servo Motors. The gripper can grip and can rotate to grab objects or for connecting with other robots in the swarm. The jaws of the gripper can be open up to 1.3" and the wrist rotates 180 degrees approximately.

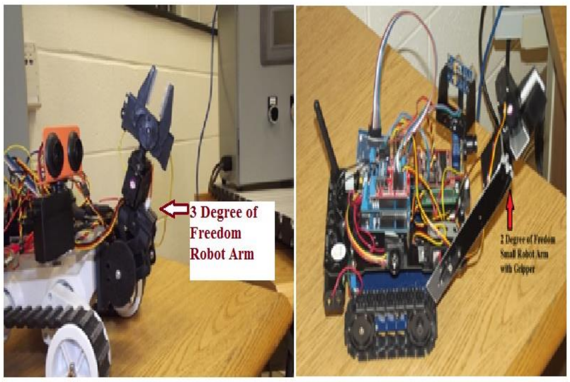

Fig. 5 Small Robot Arm with Gripper

V. COMMUNICATION AND CONTROL

A. *Communication*

One of the most important factors for more efficient cooperative robots is the communication among them and their environment [11]. Deploying a team of robot swarms to perform the specific task such as mapping, surveillance, pulling, rescuing etc requires continuous communication between the robot swarms. In our previous survey papers [3, 12], we have described all the methods of communication between the robots. Communication works in different ways and it depends on the factors such as communication range, environment, size of the swarm system, type of information to be sent/received etc. In [13], the comparison between two well known communication types – implicit and explicit has been made. The proposed robot swarm is decentralized in nature and they can communicate with each other, or/and host computer using a wireless network. Due to the advances in technology and microchip fabrication, electronic devices become more compact, smaller and consumes low power. Now days, there are so many hardware devices present in the market to accomplish the wireless communication for robot swarms. For communication, each robot swarm equipped with X-Bee module or Bluetooth Bee module or PmodWiFi module. X-Bee series 1, Bluetooth Bee and PmodWiFi are compatible to each other and use same protocol for communication. The X-Bee and Bluetooth Bee use the serial transfer mode (Tx and Rx) while the PmodWiFi uses SPI mode for transmitting and receiving the data. Using these modules we have created ad hoc communication network.

The PmodWiFi module uses SPI bus as a primary interface for communicating with PIC-Max32 microcontroller on Rover 1. The SPI bus uses four signals – SS, MOSI, MISO and SCK which corresponds to the signal selection, data in/ out and clock signal. The INT provides information of data availability and data transfer complete or not to the microcontroller respectively.

B. Control

Controlling the robot is a really difficult task, especially for a swarm system. The robots in a multi agent system are controlled using centralized or decentralized methods. The drawbacks of centralized control is explained in our previous paper [12], so we decided to use decentralized control method. If the decentralized technique is applied, the hardware structure of robots should be highly redundant, but exploit simple and more robust control strategies. The brain for the robot is its microcontroller in which the user defined inference rules and knowledge base is stored. The performance of the robot depends on its microcontroller. The primary function of the controller is to route and manipulate the communications between other subsystems on the robot such as sensing platform, actuators, navigation system, and localization system. Robot swarms try to move the robots by sending the control signals to drive the motors. We use PIC32 and Arduino Uno microcontroller for our robot swarm. The programming language used for these controllers is C++ and both controllers are compatible with each other. Most of the components used on this swarm team are bought from [14]. The PIC controller is a very powerful controller, featuring a 32-bit MIPS processor core running at 80 MHz, 512K of flash program memory and 128K of SRAM data memory. In addition, the processor provides a USB 2 OTG controller, 10/100 Ethernet MAC and dual CAN controllers that can be accessed via add-on I/O shields.

Arduino Uno is open source hardware platform, which adds flexibility in our robot swarms. This board based on the ATmega328, has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. Ultrasonic sensors as well as sharp IR sensor are connected to the analog input pins, encoders connected to the digital input pins of the controller. This board can be powered by USB port or by 3- 6VDC an external power supply. Pin 0 and Pin 1 are used for TTL serial data receiver (Rx) and data transmitter (Tx).

C. Power Supply

To keep the robot swarm running, we need to provide relatively long lasting power to them. We have chosen rechargeable Nickel Metal Hydride (NiMH) and Lithium Polymer batteries as a power supply for our robot swarms. These batteries are small in size, lighter in weight and easy to install on the chassis.

Nickel Metal Hydride battery has a high electrolyte conductivity rate which allows for high power applications, and is cheaper than Li-Ion batteries, with high shelf life but self-discharge rate is higher than other batteries. On the other hand Lithium polymer batteries are another form of rechargeable batteries (LiPo) composed of several identical cells in parallel addition which increases discharge current. These batteries are expensive, slim, lighter in weight, and have stable overcharge.

VI. Power Distribution and Management

In the swarm robotics, the cooperation among the individual autonomous robots depends on several design parameters such as communication, and management of resources. The overall power consumption can be calculated by adding the current consumed by each sensor, actuators, microcontroller and all other electronic components that are mounted on the robots. We also have to consider the other factors that affect the power consumption such as its working environment, type of terrain, elevation, how many times gripper close and pull an object. The operating current or power of each component can be found from the data sheet provided by manufacturer.

We measured the time for which sensors and actuators will be in use or active and multiply this time by their operating current, for example, if the ultrasonic sensor uses 20mA when on, and will be on 80% of the time, you get 0.8 x 20mA = 16mA.

TABLE III Total Power Consumption for Rover 1

Sr. No.	Component	Rating	Operating Time (%)	Current Consumption * No of Components	Total
1	Ultrasonic Sensors (SRF02)	4 mA	70%	2.8 mA * 2	5.6 mA
2	Ultrasonic Sensors (URM V2)	20 mA	100%	20 mA*1	20 mA
3	IR Sensors (Sharp)	33 mA	50%	16.5 mA * 1	16.5 mA
4	Temp and Humidity sensor	4 mA	10%	0.4 mA *1	0.4 mA
5	Servos (HS 422)	120 mA	50%	60 mA * 4	240 mA
6	Wheel Drive Motors	160 mA	100%	160 mA * 1	160 mA
7	Microcontroller (PIC)	90 mA	100%	90 mA * 1	90 mA
8	Encoders	4 mA	100%	4 mA * 2	8 mA
9	Motor Controller	10 mA	100 %	10 mA * 1	10 mA
10	Miscellaneous	100 mA	100 %	100 mA * 1	100 mA
				Total	650.5 mA

On this rover, a 2000mAh Lithium-Polymer battery is used to supply the power, and the total power consumed by this rover is 650.5 mA. So the battery lifetime can be calculated as

Battery Life = Battery Capacity / Total power consumed or required for robot

= 2000mAh/650.5mA

= 3.07 Hrs.

TABLE IV Total Power Consumption for Rover 2

Sr. No.	Component	Rating	Operating Time	Current Consumption * No of Components	Total
1	Ultrasonic Sensors (EZ1)	2 mA	70 %	1.4 mA * 4	5.6 mA
2	IR Sensors (Sharp)	33 mA	50%	16.5 mA * 1	16.5 mA
3	X - Bee	250 mA	80%	200 mA * 1	200 mA
4	Servos (HS 422)	120 mA	50%	60 mA * 2	120 mA
5	Wheel Drive Motors	250 mA	100%	250 mA * 1	250 mA
6	Microcontroller PCB (Arduino V3)	100 mA	100%	100 mA * 1	100 mA
7	Encoders	4 mA	100%	4 mA * 2	8 mA
8	Miscellaneous	150 mA	100%	150 mA * 1	150 mA
9	Ultrasonic Sensor (Seeedstudio)	15 mA	100%	15 mA * 1	15 mA
				Total	815.1 mA

On this rover, a 2200mAh Lithium-Polymer battery is used to supply the power, and the total power consumed by robot = 815.1 mA. So the battery lifetime can be calculated as

Battery Life = Battery Capacity/Total power consumed or required for robot
= 2200mAh/815.1mA
= 2.69 Hrs.

TABLE V Total Power Consumption for Rover 3

Sr. No.	Component	Rating	Operating Time	Current Consumption * No of Components	Total
1	Ultrasonic Sensors(SRF2)	4 mA	70 %	2.8 mA * 2	5.6 mA
2	IR Sensors (Compound)	20 mA	50%	10 mA * 1	10 mA
3	Camera (Blackfin)	145 mA	80%	116 mA * 1	116 mA
4	Servos HS 422	120 mA	50%	60 mA * 3	180 mA
5	Wheel Drive Motors	73.7 mA	100%	73.3 mA * 2	146.6 mA
6	Microcontroller (Uno)	50 mA	100 %	50 mA * 1	50 mA
7	Ultrasonic Sensor (Ping)	20 mA	100%	20 mA * 1	20 mA
8	GPS/GPRS	100 mA	80%	36 mA * 2	72 mA
9	Laser Range Finder	40 mA	90 %	100 mA * 1	70 mA
10	Miscellaneous	100 mA	100%	100 mA * 1	100 mA
				Total	770.2 mA

On this rover, a 2400mAh Lithium-Polymer battery is used to supply the power, and the total power consumed by robot = 770.2 mA. So the battery lifetime can be calculated as

Battery Life = Battery Capacity/Total power consumed or required for robot
= 2400mAh/770.2mA
= 3.11 Hrs.

TABLE VI Total Power Consumption for Rover 4

Sr. No.	Component	Rating	Operating Time	Current Consumption * No of Components	Total
1	Ultrasonic Sensor (MaxSonar)	3.1 mA	80%	2.48 mA * 2	4.96 mA
2	IR Sensors (Sharp)	33 mA	50%	16.5 mA * 1	16.5 mA
3	Camera (Blackfin)	145 mA	80%	116 mA * 1	116 mA
4	Servos (HS 422)	120 mA	70%	84 mA * 1	84 mA
5	Wheel Drive Motors	100 mA	100 %	100 mA * 2	200 mA
6	Microcontroller Uno	50 mA	100 %	50 mA * 1	50 mA
7	Encoder	20 mA	100%	20 mA * 2	40 mA
8	Laser Range Finder	40 mA	90%	36 mA * 2	72 mA
9	X-Bee	250 mA	80%	200 mA * 1	200 mA
10	Miscellaneous	100 mA	100 %	100 mA * 1	100 mA
				Total	883.46 mA

On this rover, a 2000mAh Lithium-Polymer battery is used to supply the power, and the total power consumed by robot = 883.46 mA. So the battery lifetime can be calculated as

Battery Life = Battery Capacity/Total power consumed or required for robot
= 2000mAh/883.46mA
= 2.2 Hrs.

TABLE VII Total Power Consumption for Rover 5

Sr. No.	Component	Rating	Operating Time	Current Consumption * No of Components	Total
1	Ultrasonic Sensors	4 mA	70 %	2.8 mA * 2	5.6 mA
2	IR Sensors (Sharp)	33 mA	50%	16.5 mA * 1	16.5 mA
3	Servos	120 mA	70%	84 mA * 1	84 mA
4	Wheel Drive Motors	100 mA	100 %	100 mA * 2	200 mA
5	Microcontroller Uno	50 mA	100 %	50 mA * 1	50 mA
6	Encoders	20 mA	100%	20 mA * 2	40 mA
7	X-Bee	250 mA	80%	200 mA * 1	200 mA
8	Miscellaneous	100 mA	100%	100 mA * 1	100 mA
				Total	696.1 mA

On this rover, a 2000mAh Lithium-Polymer battery is used to supply the power, and the total power consumed by robot = 696.1 mA. So the battery lifetime can be calculated as

Battery Life = Battery Capacity/Total power consumed or required for robot

= 2000mAh/696.1mA

= 2.87 Hrs.

VII. Experimental Results

We have designed and built five UB swarm robots and performed several experiments to demonstrate the system's feasibility (video clips are available on the Web). The fig. 6, 7, 8, and 9 shows the images of UB robot swarm after implementing and mounting all the sensors and actuators. The hardware architecture of UB robot swarm is reconfigurable and can be reassembled at any time. Also the hardware architecture is very flexible; we can connect any type of sensors without doing any modification to it. This robot swarm was tested for a set of different experiments such as object avoidance, object transportation, human rescue, wall painting and mapping.

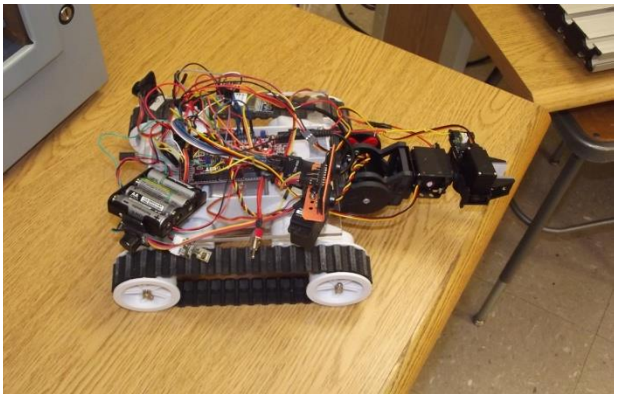

Fig. 6 UB Robot Rover 1

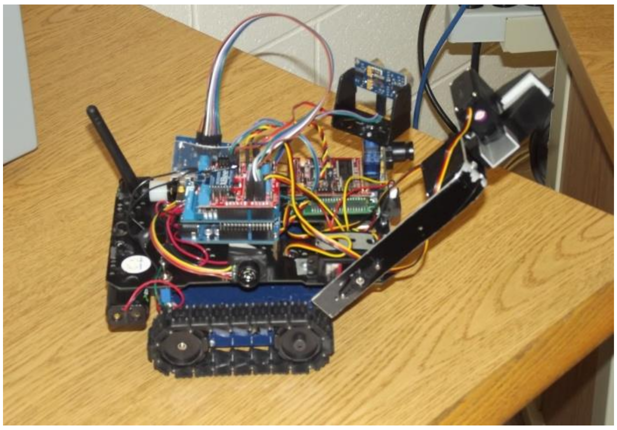

Fig. 7 UB Robot Rover 2

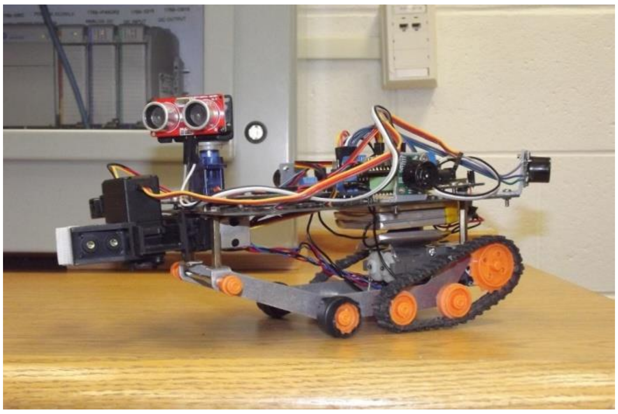

Fig. 8 UB Robot Rover 3

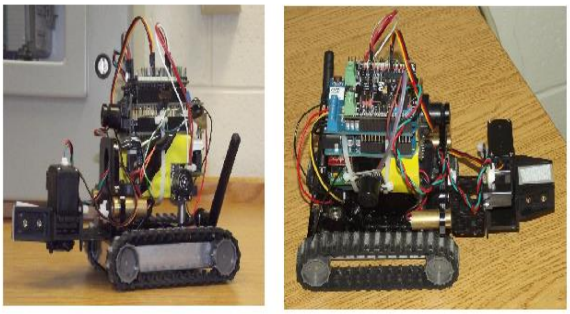

Fig. 9 UB Robot Rover 4 and 5

From the calculated power as shown in tables 3, 4, 5, 6 and 7, each robot consumes between 650 mA to 900 mA, which ensures continuous operation for a minimum of at least three hours. For this experiment, we decided to take three different sets of measurements. The first set of measurement taken while the robot rover is with load and full motion. The full load means, all the sensors, actuators, communication units, and microprocessor are in 100% working mode. So in 100% working mode, the discharged rate of battery will be very fast and robot rover will perform a task for three hours only as shown in figure 10, 11, 12, 13, and 14 with a blue line. In the second set of measurements, the robot rover is in full motion with no load. In this experiment, only drive motors and only one sensor are in on mode while other sensors, actuators were in off mode. The discharged rate of battery is slower than the first case as shown in figure 10, 11, 12, 13, and 14 with a red line. The robot rover performs the task longer than in the first case. To save battery power, we decided to do power management on the robot rover by choosing which sensor and actuator should be on for task completion. So in the algorithm, we control the on and off action of sensors, actuators, and drive motors depending on the task. In this power management method, sensors, actuators, and other components will be on only when needed; otherwise, they will go in sleep mode so that we can save battery power. The experimental measurements were plotted on graph as shown in figure 10, 11, 12, 13, and 14 with a black line. We can see from the graph that robot performs task longer than the first two sets of measurements and the battery discharge rate is very slow.

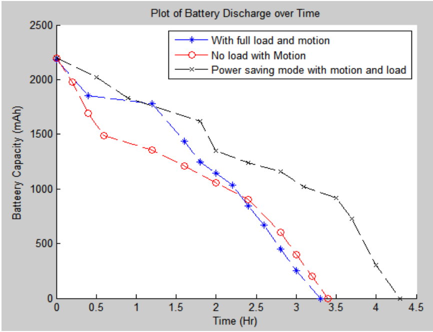

Fig. 10 Battery Capacity Vs Operating Time for Robot 1

For each robot of the UB swarm, current consumption is measured at different time intervals and plotted the graph in Matlab.

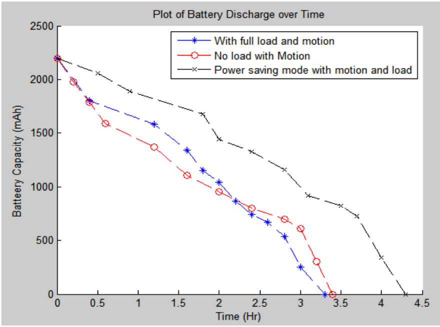

Fig. 11 Battery Capacity Vs Operating Time for Robot 2

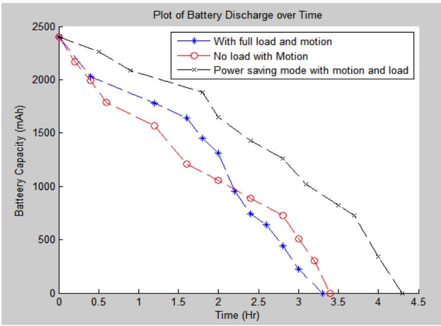

Fig. 12 Battery Capacity Vs Operating Time for Robot 3

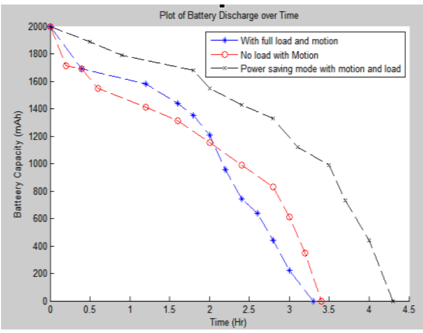

Fig. 13 Battery Capacity Vs Operating Time for Robot 4

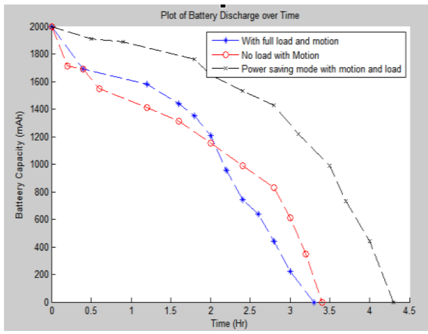

Fig. 14 Battery Capacity Vs Operating Time for Robot 5

The experimental measurement shows that the battery life is extended by 45 to 80 minutes by using power management technique.

VIII. CONCLUSION

UB swarm system consists of five robots which are heterogeneous in sensory units, microcontroller, functionality, and size. The proposed hardware architecture of heterogeneous robot swarm is designed, built and tested. We describe all the hardware components used to build UB robot swarm. The power consumption and management for UB swarm with fault detection is also addressed in this work. We also present the results obtained from this work. The UB Swarm system uses both centralized and decentralized control strategies within the swarm. The robot-to-robot and robot-to-environment interaction provides the task oriented, simple collective swarm behavior.

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