RF Indoor Intrusion Detection System

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Abstract— **In this paper a new RF (Radio Frequency) detection system has been descried. The proposed intrusion detection system uses one or more RF transmitters that emit RF into the space along with a well planed network of RF receivers for detection, the use of Degree of Angle (DOA) has been considered to locate intrusion. The captured RF signals are processed using developed digital space algorithms. Though in many aspects, the system works similar to that of ultrasound detector but, in this paper the immediate advantages of proposed RF Intrusion Detection System (RFIDS) with better clarity, higher frequency and higher speed of processing are highlighted. This system exhibits consistent reliable pattern of detection clearly distinguishable before and after intrusion. In such cases, even if the direct path is not obstructed, the reflected paths are definitely affected and hence the captured signals differ and can be analysed. In the proposed technique unlike the other sensory detection systems, there is no blind spot, which gives a truly contravene-less indoor intrusion detection system.**

Index Terms— **RF (Radio Frequency), DOA (Degree of Angle), RF Intrusion Detection System (RFIDS), Signal Processing.**

I. INTRODUCTION

Unexpected intrusion is a major problem in maintaining the security and safety of highly confidential protected areas. Current indoor intrusion detection systems use a variety of technologies, out of which Pyroelectric / Infra-red and Ultrasonic technologies are most commonly used systems to detect moving objects within a confined space. However, they require line of sight [1]. Video systems together with some kind of object recognition software are better alternatives to protect a wider area but still they suffers similar line of sight problem. In such systems, there are blind spots in the space that the intruder may be able to take advantage, and hence to defeat the purpose of the system [1, 2]. To overcome the blind spots, verity of techniques are proposed, some of them use combination of different hardware and software techniques.

For modelling analyses and predictive maintenance by Signal Patterns, the use of autocorrelation function for the following two purposes are recommended [1, 2]:

1. To detect non-randomness in data.
2. To identify an appropriate time series model if the data are not random.

Where for given measurements, $Y_1, Y_2, ..., Y_N$ at time $X_1, X_2, ..., X_N$, for the lag *k,* the autocorrelation function is defined as

$$\tau_k = \frac{\sum_{i=1}^{N-k}(Y_i-\overline{Y})(Y_{i+k}-\overline{Y})}{\sum_{i=1}^{N}(Y_i-\overline{Y})^2} \qquad \text{---(1.1)}$$

Although the time variable, X_i, is not used in the formula for autocorrelation, the assumption is that the observations are equi-spaced in time. Autocorrelation is then a correlation coefficient. However, instead of correlation between two different variables, the correlation is between two values of the same variable at time intervals $\boldsymbol{X_i}$ and $\boldsymbol{X_{i+k}}$.

When the autocorrelation is used to detect non-randomness, it is usually only the first (lag 1) autocorrelation that is of interest. When the autocorrelation is used to identify an appropriate time series model, the autocorrelations are usually plotted for many lags [3,4].

In signal processing, given a signal f (t), the continuous autocorrelation $R_f(\tau)$ is the continuous cross-correlation of f (t) with itself, at lag τ, and is defined as:

$$R_f(\tau) = f^*(-\tau)f(\tau) = \int_{-\infty}^{\infty} f(t+\tau)f^*(t)dt$$
$$= \int_{-\infty}^{\infty} f(t)f(t-\tau)dt \qquad \text{---(1.2)}$$

II. INDOOR INTRUSION DETECTION SYSTEM

In indoor security system using RF (Radio Frequency) signal processing, the knowledge of location, input - output signals and their pattern are essential. Usually, the location's regular signal pattern, in contrast with the feedback signal is known. If the feedback signal corresponds to the regular signal, it is normalisation case, and if the feedback signal does not correspond to the regular signal then it signifies an intrusion [5, 6, and 7].

In this paper the focus is not only to detect but also to locate the intrusion. In RF systems, it is considered to use DOA (Degree of Angle) to locate the intrusion. In 3D location, three angles have to be considered and determined namely; (1) angle of elevation, (2) angle of depression and (3) angle of horizontal turn. The 1-D autocorrelation coefficient (ACC) describes the relationship between X(i , j) and X(i , j+ τ) or X (i + τ, j), while the 2-D ACC describes the relationship between X(i , j) and X(i + τ_1, j + τ_2) in 2-D space. Simply, a 2-D ACC may be constituted by two 1-D ACCs. Assume the horizontal and vertical ACCs are $\rho_H = \exp(-\alpha_1\tau_1)$ and $\rho_V = \exp(-\alpha_2\tau_2)$ where τ_1 and τ_2 denote pixels' distance in horizontal and vertical

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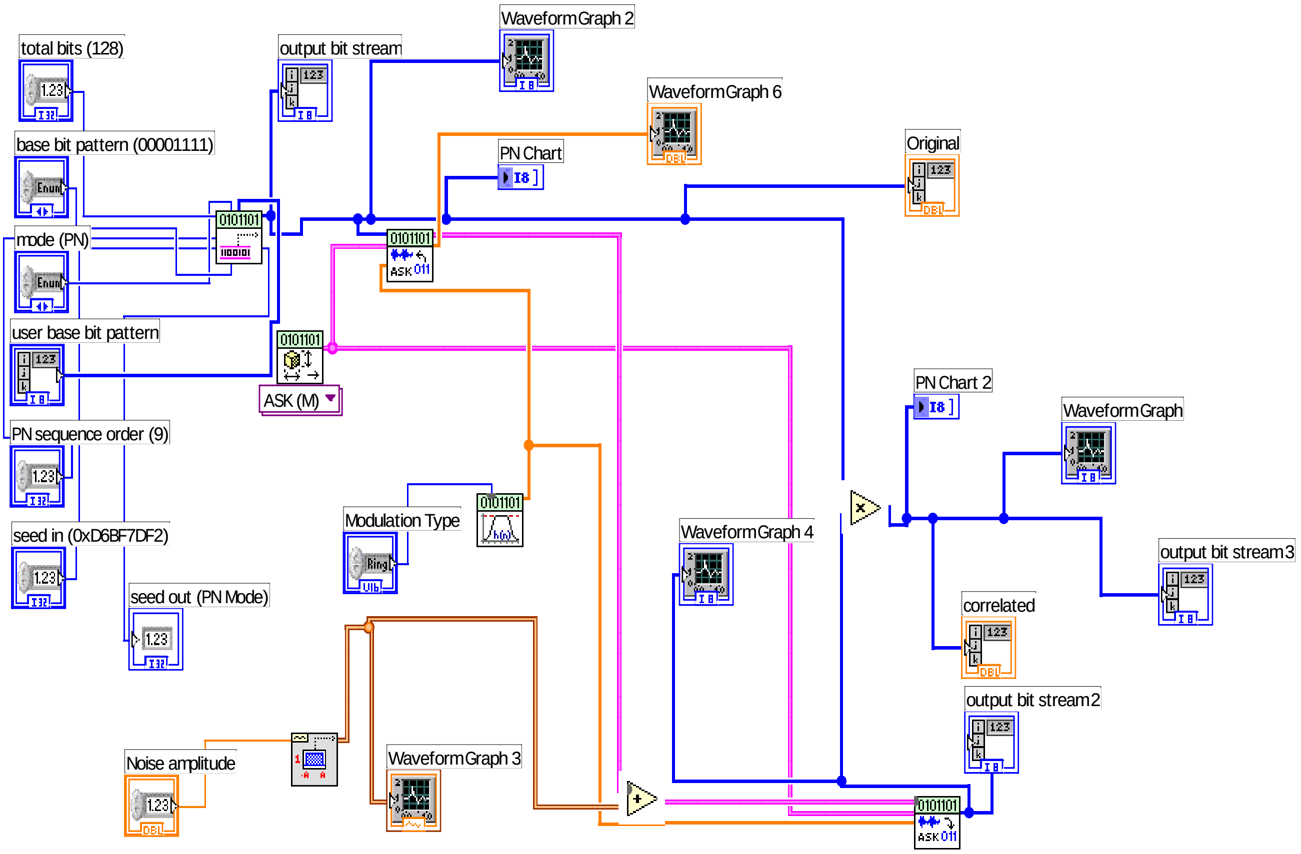

Fig. 1. Indoor Intrusion Detection System regular signal

directions. We get a 2-D ACC as in equation (2.1) :

$$\rho(\tau_1,\tau_2)=\exp(-\alpha_1\tau_1)\bullet\exp(-\alpha_2\tau_2)=\exp[-(\alpha_1\tau_1+\alpha_2\tau_2)] \qquad \text{---(2.1)}$$

Using the same method, it is possible to get a moving image's ACC (or so called 3-D ACC):

$$\rho(\tau_1,\tau_2,\tau_3)=\exp[-(\alpha_1\tau_1+\alpha_2\tau_2+\alpha_3\tau_3)] \qquad \text{---(2.2)}$$

Where $\exp(-\alpha_1\tau_1)$, $\exp(-\alpha_2\tau_2)$, and $\exp(-\alpha_3\tau_3)$ express intra-line, intra-frame, and inter-frame correlation, respectively; τ_3 & τ_2 indicate the distance of two pixels at position (i , j) of two frames; α_1,α_2 and α_3 are determined by the content of an image [8-12].

In the proposed technique, "Lab VIEW" was used for simulation and design of indoor intrusion detection system as shown in Fig.1. Here, the system compares received signal with that of regular signal while considering different types of reflections. It comprises single reflection, multiple reflections between parallel planes or multiple reflections within the media at various approach angles while determining the position of intrusion.

When simulating the radio characteristics of an indoor environment, we cannot ignore the trade-off between accuracy and time efficiency. Using deterministic propagation modelling Maxwell's equation to simulate radio propagation will produce results with accuracy close to actual radio propagation. However, it is time consuming and large computation resources are needed. Ray tracing utilises the fact that at high frequencies, radio wave behaves in a ray like fashion. Therefore radio wave propagation can be modelled as ray propagation Bertoni [13].

III. SYSTEM SIMULATION

Channel characteristics of radio propagation are generally affected by variation of signal strength, which has large-scale component and small-scale component. Large-scale path loss of radio propagation is modelled by predicting the average received signal at some arbitrary points / distance from a transmitter. Free space propagation model is usually used to predict the received signal strength when the transmitter and receiver have a clear, non-obstructed line of sight between them. Signal strength received by a receiving antenna with separation distance *d* can simply be represented by Seidel and Rappaport [14] free space equation (3.1):

$$P_r(d)=\frac{P_tG_tG_r\lambda^2}{4\pi^2d^2} \qquad \text{---(3.1)}$$

Where P_r is receiving power and G_t & G_r are antenna gain of transmitter and receiver respectively.

Path loss prediction models in an indoor environment have been intensively investigated to provide proper characterisation of wireless channels. Path loss prediction model in general is a function of distance to the nth power.

$$\overline{PL}(d)\propto\left(\frac{d}{d_0}\right)^n \qquad \text{---(3.2)}$$

where $\overline{PL}$ is the mean path loss and *n* is the mean path loss exponent. Path loss exponent represents how fast path loss increases with separation distance between transmitter to receiver (*d*) and the reference distance (d_0).

The absolute value of path loss is defined as the total path loss in dB from a transmitter to the reference distance (d_0) and the additional path loss from reference distance to the receiver (*d*) as explained in Feher [15]:

$$\overline{PL}(d)[dB] = PL(d_0)[dB] + 10\log\left(\frac{d}{d_0}\right)^n \qquad ---(3.3)$$

For indoor propagation, reference distance (d_0) 1 m is commonly chosen and PL(d_0) is assumed equal to 1 m free space propagation loss. Measurement results show that this assumption is considered to be valid and proposed by Seidel and Rappaport [14] as:

$$\overline{PL}(1m)[dB] = 20\log\left(\frac{4\pi}{\lambda}\right) \qquad ---(3.4)$$

The signal in indoor environment may go through walls and partitions. Partitions that are formed as part of the building structure are called hard partition and partitions that may be moved and which do not span to the ceiling are called soft partitions. To achieve more accurate result in characterising indoor radio propagation, the environment effects must be taken into account.

In an indoor environment, transmitted signals experience reflection, refraction and scattering and reach the receiver by more than one path. The resultant signal varies widely in amplitude and phase depending on the distribution of the intensity relative to the propagation time of the signal. This phenomenon is known as small scale fading effect by multi-path propagation. Two major effects of multi-path fading are:

1. rapid changes in signal strength over a small distance
2. time interval and delay spread as a result of multi-path propagation delays.

Multi-path fading greatly affects small-scale components of an indoor propagation channel. The small-scale components are the result of multiple radio propagation paths, which arrive at the receiver with different strengths, delays and phases. The multi-path signals can interfere constructively or destructively of the original signal such that the received power can vary up to tens of dB's. The large-scale variations are typically modelled as lognormal random variables while the small scale variations are usually modelled as random variable with Rician probability density function (PDF) for line-of-sight (LOS) and Rayleigh probability density function for obstructed propagation.

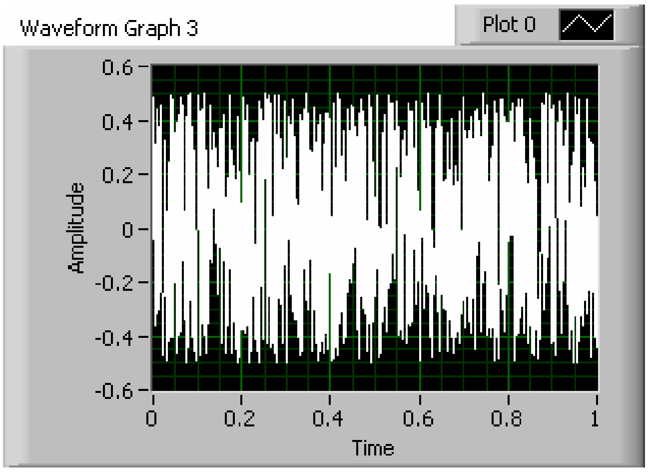

Fig. 2-a. Output Waves of Indoor Intrusion Detection System

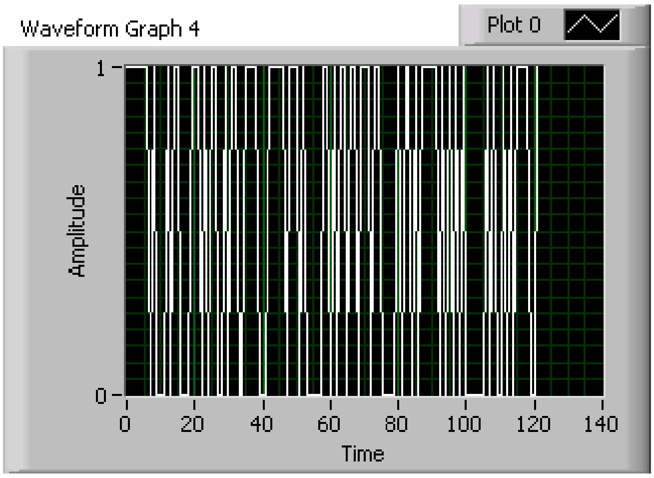

Fig. 2-b. Output Waves of Indoor Intrusion Detection System

Image method is suited easily for indoor radio propagation with low complexity of geometries and low number of considered reflections. In this case, due to high frequency, it can be assumed that reflecting planes in indoor environment behave like a mirror. Propagation path travelled by a ray from a transmitter to a receiver is obtained by connecting source to reflection point and then to the receiver point. When a ray undergoes multiple reflections, the image of the radio source with respect to a particular plane face is determined first, and then this source image is mirrored to another plane face until all relevant planes are finished. The application of image ray tracing is restricted to several reflections only, thus applicable to indoor environments only. For simplicity, there are two techniques to trace the complete path. One is forward ray tracing method when the image method starts at the source and traces the reflecting mirrors to the receiver. Another one is backward ray tracing method where it starts from the receiver and traces back to the transmitter location.

In order to determine the signal strength arriving at the receiver location, the calculation of the transmission and reflection coefficients of the complete propagation path is required. The radio signal can be categorised into a horizontal and vertical polarisation.

When a signal is transmitted through or reflected off a wall or partition, the degree of signal attenuation and the amount of phase change depend on the complex transmission and reflection coefficients, respectively. These are computed from the complex permittivity of the materials encounter the signal rays. This includes the LOS calculations and the single reflection method off the ground and parallel reflections along walls and non-parallel reflections

IV. CONCLUSION

In this paper, the proposed system and its challenges as involved in generalising the RF configurations for transmitting and receiving the signals have been considered.

Development of the required signal processing algorithms that can distinguish the presence of any objects in space was investigated and shown to be an efficient very reliable intrusion technique. With this system, calculations using the LOS, single reflection, multiple reflections between parallel planes and multiple reflections within the media at various approach angles showed very consistent results at the receiver end. The result of experiments and that of the simulator clearly showed a correlation between both the field distributions. This system exhibits consistent reliable pattern of detection clearly distinguishable before and after intrusion. In this technique unlike the other sensory detection systems, there is no blind spot, which in turn gives a truly breach-less reliable indoor intrusion detection system.

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