Development Of An Algorithm For a Target Platform-following Robot Using LoRa Signals

Ojal Bhatnagar
Student
School of Electrical Engineering
MIT Academy of Engineering
Pune, India
obhatnagar@mitaoe.ac.in

Natasha Surendran
Student
School of Electrical Engineering
MIT Academy of Engineering
Pune, India
nsurendran@mitaoe.ac.in

Md. Mahfooz Alam
Student
School of Electrical Engineering
MIT Academy of Engineering
Pune, India
malam@mitaoe.ac.in

***Abstract*—The proposed paper deliberates the results and observations during the development and testing of a 'Target-following Unmanned Ground Vehicle(UGV)'. In this paper, various present-day wireless technologies such as ZigBee, SigFox, Wi-fi are studied and compared. The paper also discusses the benefits of LoRa protocol in terms of power requirement, range of communication, communication rate, etc. Furthermore, the developed and tested algorithms are explained for the task of controlling a robot to autonomously follow a target. The results showed that for a range of 850m, the point-to-point communication link had a high accuracy, after which it degraded. This relation between the distance and Received Signal Strength Index(RSSI) is explained graphically. The tests conducted in this proposed approach received a signal power ranging from -20dB to -125dB as the distance increased.**

***Index Terms*—LoRa Modulation Scheme, GPS Tracking, Comparison of Wireless Technologies**

I. Introduction

A LoRaTM protocol defined by SemTech, is a popular choice for low power long range wireless communication, usually in the field of IoT and LPWAN networks [1]. The spectrum spread applied to a LoRa signal is a derivative of CSS (Chirp spectrum spread), this results in an increase in the link budget, increased resistance to channel noise, doppler effect and multipath fading [2]. In our application we have transmitted GPS coordinates a target body, all this data is transmitted in the form of a 1D array between the receiver and the transmitter. Further at the receiver end this received array is compared with the position of the mobile system and decision-making takes place for the motor control. The main requirements to be met while selecting a communication technology were: low power consumption and conservation of battery life for other essential tasks and communication over long distances and efficiently between the target platform and follower platform. It is modelled for an AWGN channel, as multipaths are not considered for the LoRa signals.
LoRa WAN gateways significantly increases the range of the signals to be sent, however in this paper, the tests have been conducted without the use of gateways, using Line-of-Sight communication.

II. Background & Comparison of Technologies

A. SigFox

SigFox is a proprietary network owned by SigFox, used for narrowband radio communication signals using BPSK modulation. The Maximum Transmission Unit (MTU) for SigFox is 12 data bytes. SigFox network is used in IoT applications and is available in 36 countries, it operates in three frequency bands for Europe, USA & Asia, which are same as that for LoRa.

B. ZigBee

ZigBee is a specification for low power devices in a personal area network. It is based on IEEE 802.15.4 protocol, and is a low bandwidth, low data rate communication with a range of 10-20 meters. The MTU is 104 data bytes. Zigbee uses three operational frequency bands 868Mhz, 915MHz & 2.4GHz. The modulation scheme used for Zigbee is DSSS along with either BPSK or O-QPSK.

C. Wi-Fi

Wi-fi is the most popular network protocol used worldwide, based on IEEE 802.11b or IEEE 802.11a /g protocol. It operates on three frequency bands at 2.4GHz, 5GHz or 60GHz, the MTU for Wi-Fi is 1500 data bytes and depending of the IEEE protocol, the signal is modulated differently.

D. Bluetooth

Bluetooth is another commonly used, small-range network protocol. It is based on the IEEE 802.5.1 standard and operates in the Ultra High Frequency (UHF) band. It is mostly used for short distance, low power communications like file transfer between mobile phones or for smart watches and fitness trackers [6].

E. LoRa

LpWAN, is the latest addition to the wireless long range network protocols, the data is converted in LoRa packets, i.e the signal is applied with CSS, and the network operates in 3 frequency bands 868MHz(Eu), 915MHz(US), 433MHz (Asia) and the MTU is 255 data bytes , over a maximum range of 10km in rural areas. A LoRa packet has the following structure:

Fig. 1. Structure of a LoRa packet

III. SYSTEM MODEL AND ARCHITECHTURE

A. Block Diagram

The setup used for point to point communication requires am I.C for LoRa modulation and packet formation these are developed by Semtech, a GPS receiver we have used a L80 board, and a microcontroller to interface between the GPS receiver and the LoRa transmitter, apart from these on the receiver end additionally motor driver and motor setup is required. All of this is expressed in the following block diagram for the transmitter and receiver of our system.

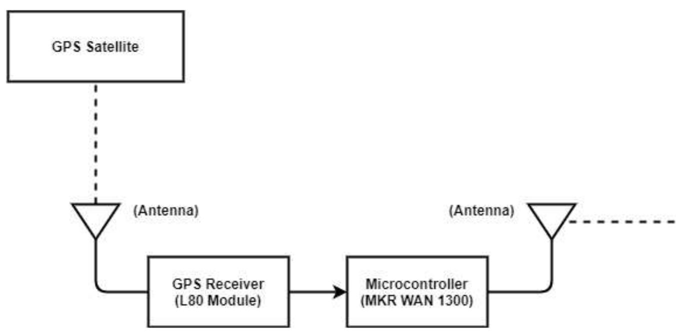

Fig. 2. Transmitter side block diagram

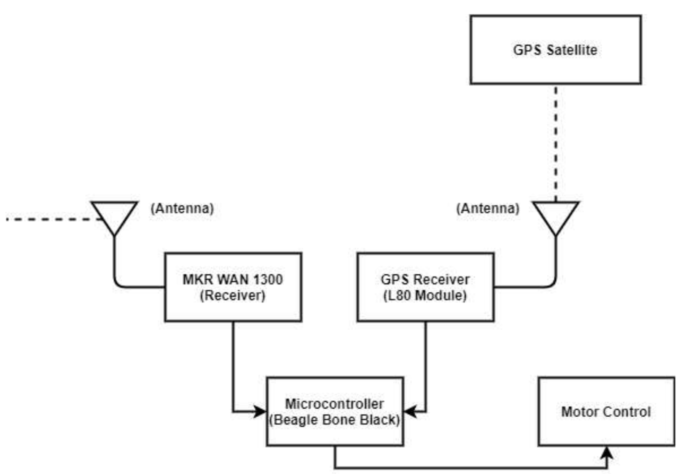

Fig. 3. Receiver side block diagram

Transmitter components: the GPS receiver, and microcontroller and LoRa trans-receiver combinational board. Receiver components: another GPS receiver is present at the receiver end, along with a master controller and LoRa trans-receiver.

B. Flow of Tasks at the Transmitter Side

At the transmitter end, the modulation takes place in the following manner:

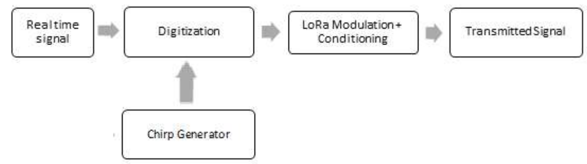

Fig. 4. Block diagram depicting: lora modulation process

1) The real time signal is digitized into a string of bits. in the information bearing sequence is grouped to form symbols (the no. of symbols depends on the bits in the ADC), $s_k \epsilon \{M = 2^m\}$
2) The whole signal bandwidth is divided into 2^m (m = no. of bits) sub bands, each frequency (f_k) corresponds to a unique symbol, such that:
$$\frac{f_{max} - f_{min}}{2^n} \times k = f_m \tag{1}$$
where $k = 1, 2, 3, ...2^n$
3) The string of symbols and each symbol mapped onto a set of signals defined is as ($s_k(t)$)
$$S_k(t) = A_k \times e^{j \cdot 2\pi \cdot f_k(t) \cdot t} \tag{2}$$
$f_m = f_m + f \times t$ where, $T_{m-1}(S.F) \leq t < T_m(S.F)$
4) The default transmitted signal is a continuous up-chirp from f_min to f_max whereas for the transmission of the data symbol the upchirp starts from the corresponding frequency of that symbol.
$$T(t) = \sum_{k=1}^{M} s_k(t) \tag{3}$$
where, T(t) = Transmitted signal
s(t) = Symbol transmitted for each time period
k = number of symbols transmitted

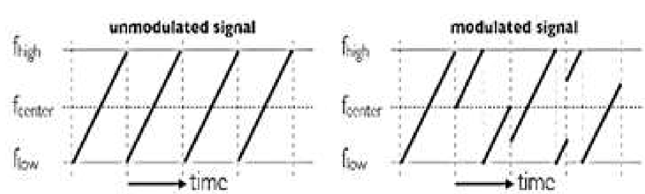

Fig. 5. LoRa modulated signal

This modulation is used to convert the GPS coordinate data into packets of information by LoRa protocol, this is done as per the following flowchart:

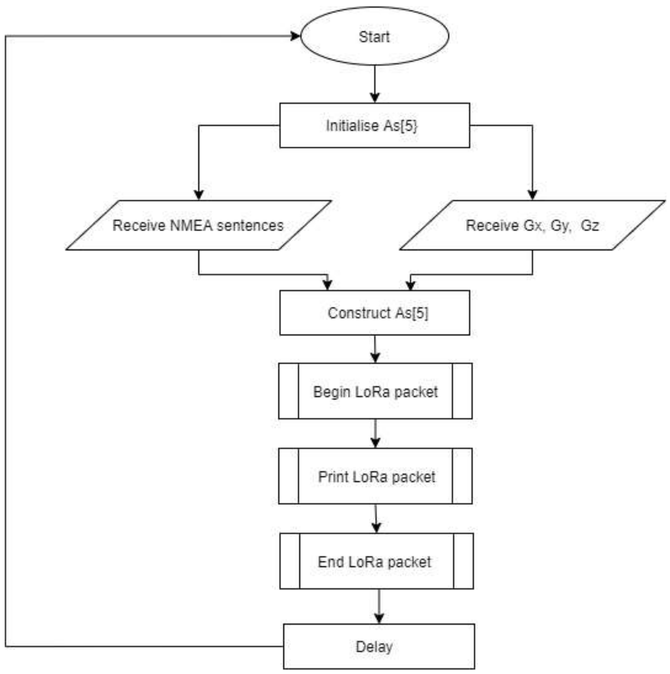

Fig. 6. Algorithm for packet transmission

Here, As = array of positional data

Gx, Gy, Gz= orientation along the x, y and z axis

C. Flow of Tasks at the Receiver Side

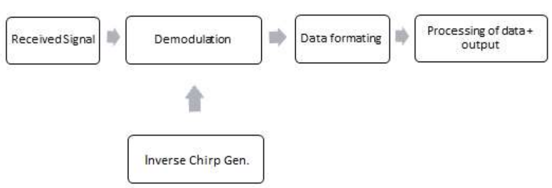

Fig. 7. Block diagram depicting: lora demodulation process

1) The received signal is in the form of chirps as per the pre-decided spread factor.
2) This signal is multiplied with the conjugate constant downchirp varying from f_{max} to f_{min} of the same spread factor. This results in constant signals:

$$S_k(t) = A_m \times e^{j\cdot 2\pi\cdot(f_n+f\cdot t)\cdot t}$$

$$S_l(t) = A_m \times e^{j\cdot 2\pi\cdot(-f\cdot t)\cdot t}$$

$$= {A_m}^2 \times e^{j\cdot 2\pi\cdot(f_k)\cdot t} \tag{4}$$

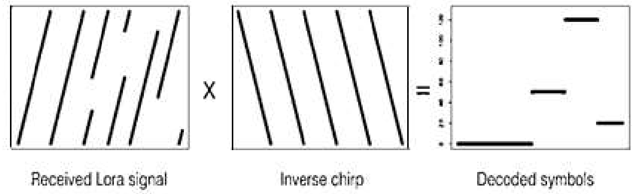

Fig. 8. LoRa demodulated signal

where, f_k = constant symbol specific frequency and, A_m = signal amplitude

3) Once the symbols are received in terms of signals with constant frequencies, these are mapped to corresponding symbols according to their frequencies [1]. This type of demodulation and signal reconstruction is used to regenerate the array of position received from the target. An array of the same format is constructed for the mobile tracker platform, both these arrays are compared to find the distance between the target and the tracker platforms and accordingly commands are given to the motor driver in the following manner:

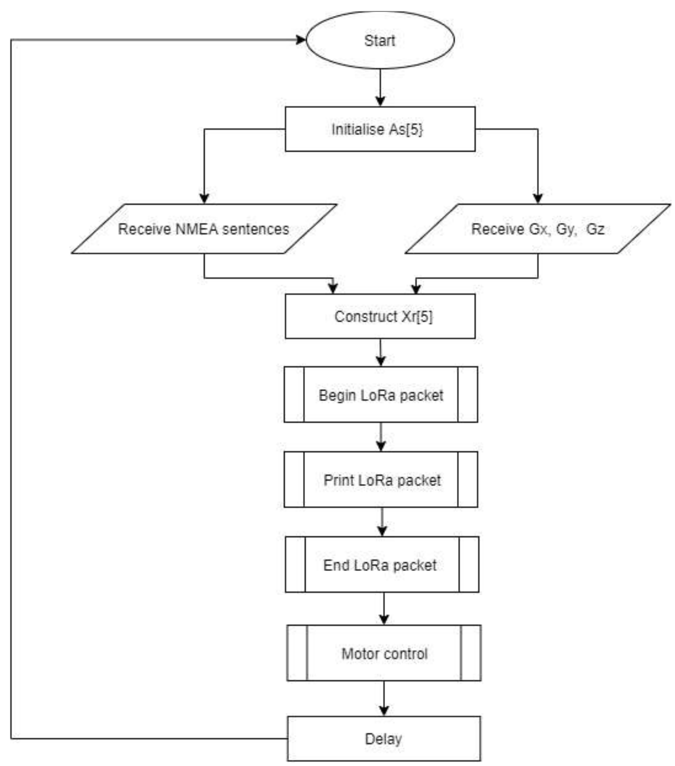

Fig. 9. Algorithm for packet reception

Mathematical properties of the modulated signal:

a. *Correlation of symbols*
Considering a Line-of-Sight(LoS) path, with an Additive White Gaussian Noise (AWGN) channel, the received

signal, $R(t)$ is:

$$R(t) = T(t) + n(t)$$

Where $n(t)$ is the white noise in the channel and, $T(t) = \sum_{m=1}^{m} S_m(t)$ i.e., a collection of individual symbols, all in the form of chirps, last in a separate single symbol time (Ts) period. Another consideration is that all symbols are equiprobable to be transmitted, so they act as random variables. Thus, for $S_m(t) = S_1(t) + S_2(t) + ...S_n(t)$
Correlation of two symbols,

$$Corr(S_a(t), S_b(t)) = Corr(e^{j\cdot 2\pi\cdot(a\times\frac{B}{M}+nT_s)} \times e^{j\cdot 2\pi\cdot(b\times\frac{B}{M}+nT_s)}) = 0 \qquad \text{(for } a \neq b\text{)}$$

Another property used for symbol regeneration at the receiver is to correlate the received symbol $r(t)$ with all possible symbols, in this case,

$$Corr(r(t), S_i(t)) \qquad ....i(\textit{symbol index}) \in (1, 2^n)$$

$$Corr(r(t), S_i(t)) = \int_{t=-\infty}^{\infty} r(\tau) \times S(t-\tau)d\tau$$

This will be maximum when $r(t) \approx S_i(t)$
Such that,

$$Corr(S_a(t), S_b(t)) = \begin{cases} E_s + \phi_n & \text{a = b} \\ \phi_n & \text{a} \neq \text{b} \end{cases}$$

Where, E_s is the maximum signal output of Correlation operator and ϕ_n is the maximum output of noise.

b. *Bit Error Rate (BER)*
Noise is a random variable following Gaussian distribution with μ_n as the mean and ${\sigma_n}^2$ as the standard deviation,

$$f_p(p) = \frac{1}{\sqrt{2\pi{\sigma_n}^2}} \cdot e^{(n-\sigma_n)^2/2{\sigma_n}^2}$$

For the signal random variable, that is, the data symbol generated at the transmitter with μ_p as the mean and ${\sigma_p}^2$ as the standard deviation,

$$f_p(p) = \frac{1}{\sqrt{2\pi{\sigma_p}^2}} \cdot e^{(p-\sigma_p)^2/2{\sigma_p}^2}$$

Then bit error probability is expressed as,

$$P_b \approx (BER\%) \times P_r[p - n > 0]$$

$$P_b \approx (BER\%) \times Q \cdot \left(\frac{\mu_n - \mu_p}{\sqrt{{\sigma_p}^2 + {\sigma_n}^2}} \right)$$

Where Q function or the tail function of the standard distribution of same variable with mean μ as the mean and σ^2 as the standard deviation,

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} e^{\frac{-u^2}{2}} du$$

D. GPS Data & Trilateration

The data transmitted in the above explained flowchart are GPS coordinated, from the target platform to the following platform. Namely it's the latitude, longitude and the speed of the platform, these the received using a L-80 GPS receiver which receives this data at a baud rate of 4800 symbols /sec from a minimum of 4 satellite. The goal is to find the coordinates and information (latitude, longitude, altitude, speed…etc.) of the GPS receiver this is done is the following manner:

i. The satellite sends the time of transmission and the receiver notes the time of reception based on the time taken for the signal to reach, the known velocity of the signal and the distance between the GPS receiver and the satellite is calculated.
ii. Based on the distance between the satellite and receiver, it is known that the receiver lies somewhere on a sphere of that distance with the satellite in the center.
iii. When another such a sphere is formed for a second satellite, it can be deduced that the device lies on the intersection of the two spheres which is a 2D circle. With one more such satellite sphere from a third satellite, it can be further said that the device lies on the intersection of the third sphere and the circle from first and second sphere. This is further true for only two distinct points on the circle, of these two points in space. Since it is known that the device must be on the surface of earth, a single point can be found that satisfies all these criteria. This is the 3D position of the GPS receiver device; thus three satellites are required to localize the three spatial coordinates.

IV. Results

- The achieved maximum distance for effective communication in Non Line-of-Sight (N-LOS) was found to be 850 m with an RSSI of -120dB.
- LoRa data packets are formed and decoded for the GPS data at both ends of the communication channel.
- The algorithm was found to be accurate 65% of times.

A. Tables & Graphs

a) RSSI vs Distance: Figure 10 is a graph that plots the values of RSSI (in dB) with distance (in cm).

b) Comparison of Communication Technologies: To choose the technology to be used for transmission of data between the transmitter and receiver side, we considered the wireless communication technologies: SigFox, ZigBee, WiFi, LoRa. These were listed and compared based on the criteria of: modulation scheme, range of the wireless technology and bandwidth (or operatng frequency band).

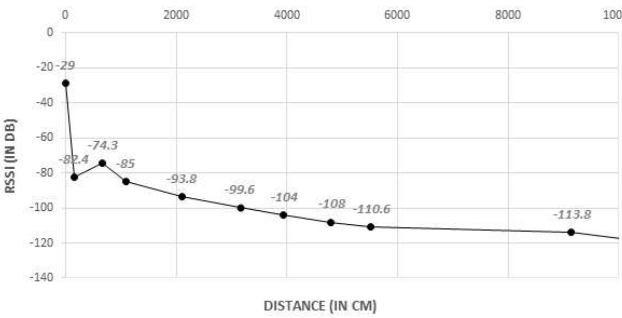

Fig. 10. Graph depicting change in RSSI values (in dB) with distance (in cm)

Network Protocol	Parameters		
	Modulation Scheme	**Range**	**Bandwidth (Freq. bands)**
SigFox	*IEEE 802.11* DBPSK (uplink) GFSK (downlink)	30-50km (Rural) 3-10km (Urban)	BW(uplink)= 1.5 kHz BW(downlink)= 100Hz-600Hz
ZigBee	*IEEE 802.15.4* 868MHz: DSSS+ BPSK 915MHz: DSSS+BPSK 2.4GHz: DSSS+O-QPSK	10-20m	BW(uplink)= 1.5kHz BW(downlink)= 100Hz-600Hz
WiFi	*IEEE 802.11b* DSSS/CCK + QPSK *IEEE 802.11a/g* OFDM +(BPSK/QPSK/16-QAM/64-QAM)	2.4GHz, up to 95m (Outdoor) 5GHz, up to 30m (Outdoor)	22MHz (each channel at a increment of 5 MHz)
LoRa	*IEEE 802.11ah* Derivative of CSS	Up to 10km (Rural) Up to 6km (Urban)	BW = 500kHz (Europe) BW = 250 kHz (USA) BW = 125kHz (Asia)

TABLE I
COMPARATIVE STUDY OF COMMUNICATION TECHNOLOGIES

V. CONCLUSION

The presented paper discusses a brief introduction to the problem statement and the goals of this project, followed by a literature survey and a study of the commonly used technologies for similar problem statements and tasks, it has been tried to cover industrial level technologies as well as personal user level technologies. This is followed by the direction of approach and explanation of all the tasks implemented. Finally, a summary of the results achieved is given under the results and the open issues are mentioned.

A. Open Issues

(a) Improvement in the accuracy and precision of the proposed approach is required, this can be done by using more sensitive devices and/or addition of machine learning aspects in the algorithm for minimization of errors and prediction of the next position based on previous path.

(b) The jitter of the motor has to be reduced this can be achieved by reducing the interval between consecutive received signals.

(c) Image processing can be used to extract more information from the target site.

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