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Optronics in Integrated Air Defence

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Introduction

The aim of this paper is to review the use of Optronic sensors in Integrated Air Defence Systems, concentrating mostly on **Infra-Red Search and Track (IRST)** sensors. Optronic sensors are used today in **Very SHOrt Range Air Defence (VSHORAD)** and **SHOrt Range Air Defence (SHORAD)** weapon systems. Their operating range is typically 10 km or more, and they are particularly useful against low level targets. Optronic sensors are 'line of sight' sensors whose range performance is dependent upon the signal level emitted by the target (its signature) and the absorption of that signal by the atmosphere between the target and the sensor.

This paper concentrates on sensors which operate in the infra-red waveband between 8 and 12 micrometres in wavelength. Two distinct types of optronic sensor are used today :-

Thermal Imaging (TI) equipments, which are used to produce a picture of the target for classification and engagement purposes. The advantages of TI sensors are that they operate for 24 hours of the day and have the ability to penetrate certain poor visibility conditions, usually producing a picture of the target beyond the visual range to the target. TI sensors are widely accepted as an essential component of modern VSHORAD and SHORAD systems, and are in widespread use today.

Infra-Red Search and Track (IRST) equipments, which are used to search for targets, detect and track them before they are handed over to the weapon operator. IRST equipments have the same advantages as TIs of 24 hour operation and detection beyond visual range. They also have the advantage over the more widely used radar sensors that they are passive. A drawback of IRSTs is that, when used in isolation, they do not provide the range to the target. IRST sensors are not yet in widespread use, although they are expected to become increasingly adopted in future air defence systems. Indeed, ground based IRSTs have a number of benefits when considering the scenarios likely to be encountered by crisis reaction forces.

As well as providing a dedicated and automatic alerting capability for VSHORAD and SHORAD weapons, IRST equipments can also be networked to contribute to the **Local Air Picture (LAP)**. The networking can either be with other IRSTs to provide a fully passive system, or with radars to combine the advantages of both passive and active sensors.

This paper starts by discussing two specific operational areas:-

- The vulnerability of alerting sensors, particularly in relation to experiences gained from recent conflicts.
- The expected performance of IRST sensors against the evolving air threat.

Some results of track fusion experiments are then presented, followed by some suggestions for future developments to IRST sensors which would improve the overall effectiveness of future air defence systems.

Sensor Vulnerability

Recent conflicts have given an important insight into modern air defence tactics. In the Gulf War and in the Kosovo conflict an essential part of the allied campaigns was the Suppression of Enemy Air Defences, or SEAD. The air defence weapons aimed against the allies depended almost exclusively upon radar sensors for their effectiveness. Without radars these air defence weapons became virtually useless. The vulnerability of these radar sensors can be explained as follows :-

- **Easily detected.** Since radars are active sensors they emit electro-magnetic radiation which can be easily detected by approaching aircraft.
- **Provide unique signature.** The characteristics of radars which are used with specific air defence weapons are well known. The attacking pilot can often identify which weapon he is approaching and modify his attack profile to stay outside the engagement envelope.
- **Vulnerable to Electronic Counter-Measures (ECM).** Jamming techniques are used to make the radars ineffective, and this usually prevents the launching of the associated air defence weapon.
- **Vulnerable to Anti-Radiation Missiles (ARM).**
- **Subject to Emission Control (EMCON).** Radars which have not been jammed by EMC or attacked by ARM will often be switched off, to preserve them for future action.

IRST sensors are not vulnerable to the problems described above.

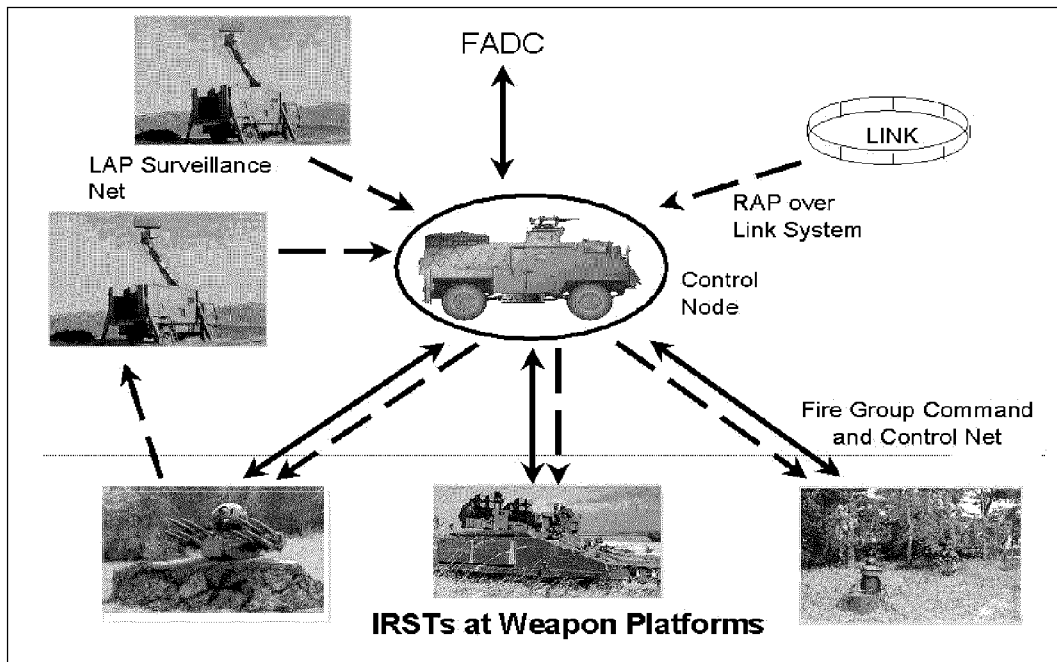
It is, therefore, not surprising that the allied air campaigns in The Gulf and Kosovo concentrated on SEAD, mostly directed against the radars. This was achieved by two main methods :-

- **The use of ARM.** In the Kosovo campaign last year more than 48 F-16s were deployed with ARMs, and by the end of hostilities more than 300 were fired against radars.
- **The use of EA-6B Prowler jamming aircraft.** 66 aircraft were in operation in Kosovo, which represented the balance of all of the aircraft available to NATO. The remaining aircraft were deployed on enforcement duties in Iraq. It is now recognised that there is a shortage of jamming aircraft, and plans are being considered to increase their number for the future.

The importance of the SEAD tactic to the NATO campaign in Kosovo can be understood when it is considered that out of the total number of 37,465 air sorties, 14,006 were SEAD missions. Also, every air sortie was accompanied by a Prowler jamming aircraft for protection.

It is clear that air defenders in the future will face significant difficulties if they rely entirely on radar sensors for surveillance. The most robust system will be a combination of radar and IRST sensors connected together in a network to provide C2 information to all firing units. A possible networked arrangement for the future is shown in Fig.1, with the IRST and radar sensor outputs combined at a control node. The shorter range IRST equipments are deployed with the weapons to provide local coverage, including effective detection against helicopters and aircraft using terrain screening. At the same time the IRSTs can also contribute to the LAP. This deployment provides a robust fallback mode in which the IRST sensors will remain fully operational, allowing autonomous weapon operation even if the active sensors and C2 network are lost.

Fig. 1 Future network concepts



The Evolving Threat

The air threat is continuously evolving. In the past the traditional fixed and rotary winged manned platforms have been most prevalent, but in the future there will be increasing numbers of **Unmanned Aerial Vehicles (UAV)** and cruise missiles. Future air defence systems must deal with these new threats. As well as reducing in size, these future targets will also reduce their signatures (reflections and emissions) by employing stealth technology. These two factors will result in both the radar cross-section and the thermal signature of the targets reducing significantly. The best chance of locating them will be provided by a combination of sensors.

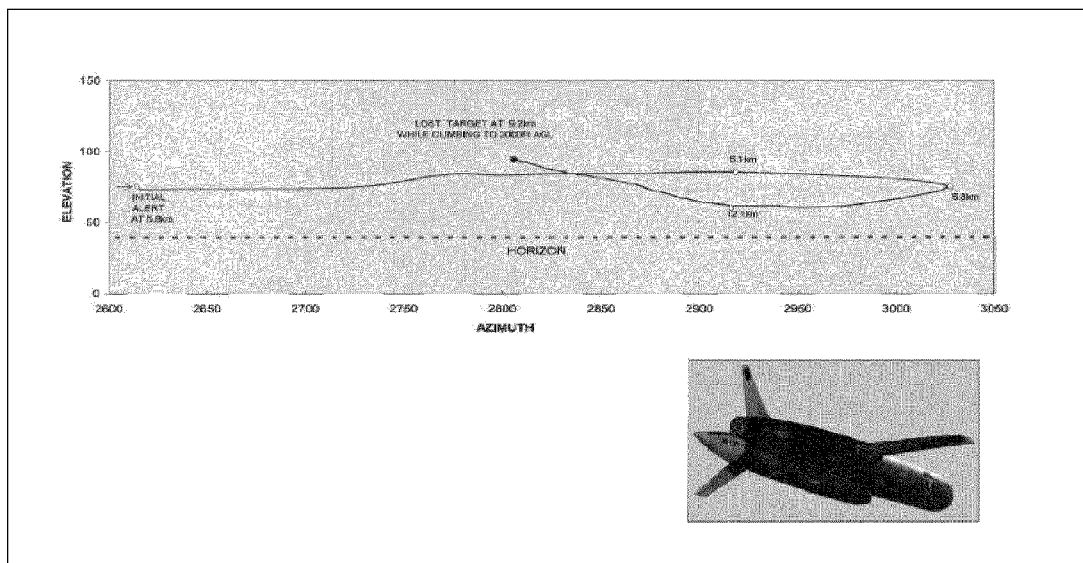
Dramatic reductions can be made in radar cross-section by shaping the outside contours of an aircraft to reduce the reflected signal. Thermal emissions can be reduced by burying the engines inside airframes and minimising the visibility of hot tailpipes. However, IRST equipments operating in the 8 to 12 micrometre waveband have good sensitivity against targets at ambient temperatures and can detect them by the thermal emissions from their skin surface, without the need to see the engines. These emissions are increased as the target speed increases due to the frictional heating of the skin as it passes through the air : a target travelling at high subsonic speeds suffers a temperature increase of more than 30 degrees Centigrade due to friction with the air.

Trials have shown that aircraft which are stealthy to radar can easily be detected by TI and IRST equipments. Indeed, the stealth coatings used on some aircraft seem to slightly increase the frictional heating with the air, and therefore enhance the thermal signature.

The lower signatures of UAVs and cruise missiles will require greater sensitivity from all sensors in the future, especially if they are to be detected under adverse conditions. However, current generation IRST equipments already have an effective capability against these threats. Fig. 2 shows the track of a BQM-74 drone, which is used to simulate a cruise missile, being detected and tracked by the UK IRST, ADAD (Air Defence Alerting Device). After being dropped from its carrier aircraft, the BQM-74 was first detected at a range of 5.9 km in good weather conditions, and was continuously tracked while it completed a circuit in front of the test area. It was lost at a range of 9.2 km when it deployed its recovery parachute. At this point it

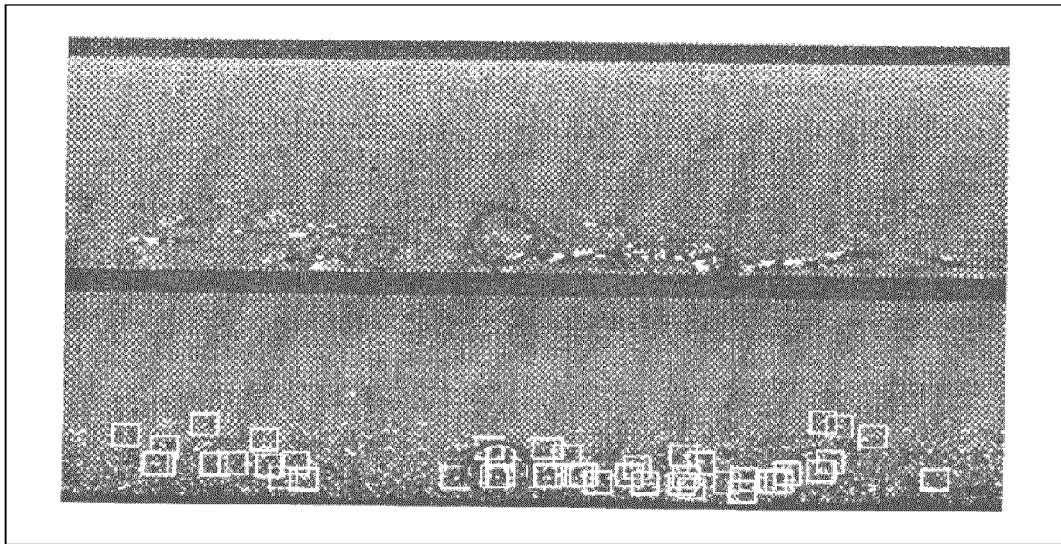
ceased to exhibit aircraft-like characteristics and the software algorithms within the ADAD processor rejected it as a true target.

Fig. 2 ADAD track of BQM-74 target drone



Another problem occurs for air defenders when sensors are attempting to detect low-level targets amongst the clutter arising from objects on the ground. Processing techniques must be sophisticated enough to discriminate real targets within the clutter background in these conditions. Fig. 3 is a frozen frame from the ADAD IRST video showing target detection in a heavy clutter environment. Such a picture was obtained using special test equipment, and is not available to the operator using a standard ADAD. The upper picture is unprocessed ADAD video, and the lower picture is the filtered video complete with detection boxes. The ADAD has detected a helicopter target (position marked by the circle) against a warm ground background which has a high level of clutter in the thermal waveband. The square boxes denote the clutter points detected by the IRST but rejected by the software algorithms because they do not have the characteristics of a real target. The operator is only aware of the real target, which is indicated to him on a separate display unit. As with most IRST alerts, the declaration range is longer than the visual range, and the high resolution thermal camera used to confirm the detection was unable to locate the target until it had approached closer, which was more than 15 seconds after the initial ADAD alert.

Fig. 3 Target detection by ADAD in a heavy clutter environment



Track Fusion

At the moment IRSTs are used as dedicated sensors, operating in association with a specific weapon platform. However, additional benefits can be obtained by fusing the track information from two or more sensors to provide more comprehensive information on the target and to provide a contribution to the LAP. Trials have been carried out fusing the tracks from two IRST sensors, and also fusing the tracks from an IRST and a radar sensor. The IRST/IRST fusion work was carried out by Pilkington Optronics together with the UK Defence Evaluation and Research Agency (DERA), and the IRST/radar fusion work was carried out by Pilkington Optronics, DERA and BAE SYSTEMS.

Fig. 4 shows the results of one of the early IRST/IRST fusion trials on an approaching helicopter target. Special software was used to fuse the two tracks of the same target. These tracks were separately declared by each of the two IRSTs before being fused. It is important to note that the IRSTs were not synchronised in any way, and so the individual detections made by each sensor were at different times, and therefore the target positions were different at the times of the detections. The IRSTs are located at the red spots in Fig. 4 and the fused track is shown by the blue line. The black line shows the target track as recorded by a radar for comparison. It can be seen that a successful fusion has been made from the two separate IRST tracks.

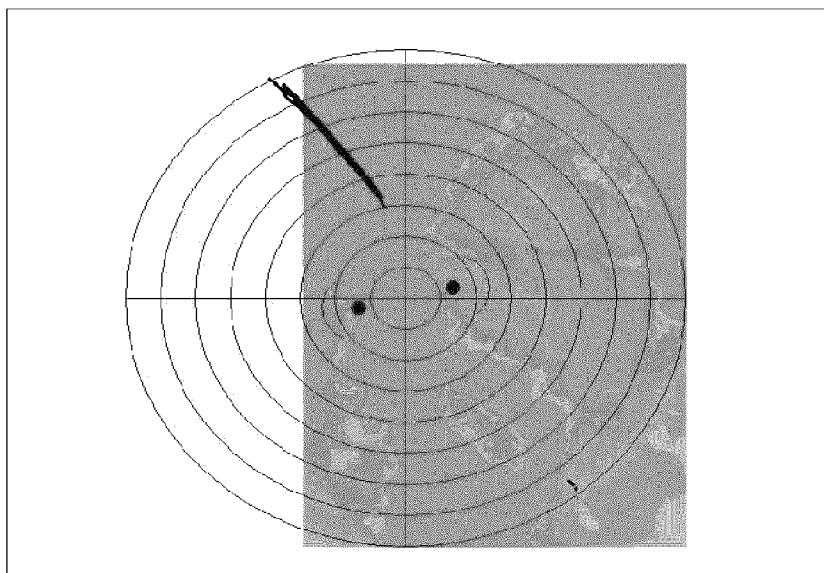
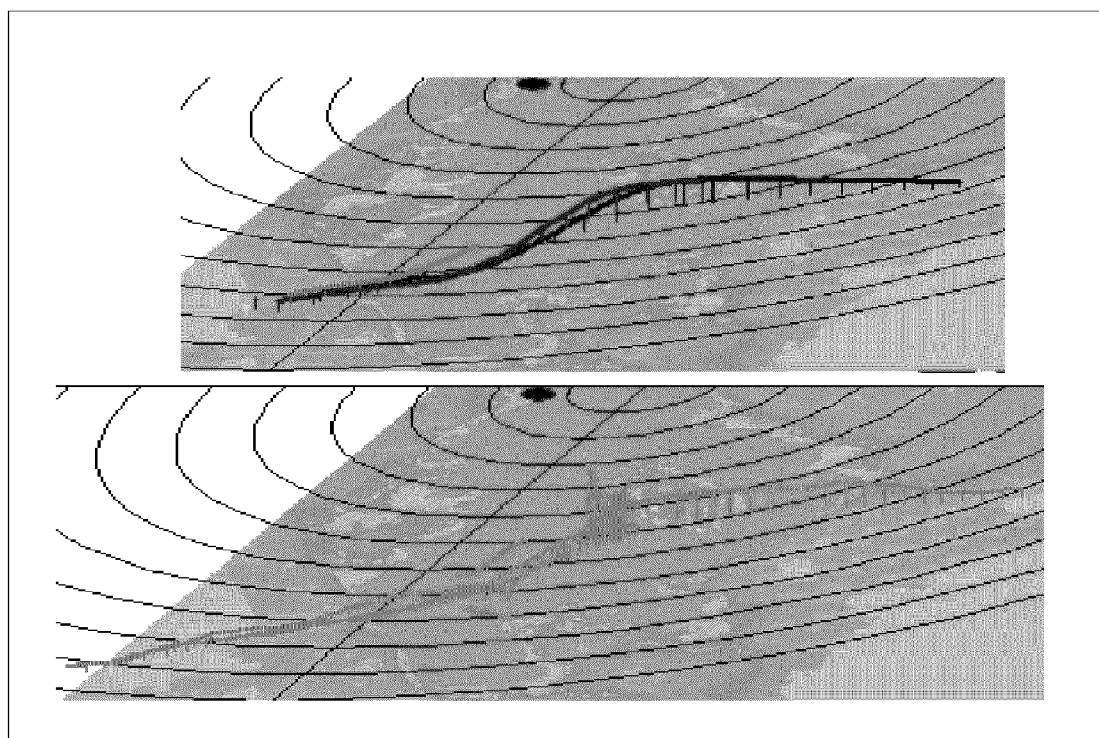
Fig. 4 ADAD / ADAD track fusion - helicopter

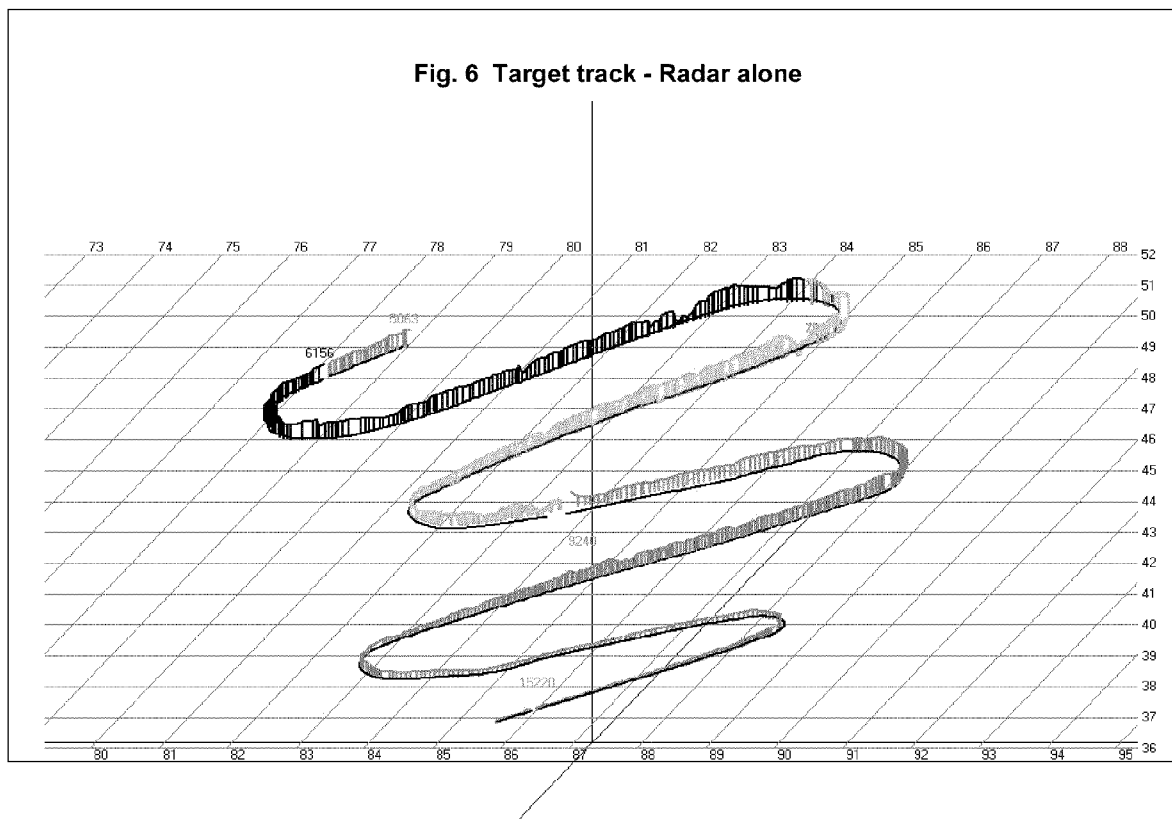
Fig.5 shows a further track fusion experiment with two IRSTs, this time on three aircraft following close behind one another. The picture is an isometric view, and this time the IRST fusion tracks and the radar comparison tracks have been separated into two views for clarity. Once again it can be seen that the IRST fused tracks have produced a true picture of the target tracks. Indeed, the higher resolution of the IRSTs compared with the radar has produced a very smooth and accurate 3-dimensional track of each target.

Fig. 5 ADAD / ADAD track fusion – 3 aircraft

The higher resolution of IRST sensors compared with radar arises from the shorter operating wavelength. This has benefits in addition to the smooth/accurate tracks mentioned above :-

- ***better spatial discrimination*** is provided between targets which are close together, giving earlier warning of a formation attack.
- ***virtual immunity to multi-path transmission*** effects, which means they are not susceptible to spurious detections caused by reflections close to the ground.

The IRST/radar track fusion work is still continuing, but some initial findings can be described here (these results were first presented as part of a paper at the VIIIth European Air Defence Symposium, Ref. 1). Fig. 6 shows the radar only track of a helicopter approaching on a zig-zag track. The solid black line represents the output from the GPS receiver on the target aircraft, which outputs the ground position but does not provide any altitude information. Altitude from the radar is indicated by the vertical bars, their absence indicates missed measurements. A different colour is used when a break occurs in the track and a new track is started. It can be seen that breaks in the tracking caused four separate tracks to occur, and the indicated altitude is quite variable. When the track data from one IRST is combined with the radar (Fig.7) it can be seen that a fully continuous track is achieved with better elevation information. In other words, the track has become more robust and more accurate. In this trial situation the IRST was co-located with the radar, although in a tactical situation the two sensors would be separated by a safe distance to avoid the IRST becoming damaged if the radar should be attacked by an ARM.



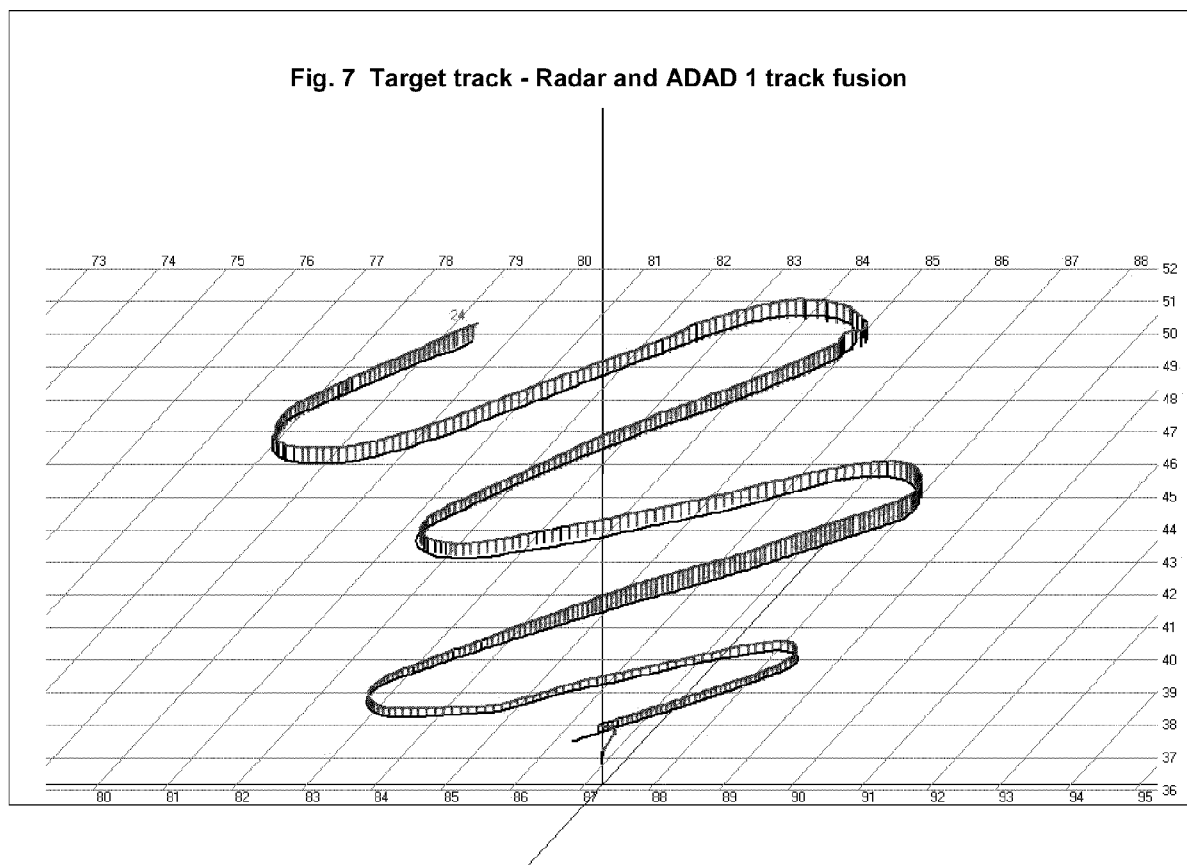
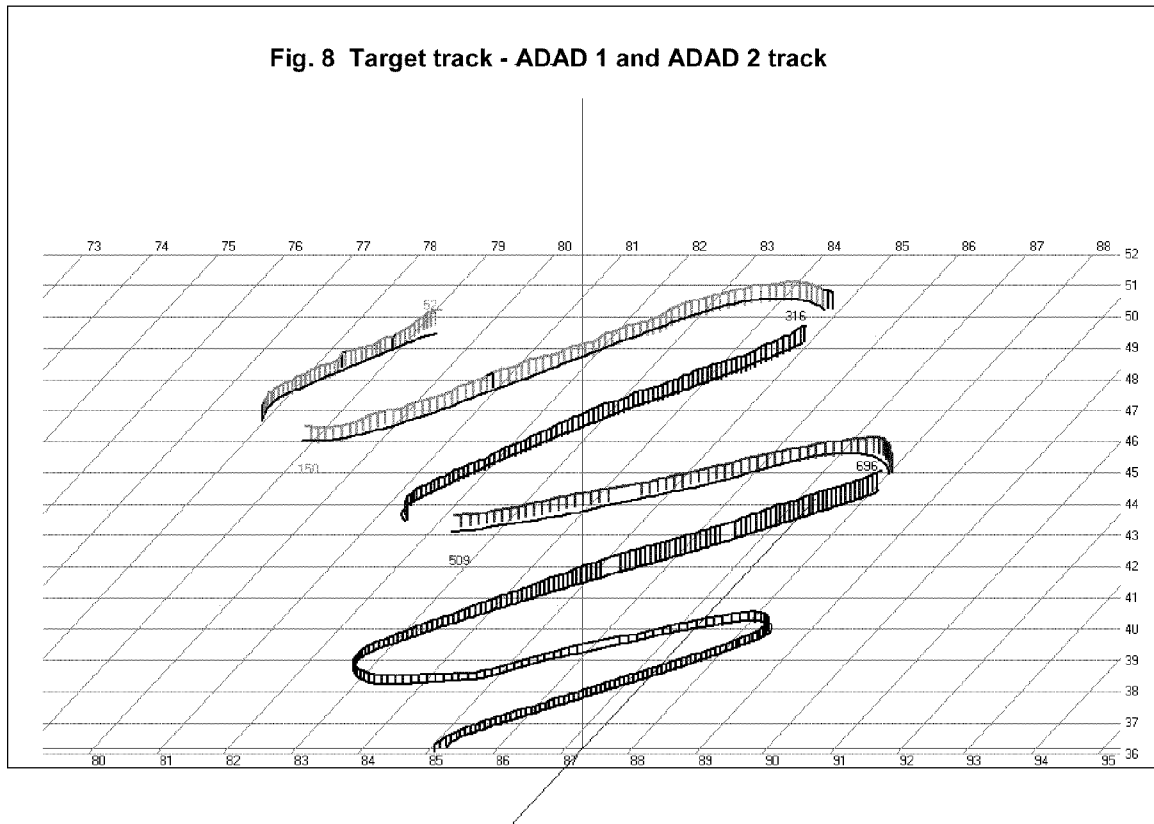


Fig. 8 shows the same mission as recorded by the tracks fused from two IRSTs, without the radar. Good target track information has been produced, although there are some breaks in the track at the turning points. This was caused by one of the IRSTs breaking track on the target for a short time and, although the other IRST was still tracking the target, the current prototype software is only designed to show a track when both are present. In this trial arrangement the two ADADs were only 1.6 km apart, which is not an optimum fusion arrangement because they both viewed very much the same aspect of the target.



These results show the benefits of networking sensors to produce a LAP. When all of the sensors are operating an accurate and robust air picture is produced, overcoming any minor shortfall in an individual sensor and providing more information than any of the sensors could provide on their own. If one or more sensor fails, useful target information is still produced. If the radar is not available due to the effects of ECM or ARM, the two IRSTs will still produce a high resolution target track in 3-dimensions.

One important conclusion which has come out of the multi-sensor fusion work is the need to know the individual sensor positions very accurately. Initial conclusions are that sensor position must be known with an error of 2 to 5 metres in three dimensions if satisfactory track fusion is to be achieved. Also, accurate time registration of the data is required, with a registration of better than one tenth of a second needed if agile targets are to be tracked successfully. These effects have been investigated by the Pilkington Optronics / DERA / BAE SYSTEMS team (Ref. 2).

The Future

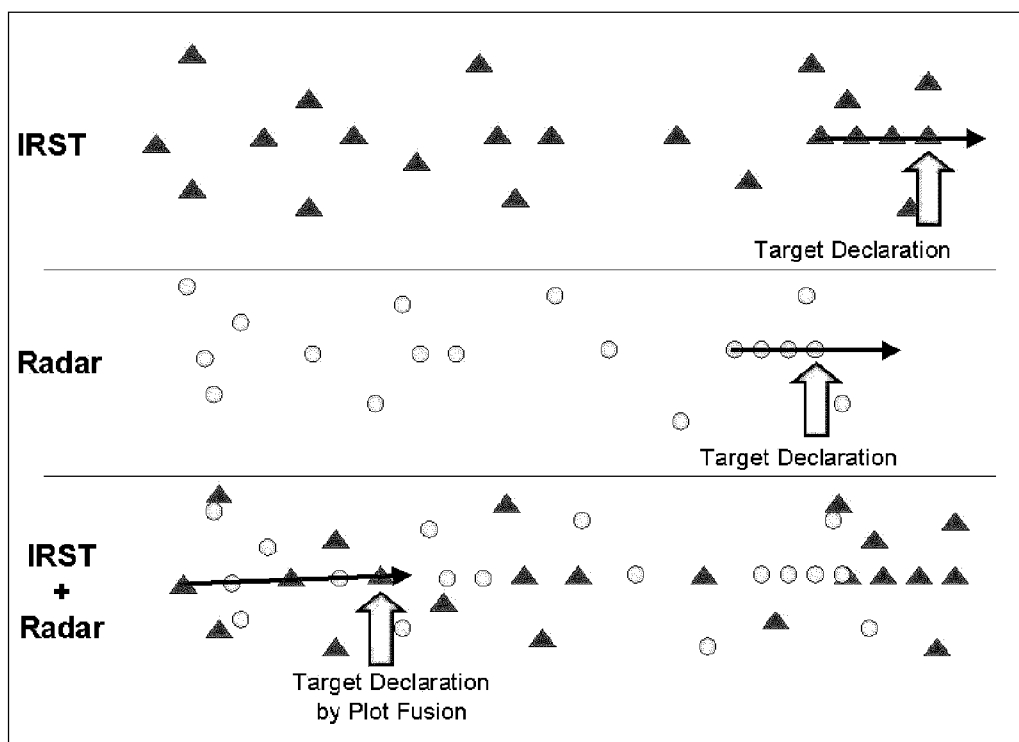
The commitment of air defence forces to IRST equipments for the future is now well established. In the recent JPG 28/30 feasibility study, both consortia of companies concluded that IRSTs would play a prominent role at the weapon platform in future VSHORAD and SHORAD systems. Also, they concluded that networking of sensor data will be required to provide information into the LAP. Also, in the UK studies have just started into the future air defence programme IGBAD, or **I**ntegrated **G**round **B**ased **A**ir **D**efence. It is certain that passive sensors will be a part of IGBAD, and it is expected that the next IRST sensor will either be a modified version of ADAD or a next generation equipment derived from ADAD.

Major evolution areas for the IRST sensor itself are increased sensitivity and operation on-the-move. Increased sensitivity, and possibly increased resolution as well, will be made possible by using future generations of detectors. This will enable targets with lower thermal signatures, e.g. UAVs and cruise missiles, to be detected at longer ranges and in a wider range of weather conditions. In addition, new scanning techniques will allow the possibility of reconfigurable scanning. This will mean that a very wide scanning area can be used to search for a target initially, which could be adjusted according to the perceived threat, e.g. a larger vertical field of view would be used for high attack angle targets such as bombs and some types of missile. After initial detection the scan area could be made smaller to achieve a more accurate track on the target and enable a smooth hand-over to the weapon. A picture output could also be provided to aid identification. All of these techniques are already being implemented in the airborne IRST, called PIRATE, which is currently in development for the EuroFighter Typhoon aircraft.

Operation of future ground-based IRSTs on-the-move will also be possible, so that surveillance can be carried out during mobile operations and during re-deployment. This will probably be an essential requirement for mobile crisis reaction forces. Once again, such techniques are already under development for the EuroFighter Typhoon. However, adaption of this technology for ground use is expected to be particularly demanding because the appearance of fixed clutter points which are 'streaming' past the sensor at close range will be similar to the tracks made by targets. New processing techniques and algorithms will need to be developed to ensure that an acceptably low false alarm rate can be achieved.

The benefits of track fusion have already been discussed. The challenge for the future will be to carry out sensor fusion in real time. Also, it will be necessary to establish simple and universal interfaces to achieve a genuine 'plug and play' concept, so that sensors can easily be added to or removed from an air defence network.

One important area for future research will be to achieve plot (or detection) fusion between two independent surveillance sensors. All sensors create plots of targets before these can be associated into a robust track, which is then classified as a target and declared to the operator. Often, target plots exist within the sensor processor long before a target track can be formed. The fusion work described earlier in this paper has been carried out using target tracks already declared by the sensors. If individual plots could be fused from separate sensors, there is a possibility of creating a coherent target track at a longer range than either of the two separate sensors could achieve on their own (see Fig. 9). Plot fusion also allows the possibility of lowering the detection thresholds of the individual sensors because the better correlation between the sensors will allow better false alarm rejection and clutter rejection. This will allow a further increase in detection range. The recent trials carried out by Pilkington Optronics, DERA and BAE SYSTEMS recorded plot data from the sensors as well as track data. Future analysis work is aimed at fusing this plot data and, hopefully, demonstrating the benefits described above. One word of caution must be mentioned with regard to the fusion of plot data : the data rate and computing requirements are much more demanding than for track fusion. The realisation of plot fusion in the battlefield will require large communication bandwidths and large computing power.

Fig. 9 Plot fusion concept

Conclusions

This paper has described the benefits of optronic equipment for providing effective passive sensor systems for air defence weapons. They can overcome the problems of vulnerability associated with active sensors, and they can also cope with some of the problems of the evolving threat : low signatures, low level operation and high clutter environments.

Initial trials have shown that significant benefits can be obtained by networking passive sensors with other passive sensors, and with active sensors. Future work on plot fusion should enable networked sensors to provide an accurate and robust LAP, with longer ranges than are currently possible with track fusion.

Optronic sensors can clearly offer a major contribution to the safe operation of Mobile Crisis Reaction Forces.

Acknowledgments

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