Design and Practical Implementation of Multiple Interactive Communication Systems for Multiple Robots

T.C.Manjunath*, G.V.Jayaramaiah**, D.S.S.Sudhakar[#], Dr. R.Sesha Iyer[# #],
Mrs. Ruchira Jadhav[1], S.Janardhanan*
* Research Scholars, Interdisciplinary Programme in Systems & Control Engineering,
Indian Institute of Technology Bombay, Powai, Mumbai-400076, Maharashtra, India
** Senior Lecturer, Dr. Ambedkar Institute of Technology, Bangalore-46, Karnataka, India.
[#] Assistant Professor, Production Engg. Dept., Fr. C.R.C.E., Bandra (W), Mumbai-50, India.
[1] Assistant Professor, Elex. & Telecomn. Engg. Dept., K.J.Somaiah College of Engg., Mumbai-70.
[# #] Principal, Fr. Conceicao Rodrigues College of Engineering, Bandra (W), Mumbai-50, India.
Emails : tcmanju@sc.iitb.ac.in , dsssudhakar@yahoo.com , jramgv@yahoo.com

Abstract

Inter-robot communication can be an issue, especially, if the task at hand entails carrying equipments or in the places where human safety is of great concern such as in nuclear zones, mines, etc.,. In the present work considered, it has been concentrated on designing of a interactive robot communication system between four small indigenously designed robots, using a new type of technique called as the centralized and decentralized design, which can be used for the efficient completion of the task. Different communication systems, for both types of coordination depending on the distance of communication, are designed and proposed. For the centralized system, Frequency Division Multiplexing (FDM) is used and for the decentralized system, a new transceiver is being designed for better wireless communications is used. The inter-robot communication system was being taken up as a consultation project by the institute.

Keywords : Mobile robots, Centralized control, Decentralized control, Transmitter, Receiver, Phase Lock Loop, Modulation, Demodulation.

1. Introduction

The use of mobile robots is desirable in the environment where the human intervention is impractical, for example, in the nuclear plants, underwater exploration, space explorations, etc.,. They also make the task at hand, simple, because human beings are left only with the task of controlling the system, while the actual work of running the system is being done by the machines. Also, some boring and tedious work which a normal labor does with a low efficiency can be done more efficiently and also without human intervention from a remote place. Extensive research was done in this field since two years in the institute on a four small mobile robotic systems indigenously developed in the institute as a consultation project.

But as we know, if two heads are better than one, then four arms are probably more useful than two. In a similar fashion, multi-robot system (also known as multiple robot system) can be a great boon for any complex system. Actually, networked robots can accomplish more than they could individually do by coordinating their actions and by sharing sensors and computing power. During the last few decades, major research efforts were focused on improving the performance of many mobile robots by using advanced sensors, actuators and intelligent control algorithms. But very few people have ventured into this field mainly due to the absence of a proper communication system for inter robot communication.

The coordinated operation of several robots is a challengeable control problem and is of higher practical interest where relatively little works has been done so far. As the number of mobile robots in a robotic work cell increases, planning and control of the system becomes increasingly complex. [1].

The paper is organized as follows. Section 2 presents a brief introduction to the interactive communication systems. In section 3, the decentralized communication is dealt with. Section 4 discusses about the learning algorithm for the mobile robots. The centralized communication system for the mobots is presented in section 5. Finally the results are concluded in section 6.

2. Communication Systems

Practically, it is very difficult to develop a fool proof communication scheme for a multi-robot system, as it should have some key features listed below.

- A proper channel for inter-robot communication between robots that will make their cooperation feasible.

- We will require a protocol defined commonly for all the four machines so that each team member can share their experiences.
- Also, a good communication media is a must criterion, which depends on several factors like total members, environmental noise, range of operation, etc.,.
- Each robot should have the capability to avoid collision with other robots or objects in its path. This feature is of special importance if the robots are required to work closely on a specific mission.
- The robots should work in a team thus demonstrating the "Flocking" enabling each robot to make some contribution to the task at the hand.
- Every robot should be able to learn from other robots in a manner that occurs in human society.
- Such a feature, if incorporated, will increase the learning speed as compared to the individual learning.

In the present work considered, the coordination between multiple robots is achieved in two ways. Viz., centralized and decentralized systems.

3. Decentralized system

A decentralized control method used in the present work is to equip each of the four mobile robots with a map building, planning and decision-making capability. In any unforeseen situation, the robot is able to plan a new path or find a solution without waiting for the commands from the control nerve center. The function of the control center is only limited to the broadcasting of the traffic flow information received from all the robots and the allocation of tasks in the system. Inter-robot communication becomes unnecessary since the competition for resources should be avoided and the sharing experience could improve the system performance.

In the proposed and designed decentralized control system, the coordination of multiple mobile robots is needed to achieve cooperation behavior. This paper is focused on the cooperative behavior demonstrated by multiple mobile robots, especially in the case of no global information about the robot environment. The key to achieve such cooperative behavior is the development of inter-robot communication mechanism, which is discussed in the following sections.

3.1 Individual Robots

The four robots, which are of same design, are equipped with a indigenously designed communication system for detecting obstacles. The environment perception in a multi-sensory approach is the most efficient way to provide the robot with adequate information it needs about its environment. The obstacle detection system consists of three pairs of ultrasonic sonar transducers in which one pair is looking forward, one pair is looking to the front-left and the other pair is looking to the front-right. This sonar system measures the range to the nearest obstacle in the front of the robot.

To detect the obstacles closely, echoes have to be detected whilst the ultrasonic pulse is still being transmitted, thus requiring a high detection threshold. For the detection of objects far away, a much lower threshold is required to allow for the large signal loss. Thus, in order to detect both the near and the distant obstacles, a time varying threshold system is used. The threshold in initially large, but decreases with time to a preset minimum. A time-out system is used to determine if there are objects within the range. Two back wheels are differentially driven by two small D.C. Servomotors with a chain of gear reduction units. A single castor wheel supports the front of each robot. The motor control is a closed loop operation with a pulse width modulation PWM, providing several different speeds (upto 1 m / s) and directional control.

3.2 Inter-robot communication

Communication behavior is the key design issue in coordination of our designed multi robot systems. The communication may take place directly via explicit communication facility such as radio link or indirect (pseudo communication method) through one robot sensing a change in other robots or in its environment.
Communication between cooperative agents can be regarded as either explicit or implicit. Explicit communication is defined as a specific act designed solely to convey information to other robots on the team [4]. Examples of cooperative tasks where this type of communication is used can be found in several papers [1, 2, 3, 4, 5]. On the other hand, implicit communication occurs as a side effect of robot actions, or through the way they change the environment.

Implicit communication offers several immediate advantages over the explicit form. Among them is their simplicity ; robustness to faulty communication environments, lower power consumption and stealth - ness. Communication between several robots is done using wireless LAN [3] or using infrared sensory system [4]. But, such an experiment on large number of robots is not feasible. For wide range robotic communication, a modified cellular system is thus proposed and designed. Communication can also be achieved by using token passing protocols [1]. We have proposed a new indigenous technology and discussed the design in the following section.

The concept behind the designed mobots is to provide a universal short range wireless capability . Using the 2.4 GHz band available globally for unlicensed low power uses, two mobots devices within 10 meters of each other ban share up to 720 kbps of capacity. Mobot communication is a time division multiplexed in one system that operates in the ISM Band (2.402 GHz - 2.48 GHz) and uses a digital frequency modulation method known as 0.5 BT GFSK (Gaussian Frequency Shift Keying) in which the carrier is shifted up by 175 KHz to represent "0" typically at a rate of 1M symbols per second. The 0.5 BT improves RF link's quality and reliability. The hopping rate is up to 1600 hops per second. In GFSK modulation the signal is contained in the constant amplitude envelope. Mobots is thus, a half-duplex TDMA system.

Transceiver Design

The transceiver design consists of the following.

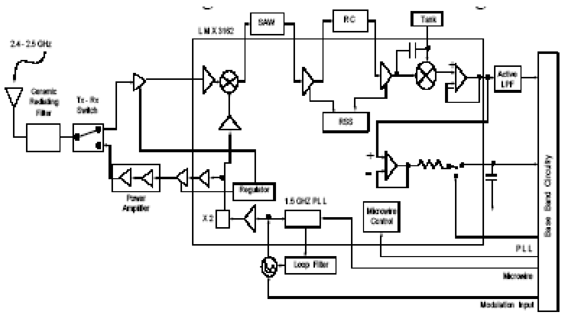


Figure 1 : Transceiver Blocks Synthesizers

LMX3162 [6] contains a PLL Phase Locked Loop IC Chip running at one half of the ISM band and utilizes a frequency doubler to synthesize the desired frequencies. This architecture alleviates the disturbance to the local oscillator (LO) when the power amplifier (PA) is switched on. The radiation is isolated by offsetting the PA Power Amplifier output frequency from the LO frequency.

Lock Time

The function of the PLL is to hop the desired carrier frequency before data transmission and reception. The time taken by PLL to settle down within an acceptable error is called the lock time . The lock time 220 µs for Mobots with 1 blind slot allows certain latency and provides enough time to acquire lock. To improve the performance as well as reduce the cost of implementation, the transceiver transmits and receives data in the open loop mode. The PLL is first locked via software (programming) at the desired carrier frequency and then shut down during the data transmission or reception. In this short duration, the VCO is subsequently modulated by the base band signal in transmit mode or idling in the receive mode. For Mobots, the maximum continuous transmit time is 5 slots, or 3.125 ms. Frequency drift can be avoided without additional circuitry by closing the PLL and receiving data. This may result in degradation of Bit Error Rate (BER) by one or two decibel(s), which is acceptable since LMX3162 gives enough design margins on sensitivity.

Transmitter

In LMX3162 [6], direct VCO modulation scheme is employed as shown in Figure 2(a) . It is simple and low cost solution in comparison to other options, such as direct RF I / Q modulation or close loop I / O modulation. In this section, LMX3162 will be demonstrated to transmit the data with the open loop modulation for the 2.4 GHz ISM band . To transmit a signal, a shaped base band signal is applied to the VCO for assuring efficient bandwidth. The amplitude of the signal from the base band processor needs to be adjusted to obtain the frequency deviation.

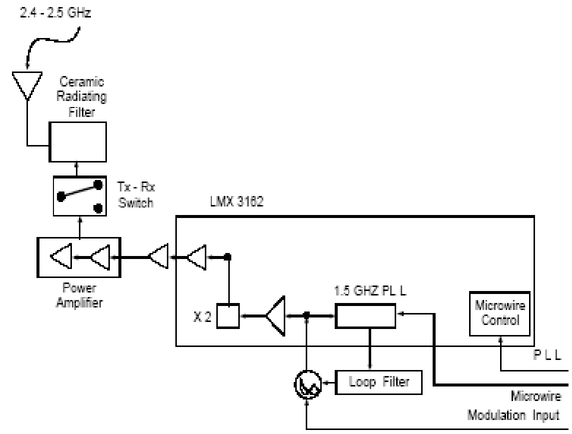


Figure 2 : Transmitter Block

With the correct amplitude of the signal, the VCO output generates the modulated signal and is connected to the input of the frequency doubler inside LMX3162. The 2.4 - GHz signal at the transmit output pin should be filtered in prior feeding to the power amplifier. Otherwise, a phenomenon called spectra regrowth may occur. Mobots signal is thus generated at the transmitter output (BT = 0.5, GFSK and 320 KHz peak-to-peak frequency deviation).

Receiver

LMX3162 [6] adopts the heterodyne receiver architecture as shown in Figure 2(b). The demodulated data can be obtained by two frequency conversions with some channel selection filtering along the receiver path. The antenna will perceive many frequencies in the air. The ISM band signals will first be selected and the image , which is 220 MHz below the signals, will be suppressed through a ceramic band selection filter. The 2.7-V regulated supply can be run from the LMX3162 internally. Once the images are suppressed, the signals can connect to the RF input of the 2.5 - GHz mixer inside LMX3162.

The LO port of the mixer is connected to the frequency doubler internally. Since the IF is 110 MHz, the LO frequency should be 110 MHz below the RF carrier frequency. The mixer has 15-dB gain With 13-dB noise figure, and the OIP # of this Mixer is 7.5-dBm. The system noise from LNA to the RC filters is about 6 dB . The analysis of the receiver is shown in Figure 3. We assume SAW and RC filters are linear and negligible for the non-linearity.

This indicates the linearity of the latter stage (IF amplifier here) is more critical. After the signal is translated to IF , it is possible to do partial channel selection. The IF signals ate limited by the SAW filter via the matching network. This SAW filter 11 is connected at 110 MHz, and has a 3-dB bandwidth of 1.5 MHz . The minimum insertion loss is about 3 dB. The SAW filter provides the selectivity and prevents spurious components to distort the signal in the following stages because of non-linearity.

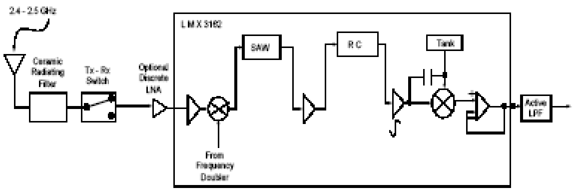
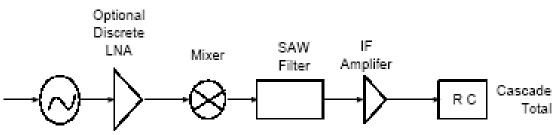


Figure 3 : Receiver Blocks



	Optional Discrete LNA	Mixer	SAW Filter	IF Amplifier	R C	Cascade Total
NF (dB)	3	1.3	3	10	3	5.97
Gain (dB)	10	15	-3	20	-3	39.00
OIP3 (dBm)	10	7.5	100	20	100	15.66
Po1 (dB)	-83	-66	-71	-51	-54	
NF (dB)		2.84	0	0.06	0	
OIP3+ (dB)	0.02	1.31	0	5.75		
Input Power (dbm)	-9.5					

Figure 4 : Receiver Chain Analysis

The IF signal is amplified and further suppressing the unwanted interference by an external RC filter before feeding to the limiter. This is because the limiter has a large DC gain and is inherently non-linear. The post-detection filtering further limits the noise bandwidth and the configuration of quadrature demodulation. MOBOTS transceiver IC can be programmed using processor, thereby reducing the hardware requirements of the system. Another way of designing the mobots is to make use of FDMA or TDMA system. Then, we have to design the transmitter as well as receiver as IC's for them are not available. Such a design will contain more hardware thereby increasing the complexity as well as the cost.

4 Learning Algorithm

There are many different actions to be performed by each of the four robots in the work cell and an algorithm called as the "Learning Algorithm" decides the action. All the data gathered by the robots is fed into a strong database., which is the world model of all the robots (mobots). This database gives the sequence of actions to be performed by individual robots and as per the learning algorithm shown in Figure 4. The learning algorithm decides the probabilities of each action and each robot performs the action with highest probability. Since each robot is having the decision making capability, they all are provided with learning algorithms.

Suppose, one robot is present in front of the other robot under consideration, then the motor should roll in such a way that our robot should avoid collision , i.e., it should roll backwards. Now this decision is an outcome of the learning algorithm. Suppose both of these robots have three controls viz., forward, backward and stop. Then, there are nine different possible output actions (T1,……,T8). Now we can consider some arbitrary conditions in which a robot may find itself:

- No obstacles in surrounding environment.
- Obstacle towards the left at some distance.
- Obstacle towards the right at some distance.

The 8 different motions of our mobots are viz., left motor (LM) and right motor (RM) can be activated in 8 different motions, Our robot is required to learn a mapping from input states to the output actions, which allows it to move freely avoiding all the obstacles in its path of motion. Each of the three input states (Q_1, Q_2, Q_3) has its own fuzzy automaton associated with it. Each automation, which is effectively a set of motor actions (T_1,……,T_8), has a set of probabilities. Taking the associated Figure 4 learning algorithm action (O_1 to O_8). The action with the highest probability is the most likely to be chosen. This method is similar to the techniques used in genetic algorithms [2].

The chosen action is executed for a short period of time and is then evaluated. If the action was successful, its probability of being selected is increased whilst if the action was unsuccessful, its probability of being selected is decreased. In both cases the other probabilities of the chosen automaton are adjusted in order to keep the total probability constant. In the following description, the performance value is 'x' (positive meaning successful and negative meaning unsuccessful), 'n' is the action that was chosen and 'y' represents all the actions, except for n.

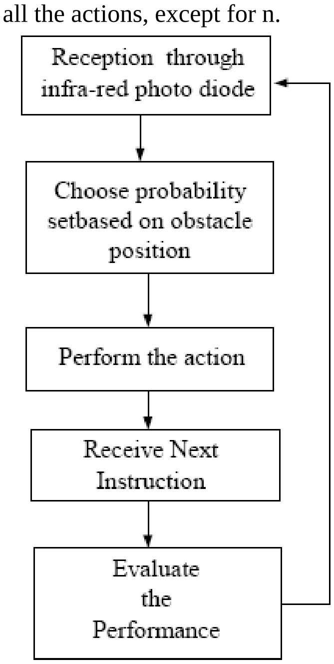


Figure 5 : Learning Algorithm Developed using AI

The rules for adjusting the probabilities are thus :
Pn = pn + x
(increase / decrease probability of chosen action)
Py = py – (x / 8)
(decrease / increase other probabilities)

Left Motor	Right Motor	Nature of operation
Forward	Forward	Forward
Backward	Backward	Backward
Forward	Stop	Forward right
Backward	Stop	Backward right
Stop	Forward	Forward left
Stop	Backward	Backward left
Forward	Backward	Spin clockwise
Backward	Forward	Spin anti-clockwise

Since we are only using a slow processor all of the probabilities are stored as signed 16-bit integers rather than as fractions. In order to evaluate ‘x’, a definition of which actions are good and which actions are bad is required. Rules were chosen which are general and hence would not give the robot any information about which motor actions to select. The basic rules are that if there is no object within range it is good to go forward but if an object is relatively near it is good to get further away from it .

Thus, if the object is in the distance it is still good to go forward but it is also good to get further away from that object. The main adaptive loop of the program is shown in Figure 4. The range returned from the front sonar sensor is used for determining whether the robot has successfully got further away from the obstacle when it is close. At this range, the front sensor can always see an object anywhere towards the front of the robot. The left and right sensors are used when the object is further away as the front sensor is unable to detect objects to the far left and right.

5. Centralized system

We will now consider the application where centralized processor is used. In these systems, a single control center handles planning and decision-making functions. Each mobile robot contains only sensors for localization and obstacle avoidance, actuators for movements and manipulations and communication facility for communicating with the control center.

All the movements of the mobile robots in the system are controlled from this center and conflicts among multiple robots are easily solved. This method has been widely adopted in manufacturing industry and warehouses where multiple mobile robots are used to transfer parts and clean warehouses. Also, there should be an arbiter to decide the mastership of the system . For this, software should be developed for carrying out polling sequence between the robots.

The master should continuously transmit message whether it is functioning properly or not. One of the best applications of the multiple mobile robots is the place where human safety is a major issue. These are the reconnaissance and surveillance activities performed by military and civilian organization. Hostage and survivor rescue missions, elicit drug raids and responses to chemical or toxic waste pills are just some of the operations requiring reconnaissance and surveillance components. For this purpose, a distributed heterogeneous robotic team that is based mainly on a miniature robotic system is developed.

Now, we will concentrate more on this system with all the details of control, communication, processing and sensing modules of the mobile robots and the central processor. The above mentioned operation requires convert action. Hence, we can make most of the robots in the team extremely small so that they can evade detection. The small size also allows them to be easily transported and allows for a greater number to be brought into use for a single operation.

These small robots we have named them as mobots and they act as the roving eyes, ears, noses etc.,. of our system. Mobots must make use of efficient resources (e.g., batteries) in order to survive for a useful period of time. These robots are interlinked with the rangers. The rangers can transport the mobots over distance of few meters and deploy the mobots rapidly over a large area. Rangers also serve to coordinate the behaviors of the multiple mobots as well as to collect and present the data in an organized manner to the people who will ultimately make use of it. In short, rangers the centralized processor, which has got the decision-making capability in order to coordinate the task of mobots and complete the mission.

5.1 Mobots

Mobots are four small toy shaped robots which were developed in order to interface the communication system with them. They are easily deployable and able to move efficiently and traverse obstacles and on uneven terrains. They are able to sense their environment and report their findings to the control center. They are controlled in a coordinated manner. All these requirements are supported by making the mobots of approximate 12 cm. Long and cylindrically shaped with around 4 cm diameters so that the launching it from an appropriate barreled device can deploy it.

Once deployed, it can roll using wheel cone on each end of the cylinder body and jump using sprint foot mechanism. Rolling allows for efficient traversal of relatively smooth surface, while the jumping allows it to operate in uneven terrain and pass over obstacles.

The small mobots are equipped with some electronics components besides this mechanical structures. Mobots contain sensor suits, which may vary with the mobots mission. They are also provided with some combination of CMOS camera, a passive infra-red sensor. They contain transmitters for transmitting video and audio signal and other sensed data and the receiver for receiving commands.

5.2 Video Information and Communication by Mobile Robots

A miniature video camera and wireless video transmitter is built in to provide visual feedback from the mobots. The camera consists of single chip CMOS video sensor and miniature pinhole lens. Unlike the common CCD type video sensors, the CMOS sensor is able to integrate all functionality within a single chip, reducing its size dramatically. Additionally, CMOS sensors typically consume 3 to 5 times less power than a comparable CCD sensor. Micro motors are utilized for the actuation. These brushless DC servomotors are very small in diameter and in length. For other communication with the mobile robots, a new transceiver chip LMX 3162 of national semiconductors, is useful for the range of about 15 meters. But, if the distance between the transmitter and the receiver is more, then we can use frequency division multiplexing system.

To transmit information, a ring of 12 LED's can be used. They must be arranged 30° apart to ensure full 360° coverage. Four photo-diodes has been used in each mobile robot to receive the information. They must be arranged 90° apart. The LED's will be having half power angle of 60° whereas that of photodiode is 120°. This combination of LED's and photodiodes allows communication regardless of the relative orientation of robots.

Information is transmitted by frequency modulating the IR carriers, with the decoding being carried out using the off-the-shelf radio frequency integrated circuits. The transmission from the central processor is received by one of the 4 photo-diodes and is mixed with the selected tuning frequency (heterodyning). A filter is used to obtain the information with the correct carrier frequency.

The received information is demodulated and passes through a low pass filter to give a digital data. The system is frequency division multiplexed, with each robot having its own channel. The message consists of 16 bytes. The first three bytes are message head used for synchronization, then 11 bytes are message body and the last two bytes are a check sum for error verification. Data is received through the transceiver at 1200 baud rate using a differential phase shift keying (DPSK) thus permitting the AFC.

5.3 Rangers

The mobots function is in conjunction with the rangers, which act as utility platforms. Rangers move the team rapidly into place and deploy them [3]. They process the sensor data as needed for mobot behaviors and group behaviors and act as coordinators for the team. Finally, they organize the data streams for presentation to the users. Rangers can carry the mobots in position over distances of up to 5 meters, giving the mobots a much greater effective range than they would have if they needed to transport themselves. Further by mounting a novel launching system on each ranger, mobots are deployed more rapidly and into places where rangers might have difficulty accessing. Rangers also are equipped with significant computing resources that allows for proxy processing of mobots behavior and mission coordination.

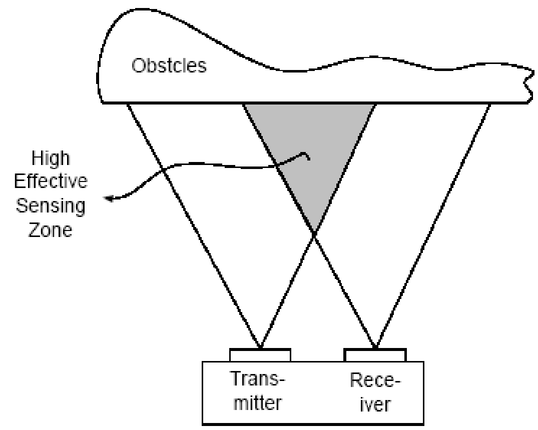


Figure 6 : High Effective Sensing Zone

5.4 Ranger Computer Resources and Software

A ranger is provided with Pentium IV 2 GHz based PC running an operating like LINUX which should an object oriented programming language based modular robotics control architecture. Ranger to ranger data communication is implemented by using a 2.4 GHz frequently hopping wireless LAN system. A proxy processing system has been developed that allows the ranger to control the mobots. The mobots limited computational resources restrict it to handling only the most basic low-level control routines such as pulse width modulation control of the motors. High-level control is achieved through this proxy-processing scheme in which the individual control algorithms that direct the motion of the mobot are run as separate threads on board the ranger's computer. This control is accomplished using a client / server style of architecture where the ranger sends command packets to the mobots using an RF data link.

5.5 Launcher

The launcher system is used to deploy the mobots around the field of operation. The launcher can selectively launch any of the four mobots in its magazine, at a selectable elevation angle and propulsion force up to a range of 5 m. mobots are launched with a compression spring . A stepper motor is used to compress the spring via a rack and pinion setup. The pinion is engaged to the motor when the spring is to be clocked and is disengaged when the mobot is launched. The mechanical energy efficiency is about 50 % due to the weight of the piston and the rack and pinion mechanism.

5.6 Flocking behavior

Flocking is a behavior that is commonly found in nature. Animals sometimes flock for protection from predators. However, flocking presents an interesting problem in the field of robotics, i.e., the robots have to get close to each other but also have to avoid collisions. With many mobile robots in close proximity, their sensors will receive much noise than when they are spread out. Therefore, it poses a challenge, which is a non-trivial task that needs to be solved.

Since a global destination is not practical in a finite environment, some form of leadership is required during flocking. The selection of the leader has to be dynamic such that the flock should be able to split up to go around obstacles, and rejoin once past the obstacle. There is no predefined leader. If one selected leader fails, one of other robots is able to declare its leadership if it is in a good position.

The rule for choosing a leader and the flocking operation of a team of mobile robots are as follows.

a) Avoid obstacle using learning algorithm based on sonar data.
b) Become a leader if it is in good position and no other robots are visible and go around.
c) Try to maintain its position if it is in a flock.
d) Speed up and head towards a flock which can be seen in the distance.
e) Return to step 1 to recursively implements this sequence of actions. Each robot to inform the other robots whether it is a leader or the follower uses the communication system.

6. Conclusion

The interactive communication systems between four miniaturized robotic systems was designed. The actions of mobile robots in a multiple robot system are completely controlled in an autonomous manner and it is a true team decision, mediated by various negotiations, decision strategies using behavior based control software is fairly general. We have also looked at close coordination between multiple mobile robots in a distributed setting. Operating the robots in a distributed setting will add complexities in terms of deciding what to do and how to coordinate behavior.

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