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Real-Time Information Fusion in Military Systems

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ABSTRACT

With the proliferation of sensors on platforms like battle ships and aircraft, the information to be handled by the battlefield commanders has significantly increased in the recent time. From a deluge of information flowing from sensors, the battlefield commander is required to make situation assessment in real-time and take appropriate action. Recent studies by cognitive scientists have indicated that decision making by individuals as well as a team suffer from several biases. For these two reasons, the battlefield commanders need assistance of real-time information fusion systems to take objective assessment of a highly dynamic battle situation in real-time. The real-time information fusion system at a single platform level as well as that applicable for geographically distributed platforms is discussed in detail in this paper. It was concluded that by carrying out these activities at the platform level as well as at 'global' level involving several platforms, the limitations in performance of any sensor due to propagation effects or due to enemy counter measures can be significantly minimised or totally eliminated. At the same time the functional effectiveness of each sensor onboard different platforms, becomes better than when it had to operate autonomously within the real-time information fusion facility. By carrying out global real-time information fusion activity in a theatre of war, all the platforms operating in the area will have the benefit of the best sensor in that area on each aspect of the capability. A few examples of real-time information fusion systems are also discussed.

1. INTRODUCTION

Information fusion is the process of arriving at a conclusion/situation assessment based on properly weighed large amount of connected information. It is easy to

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appreciate that in military systems, this is expected to be done at the time of hostilities, when the time available for the fusion activity is extremely small,the battle situation is continously changing and the information being received from different sensors on a single platform or from various platforms themselves may be incomplete, and/or inaccurate due to propagation effects and misleading due to enemy tactics. In the recent past, the number and variety of sensors on a platform (like helicopter, aircraft or ship) and ground have increased manifold, to enable surveillance, detection and identification to be carried out under hostile and unfavourable conditions. The field commanders are expected to arrive, in extremely short time (fraction of a second to few seconds), at a decision based on this deluge of information from sensors. The variety of sensors and the sources of information (like messages coming in) are very large. The sensors could be sonars, radars, lidars, thermal imaging systems, low light level TV systems, or ESM systems. In addition, decision is also to be based on intelligence reports on the enemy sightings, and possible intentions which the field commander had been briefed about. How can one person or a small team arrive at a correct situation assessment in a very short time and take expected action, which in almost all circumstances, includes taking a retaliatory action against the enemy in the shortest possible time? How can the field commander unerringly prioritise the threats facing his platform/location and engage that threat on priority with his team's limited resources? How does he optimise the allocation of his own weapon/countermeasure systems against the threats he is facing in a dynamically changing situation?

These problems are being studied in depth in the recent years by congnitive scientists[1], artificial intelligence (AI) practitioners and military system designers[2-5]. Interestingly, the cognitive scientists found that human decision-making process by an individual or a team, definitely suffers for some congnitive biases. Hence it may be stressed that the need for real-time information fusion arises not just because of the huge volume of information that the present day field commander may be receiving, but also because it is established that his decision-making process may, in all cases be suffering from personal biases. With the commendable progress made in the field of AI (especially in expert systems), image processing, sensors and processor chips, real-time information fusion systems are a reality for message-type of information as well as for imagery. In this paper, after discussing the background information for the issues to be handled, the methods used to handle information fusion is presented with some examples of information fusion systems that are entering into service elsewhere in the world. While doing this, the problems in achieving this in real-time are stressed. The paper concludes with one or two suggestions on what can be done in this field in the near future in our country.

2. BACKGROUND INFORMATION

Till a few hundred years ago, major battles were fought in the full view of the commanders on both sides. The scene that readily comes to our mind is *Geetopadesam* with armies of Kauravas and Pandavas facing each other. However, due to the technological advances, the area of action has extended far beyond what is visible and the weapon systems used have become quite diverse and numerous in any battle situation. Traditional method of using a single sensor like radar or a single communication facility has yielded place to the concept that, by simultaneously employing several sensors using several sensing techniques—both passive and active—much more detailed information about the battle situation can be gathered. The result is that immense volume of information is now available to the battle field commanders. It was soon realised that such vast amount of data cannot be utilised, especially in real-time, to carry out situation assessment by single individual like the field commander and even by a team of well-trained persons who may be engaged in handling the situation. Let us first examine the possible short-comings of a single individual or a small team of trained individuals, say, geographically distributed commanders who have to arrive at an accurate threat assessment in real-time.

Bushnell *et al.*[1] have examined how a team of geographically distributed decision makers who receive information from autonomous sensors at their own locations and communicate with each other, arrive at a joint assessment of the situation. They have studied this problem under conditions where, the team members have different information processing expertise, and their (extremely simple) sensors have different information gathering capabilities. They have also examined whether the assessment arrived at by a member of the team depends on his own earlier briefs and beliefs and/or the order in which that team member has received information from other team members. A real-time experiment was developed to simulate an environment in which the team members performed simple information fusion activity. Prior to the experiment the team members were trained extensively, but experiments were conducted with only two members representing a pair of geographically seperated commanders handling a dynamically changing situation. While the teams were permitted to discuss the strategies and coordination issues before the experiment, the two team members could communicate with each other only on computer terminals during the course of experiments. In all, 1280 individual information fusion processes were analysed and the investigators concluded that the team members indicated four cognitive biases in their information fusion process, under all experimental conditions. These are :

(i) The team members consistently overweighed the most recent information, i.e., they exhibited 'strong recency effects'.

(ii) The team members tended to use prior knowledge that they had about the situation as an anchor to judge the information that they obtained during the experiment.

(iii) The team members consistantly underweighed the other team member's information quality or expertise.

(iv) The team members did not discount the common prior knowledge as a result of communications received during the experiment.

This study clearly brings out that by their very nature, the battlefield commanders—even working under normal conditions, much less under conditions of stress and uncertainty—who are required to handle a deluge of information from sensors giving out data of uncertain and variable quality cannot be expected to arrive at the correct situation assessment in real-time, without technology coming to their aid. Information fusion techniques using AI techniques can substantially reduce this problem and bring it into the realm of a manageable problem.

In any military operation, large number of sensors are being used for several reasons. Some of the reasons are: the increase in the performance/price ratio of various sensors, different sensors being sensitive to different wavelength bands ranging from acoustic signals in the case of sonar systems to microwave and millimetric wavelengths in the case of radar systems, optical and infrared (IR) wavelengths in the case of optical and lowlevel light TV systems, thermal imaging systems, IR systems, etc. and communication systems operating at frequencies ranging from HF to millimetric waves. The propagation effects on these sensors depend upon the frequency of operation and so the deleterious effects due to propagation conditions will not be the same on all sensors or communication facilities if they are operating at different frequencies, which is a great advantage at all times. Another important reason for simultaneous deployment of several sensors is the fact that by appropriate processing of data from different sensors, information that is unavailable from a single sensor can be generated. For example, Woolett[6] has reported that by combining data from a millimetric wave radar and forward looking infrared (FLIR) system, target identification and tracking is possible at a much higher confidence level than by using either of the sensors alone. Similarly, the thermal image of an object gives information about the surface of an object which visual image of that object cannot give, whether it is camouflaged or not. Few other reasons for using multiple sensors are, increase in the number of hostile targets to be detected and/or tracked in the area of interest to us and also to provide graceful degradation of our own capability in case of sensor malfunction. With some of these considerations, the present methods of formulating, in real-time, the tactical picture of a dynamically changing battle situation which depends heavily on the expertise of a hierarchy of trained operators who are obliged to work in conditions of stress and uncertainty are beginning to be replaced by single or extremely limited number of devision makers who are significantly assisted by real-time information fusion systems.

In an interesting article titled 'Information storage—a case for the less the better', Hingorani[7] has drawn support for the theme of his article based on what human brain does. He pointed out that human brain spends as much effort in throwing away information as in accumulating information. He pointed out that nearly 30 per cent of information that we gather is not useful because it is incomplete; another 30 per cent of information is just disjointed facts and they cannot be put together in a coherent manner to mean anything. That leaves only about 40 per cent of information that we accumulate to be useful and most often this information constitutes what in particular human being regards as important information at that time. For example, survival skills, driving and writing skills, etc. are remembered by us while host of other information is forgotten. Similarly the updated information on what we remember—like the changed telephone number, revised departure of a flight which is delayed—is remembered but not the earlier (unrevised) information (unless, one is all the time comparing the latest announced time of departure of flight, with what was the original schedule). It is believed that the brain does not just store the information in its raw form, but evaluates and assimilates only that information in which it is interested and discards (forgets) all the other information. Similarly in the case of human vision also, the total information that the eye can see in a second and make meaningful sense of it, cannot be processed for a similar purpose even by the largest supercomputer in the world. The brain is believed to be able to do this by selecting what it regards, at that instant, as significant information from the scene. Thus, the human model memory organisation and information utilisation by the brain, may provide some guidance to develop information fusion systems.

3. INFORMATION FUSION TECHNIQUES

It is appropriate to mention that, in this paper data and information are not used synonymously. Information stands for the relevant knowledge which is generated as a result of data processing activity by the sensor subsystem. While (raw) data by itself is not useful for drawing any conclusions, the information even from a single sensor is useful to understand the situation to some extent. In a real life situation, it is correct to assume that there are several platforms with a diverse variety of sensors on board each of them, with the sensors collecting data on the surrounding area of interest. In order to get a better/more accurate understanding of the situation, the raw data received by various sensors on a platform can be analysed by a central processor on the platform. Let us regard each platform or ground location (having several sensors) as one node. As processing costs are coming down and communication costs are going up, most of the signal processing is done at the sensor subsystem itself, and the resulting information only is passed on to the central processor on board the platform to carry on local level information fusion. The resulting information is used by that platform for its own defensive and offensive actions, prioritisation of its own weapon assignment. A coherent 'global' picture of the situation is then generated by 'fusing' the information available from each of the nodes.

Most of the time, the number of targets is larger than the number of sensors available on a platform. All those sensors on board, whose performance is not hindered/severely deteriorated by the propagation conditions or enemy countermeasure actions, collect data in four-dimensional world of space and time. As a result of processing of kinematic data, the present and future positional information of all targets is calculated. Based on sensors like IFFN (identify friend, foe or neutral) and heuristics, the identity and intention of each target is established by each node/platform. In local fusion of information also, heuristics are used—like data from the sensor which gives the most accurate positional and velocity information under the existing propagation conditions, being given the greatest weight in finally arriving at the location and velocity of each of the targets. Here it is appropriate to mention that for nearly three decades studies are being carried out on methods of multiple target tracking. An excellent book by Blackman[8] gives all the methods currently in use for multiple target tracking.

Wooley[9] and Llinas[10] have compared classical and modern methods of multiple target tracking and indicated conditions under which some methods are more effective than others. These methods are classical inference technique, Bayesian influence technique, Dempster-Shafer evidential technique[11,12], cluster analysis, estimation theory techniques including maximum likelyhood estimates (MLE), Kalman filtering, weighed least squares and maximum entropy techniques. It is interesting to note that in each of these techniques some heuristic inputs are needed.

Classical inference technique needs *a priori* hypothesis to give probability of an observation. Bayesian method updates the likelihood of a hypothesis based on previous likelihood estimates and additional observations. Dempster-Shafer method specifies the level of uncertainty associated with the derived information. Cluster analysis can be used for analysing data based on heuristically chosen *ad hoc* classifications. Techniques based on estimation theory can use observations corrupted by noise to give the best estimate of the state. Entropy method is useful to measure the information content associated with more than one hypothesis which are themselves empirical or subjective. Few other techniques like fuzzy set theory are also being tried for decision-making in the presence of uncertainty. It is appropriate to emphasise that the input information for these methods could be the positional co-ordinates of a target, ESM data and direction of arrival information (as seen from the sensor), classification of friend, foe or neutral of the target, or any other attribute of the target. Thus it becomes obvious that, if several sensors on a platform collect/receive data about the targets and generate 'information' by local processing of data, some of the information will turn out to be complimentary and some amount of the data will be redundant. Hence even if the quality of data received by some of the sensors is affected either due to propagation effects or due to willful enemy action like employing electronic countermeasures, the target detection, classification and tracking does not get effected significantly. Thus by 'fusing' the location information and attributes of each target available from the data processors associated with each of the sensors at a node, a fairly accurate threat assessment applicable to that node could be made.

Earlier it was mentioned that for each of the methods of analysis mentioned, some heuristics are required as inputs. Wherever heuristic inputs or heuristic reasoning is involved, a properly designed expert system would be of great assistance[13] to the decision maker for arriving at the correct conclusion free from personal biases. The objectivity as well as the correctness of the decision depends upon the vastness and integrity of the knowledge in the knowledge base (KB), and the validity as well as the accuracy of the spatial and temporal information that is being generated by the sensors on board the platform (node) which also forms part of the KB, which in this respect is constantly being updated/refreshed. A simplified diagram of this expert system (ES) is shown in Fig. 1. It consists of a KB, inference engine, black board, and interface unit. Knowledge in the KB is organised in the form of 'IF THEN rules', based on extensive efforts put in by knowledge engineers to understand the intuitive part of reasoning of sensor operators, intelligence analysts, strategists, battlefield commanders and policy makers, etc. KB has got in a structured form (like lists, frames, schematic networks) the attributes of all the targets likely to be encountered, as well as the attributes of all the weapon systems and countermeasure systems onboard the platform. KB has also embedded in it all the facts and algorithms for the methods of detection, tracking and identification mentioned earlier. The information that is getting generated at each of the sensors (as a result of local processing of data being

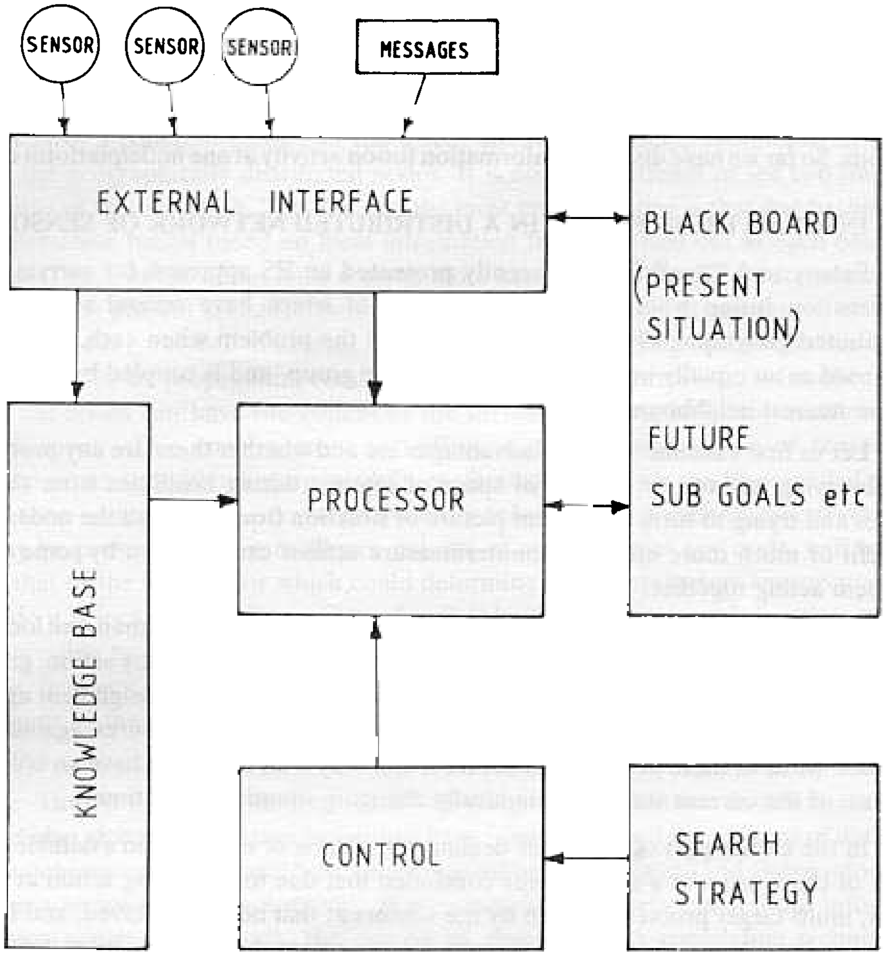

Figure 1 **Simplified model of expert system.**

received by the sensors), as well as the messages coming from other nodes, will enter into the KB of the local information fusion system through the interface facility with least amount of intervention/participation of the operator manning the information fusion expert system. The ES will display the current information about the dynamically changing targets needed by the operator, and what counter action is expected to be taken by him. The ES can also display how it has arrived at its conclusions and the recommendations (like weapon assignment, etc) are also indicated by it to the operator. While this description of the information fusion system is not too detailed due to paucity of space, it should nevertheless emphasise the point that its success/effectiveness depends upon the robustness, validity, vastness of its KB, the expertise of experts whose knowledge/expertise is engineered into the KB, the complementary nature of information flowing from different sensors. Several of the earlier mentioned methods are simultaneously used for analysing the temporal information being gathered by each of the sensors on various targets, as well as on the information gathered simultaneously by various sensors on board the platform. The above mentioned analysis will generate as far as that platform (node) is concerned, the most dependable situation assessment as seen by that platform based on the data collected by its sensors whose capabilities and characteristics are complimentary and are not too severely affected by the propagation conditions or enemy-initiated countermeasure actions. So far we have discussed information fusion activity at one node/platform only.

4. INFORMATRION FUSION IN A DISTRIBUTED NETWORK OF SENSORS

Fahmy and Titus[14,15] have recently presented an ES approach for carrying out information fusion when the platforms, each of which have several sensors, are distributed geographically. They have examined the problem when each platform is regarded as an equally important member of the group, and is coupled by data links to the nearest neighbours.

Let us first examine what the advantages are and whether there are any problems in observing an area or volume of space of interest during hostilities from several nodes and trying to form a coherent picture of situation from which all the nodes may benefit or much more effective countermeasure actions can be taken by some or all of them acting together.

The important benefits of gathering the information from more than one location are: better geographical coverage, greater survivability in case of enemy action, greater options to take countermeasures and much more effective weapon assignment against threats, minimising the effects of enemy's electronic countermeasures against our sensors. Most of these benefits will accure if and only if all the nodes have an accurate picture of the current state of dynamically changing situation at all times.

In the earlier part of the paper dealing with fusion of information available from each of the sensors at a node, it was concluded that due to the fusing action at node level, multi-target problem as seen by the sensors at that node is resolved, and target tracks and attributes of each of the targets (to the extent that the sensors at that node could detect, and the information fusion system at that node could infer) are available at the node. Now the information fusion process should process the dynamically changing information from different nodes and arrive at a consistent assessment of the overall situation (global situation).

First problem to be handled is to use the information (from local information fusion systems) from two adjacent nodes, and kinematic information of targets detected by each node to 'merge the tracks' of targets seen by both the nodes and also identify those targets which are seen by either of the two nodes but not by both the nodes. For achieving this, the multi-target tracking methods discussed earlier (to merge the tracks of same target seen by different sensors at one node) are used. Apart from the kinematic information, target attributes as determined (viz., ESM data, radar or IR signature data) by the sensors at the two adjacent nodes, and any associated heuristics which might have been used in the local information fusion systems at the two nodes are also used for this purpose. Another important test that is done before any two tracks (one from each of the two adjacent nodes) are merged is that the two tracks are referred to a common future time instant by applying Kalman filter prediction equations, to test whether the two tracks indeed refer to the same target. The new information thus generated as a result of fusing information from two adjacent nodes updates the information at both the nodes. With the resulting information as the basis, information fusion activity is carried out in the same way as was done for single node with adjacent nodes till all the nodes are covered, at the end of which all the nodes will have a coherent picture of the threat environment being monitored by sensors on the geographically distributed nodes. It is not very difficult to see two important results of this approach. The first and the most important one is that due to this global information fusion based on local information fusion carried out at each one of the nodes, each of the nodes have a much more accurate and detailed information of all the targets present at that instant in the surveillance volume of any sensor at any one of the nodes (provided of course, that the sensor's functioning was not, at that instant, too affected by propagation conditions or enemy countermeasures). In other words, all the nodes can have the benefit of the surveillance data collected at any node by any sensor. This enables more cost-effective distribution/location of sensors with different and complementary capabilities. Similar arguments can be extended to show that the accuracy of positional and velocity information of each of the targets which may be present in the surveillance volume of any sensor at any node, will be equal to that of the best sensor which could determine these parameters irrespective of the node it is located and the number of such (identical) sensors used. In other words, it is possible to have a mix of extremely accurate sensors and sensors with somewhat less accuracy, judiciously mixed and deployed at different nodes and still get the benefit of the presence of the most accurate sensor at one or few nodes or at all the nodes.

Thus it is evident that by locally carrying out information fusion at each node and also global information fusion, we have indeed reduced the amount of data which the field commander would have been required to handle if local and global information fusion techniques were not used. If we examine the locally carried out information fusion action at the node, the process of applying track correlation techniques by using one (or preferably few) of the suggested methods, data reduction takes place. The very process of correlation will help in ignoring the inconsistent portion of the data, thereby reducing the data to be handled. For example, if we assume that the ESM system is putting out a digital description word of *n* digits, *m* times per second, the direction of arrival (DOA) information arriving each of the *m* times will not exactly be the same, even if the emitter and receiver are stationary, because of the very method of determining the DOA. As a result of carrying out information fusion locally at that node, the inconsistent DOA information can be ignored if one of the radars is able to give the azimuthal information accurately. Similarly the information given by ESM receiver about the jammer characteristics will enable the radar system at the same node to call in the ECCM features (internally available for the radar) to ensure that even under those conditions the radar performance is not seriously affected. Similarly the heuristic features in the KB of the information fusion system will also reduce the search space for arriving at the most realistic threat perception, including possible intentions of the platforms in the surveillance volume covered by the sensors. Similar arguments are valid about substantial reduction of information to be handled if information fusion activity is carried out at each node as well as globally.

Information fusion methods based on AI techniques and pattern recognition techniques called templating techniques are regarded as more powerful techniques for global information fusion. A hypothesis of complex association of targets that are likely to be present in a scene form *a priori* defined pattern or a template. With the targets in the scene and their association being established by local information fusion centres, the detected pattern is compared with *a priori* defined pattern to draw conclusions. By using several possible templates in this pattern recognition process, scene recognition becomes a quick and manageable activity. As targets of military interest have to, most of the time, be deployed in association with one another, the templating is regarded as a powerful method of detecting the content and intent of a scene.

5. EXAMPLES OF SOME EXISTING INFORMATION FUSION SYSTEMS

Some real-time information fusion systems with military application are reported in literature. Survey of published literature indicates that much less than ten real-time information fusion systems are operationally deployed by late eighties while several may be under various stages of development. It is very interesting to note that several information fusing techniques are used simultaneously in each of these systems. This is apparently done to minimise the consequences of limitations of one or some of the techniques employed in a particular scenario. The most commonly used method is the ES method. Several systems under development also seem to have rule-based ES method as one of the several approachs simultaneously employed in real-time information fusion systems. Templating technique is frequently used for global information fusing in real-time.

Groundwater[16] has reported development of an information fusion ES which would assess the mission and destination of ships of various classes detected in the area of surveillance. The system needs correlated tracks of each of the vessels, track histories, locations and attributes of these and other vessels in the area of interest as input. It uses an event-driven real-time ES using OPS 5 production system on VAX/VMS environment and uses Franz Lisp programming language. When the paper was published in 1984, the system was able to estimate the mission and destination of only one ship at a time. Work was in hand to extend the capability to handle modest number of ships at a time. It was also planned to add to the KB factors like prevailing weather conditions and indicate information source accuracy so that the real-time decision-making process will be completely realistic.

Bennelt[17] has described a real-time information fusion system called 'The Air Defence Executive' which deals with threat assessment and resources allocation in real-time. The threat assessment was carried out by fusing information coming from radar and other sensors, electronic surveillance sensors, and intelligence reports. For reasoning, Inferno[18] method of approach, with object-oriented processing was found to be effective for situation assessment. An independent scheduler could pick up highest priority targets to enable resources (weapons) allocation—all these being done in a highly dynamic battle environment. It was stressed that the Air Defence Executive was developed 'as an environment for experimenting with AI techniques in the air defence domain and not as a product to see service in the near future'.

Rawles[19] described two information fusion facilities called 'All Source Analysis System' (ASAS) for the US Army and 'Enemy Situation Correlation Element' (ENSEC) for the US Airforce. These two systems carry out information fusion of tactical and strategic intelligence reports to assist battlefield commanders. These are developed recently by Jet Propulsion Laboatory. It is believed that over one million lines of code are used to run its Operating System and application programmes. It has multi-level security features to enable it to handle information of different grades of security simultaneously, with none being able to overstep security classification. An advanced version of ASAS called ASAS-X which is expected to use ESs to a greater extent than ASAS is under conceptual stage of definition.

6. CONCLUSION

It is not possible for field commanders to handle the deluge of sensor data that will be coming in continuously during hostilities. It is not possible for even a small team of well- trained experts/analysts to be able to carry out an objective assessment of the threats in a dynamically changing situation in real-time, free from personal biases and priorities and initiate counter actions like carrying out the deployment of the most optimum resources, evasive actions etc. By carrying out information fusion in real-time at local level, the limitations that may be experienced in any of the sensors on the platform due to propagation conditions prevailing at that time, or due to enemy initiated electronic countermeasures at that time can be significantly minimised or totally eliminated. At the same time, the functional effectiveness of each sensor on board that platform becomes, in each aspect, better than that of a single sensor if it were to operate autonomously in the same environment. Similarly, by carrying out area information fusion activities in real-time, all the platforms operating in that area will have the benefit of the capabilities of best sensor in that area on each aspect of the capabilities. Information fusion systems operating in real-time are beginning to move from concept proving stage to operational deployment stage just now. It is the right time for DRDO and Services to give urgent attention to this field as the effectiveness of existing sensors on different platforms like ships and aircrafts can be significantly enhanced by carrving out local and global information fusion in real-time.

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