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Foreign Object Damage (FOD) Detection by Using Radar

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***ABSTRACT**: Foreign Object Damage is defined as a damage or debris which has occurred to aircraft, vehicle, or persons, that may be attributed to an alien substance or article foreign object which has entered any component of, on, or in the airplane. FOD is a term that described any tiny particle, debris or parts which are not belong on the airport pavement surface, so it may cause any damage or harm to the airplane which passes by. This paper explain using radar system in FOD detection. The comparison among several methods that used in detection FOD are also discussed in this paper. This paper shows the huge significant of using radar in FOD detection by compared with other techniques. The comparison show also that the BiSAR system is considered an appropriate approach of using as FOD detection systems. It confirm the ability of detection and localizing upon the ground parts that have a tiny a dimension such as two centimeter height with two centimeter diameter located several meters away.*

***Keywords:** FOD, Object, Radar, FSR, RCS,* BiSAR.

I. INTRODUCTION

Generally, FOD is related with military issues, where it isn't unusual to know about FOD Walks. So, walking shoulder-to-shoulder by ground personnel search an area through the pavement, stopping to detect and remove the smallest of debris or pebbles which may found it in runway onto the aircraft operations area as shown in figure 1.[1]

Figure. 1 (Sample of FOD upon runway)

The most important aim is to sweep any parts that may be harm to the airplane or even be Swallow by engine of airplane's then cause problems on aircraft operations. The same concern for FOD exists in civilian airports, but without using the resources to conduct a military-style FOD Walk. Generally, airport operators arrange 'airport inspections' by using regularly scheduled where they patrol the airport surface, search visually for any parts which might be out of the familiar , such as the existence of FOD. For instance, when seen any piece of FOD on the surface of airport, the pilots or air traffic control may send reports to the airport operators. In several cases, the exact location and type of FOD are wrongly given, then, airport operator will spend a huge time in looking the reported area. All of the darkness, weather, brume and traffic will complicate the looking of piece of FOD by the airport operators[1]. Therefore, it is very important to find alternative methods to detect this FOD such as design and develop radar system has good resolution and has the capability to detect small items , given the exact location and size of FOD. In this paper hardware system receiver of radar has been presented.

II. FOD DETECTION BY USING RADAR

Tentative study used forward scattering radar (FSR) and its applications to automatic ground target classification in [2]**.** Fundamental theoretical analysis of radar, algorithm of target recognition and classification subsystem as shown in figure 2 are discussed.

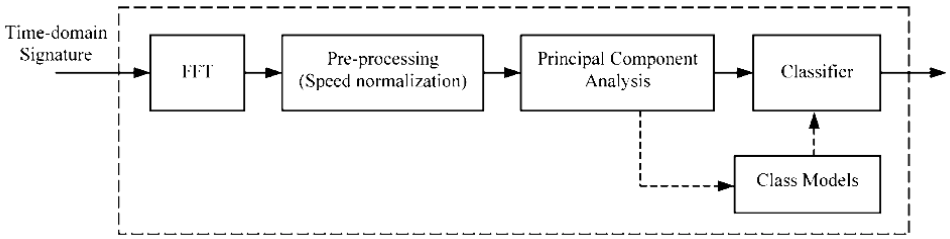


Figure. 2 Block diagram of the vehicle classification system

The effect of shadow inverse synthetic aperture radar is used in target recognition. The system contains (micro-radar) as microsensor with an operational distance restricted by (LOS) line of sight. odBm CW is generated as transmitter signal at band carrier frequency of 900 MHz with perpendicular polarisation. The signature of vehicle will obtained in receiver by using nonlinear processing, when receiving signal have both of the signal with the Doppler components and direct signal, is passed via an amplitude detector. Then, the low pass filter (LPF) lets Doppler component to come by only and it is the vehicle signature which is stored in the receiver. Offline classification system are also used to get a number of vehicle signatures for several cars. This kind of sensor gives sufficiently high sensitivity for target classification with robust to external conditions. However, there are unsolved problems, such as select the best frequency, a more exact with intelligent velocity estimation algorithm like a case for changing target velocity and an using extra sophisticated advantage processing and classification algorithms.[2]

Every year, the aircrafts industry are spend millions of dollars . That costs comes from spending of damaging the engines or airframes and comes also from changing schedule of flights for instance delays or cancellation flights as will also from other issues respective on the employees. from other side, there are an important issues related on the human life. FOD put the safety of the human life at risk when the aircraft at the risk. a survey of the aircraft industry has been indicated recently that FOD are reported as dangerous likely potential ground-based may be a catastrophic aviation event**[3,4]**. Our paper will answer these questions, the problems encountered of the systems to detect this FOD have been explained as well as answered why errors occur in some systems, then improve the current systems to get on best results.

In [5] they explained the FOD detection application by using (73- 80 GHz) mm-Wave front-end compact broadband, and the system design that have different low-profile, low-cost mm-Wave sensors located upon the runway as shown in figure 3. A small airport in South of France (Aix Les Milles) is also Tested. High sensitivity and simultaneous the capabilities of objects detection are achieved. However, some of objects are very difficult of detection as shown in the measurements. The overall size was not the critical factor in the tests specially the very thin plate (such as less than 5 mm) compared with a large size. Therefore, this technique has a problem in detect parts smaller than the nut.

Figure. 3 Sensor (planar folded that reflect array antenna)

While [6] the detection and classification of FOD has being ingested for a jet engine by using a low power microwave radar. They concluded that; using radar is considered successfully to detect most of the FOD events although two parts are not detected were both low (RCS) non damaging objects. On other hand, the classification has been 82 percentage achieved in probability of correctly classifying the damaging and non-damaging FOD.

The discussion of the FSR (Forward Scattering Radar) technique in [7] is presented that the possible applications and the limitations of FSR**.** The experimental results are supported in this research for the FSR

feasibility study in detection and classification the automatic ground target. The high sensitivity of detection and classification target in FSR have been confirmed in this study. It is also proved that FSR system has an enormous potential based on the presented result. It is considered as an alternative successfully system to detect ground target and classification . It is also suitable in several applications that currently microwave fences by using FSR for ground target classification.

Standard deviation method are used to estimate the velocity of FSR, the description of the FSR systems theory concisely with practical experiments in the same time to evaluate the possibility of like a system in real-life scenarios by [8]. Using ideal ground vehicle (like Lorry or car) as a target to collect all data in real experimentation. The proposed system calculate the standard Deviation of each raw radar signal. The Standard Deviation information is using to guess the velocity of the target. This technique gives a well results in evaluation the velocity of vehicle by FSR baseline. By analysing 850 experimentally the car signatures has been obtained, the system performance is evaluated and the system efficiency is confirmed. The proposed scheme gives a better efficiency when compared with the earlier scheme in (Blackman, et. al, 2000). This study also explained the possibility of extracting the extra hidden data by the FSR signal through signal processing scheme [8].

While in [9] the evaluation of the network of micro sensors FS radar has been discussed and detect of ground targets with classification it. The real experiments is discussed with FS radar systems theory in the same time to assess the possibility of such a system scenarios in real-life, in terms of resolution and power budget analysis. an excellent resolution is obtained and demonstrated in their study; the target's horizontal dimension is the same of the system potential resolution. The obtained also very high system dynamic range. They Presented in the last of study easy algorithm used in a small target detection when the signal is hidden inside the bigger target signal.

The FSR possibility with its automatic ground target application (AGT) classification has been undertaken. The essential theoretical investigation of the radar , the algorithm of target recognition as well the classification of target subsystem are presented in [2]. Using the impact of shadow reverse artificial aperture radar for target recognition. The also discussed in the last the results and set-up of experimental radar. The results obtained by applied experiments that advanced in-house. There are still few of unsolved troubles, such as the selectivity of optimal frequency, a extra accurate with smart velocity assessment algorithm together with a case for target velocity (non-constant) and an employment of a extra advancing advantage classification and processing algorithms [2].

While [10] discussed the Doppler signature and the problems of extracting in different interference environments. To predict the existence of target they used the Hilbert Transform and Wavelet technique. The complete analytical study of predicting the target existence by using FSR has been discussed after the description of the system. Then, the proposed algorithm has been evaluated by realising both sets of practical experimentation as shown in fig 4. Lastly, it concluded that; the proposed technique could detect the signal of the target under the influenced of high clutter successfully. The results proved that; the FSR could be used successfully to classify the automatic ground target system. However, future works discussing extra issues of Wavelet trends to be FSR ready in realising of real.

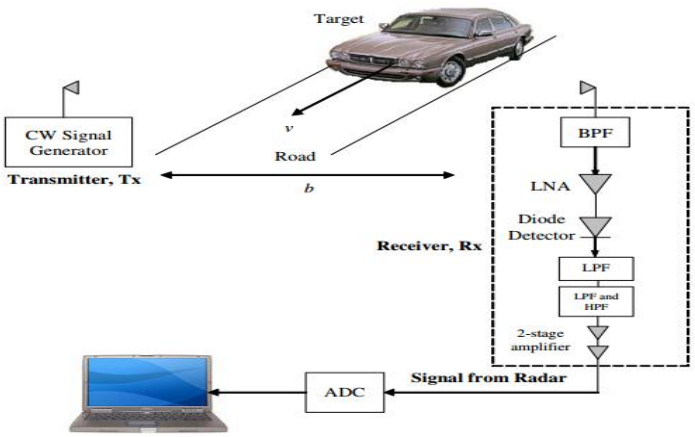


Figure.4 FSR outdoor experimental set up

In addition to [11] which is using FSR to detect ground target and present a signal processing algorithm as shown in fig 5. The impact of the procedure is shown using two experimental data and simulated depending on the corresponding filtering scheme, then calculate the relation between a some of pre-defined reference functions and the received signal.

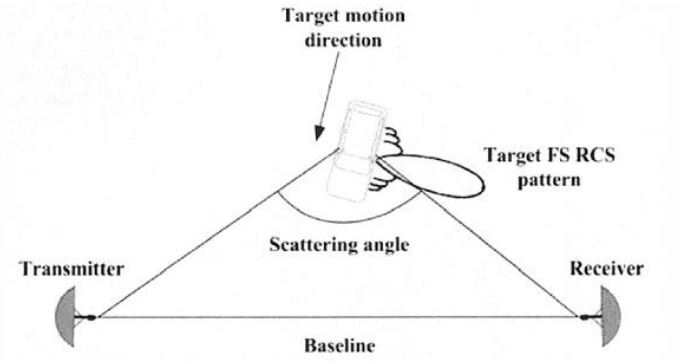
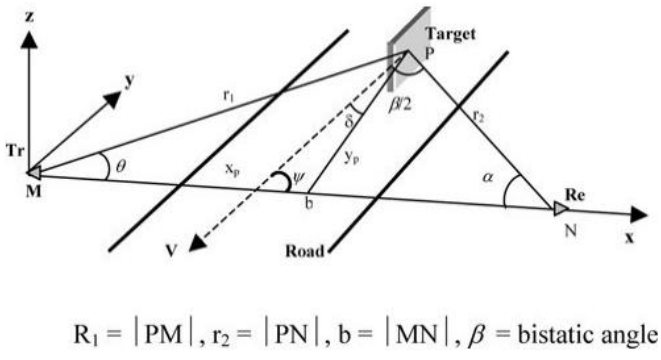


Fig.5 Ground FSR configuration

They also present the processing algorithm of quasi-optimal signal by using ground FSR, the target parameters have been appropriate definitions of, the velocity and passage point in specially. It is so important to Know the parameters if achieve the maximum SNR via signal compression. It was test the procedure for two of experimental data then simulated. The results of experimental was very good and show a good compatibility together achieved through simulation. Lastly, the algorithm of signal processing has the capability of finding the target and distinguish it in the received signal while still the system doesn't has resolution range [11].

They suggested a precise scheme to analysis of power budget to distinguish target on ground by using FSR. The range equation amendment is also utilized, the received power of target is definition as the crossing of both reflected and direct waves when good chosen of heights of both antennas that should be less than the wavelength of radar. The suggested FSR could be used for FER nodes of micro-sensor wireless network and considered as electronic fence for working lifetime to be capable of detect the targets on ground like humans or vehicles [12]. An Optimum algorithm to detect mini radar cross section (RCS) high-speed targets for bi-static FSR is suggested by [13]. The research is explained that the effectiveness of using correlation of filtering (Multi Channel) specially with this systems due to utilizes continued signal of quasi-harmonic.. Ideal treating of complex-linear-frequency-modulated-signal gives important reduction of losses energy inherent in previous method spectral analyses depending on time treating algorithms. Therefore, the suggested method of detection the high speed target develops to detect characteristic of FSR then increase the coverage[13].

An experimental study and analytical for distinguish the Doppler signature for ground target detection in FSR is presented in [14] as shown in figure 6.



$R_1 = |PM|$, $r_2 = |PN|$, $b = |MN|$, β = bistatic angle

Figure.6 FSR general layout

The signal of the target in high clutter influencing are effectively identified by suggested technique. The results are proved that the possibility of using FSR as an automatic system to classify the ground objects. However, to say the FSR system is ready as realised in actual application they propose method that contain applied cross range resolution of FSR as well a progressive classification scheme [14].

Meanwhile, the experimental studies and analytical of radar cross-section of air parts through bi-static forward scattering (BFS) radiolocation are presented in [15]. The detection zones of a BFS radar has been assessed then compared to those get it via field test. This exams of a full-scale prototype in a BFS radar gave a well covenant of the calculated as well the investigational guesses of RCSs of different air parts as well zones of radar detection. An active possible of a FSR was confirmed. The possibility of applied radiolocation of actual air pars has confirmed [15].

An developed joint time frequency scheme are used and assessed for Shadow image of BFS radar (BFSC). The advanced algorithm of joint time frequency achieved an effective and strong scheme to remove both of land mess and straight signal for shadow imaging of BFSC, that considered as aspects to impact the image quality [16].

While in [17], the effective noise intervention adaptive reparation algorithm in CW FSR with antenna array is discussed. The special advantage of utilizing antenna array was digital beam figuration achieved after determine the altitude in the channel receiver for elements of the array. The investigations results explained that the problem of effective noise intervention adaptive reparation was successfully resolved in FSR with antenna array , while performing the processing of space-time after detecting of altitude for the channels of receiver in the elements array. The best is utilizing Wiener decision. The special advantages for like this cases is actual correlation matrix of the intervention . what causes the figuration of both uniform gaps in the pattern of antenna array[17].

Finally, Synthetic Aperture Radar is suggested in creating the image of radar in the land and used for detection of the ground object which is using also for different applications like FOD, that is considered an significant issue in the safety of flying. A Circular-BiSAR is suggested in [18] as shown in figure 7.

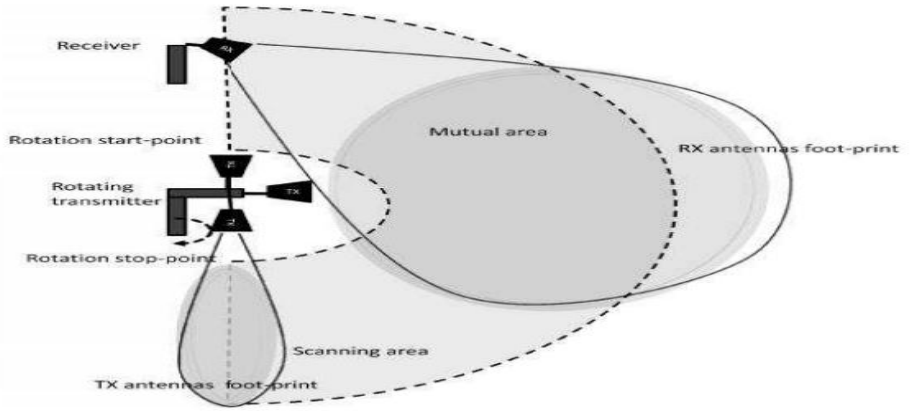


Fig.7 The layout of circular-BiSAR

The circular motion let it applied but the bistatic configuration gives several benefits. Wideband Linear Frequency (LFM) Modulated chirp pulses are used for both of transmitter then receiver of elimination pulses to and from the below test object. The model of simulated has been improved in this system that analysis the transmitter receiver, signals of LFM and Doppler by taking in the account both of the movement and the distances between antennas. A model system is introduced, as well as several experiments have been presented to distinguish and localize different objects depending on their refection features of microwaves. A processing algorithm has been also presented in [18] to prove the detection. The results confirm the capability of detection and localizing on-the ground objects with as small a dimension as two centimeter height and two centimeter diameter located several meters away [18].

III. DISCUSSION

The comparison among previous techniques that using to FOD detection are presented and discussed in Tables 1:-

Table 1

No.	Authors	Approach	Achievements	Demerit	Significant points in this technique

1.	[5]. P. Feil, W. *et al,. 2008.*	Using frequency (73-80GHz) mm-wave front-end	- High sensitivity. - - The capability of Simultaneous objects detection.	- Couldn't detect very thin object (<5mm).	Using high frequency
2	[6]. David J. et al,. *2000.*	High resolution radar development since the mid-eighties	- aircraft wake vortex detection - mine detection. - Using radar in monitoring the health of gas turbines. - Thus, the capability of classification and detection FOD entering the engine as damaging or non-damaging.	- Small error (<18%)	Development existing system
3	[7]. R.S.A et al,. *,2006*	Suggest using 890 MHz ground-based FSR for targets automatic classification using their Doppler signature	- Low cost. - Simple. - Easy to install. - Use narrow signal at low frequency. - Robust to any weather conditions.	- May can't to detect very thin objects, to using small freq. (as I see)	Using Doppler signature
4	[8] Mutaz Salahet al,. *2009*.	Estimation the velocity of FSR by using standard deviation approach.	- Measure vehicle velocity.		Measuring of Vehicle velocity by using relationship of time-domain signature with velocity of the vehicle as assessed from the captured video footage.
5	[9]. Mike Cherniakov et al,. *,2005.*	Using micro radar in ground target detection	- Simple algorithm of small targets detection.		ability to distinguish between two targets without refer to the distance between transmitter and receiver
8	[10]. Mohamed *et al,. 2008*	Using high frequencies to reserve the details and don't omitted it that don't effected by noise	- The capability of increase the transmitter-receiver distance to ~20m		Using high frequency
9	[11]. Chen et al,. *,2008.*	Utilizing of quasi-optimal	- Ability to extract the target	- Has no range	based on the matched

		signal processing algorithm for ground FSR depending on matched filtering scheme	range from the structure of the receiver signal.	resolution.	filtering approach
10	[12]. V. Sizovet al,. *2007.*	Detection of ground target by analysis of FSR with applications when the height of both antennas are less than wavelength	- Ability to detect ground target such as human and vehicles…etc	- omni-directional is distributed and only in space.	Using antennas in micro-radar sensors have not directivity practically due to their small dimensions and should be omni-directional
11	[18]. Mojtaba et al,. 2013	Suggest of Bistatic Synthetic Aperture Radar (BiSAR) in producing a radar image of the ground and used for the ground object detecting that used in Foreign Object Detection.	Ability of detection and localizing on-the land parts have small dimension such as two centimeter altitude and two centimeter diameter positioned on several of meters away.		Doppler and LFM signals taking into account both of the movement and distances of the antennas has been used.

IV. CONCLUSION

Typically, the word of FOD is utilized of describe any small part, debris, or particle which isn't belong on the pavement surface of the airport, that has the ability to cause hurt or harm to an airplane that passes by. In this paper explaining who using the radar system in FOD detection. Several researches that suggested different schemes of FOD techniques have been compared and discussed in this paper. The comparison and discussion show that the huge significant of using radar in FOD detection by compared with other techniques. The comparison also show that the BiSAR system is considered an appropriate approach of using as FOD detection systems. By some of adjustments will achieve more coverage. It confirm the ability of detection and localizing on-the land objects have a small a dimension as two centimeter height and two centimeter diameter located several meters away.

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