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SWARM ROBOTICS FUNDAMENTALS AND APPLICATIONS

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***Abstract*— In nature it is observed that many insects like bees and ants work in unison .Efficiency of these swarms has been observed to be higher than any individual. Inspired from them, the concept of swarm robotics is presently being researched. This paper aims to explain the basics of swarm robotics and a comparative study of the three fundamental swarm projects. This paper can emerge as a stepping stone for the further developments in the fields of Swarm Robotics. The main aim of this paper 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.**

Keywords— Agent, Jasmine, Kilobots, Colias.

I. INTRODUCTION OF SWARM SYSTEMS

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.[8]

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.

II. 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 trade offs 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.

III. SELECTION CRITERIA FOR THE 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 chose the projects.

1. Simplicity of hardware
2. Simplicity of software platforms
3. Generalized application domain

The main aim of this paper 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.

Let us elaborate the selection criteria of the projects.

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 criteria. 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 protocols.

TABLE I: SELECTION CRITERIA

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

IV. OVERVIEW OF PROJECTS

A. *Kilobot*

Kilobot[3] 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 behaviour of robots. It is a best platform to study AI algorithms on hardware platform. Collective Behaviour: Collective behaviour is an action which is a result of forces due to environmental conditions. It is a result due to spontaneous acts and is not decided in advance. Collective Behaviour is a branch of Artificial Intelligence which has not been explored yet. According to it, if a group of robots with only basic algorithms to do tasks are told to accomplish a task collectively, then the results vary every time. These changes are result of collective behaviour.

Fig. 1. Kilobot (K-Team.org)

Design:

Kilobots are designed in a very optimized and efficient way. The main advantage is its reduced size as compared to current projects. Though the Kilobots are low-cost, they maintain abilities similar to other collective robots. These abilities include differential drive locomotion, on-board computation power, neighbour-to-neighbour communication, neighbour-to neighbour distance sensing, and ambient light sensing.[7] Additionally they are designed to operate such that no robot requires any individual attention by a human operator. This makes controlling a group of Kilobots easy, whether there are 10 or 1000 in the group. [manual]

a) Battery :
Rechargeable Li-Ion 3.7V, for 3 months autonomy in

sleep mode. Each Kilobot has a built-in charger circuit, which charges the onboard battery when +6 volts is applied to any of the legs, and GND is applied to the charging tab. [7]

b) Communication :
Kilobots can communicate with neighbours up to 7 cm away by reflecting infrared (IR) light off the ground surface. However, as compared with other projects, the number of IRs are significantly low. The projects like Colias and Jasmine use more than 3 IR pairs, Kilobots use only one. This can be explained on the basis that Kilobots work in more longer swarm of up to 1000 robots as compared to others.[7]

c) Movement:
Each Kilobot has 2 vibration motors, which are controllable, allowing for differential drive of the robot.[7] Each motor can be set to 255 different power levels. When a motor is turned on, it rotates the robot at an angle of 45'.[5] When both the motors are on, the robot moves at a speed of 1cm/s

d) Micro-controller:
The Kilobot project uses Atmega 328 as its brain. This is very user friendly in terms of software development stages. It uses WinAVR compiler along with eclipse. For software development specially designed Kilobotics software is used.

B. *Jasmine*

1. INTRODUCTION

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. Its size fits in a 3 x 3 x 3 cm cube. It is designed specifically, so that it can be easily reproduced at home.[1]

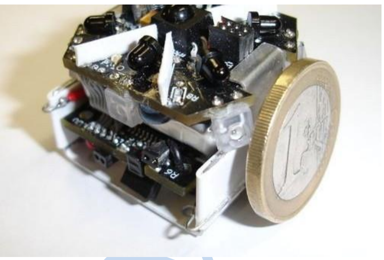

Fig. 3. Jasmin Robot. (swarmrobot.org)

2. *GENERAL DESIGN*

General design of the robot is such that it is divided into 3 levels. I.e. the upper main control board and the lower motor control board and the most top most level consisting of IR transmitters and receivers. 6 IR TX and RX pairs are placed at the top of the PCB at 60 deg separation to complete a 360 deg around the robot.[1] This "Sandwich design "philosophy extends to extension and distribution of control in micro-controllers into 2 different categories namely the main board and the motor control board.

a. Odometrical System

It's an encoder –less design, where optical reflection as pulses is used in calculation the position of the robot relative to its starting position .To implement this, the authors have used 2 micro-controller architecture Atmega 168 and Atmega 644. Atmega 644 is motor control board as Atmega is used for basic data abstraction from the reflective IR Led and Receivers. Pulses are received from the IR receivers which are then converted to relative odometry data which is passed on to Atmega 168 to be further processed into algorithms.

b. Power and Power Management Board

The robots are powered by a Li – Po battery of 3.7 V of 550 mAh capacity .Main consumers of power are the two motors and IR transmitters. Lithium – Polymer is selected for its high energy density, high output current supplying capability and small size. As Jasmine is micro-robot is small battery with high energy density is preferred.

3. *SPECIAL FEATURES : -*

a) Docking station for auto recharging

The robots have a charge monitoring IC device, it monitors the battery charge levels, Total current consumption of the circuit .When the voltage and current reach a certain level, a CHRG signal is set to high indicating depleting charge. That is when the robot navigates to the power-rail to charge itself.

b) Colour Sensor

Colour sensor was mounted sideways for efficient use of space. Colour sensor is used for basic mapping of the environment. Specific colour values can be coded to be notified as a danger area. The robot can be programmed to turn around and flee the area etc .

C. *Colias [6]*

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, neighbouring 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. The robot has two boards which perform different functions. The upper board is for high-level tasks, such as inter-robot communication; however, the lower board is designed for low-level functions such as power management and motion control.[5]

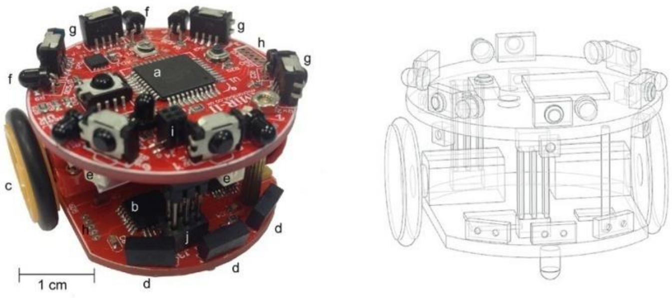

Fig. 2. Colias Robot [5]

1. Controller

It has two ATMEL AVR micro-controllers in parallel. micro-controller1 is a Atmega-168,and micro-controller2 is a Atmega-644. With serial communication, the robot has three different links, namely, RS-2321, I2C2 and the SPI3. In general, all three serial links (buses) can be used to establish a connection between the processors. Moreover, these links are used to communicate with the external modules, such as the camera, the external memory and the robot-PC link.

2. Motion

Two mini DC motors ,two wheels with a diameter of 2.2 cm actuate Colias with a maximum speed of 35 cm/s. The rotational speed for each motor is controlled individually using a pulse-width modulation (PWM) technique

3. Sensory system

The Colias uses IR proximity sensors, light sensor .Two different types of IR module, namely, short-range sensors (bump sensors, see Figure 1d) and long-range sensors(proximity sensors, see Figure 1 e and f). A combination of three short-range sensors and an independent processor grants the capacity for an individual process for obstacle detection which works in parallel with the rest of the system.

4. Inter-robot Communication

Infrared is a suitable choice as an inter-robot communication medium for robotic swarm applications compared with other wireless communication techniques, such as radio frequency. The advantages of using IR in swarm applications include position estimation, neighboring robot recognition and direct communication, and they can be utilized for obstacle avoidance [5].Colias translates its IR receivers' values to estimate the distance and bearing of neighboring robots. The distance of a neighbor can be simply judged by the amplitude of the received IR.

TABLE NO 2: COMPARISON OF FUNDAMENTAL PROJECTS

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

CONCLUSION

The paper thus classifies on the various projects of Swarm Robotics based on the fundamental criteria. It further elaborates on 3 Swarm Projects: Kilobots, Jasmine, Colias. On comparing them, it is found that all the Swarms prefer a communication using IR sensors. Also, simple hardware design along with intelligent algorithms has been a challenge. All the further projects on Swarm Robotics can explore in depth based on the conclusions found in this paper. Thus this paper can prove to be a stepping stone for the high end research work. The kilobots have proved to be efficient only when present in high number.[3] Colias uses the intelligent algorithm of honeybee aggregation[5], Jasmine is a comparatively costly swarm but gives an advantage in automatic battery docking system.[2]

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