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SDR Based UGV for Covert Surveillance

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Abstract—The need for newer, better, safer and secure ways of controlling the motion of a Unmanned Ground Vehicle (UGV) as well as communication mechanisms between the UGV and the Base Station (BS) has ever been on a rapid rise since the beginning of the 21st century. Simultaneously, with the advent of digital radios and its rapid expansion in today's ever growing communication world, the need for exploiting them in all forms and modes of communication has always been a challenge to researchers. Typically UGVs are designed for surveillance. Presently, the UGVs are designed to work in line-of-sight frequency ranges i.e. VHF/UHF. Even the control of the UGV from the BS is done either using Wi-Fi, ZigBee protocol or with the help of RF trans-receiver link in line-of-sight frequency ranges. This paper explores the concept of integration of Software Defined Radio (SDR) with a UGV. Integrating SDR with a UGV gives rise to numerous advantages that can be used by defence, civil personnel and researchers alike. The SDR, on-board, can carry out the dual function of not only controlling the motion of the UGV but also transmitting the live video feed from the UGV to the BS. More so, the SDR gives a unique advantage of working in wide band of frequencies. This means, SDR can conveniently switch between line-of-sight frequencies (i.e. VHF, UHF etc) to beyond line-of-sight frequencies (i.e. HF). This unique advantage helps the defence personnel to carry out surveillance deep inside enemy territory. The SDR on-board the UGV, will initially send the live feed in line-of-sight frequency range. The moment UGV is beyond line-of-sight range of the BS, the SDR on-board will automatically switch over from line-of-sight frequency range to beyond line-of-sight frequency range. We have developed an algorithm, which would enable the SDR to switch over from VHF/UHF frequency ranges to HF frequency range, when the UGV is in beyond line-of-sight range. This would also enable us to control the motion of the UGV from beyond line-of-sight range. Our approach of integration of SDR with UGV can be used for covert activities like surveillance, deep inside enemy lines, without worrying about the UGV being in line-of-sight range with the BS.

Index Terms — Covert surveillance, Integration of SDR with UGV, Robotics, SDR, SDR for surveillance, SDR with Robotics, UGV

1 INTRODUCTION

An Unmanned Ground Vehicle (UGV) is a vehicle, according to the standard definition, not manned by anyone, though it is controlled by humans or can move autonomously. Typically UGVs are designed for surveillance, used primarily by defence forces across the globe. A UGV can be remote controlled via RF link. Typically Wi-Fi is used for this process. There are standard commercially off the shelf products, which help in controlling the motion of the UGV through an RF link. Apart from Wi-Fi, we can also use ZigBee protocols to control the motion of the UGV. As per 802.11b IEEE standards, the Wi-Fi transmission frequency range is around 2.4GHz. As per 802.15.4 IEEE standards, the ZigBee transmission frequency range is also around 2.4 GHz. Thus, to control the motion of the UGV viz Wi-Fi or ZigBee, the Base Station (BS) and the UGV need to be in line-of-sight with each other. As mentioned earlier, UGVs are designed for surveillance. A camera / webcam is fitted on the UGV and we get live feed transmitted from the transmitter fitted on board of the UGV and the same is received by the receiver at the Base station. Again, this transmission / reception is also done using line-of-sight frequencies such as Wi-Fi or ZigBee or using a normal RF transmitter & receiver. To receive the live feed from the UGV, the Base station has to in Line-of-sight with the UGV. The moment they are beyond Line-of-sight, the transmission is broken.

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Consider a Wi-Fi enabled robot as explained in the paper "Designing And Implementing a Wi-Fi Enabled Robot". The robot is built on a 4-wheel chassis powered by a Linksys router and an Atmel microcontroller[1]. Laboratories also design custom based robots depending upon the requirement. A case in point is RISCBOT, built at RISC Lab, University of Bridgeport, which utilises a room visual identification for localization and provides live feed over the WLAN network through the Internet. However, the region of the operation of the robot is limited by the coverage of wireless access point [2].

In this paper, we have proposed a novel architecture, which would enable an SDR to switch over from one frequency range to another, thus eliminating the problem of line-of-sight, as prevalent in the existing system. Also, an algorithm of frequency hopping is developed, which would enable the UGV to perform covert surveillance deep inside enemy territory, even when the enemy has used electronic counter mechanisms such as jamming.

The rest of the paper is organised as follows. In section 2, we look at various drawbacks of the existing prevalent system. In section 3, we highlight the integration of SDR with UGV and the reasons of choosing SDR over other trans-receivers. In section 4, hardware design of the UGV is discussed. The proposed architecture is discussed in section 5. The experimental results are discussed in section 6. The paper ends with a discussion on conclusion and future work in section 7.

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2 Drawbacks of the Existing System

There are some inherent drawbacks of the existing system of surveillance and data transmission by the UGVs. These can be improved upon by making some fundamental changes in the method of data transmission and reception by the UGVs, much different than what is used today. Let us first understand the inherent drawbacks of the existing system and then elaborate on the methods used to eliminate those drawbacks.

The existing UGVs transmit the live video feed using either Wi-Fi or ZigBee protocols. Some even use a normal RF trans-receiver link to send the data. Now, suppose we are using the UGV for surveillance deep inside enemy territory, there are possibilities that the enemy would use Electronic Counter Measures (ECM) such as Jamming, which would restrict the live feed transmitted by the transmitter on-board the UGV and received by the Base Station (BS), resulting in BS not being able to receive the data due to interference by the enemy. Thus, when designing the UGV, it becomes imperative to consider implementing Electronic Counter Counter Measures (ECCM), such as Frequency Hopping (FH), which when implemented, it can be used by the transmitter on-board the UGV to transmit the live video feed to the BS, even when the enemy has resorted to jamming mechanisms.

Also, consider a case when the UGV and the BS are beyond line-of-sight range of each other. In such a case, we will not be able to do any of the following:

1. BS will not be able to receive the live feed from the camera mounted on the UGV.
2. We would not be able to control the UGV from the BS, since both these functions are currently carried out using line-of-sight frequency ranges

Thus, it is imperative to focus on the above drawbacks and design an efficient system integrated with current edge technology.

3 Integrating Software Defined Radio (SDR) with UGV

To eliminate the above mentioned drawbacks, a novel solution in terms of integrating SDR with UGV has been proposed in this paper. Not only the nuances of such an integration has been elaborated, but also the behavior of the integrated system and future scope of this integration has been elucidated in this paper

3.1 Benefits of Integrating SDR with UGV

Integration of SDR with a UGV brings out the unique advantages that the SDR offers and provides flexibility to the whole system. The benefits of such an integration are as follows:-

1. SDR can be programmed for frequency hopping in a given band to eliminate the data transmission loss due to the use of Electronic Counter Measures by the enemy. Electronic Counter Counter Measures (ECCM) can easily be applied in SDR, enabling the UGV to perform surveillance operations in the enemy territory without worrying about the use of electronic jammers by the enemy.
2. SDR has a unique capability to switch over from one frequency range to the other. Here, we are talking of a scenario where the UGV and the BS are in beyond line-of-sight range of each other. IN such a scenario, ideally, the data transmission would have lost, but the SDR, on-board the UGV, can be programmed to automatically switch over from VHF/UHF to HF range eliminating the problem of line-of-sight.
3. The entire system can be programmed in such a way that SDR would be able to control the motion of the UGV. As mentioned above, ideally the motion of the UGV is controlled by using a Wi-Fi link, ZigBee protocol or by using a normal RF trans-receiver. With SDR on-board the UGV and programmed to control the motion of the UGV, it thus gives double benefits of not only controlling the UGV from beyond line-of-sight range but also controlling it through a frequency hopping link. This means that integrating SDR with UGV will help in jamming free surveillance by the UGV, deep inside enemy territory, without worrying about the UGV being in line-of-sight range.

3.2 Reasons for choosing SDR over other trans-receivers

There are numerous types of trans-receivers readily available in the open market. SDR possess huge advantages over other trans-receivers and these can be utilized in the integrating it with a UGV. The advantages that the SDR brings out in this integration, which other trans-receivers would not be able to achieve are:-

1. SDR can be programmed to switch over from one frequency range to another. Thus, using a wide band antenna, we can easily switch over from VHF/UHF frequency range to HF frequency range.
2. SDR can also be used to control the motion of the UGV. Thus, using a single communication link between the UGV and the BS, we can not only transmit the live video feed using SDR, in a frequency hopping mode, but also using the same link, control the motion of the UGV, both in VHF/UHF and in HF frequency ranges.

All the above advantages are possible to achieve with a open source software development toolkit called GNU Radio. It provides signal processing blocks to implement software radios. It can be used with readily available low-cost external RF hardware to create software defined radios[3].

GNU Radio Companion is a graphical user interface similar to Simulink. It allows you to create signal processing applications by drag-and-drop. Also, we can write signal processing and radio application programs using Python Programming Language[4].

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4 Hardware Architecture

The chassis of the UGV is made up of aluminium alloy and weighs approximately 0.8 kg. The chassis is fitted with four separate mountings to drive each wheel. This design of the UGV is customized and it has mountings for circuits to control the motion of the UGV, for SDR and circuits used for functioning of the SDR.

4.1 Overview of the Integrated System

The UGV consists of two layer platform. The lower layer houses the motherboard used for functioning of the SDR. The flip side of the lower layer houses the four individual drive motors, micro-controller and power supply used for the motion of the UGV. The upper layer is elevated above the lower layer and it houses the SDR and the power supply for the SDR. The complete integrated model is shown in Fig 1

Fig 1. Integrated Model of SDR with UGV

The live feed will be captured with the help of the camera mounted on the UGV and this will be transmitted to the BS with the help of SDR also mounted on-board. The BS will also have an SDR, which would receive this transmission. The overall system is shown in Fig 2

Fig 2. An Overview of the complete system

4.3 SDR used in the Integrated System

The USRP1 is the original Universal Software Radio Peripheral hardware (USRP) that provides entry-level RF processing capability. It is intended to provide software defined radio development capability for cost-sensitive users and applications. The architecture includes an Altera Cyclone FPGA, 64 MS/s dual ADC, 128 MS/s dual DAC and USB 2.0 connectivity to provide data to host processors. A modular design allows the USRP1 to operate from DC to 6 GHz. The USRP1 platform can support two complete RF daughterboards. This feature makes the USRP ideal for applications requiring high isolation between transmit and receive chains, or dual-band dual transmit/receive operation. The USRP1 can stream up to 8 MS/s to and from host applications, and users can implement custom functions in the FPGA fabric [5]

TABLE 1
List of Hardware used in the Integrated System

Sr No	Device	Location of the device
1	USRP -1	Base Station, Mounted on the UGV
2	XCVR250 (Dual Band)	Base Station, Mounted on the UGV
3	VERT2450	Omnidirectional Antenna for all USRP

5 Proposed Architecture of the System

A novel architecture is proposed in this section, which would help us create an environment for simulation of automatic switching of SDR from one frequency range to another, while simultaneously maintaining the handshaking link between the UGV and the BS and also controlling the motion of the UGV.

To implement this model, we use one SDR, which is mounted on the UGV and two SDRs connected to the same computer at the Base Station (BS), out of which one SDR is tuned to a frequency of 500MHz and the other is tuned to a frequency of 29MHz, while the SDR mounted on the UGV is able to switch between these two frequencies, as and when required.

5.1 Basic Block Diagram of the Proposed System

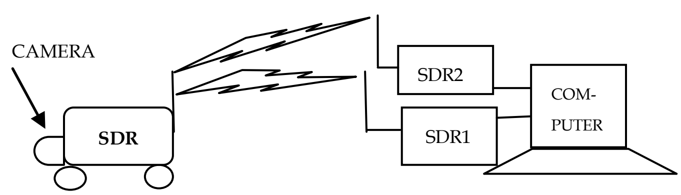

Fig 3. Basic Block Diagram of the Proposed System

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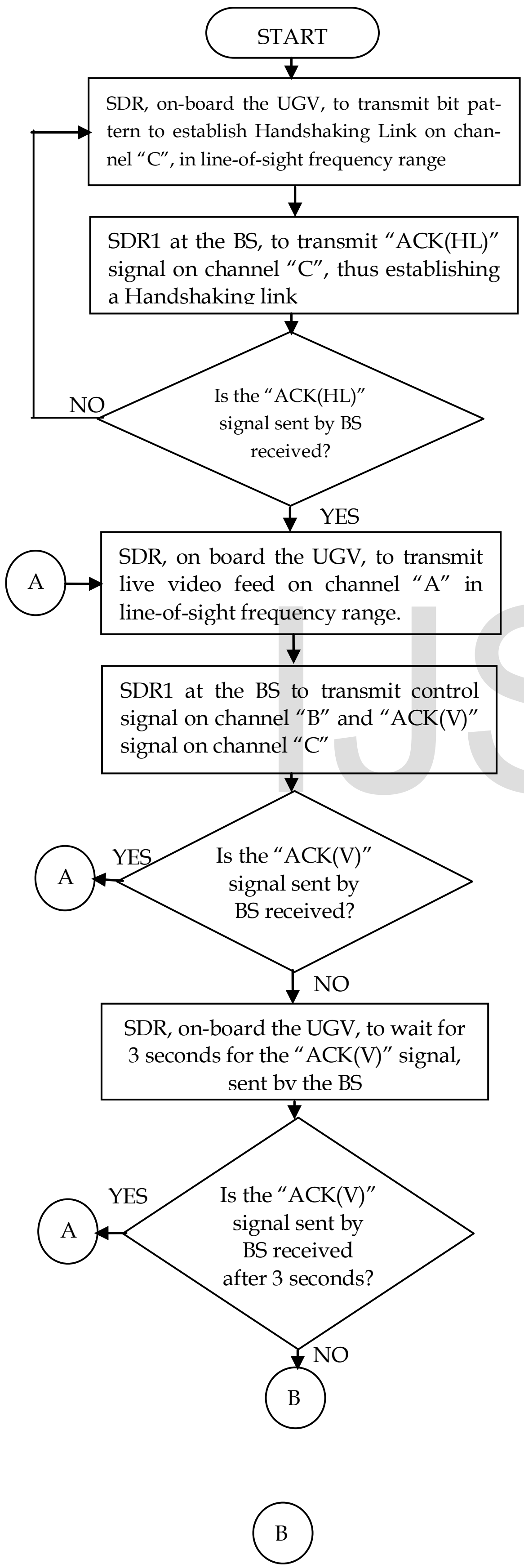
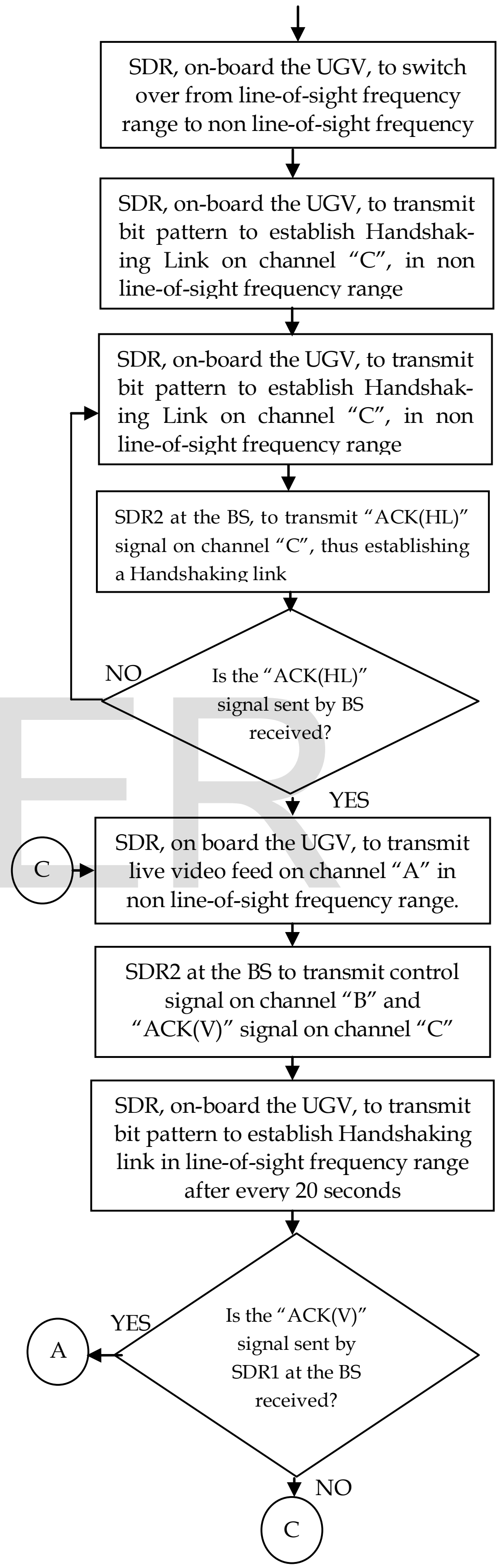
5.2 Flowchart of the Proposed System

In this section, the flowchart of the proposed communication architecture between the UGV and the BS is explained.





5.3 Automatic Switching by SDR

As explained above, the reason for choosing SDR over

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other trans-receivers is that SDR has a unique capability to switch over from one frequency range to another. In this section, we propose the mechanism / architecture which enables the SDR to control the motion of the UGV while simultaneously switch over from one frequency range to another.

Firstly, a link needs to be established between the SDR on-board the UGV and the BS. This is called an Handshaking link. It is nothing but a bit pattern sent by the SDR on-board the UGV to the SDR at the BS. After receiving this bit pattern, the SDR at the BS sends an "ACK" signal to the SDR on-board the UGV. Once this "ACK" signal is received, the handshaking between the two SDRs is complete and a link is established between the UGV and the BS.

Now, for all communication between the UGV and the BS, we assume a bandwidth of 30MHz. This 30MHz bandwidth can further be subdivided into the following :-

1. 28 MHz - To transmit live video fed from the UGV to the BS, henceforth called as channel "A"
2. 1 MHz - To transmit control signal from BS to the UGV, to control the motion of the UGV, henceforth called as channel "B"
3. 1 MHz - To transmit bit pattern from the UGV to the BS and to receive "ACK" signal from the BS to the UGV, henceforth called as channel "C"

Step 1 : To establish communication between the UGV and the BS

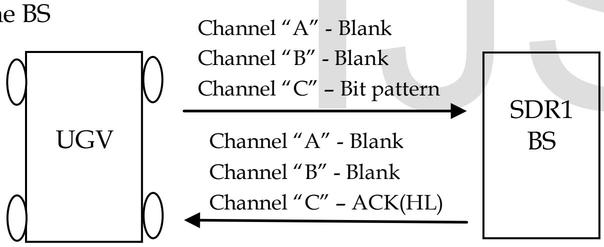


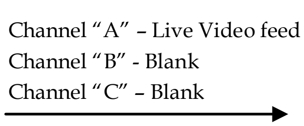
Fig 4. Handshaking Link between the UGV and the BS

As you can see from the fig 4, initially the SDR on-board the UGV transmits a bit pattern in channel "C" in the 500 MHz band i.e. line-of-sight frequency range, to establish Handshaking link, to the BS. The SDR1 in BS, in turn, sends an "ACK" signal again in channel "C". Thus, the Handshaking is complete and a link between the UGV and the BS is established in the 500MHz frequency band.

Step 2: Transmission of live video feed from the UGV to the BS at 500 MHz frequency band

Once the handshaking link at 500 MHz is established, the SDR on-board the UGV, starts transmitting the live video feed, in channel "A" to SDR1 at the BS. The SDR1 at BS, in-turn, would now send the control signal in channel "B" and "Frequency Control" signal in channel "C".

As long as the SDR on-board the UGV receives this "ACK" signal, the transmission continues in 500 MHz frequency band.



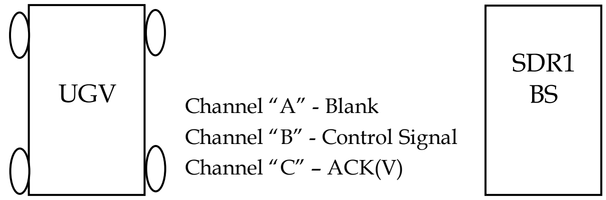


Fig 5. Transmission of live video feed at 500MHz

Step 3 : Switching over from 500MHz to 29 MHz

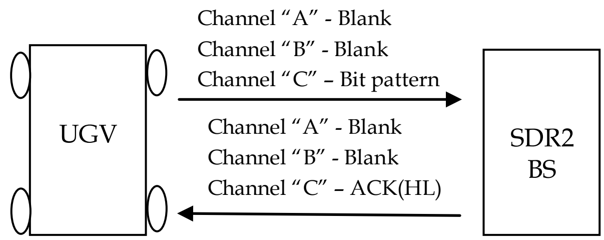


Fig 6. Switching over from 500MHz to 29MHz

Now, if the UGV is out of line-of-sight with the BS, it would not receive the "ACK" signal from the BS. At this juncture, it would wait for 3 seconds for the "ACK" signal to be received. If the "ACK" signal is still not received, the SDR on-board the UGV would now switch over from 500 MHz to 29 MHz and it would send a bit pattern, in channel "C" in 29 MHz frequency band, to intimate SDR2 at the BS that it has switched from 500 MHz to 29 MHz frequency band. The SDR2 at the BS, in turn, would now send an "ACK" signal in channel "C". Thus, again, the handshaking between the UGV and the BS, is achieved and the SDR, on-board the UGV, starts transmitting the live video feed at 29 MHz

Step 4 : Transmission of live video feed from UGV to the BS at 29 MHz frequency band

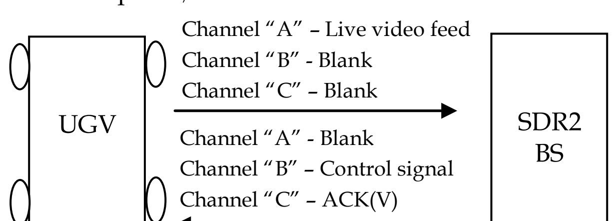


Fig 7. Transmission of live video feed at 29 MHz

Once the handshaking link at 29 MHz is established, the SDR on-board the UGV, starts transmitting the live video feed, in channel "A" to SDR2 at the BS. The SDR2 at the BS, in-turn, would now send the control signal in channel "B" and "ACK" signal in channel "C". Thus even when the UGV is out of line-of-sight range from the BS, the transmission continues without interruption and also the BS is able to control the motion of the UGV via SDR on-board. Thus, with the help of this switching mechanism, the UGV is able to do covert surveillance deep inside enemy territory.

Step 5 : Switching back from 29MHz to 500MHz

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After every 20 seconds, the SDR on-board the UGV, now transmitting at 29MHz, would try to establish a link in the 500MHz frequency band, by transmitting a bit pattern in channel "C" and waiting for an "ACK(HL)" signal from SDR1 at the BS. If an "ACK(HL)" signal is received, then now the transmission begins at 500MHz and if the "ACK(HL)" signal is not received, the transmission continues at 29MHz only.

This process is repeated till the time the UGV is in the line-of-sight range of the BS.

5.4 Electronic Counter Counter Measures (ECCM) in the proposed system

Frequency Hopping is a method of transmitting radio signals by shifting carriers across numerous channels with pesudorandom sequence, which is already known to the sender and receiver[6]. We use frequency hopping mainly to avoid interference.

For covert surveillance deep inside enemy territory, we need to ensure that we are able to receive the live video feed from the UGV to the BS, as well as control the motion of the UGV, when the enemy has active electronic counter measures like Jamming etc. Thus effective ECCM measures like Anti-Jamming or Frequency Hopping (FH) needs to be implemented.

In this section, we propose a frequency hopping mechanism, which would not only enable us to receive the live video feed from the UGV to the BS, but also enable the BS to control the motion of the UGV, deep inside enemy territory.

We propose to take a 30MHz band of frequencies, for e.g. if we are transmitting in the 500MHz frequency band, we would hop multiple frequencies. Similarly, while using the 29MHz frequency band, we would hop multiple frequencies in the range of 15MHz to 29MHz. We have developed an algorithm which would hop more than 50 times in one second, in the given range of frequencies.

6 Experimental Results

The entire system of transmitting the data from the UGV to the Bases Staion (BS) in the automatic switching environment i.e. switching from Line-of-sight (LOS) frequency range to Beyond Line-of-sight (BLOS) frequency range, was simulated in MATLAB. Also, hopping from one frequency to another in a 30MHz frequency bandwidth was also simulated in MATLAB.

The results of both the simulations have been found satisfactory and the proposed theory and approach of using an SDR based UGV for covert surveillance can be implemented. Fig 8 shows the automatic switching from 500MHz to 29MHz.

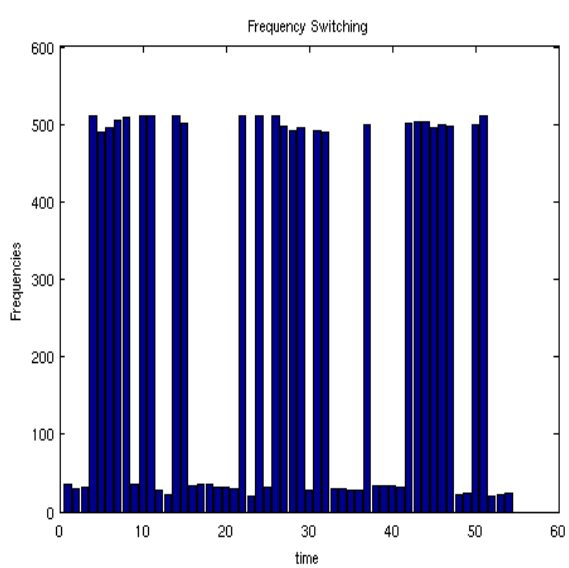

Fig 8. Automatic Switching from LOS frequency range to BLOS frequency range

Considering a frequency band of 30 MHz for frequency hopping, the graphs below shows how frequency hopping can be implemented within the said frequency bandwidth.

Fig 9 shows how frequency hopping can be implemented considering 500 MHz, following a random hopping pattern.

Fig 9. Frequency Hopping keeping 500MHz as centre frequency

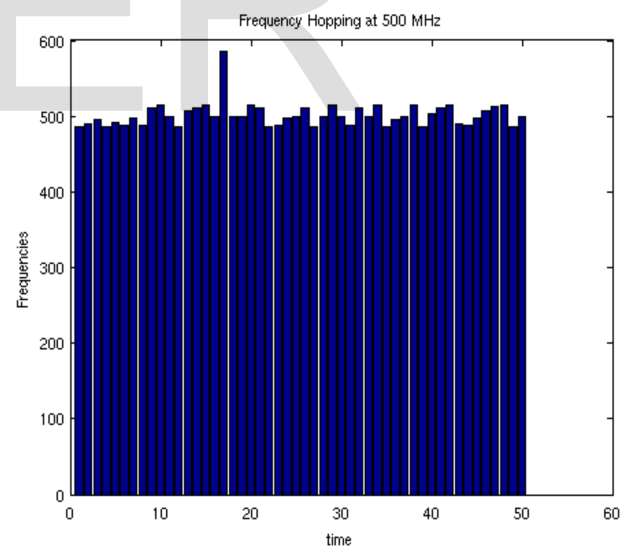

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Fig 10 shows how frequency hopping can be implemented considering 29 MHz, as centre frequency and hopping between 15MHz to 29MHz, following a random hopping pattern.

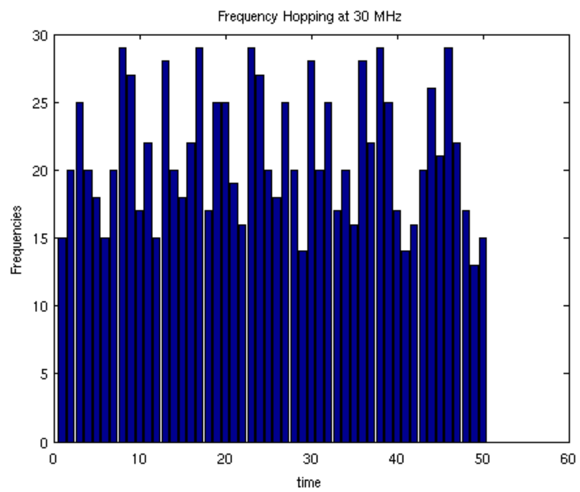

Fig 10. Frequency Hopping keeping 29MHz as centre frequency

7 Conclusion and Future Work

There are a multitude of UGVs readily available in the open market. The current UGVs are controlled by using Wi-Fi communication protocols, ZigBee or using a single frequency transmitter and receiver. Integration of next generation of Digital Radio such as SDR, with a UGV automatically combines the advantages of both systems.

With this design of the integrated system, not only the integration of SDR with a UGV is possible but also receiving the live video feed and controlling the motion of UGV through a frequency hopped signal is also possible, thus eliminating the effect of electronic jammer (if any) being used by adversary. With this integrated system, our effort was to harness the advantages of integration of SDR with UGV and also to develop / simulate a prototype of such an integrated model.

Potential future enhancements to this work include :-

1. Developing an integrated communication network using SDR based UGVs.
2. Remote mine detection can be incorporated using the SDR based UGV.
3. Remote firing, from a gun mounted on the UGV, can also be incorporated using this integrated model.

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