An OFDM Based Solution for Wireless Control of Serpentine Robot Employed in a Mobile Adhoc Network (MANET)

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Abstract: - The world has been suffering from many natural and man caused catastrophic disasters during the last decades, such as large-scale earthquakes and terrorist attacks. In such events, collapsing of houses and buildings in large areas is almost inevitable. The basic idea of designing a biologically inspired robot is to study its natural behavior with an equivalent robotic model to be employed further in some specific job like disaster management. This work has been executed for controlling a series of snake robots involved in a hazardous environment like coal mines. The controller designed with DSP processor for high sped processing (225MHz) and sharp edge filtering facilities are programmed to execute a set of files to exhibit lateral undulation, rectilinear motion, concertina movement etc. The novelty of this work is on controlling all the snake agents within the network via a wireless link from a remote station building a map of the unknown environment from the transmitted data in a secured way. Problems due to inter-symbol interference (ISI), multipath fading and limitation of ISM band have also been considered.

Key-Words: - biologically inspired robot, snake robot, OFDM, MANET

1 Introduction

As per the basic advantage of the snake robot or any biologically inspired robot over any automated guided vehicle (AGV), the snake robot can execute multiple numbers of motions with its special structural design to handle any unknown hazardous situation thus perfectly suitable for disaster management. Our main target in developing a serpentine robot under SUPRA Institutional Project (SIP-24) funded by Council of Scientific and Industrial Research, Govt. of India , is to study the dynamic analysis of snake robot with its main four movements [1], controller design with high end processors [2],[3] to achieve all of the four movements and guiding its navigation and data transmission from the robot with wireless communication while working in a coal mines to execute rescue operation[4],[5].

In the earlier days engagement of human workers or trained dogs in searching victims and subsequent rescue operations from the rubble of collapsed buildings was a major problem to be faced in disaster management. Motivated researchers have set up very innovative paradigm in this field to give a number of practical and useful search-and- rescue robotic systems [6]. In an effort to relieve the burden of time-consuming activities and difficulties in trajectory planning of AGVs for unknown environment a versatile robot is required. The pioneering work in developing biologically inspired robots was carried out by S. Hirose [7] in 1972. Since then a variety of different snake robots have been designed [8], [9], [10], [11], and [12], some of which are currently used for the inspection of pipes [13], for example. A review of snake robots can be found in [14] and [15]. Most of these robots have been designed for locomotion on ground, and only a few working examples of swimming snake robots currently exist. The most interesting ones are the eel robot REEL II [16], the lamprey robot built at Northeastern University [11] and the spirochete-like HELIX-I [17]. Another work also carried away in [18], to build an amphibious snake-like robot that can both crawl and swim for outdoor robotics tasks, taking inspiration from snakes and elongate fishes such as lampreys, and to demonstrate the use of central pattern generators (CPGs) as a powerful method for online trajectory generation for crawling and swimming in a real robot. AmphiBot II, presented in [19], is the new version of AmphiBot I [20], [21], with comparison to its predecessor, features a significant number of improvements, like: A better mechanical design, more powerful motors, wireless communication capabilities, onboard CPG running on a microcontroller, therefore removing the need of running the controller on an external computer The research will continue in all the directions to explore the maximal use of snake-like robots.

This paper delivers an overview on the design and development of a free moving wheeled snake-like robot prototype having a provision of wireless control for human–robot interface. Design of this snake robot is done considering a four segmented robot i.e. two sets of three inter-segment joints one for horizontal motion and one for vertical motion each with two degrees of freedom so that the robot can execute all its four movements as per requirements. Section II gives an overview on the dynamic analysis of the serpentine robot. In this portion of the paper the backbone curve of the snake robot with three joints has been described. Section III illustrates the details of controller designed for DC motors with wheels connected to each segment of the snake robot. Later in section IV, the wireless control technique using OFDM has been discussed that improves the efficiency of the snake robot in terms of multipath fading [22] and Mobile Adhoc Network (MANET) [23] while employed in an area like coal mines. Finally, in section V relevant results infers the usefulness of OFDM in MANET with snake robot followed by section VI concludes with some provisions of relevant applications of OFDM to justify the involvement of snake robot in disaster management.

2 Backbone Curve for Snake Like locomotion:

To illustrate the dynamics of serial linked robot (SLR) we can refer to its most popular example i.e. serpentine robot for the ACM curve. In serpentine robot there is a sinusoidal movement along an axis which is the direction of propagation. Fig. 1-(a) and (b) shows a serpentine movement in two dimensional axes and its relevant ACM curve, respectively. The ACM executes its winding movements by means of actuators positioned along its body. The ACM has an arbitrary configuration on a plane, and if it performs two-dimensional movements there, these can be expressed by the kinematic relationships expressed through equation 1 to 8.

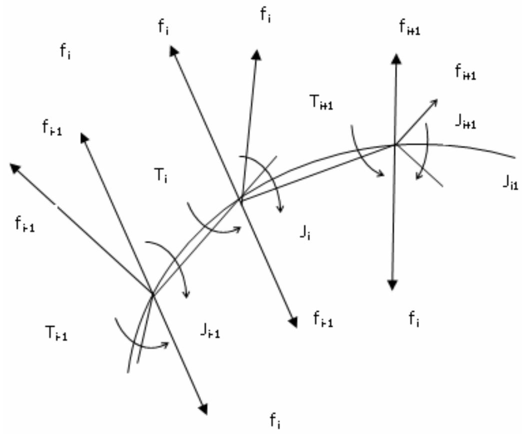


Fig 1: ACM curve for Serpentine Motion

When the actuator positioned at an arbitrary joint J_i gives rise to joint torque Ti, a force defined as,

$$f_i \triangleq \frac{T_i}{\delta s} \tag{1}$$

is produced at joint Ji and joints Ji-1 , Ji+1 or either side of it.

The tangential force density function ft(s), integrated over the whole body of the ACM (length L), is no longer than the propulsive force of the tangential force of the ACM. Consequently, if we call this the tangential force (propulsive force) and denote it Ft, we can express it as follows:

$$F_t=\int_0^L \frac{d\,T(s)}{ds}\,\rho(s)\,ds \tag{2}$$

Where, $\rho_i = \frac{\theta_i}{\delta s}$, as δs is supposed to be infinitesimal.

When we consider the ACM's locomotive movement normal force is the force which resists external force and the total of the absolute values of the normal force over the body provides an indication of the efficiency of the ACM's locomotive movement. Accordingly, we will define this as normal force 'Fn', and express it as follows:

$$F_n=\int_0^L \left| \frac{d^2 T(s)}{ds^2} \right| ds \tag{3}$$

Because of the limits to the power which the actuators positioned on the ACM's body can generate there are many cases when its posture and speed of movements are restricted. For this reason, in this section power can be formulated for a moving body with speed 'v' along body axis's'.

$$P_i = T_i \frac{d\Theta_i}{dt}$$

Or,

$$P(s)=T(s)\frac{d\,\rho(s)}{ds}v \tag{4}$$

Through equation (4) we express the torque distribution and curvature distribution by the continuous functions T(s), ρ(s) and the power density function is known as Pi/ δs.

During locomotion it is necessary that this value P(s) be below the maximum upper limit normally determined by the performance of the actuators.

On the basis that the hypothesis that the antagonistic muscle alternately repeat contracting and relaxing movements of uniform speed when the snake is gliding steadily, we can use the standard form of Fresnel's integrals and get the following expression for serpenoid curve:

$$x(s) = s\,J_0(\alpha) + \frac{4l}{\pi}\sum_{m=1}^{\infty} J_{2m}(\alpha)\left(\sin\ \frac{m\pi s}{l}\right) \tag{5}$$

$$y(s) = \frac{4I}{\pi}\sum_{m=1}^{\infty}\frac{(-1)^{m-1} J_{2m}(\alpha)}{2m-1}\left(\sin\frac{(2m-1)\pi s}{l}\right) \tag{6}$$

Where, Jn (α) is the Bessel function and is expressed as,

$$J_n(\alpha) = \left(\frac{\alpha}{2}\right)^n \sum_{m=0}^{\infty}\frac{(-1)^m}{m!\,\Gamma(n+m+1)}\left(\left(\frac{\alpha}{2}\right)^{2m}\right) \tag{7}$$

3 Controller Design for Multi segmented Robot:

In an m-segment SLR, there are m-1 joints that are controlled to follow a perfect ACM curve. Each joint is supplied with a signal that needs to be controlled to achieve an overall serpentine movement. Here the main task is to design a DC motor controller for individual method, such as, Bode plot and Root Locus approach to compare the system transfer function $h_m(n)$ for the similar system in different method.Fig-3 shows the stages of designing a DSP based controller in CCS v 3.1 platform followed by the DC motor specification (Table-2) used in developing the joints of the SLR. Fig-4 and 5 reflect the results of transient response and impulse response of the system obtained in TMS320C6713 platform.

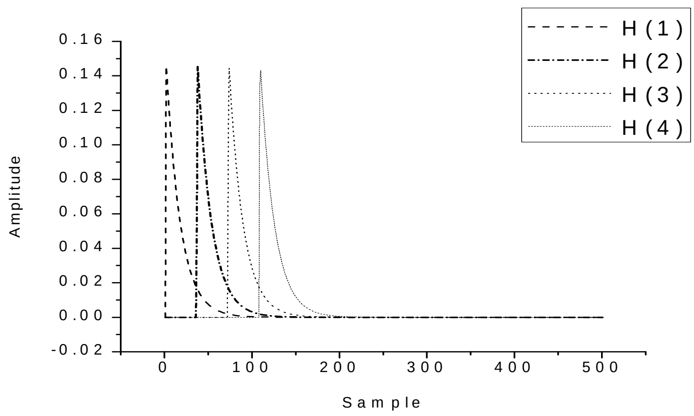
The flow chart shown below in Fig-3 states the design procedure of DC motor controller for any SLR. The main advantage of SLR is that the total process of controller design for individual segment is repetitive in nature though the transfer function $h_m(n)$ of each controller has different impulse response shown in Fig-4 and 5. While we go for design of a controller we need to have some input regarding its gain margin (GM), phase margin (PM), maximum peak(M_p) ,rise time (t_r), settling time(t_s), etc. Hence we can calculate the damping ratio and undammed natural frequency to find the zeros and poles of the stable control system. The data(i). m file generated throughout the whole process contains the definition of each controller as I varies from 1 to m. Each .m file generated in this process may consist n (here, =200) number of floating point values depending on the sampling rate(92 KSa/s) and operating frequency (225 MHz) of the DSP processor.

In our case, 1.2 watt DC motor from MAXON Motor has been used which is smaller in size and suitable for our desired SLR. Table-2 shows detailed specification of this motor.

Table-2 Technical Specification of Maxon RE-max DC motor (model No.-203889), 1.2 watt

Parameter	Value
Armature Inductance*(La)*	0.223 mH
Armature Resistance *(Ra)*	11 ohm
Rotor Inertia*(Jm)*	0.306 gcm^2
Torque Constant*(Ki)*	5.08 mNm/A
No load Speed	11100 rpm
No load Current	10.4 mA
Speed/Torque Gradient	4050 rpm/mNm

3.1 Graphical Method Approach or Root-Locus Approach



. **Fig 2:** Impulse Response of Controller Designed with Root Locus Method

3.1 Frequency Response Approach or Bode Plot Approach:

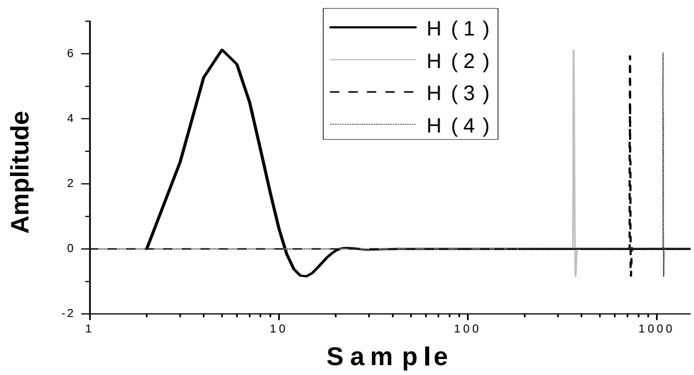


Fig 3: Impulse Response of Controller Designed with Bode Plot Method

4 Implementation of OFDM Technique in MANET Architecture:

Disaster management in terms of time of operation and efficiency of performance given by robot needs some improvements and hence the concept of multiple number of snake robot have been employed for navigation in the targeted area i.e. coal mines. As the data transmission in between the robot and remote station is a matter of importance, the reliability of the wireless network is been tested. After a number of trials it has been noticed that range of data transmission through an RF link gets reduced and the reliability of the transmitted data reduces due to multi-path fading. To avoid this problem implementation of orthogonal frequency division multiplexing was considered.

The concept of OFDM implementation in MANET architecture is described in Fig. 4. A group of snake robots having four segments individually were considered in this case. Transfer function of motor controllers are stored as impulse response in data files and each segment of snake robot are loaded with those data files within their controller memory. Thus the programming burden on the controller head gets reduced and this topology opens a scope for changing those data files from remote station via wireless link. The controller exhibits phase shifted sinusoidal output from each segment so that the entire snake body can follow the ACM curve for snake-like movement. Output from each segment of snake robot is shown in fig.7.

Going to the depth of implementation technique we can consider N numbers of four segmented snake robots in network which communicates to the remote station using an ISM band that is very limited in nature. Thus introduction of frequency division multiplexing (FDM) technique only would have failed in this circumstances. Code Division Multiple Access (CDMA) has also its limitations , while implementation of OFDM in MANET network can lead us to the solution of wireless control of multi-agent snake robots for disaster management. Each segment of snake robot has been allotted a narrow band for communication and while the every agent of the network are identified with an orthogonal code. Thus the band requirement for communication and control reduces to:

$$BW = S \times B \qquad (8)$$

Where BW is the total bandwidth required by the network

S is the number of segment in snake robot which is 4 in our case

B is the narrowband allotted to each snake in employed in the same network

From the above equation it can be seen that the required bandwidth is independent of number of agent in the network.

Fig.5 describes the modulation technique of this architecture. Data from each segment comes in its allotted band after being multiplied by its identity code and received at the receiver end with re-multiplication with the same code. Hence the data transmission is secured. It has been tested that the reliability of transmitted data improves with OFDM techniques .

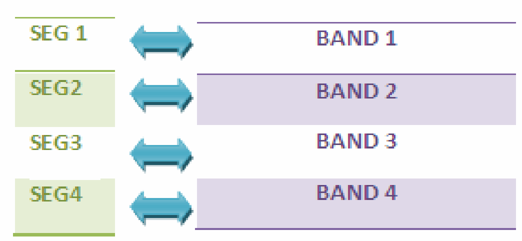


Fig 4: Frequency Band Allocation for Different Segment of a Snake Robot

The snake agents are responsible for collecting data from the environment with an array of sensors mounted on their body in different segment. The data from individual sensor are transmitted with via specific band as per their position of mounting on the snake body. As each snake has their individual ID code the transmitted data is then multiplied with a pseudo code before transmitted finally from the snake body. Thus numbers of data coming from the field are separated at the receiver end after re-multiplication of proper pseudo code which thus vanishes to deliver original message to the controller station. A human-PC interface can also be establish to monitor the snake agents from a remote station and to rescue them in case of emergency by processing data for movement in reverse direction. The limitation of ISM band is different in different country. We have considered 2.4 GHz for India to be suitable for our communication. A RF modulator circuit of frequency 2.4 GHz is used additionally after coding the message signal as shown in fig.5. From fig.6 (a) to (d) coding of individual data are shown.

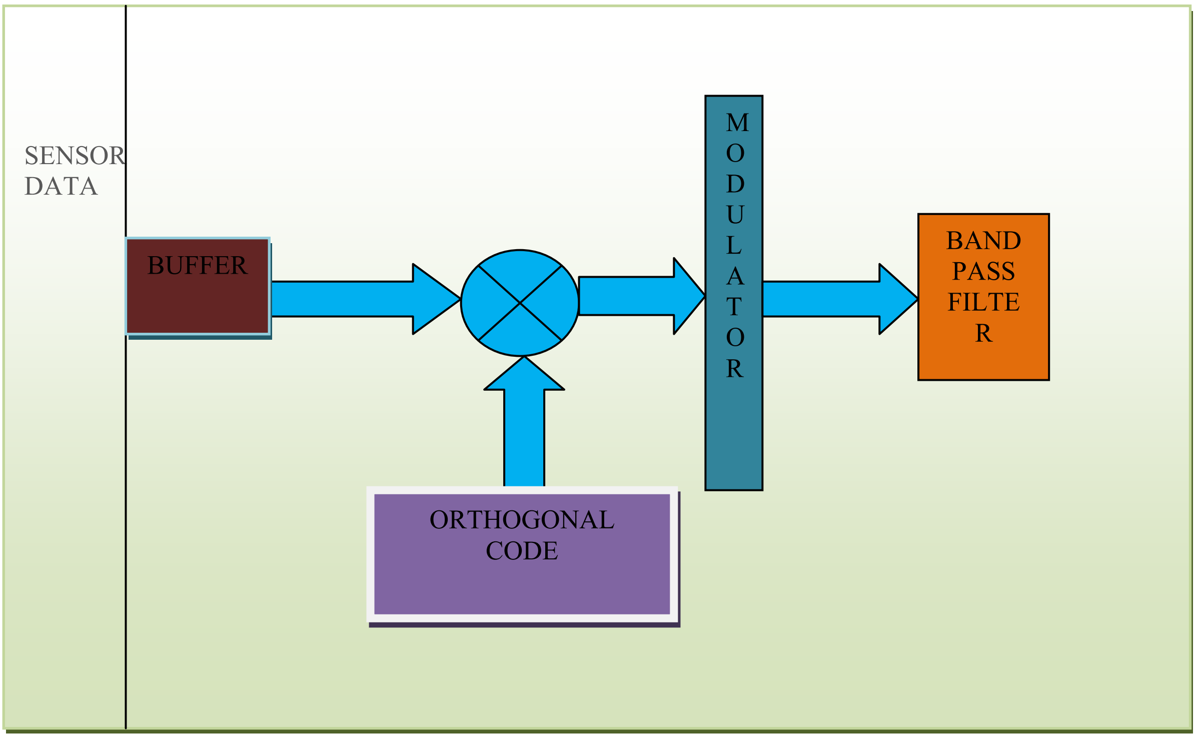


Fig 5: Modulation Technique with Different Orthogonal Code for Different Snake Robot

5 Result and Discussion:

A network consisting four numbers of agents and each agent having four numbers of segments are been considered and each segment are tested while transmitting sensor data in their allotted bandwidth. The pseudo code for each agent is formed with the help of a W-matrix which is shown in eq. 9. Data coding is shown through fig. 6 (a0 to (d) from different agent while transmitting four individual alphabet ‘C’ from snake 1, ‘S’ from snake 2, ‘I’ from snake 3 and ‘R’ from snake 4. The target of this communication technique is to transmit a data file of impulse response of the designed controller to individual segment of a snake robot that will process the file data to exhibit a snake like motion and can move in reverse direction after if the sequence of transmitted file is been altered.

$$W_4 = \begin{bmatrix} +1 & +1 & +1 & +1 \\ +1 & -1 & +1 & -1 \\ +1 & +1 & -1 & -1 \\ +1 & -1 & -1 & +1 \end{bmatrix} \quad (9)$$

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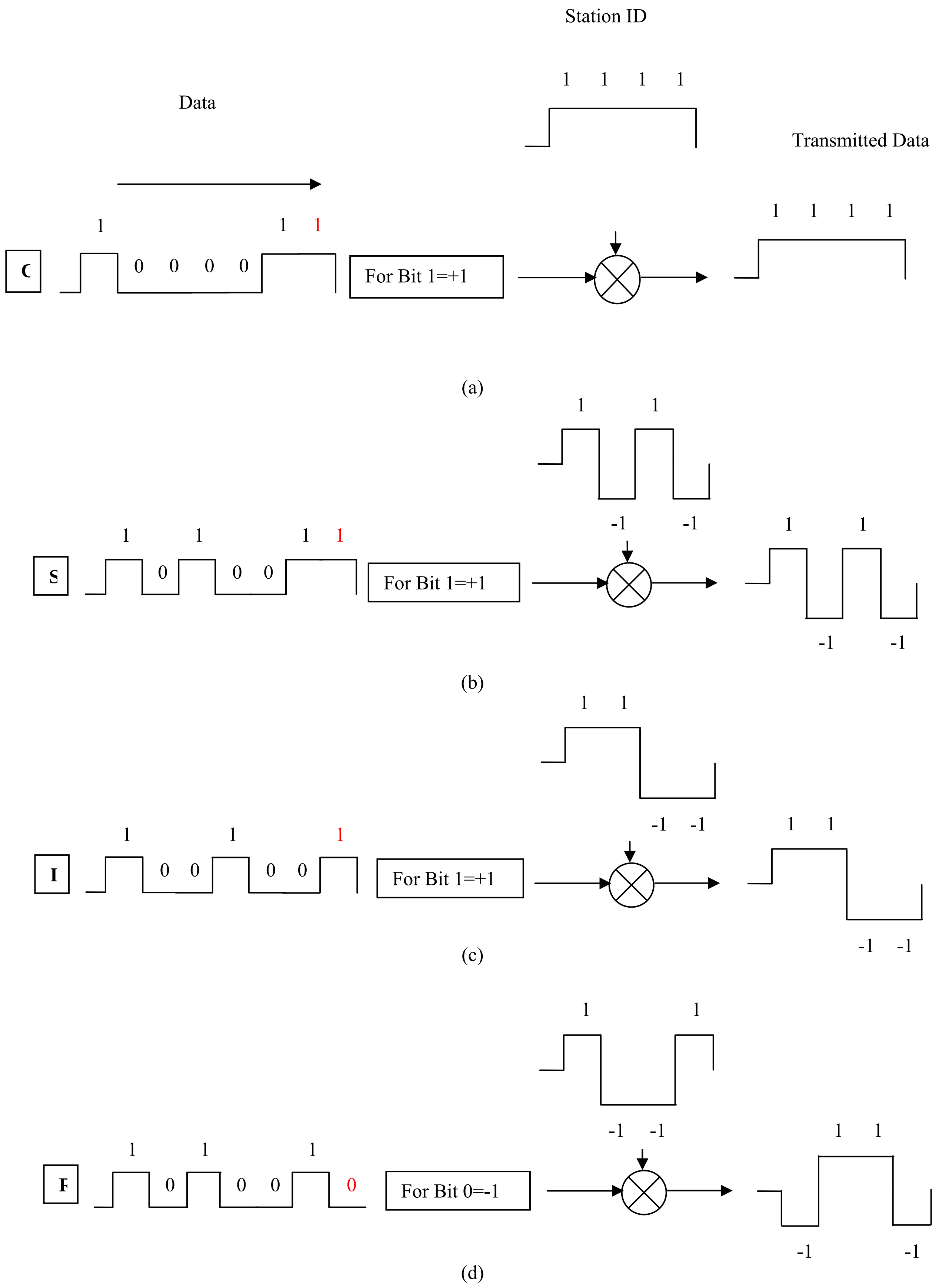

Fig 6: Modulated Data Transmission from Individual Snake Agent in a Limited Bandwidth

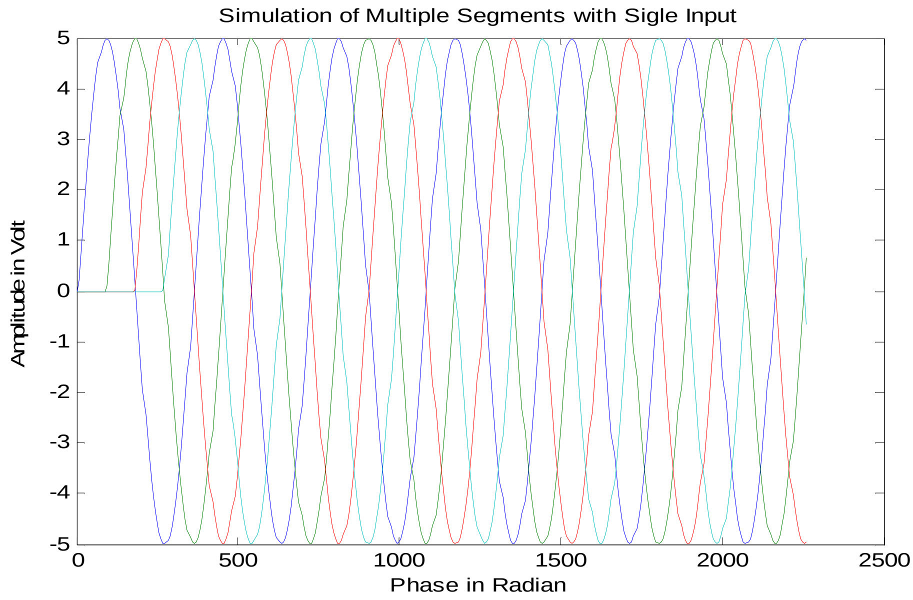

Fig 7: Phase Shifted Sinusoidal Motion from Controller's point of View Designed for each Segment of a Snake Robot

6 Conclusion:

Coal mines is one of the areas affected by multipath fading and these type of hazardous environment cannot be controlled with trajectory planning by a single robot. Life time of the robot is also a matter of importance in the rescue mission. In this regard a strong communication setup is required for trans-receiving data between robot and remote station. This method of channelizing each sensor data into individual band and coding technique can enhance use of narrowband in robotic application. Application of OFDM has different aspects in terms of wireless communication. Specially, OFDM is an advanced modification in frequency division multiple access to reduce multipath fading. Disaster management is one of the victims of multipath fading .Wireless control has met the secured data transmission level with the advent of OFDM and further modification is required as the application changes from controlling a single vehicle in a Multi-agent Adhoc Network(MANET).

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