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Comments on airborne ISR radar utilization

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ABSTRACT

A sensor/payload operator for modern multi-sensor multi-mode Intelligence, Surveillance, and Reconnaissance (ISR) platforms is often confronted with a plethora of options in sensors and sensor modes. This often leads an over-worked operator to down-select to favorite sensors and modes; for example a justifiably favorite Full Motion Video (FMV) sensor at the expense of radar modes, even if radar modes can offer unique and advantageous information. At best, sensors might be used in a serial monogamous fashion with some cross-cueing. The challenge is then to increase the utilization of the radar modes in a manner attractive to the sensor/payload operator. We propose that this is best accomplished by combining sensor modes and displays into 'super-modes'.

Keywords: radar, ISR, utilization, modes

1 INTRODUCTION

The trend in Intelligence, Surveillance, and Reconnaissance (ISR) collection systems is towards multi-sensor, multi-mode systems. A typical suite of sensors for an aircraft might include

1. Electro-Optical (EO) Full-Motion Video (FMV),
2. Infrared (IR) FMV,
3. Synthetic Aperture Radar (SAR) with Ground-Moving Target Indicator (GMTI) radar, Dismount-GMTI (DMTI), Inverse-SAR (ISAR), and other maritime modes,
4. Hyper-Spectral Imaging (HSI) sensors,
5. Signals Intelligence (SIGINT) and Electronics Intelligence (ELINT) sensors, and
6. Automatic Identification Systems (AIS).

There are obviously many more sensors that might fit various ISR missions.

In spite of the availability of a suite of sensors, often the operation of this suite is delegated to as few as a single sensor payload operator. This is particularly so for Unmanned Aerial Vehicles (UAVs), also known as Remotely Piloted Aircrafts (RPAs). Furthermore, these sensors are typically not integrated beyond perhaps the ability to cross-cue between them. The radar itself is typically multi-mode, often including several SAR modes, several GMTI/DMTI modes, and perhaps Maritime Search, ISAR, and other modes. This means that perhaps a single operator needs to manually select which sensor onto which to focus his attention, and which mode to operate, generally to the exclusion of all others, particularly in tactical situations where decisions have to be made real-time. Any sensor coordination is done manually by the already overworked sensor payload operator. Nevertheless, sensors are typically used in a serial monogamous fashion. As a consequence, typically the most easy-to-use and intuitive sensors such as EO/IR FMV receives preferential usage, with others such as the radar are often severely underutilized. In fact, the very popular UAV-based EO FMV has been termed "Predator-porn", or "crack-cocaine for the commander." The payload operator training reflects this. This impediment to efficient usage of the entire sensor 'suite' is probably the single biggest handicap to current tactical ISR systems. The greatest instrument in the world is useless if it is never turned on.

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A typical reaction amongst radar system proponents is to attribute this to a lack of operator training on the utility and utilization of radar. Military and other government agency schools for payload operators are very EO/IR-centric, often with very little training on SAR/GMTI or other radar modes. The sentiment in the radar community then becomes "If only we can train the operators better, then they will love our radar and use it all the time (instead of their other sensors)." While more training for sensor operators is never bad, this approach does not address the fundamental truth that EO/IR FMV is easier and more intuitive to use than any radar modes or products, and will always be the sensor of choice when available, and by a large margin. Training would have to "break" this natural behavior before inducing a new practice. This will be difficult at best, and more likely not at all achievable. Insisting on a second operator dedicated to the radar is typically a doctrinal change, and also not at all very likely.

Recall that to a radar operator, the radar 'is' the command/control console and display. He is generally oblivious to radar functionality except as it interacts with his controls and display products. The solution to increasing radar utilization then lies in the adage "If you want your radar to be used, you have to make it easy to use." This means that "if you want the radar to be turned on, you have to do it in a way so as to not turn off the favored EO/IR FMV sensor (or indeed any other sensor)." That is, the radar needs to operate in a manner to "augment" other sensors, and not to "replace" them, not even for just a little while. This also means minimizing any competition for the attention of the operator.

The answer is 'not' to move some knobs around on the radar console, or even more elaborate designs for the radar operator interface. The fundamental need is to off-load the sensor coordination task from the sensor payload operator, and assign this to an automated mission executive function (computer), that acts as an intelligent assistant to the payload operator. The radar needs to be cognizant of the other sensors, and blend itself into the other sensors' operation and information display accordingly.

We propose herein to address this problem of tactical radar utilization by elevating the radar from the back-seat role that it typically fills. The strategy is to integrate the radar into the other sensors' operation by fostering an automatic coordination between them, both in operational control, and in integrating their data/information products. The integrated sensor products will add situational awareness without adding to the burden of the payload operator. In this fashion, the radar will add operational benefit without adding operational cost. While specifically addressing the UAV platforms, the proposals herein are applicable to any multi-instrument ISR payload sensor suite. This is NOT classical sensor or data fusion. In addition, this is 'beyond' sensor cueing.

Herein we will concern ourselves primarily with integrating SAR/GMTI radar modes with EO/IR FMV sensors. However, at times we will comment on other synergistic groupings as well. For example, to add further utility to both EO/IR and radar sensor data, we advocate to also integrate all sensor products with 'library' data such as Digital Terrain Elevation Data (DTED) and archival imagery such as from Google™ Earth. We also recognize that image manipulation is very processing-intensive. However, the advent and advance of Graphical Processing Unit (GPU) technology, and similar image manipulating engines, allows unprecedented image processing abilities. Finally, we stipulate that anytime we automatically adjust the control of one sensor based on another sensor's information, we are talking about cognitive actions. As such, the concepts discussed herein dovetail with cognitive sensor operation, including cognitive radar concepts.[1] This paper abridges an earlier more comprehensive report.[2]

2 DATA DISPLAY

Herein we are not concerned about how data is saved or stored in a computer or memory archive. Rather, we discuss how the data is displayed to a tactical user. We distinguish a tactical user from a more conventional image analyst in that a tactical user typically has a more urgent need to extract information from his sensor suite to make real-time decisions, whereas a more conventional image analyst has the luxury to be more studious of his data set.

2.1 Perspectives

The world is essentially 4-dimensional (4-D), with three spatial dimensions and one time dimension. The spatial dimensions answer "Where?" and the time dimension is no less important in answering "When?" An image is inherently 2-dimensional (2-D). A video is generally merely a time-sequence of 2-D images.

Consequently, an image, or even an image stream is necessarily a projection of the 4-D world into a 2-D image, or image sequence. That is not to say that 2-D images cannot be augmented with information to tell us something about the collapsed or otherwise missing dimensions. This is routinely done with elements like contour lines and time clocks. Nevertheless, what we view on an information display is generally a 2-D projection. This of course means that we should take some care in choosing the projection, or perspective, that we wish to display. Clearly, choosing a wrong perspective or leaving ambiguity in the knowledge of the perspective can render displayed data effectively useless. Choosing a perspective is not always straightforward, because different sensors offer different degrees of accuracy and precision in the various dimensions. For example, EO/IR sensors offer native dimensions of azimuth and elevation angles with respect to the sensor boresight, whereas SAR offers range and azimuth native dimensions. We do note that since the beginning of radar there have been a variety of radar display formats, each with advantages and disadvantages for various purposes.[3,4] We offer however that there are two principal perspectives that are natural and/or intuitive for modern tactical ISR displays. They are

1. Plan View, and
2. Platform View.

These are illustrated in Figure 1. We discuss these two perspectives in turn.

Plan View

A plan view is a top-down god's eye view from above. It is sometimes called a "map view." Early radar displays of this perspective were also called Plan Position Indicator (PPI) scopes. In digital displays, scaling of pixels allows alignment with, and layover onto, a map. Pixel-spacings (if not resolutions) need to be constant in both dimensions in a horizontal plane. This allows easy, and highly desired, intuitive distance measures between image features. Map orientation is typically with North to the top of the display, although other orientations such as alignment with long features such as roads, or aircraft direction of travel, may also be valuable from time to time.

Platform View

A platform view is the perspective of an on-board operator, sometimes called an "oblique view," and often termed a "cockpit view." It is the equivalent of an aircraft pilot/passenger "looking out the window." This is the normal EO/IR FMV perspective.

2.2 Combined Products

The ability to combine EO/IR and SAR imagery, and GMTI data products, with DTED information, and other library data (e.g. Google™ Earth) allows some interesting renderings and data presentation. We list several of these here.

- Render SAR Coherent Change Detection (CCD) image maps into EO/IR imagery
- Render GMTI detections into an EO/IR FMV stream
- Render VideoSAR with EO/IR FMV in the same image

We also note that since we are discussing combining EO/IR imagery with radar products, the two sensor types must be coordinated in their data collection. This is sensibly accomplished in an automated fashion. Since EO/IR is the popular sensor of choice for the payload operator, the natural entry into the coordination is to slave the radar operation to the EO/IR camera in some fashion. This reduces the need for radar training, and obviates the need for independent radar control by a multitasked/multiplexed operator, and yet enhances the EO/IR product.

Plan View

Platform View

Figure 1. Comparison of Plan View and Platform View of Grand Canyon National Park, AZ.

<u>Ortho-rectified Imagery</u>

We are assuming for convenience single-vision EO/IR systems, that is, non-stereoscopic systems. We are also assuming non-elevation-interferometric radar systems. These are the predominant systems in operation today, and this report discusses developments that are of utility to those operational systems.

EO/IR imagery and SAR imagery are both 2-D renderings, and in fact projections of the three spatial-dimension target scene into imaging planes. A problem is that their projections are substantially different if simultaneously collected from the same platform. Recall that an EO/IR image is projection along azimuth and elevation angles with respect to the sensor boresight, whereas a SAR image is a projection along azimuth angles and slant-range. As a consequence, EO/IR and SAR images cannot generally be simply overlaid onto each other. What is missing to allow warping one to register with the other is knowledge of the scene topography, that is, the 3-D nature of the scene being imaged by either sensor. Furthermore, since the projections are different, so too are their respective abilities to resolve in specific directions.

The process of correcting image data for otherwise projection uncertainties or errors is called ‘ortho-rectification’. Most ortho-rectification processes are concerned with correcting imagery to allow a more accurate plan view, that is, worrying about a new projection onto a conventional map. However, with sufficient DTED information, it is possible for either image to be ‘corrected’, and then re-projected into ‘any’ new imaging plane. We note that DTED level 2 data (30 m post spacing) is available for a large portion of our planet from the Shuttle Radar Topography Mission (SRTM). Other more precise databases also exist for some areas. In fact, the adjustment with DTED data allows a 3-D surface model to be built, that can then be rotated to any new perspective. This would also be true for image products like SAR CCD.

Modern processors could even allow EO/IR FMV to be ortho-rectified and re-projected in real-time. For example, an oblique FMV can be re-projected onto a plan view map.

As a final note to this section, we note that databases of optical imagery projected onto DTED surfaces do exist. One such product is in fact Google™ Earth. Context to any imagery would be added by using, say, Google™ Earth as a canvas onto which to drape any new image products. This is already routinely done with 'flat' images. Draping images and even video with improved DTED information, and allowing re-projection, is also becoming more common.

2.2.1 Plan View

2.2.1.1 SAR

Draping a SAR image onto DTED with an EO product or map underlay is now featured in many sensor ground stations and image analysis workstations.[5] This has several important ramifications.

- This perspective is aided by forming the SAR image onto a rectangular grid as projected *on the ground plane*, or more precisely on a horizontal plane at the nominal ground level. This means equal pixel spacing in orthogonal dimensions *on the ground plane*.
- A natural accompaniment to equal pixel spacing *on the ground plane* would be equal resolution *on the ground plane*.
- The SAR image is preferably formed taking into account DTED so as to minimize layover, or foreshortening, effects.[6]
- Since most maps are displayed with the north direction towards the top of the map, the SAR image should also be suitably rotated to align easily with the map orientation. This suggests, for example, that VideoSAR products should be formed, or rotated to, a constant geographical orientation in spite of aircraft bearing.

We note for completeness that some utility has been found for transforming overhead EO imagery to the SAR's native perspective, i.e. with range/azimuth coordinates.[7] This is the reverse of projecting SAR images to a plan view.

2.2.1.2 GMTI

In this discussion we will allow for multi-channel azimuth-interferometric GMTI radar systems (otherwise known as endo-clutter GMTI systems) because they are already operational, and becoming more so. These are perceived as necessary (although sometimes erroneously so) for dismount detection. Dismount detection GMTI also is known as DMTI.

GMTI radar outputs typically just detection reports. There is no 'image' per se. The detection reports typically include location (range and bearing), velocity, and target 'size'. The detection reports are generally placed onto a plan-view map, but suffer the same lack of precision in the elevation dimension as do SAR image features. GMTI detections are often further filtered by a tracker.

DTED data is currently used to provide assistance to the GMTI detection algorithm by clarifying stationary clutter locations in the range-Doppler map, thereby mitigating a problematic false alarm source. However, the use of DTED data to better place a target detection in 3-D space is less common as reported in the literature. Terrain effects on GMTI performance often remain problematic. Making GMTI work 'better' in mountainous terrain is presently a sought after goal across the GMTI community. Figure 2 illustrates a notional map overlay.

Of course, we might place GMTI target detections onto a map that includes underlays from other sensors, such as perhaps EO, satellite imagery, or even SAR.[8,9,10] These underlays would add useful context to the GMTI data. Further utility would be added by attaching mensurated target data to target detections, perhaps in the form of coded map symbols, or perhaps with informational text tags. Furthermore yet, track data perhaps in the form of a snail-trail would also be useful.

Another issue with any projected imagery is occlusion (shadowing) by terrain features. In particular for GMTI target detections on a map, situational awareness would be considerably enhanced by also mapping terrain that is unobservable by the radar, that is, mapping the radar shadow region along with the detection reports.

This discussion of GMTI data display is generally also very applicable to Maritime Wide Area Search (MWAS) modes.

2.2.2 Platform View

As previously stated, this is the perspective of “looking out the window.” The question then becomes “How do we add radar data to the perspective of ‘looking out the window?’” Fortunately, we have an excellent archetype for this in the Heads-Up Display (HUD). The HUD is any transparent display that presents useful data to a user without requiring the user to look away from his usual viewpoints. Radar data projected onto a manned aircraft’s windshield/windscreen was demonstrated as early as 1941 for an Air-Intercept (AI) radar.[11] It’s descendant, the HUD, continues to be an essential information display technique today.[12] We note that a more recent technology very much related to HUD is the Helmet-Mounted Display (HMD).

Since an EO/IR camera is essentially “looking out the window,” it seems only natural to combine radar data directly into the FMV stream, in a manner similar to HUD operation if a pilot/operator were indeed resident on the aircraft looking out the window. We examine some notional HUD-like products next.

2.2.2.1 SAR

Synthetic Vision generally refers to a computer-mediated reality system that constructs an environment from a database of terrain features, usually an archive of some sort.[13] Enhanced Vision generally incorporates other sensor data to augment more conventional vision systems in low-visibility environments.[14] While technically separate modalities, these terms are nevertheless often used interchangeably.

Projecting a SAR image that has been warped and registered to coincide with a FMV stream in a manner similar to a HUD falls somewhere in-between these two. Real-time machine-analysis of the EO/IR FMV could automatically modulate the degree to which SAR images are applied or utilized in this manner. The sensor operator only knows that when the EO/IR is occluded, as perhaps by clouds, the SAR automatically “kicks-in.” Furthermore, this can be done with more than just the SAR image itself. SAR image products like CCD and other measures and enhancements can also be transmogrified to HUD-like display in an FMV stream as well. Or perhaps merely detections of meaningful changes could be superimposed onto the FMV stream.

2.2.2.2 GMTI

Recall that GMTI outputs primarily detection reports rather than an image, although we recognize that the same data can often be processed into a SAR image of the illuminated scene. Nevertheless, for now we will consider only the target detections themselves, albeit mensurated with relevant data. The incorporation of DTED data to place a ground-target detection report in 3-D space would allow increased accuracy and precision of the target location, correcting the elevation uncertainty plaguing most current systems. Coupled with 3-D scene topography data, these detection reports can be correctly placed into a FMV stream. We additionally offer the following observations.

- Note that an independent measure of target height can discriminate ground-vehicles from low-flying airborne vehicles (e.g. ultralight aircraft, hang-gliders, and unmanned remotely-piloted aircraft).
- Symbology and auxiliary information tags can also be projected.
- Any uncertainty in target position might be accommodated with projecting error ellipses along with the most likely target position.
- Target tracks, perhaps in the form of a snail-trail, can also be accordingly projected.
- As with the plan view perspective, this discussion of GMTI data display is also quite applicable to MWAS and similar modes.

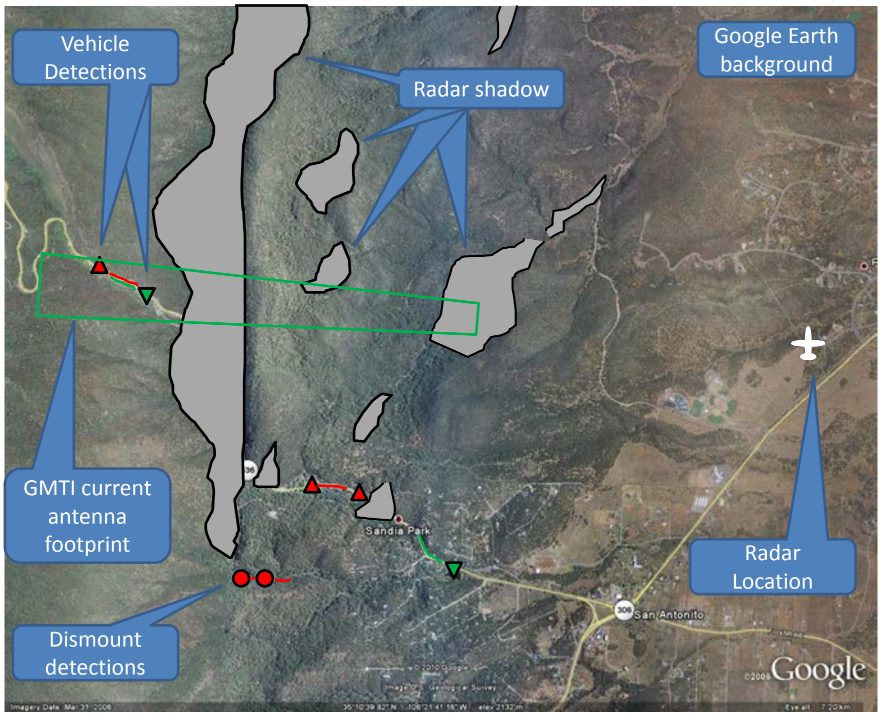

Figure 2. Notional GMTI detection overlay onto Google™ Earth map, with grayed out regions of radar shadow. Note that the occluded regions due to radar shadow include a significant amount of roadway, likely resulting in track loss. The existence of occluded regions is not generally present in GMTI reports.

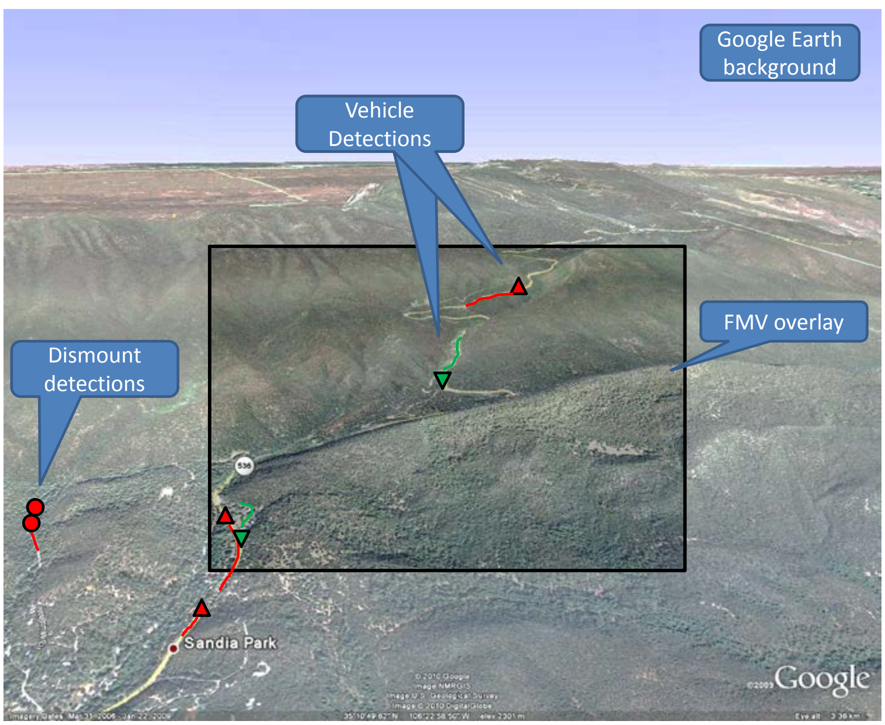

Figure 3. Notional combined sensor product. FMV may be overlaid onto Google™ Earth backdrop with GMTI detections placed at correct 3-D positions. Note that with this perspective (from the platform location), radar shadows are not visible.

3 COMBINED MODES

The idea of automatically coordinating sensors is not new in this report. We also note that momentum in the ISR community is building in this direction. For example cross-cueing is almost ubiquitous. Beyond this, many maritime search radars already integrate MWAS modes with AIS data (e.g. Telephonics RDR-1700B[15]). Multi-mode and Multi-sensor detection, tracking, and identification systems have been developed.[16] Indeed, concepts for collaboration between different radar modes are common. We now offer to take this collaboration idea and expand it to perhaps the following notional scenarios.

The radar might be slaved to the EO/IR FMV control. For example

1. EO/IR FMV automatically tasks a GMTI/DMTI stare mode to provide concurrent motion detection of the scene being watched.
2. EO/IR FMV automatically tasks a VideoSAR/VideoCCD surveillance mode to provide concurrent motion detection of the scene being watched.
3. EO/IR FMV automatically enables SAR when cloud obscuration is autonomously detected.

The radar might be slaved to other sensors in some fashion. For example

4. SIGINT/ELINT detections automatically task EO/IR sensor to investigate location/direction of emission, perhaps SAR/GMTI, too.
5. All maritime AIS ‘hits’ automatically task the radar to generate ISAR images of the ships to verify ship class, and mitigate spoofing.

Some radar modes might be slaved to other radar modes. For example

6. MWAS detections automatically generate High Range Resolution (HRR) profiles of all detections. This is done perhaps between sweeps.
7. MWAS detections automatically generate ISAR images of all detections. This is done perhaps between sweeps.
8. MWAS detections automatically generate ISAR images of all detections that do not have corresponding AIS detections. This is done perhaps between sweeps.

In some cases, other sensors might be slaved to the radar. For example

9. MWAS detections automatically generate EO/IR images of all detections.

Enhanced cognition might allow the radar to perform autonomously, without tight operator control/attention.

10. An awareness of map position would cause automatic switching between MWAS and GMTI search modes.
11. Radar search modes are run in the background while attention is focused on other sensors. The operator is alerted if GMTI targets are detected in specified region(s) of interest.

Of course an operator would be allowed to override any coordination and work with individual sensors separately, in the conventional manner. Nevertheless, the intent here is to have automatic coordination of sensors or modes of sensors. This offloads the coordination task from the sensor payload operator. Benefits include the following:

- Greater utilization of the individual sensors, especially the non-EO/IR FMV sensors. Sensors and modes are automatically coordinated. An operator doesn’t have to choose between sensors. He gets to easily operate several at once, with a common control.
- Less training required to operate sensors like the radar in all its modes.
- Simplified sensor operation. For example, by ‘slaving’ the radar to the EO/IR, we work the radar by commanding the EO/IR.
- If this coordination is automated inside the aircraft, then command/data bandwidth is reduced between aircraft and ground station.

- Sensor/mode switching is faster, decreasing latency for actionable ISR. You don't have to wait for the sensor payload operator to do it.
- Operator can focus on interpreting the data instead of operating the sensor suite.

Think in terms of an expensive full featured fully adjustable camera, but that still has an 'automatic' mode for easy operation 'when you just don't feel like messing with it'…

The automatic and unconscious coordination of sensors, and combination of sensor data would occur in a mission executive processor, perhaps also described as a sensor management or sensor coordination computer. While we propose to do all this on a single aircraft, it has been suggested that this could also be adapted to coordinate sensors across different aircraft as well, or across different sensor domains such as ground-based, space-based, etc. A side benefit to the architecture proposed below is that sensor service requests from multiple users/operators might be sorted, prioritized, and queued by the same sensor management computer.

Figure 4 illustrates the current paradigm for operating UAV sensors. The operator selects between sensors and sensor modes. Sensor operation is serial and monogamous, or at best 'multiplexed in time'. The burden of managing and collaborating sensors is on the operator. The operator is required to have expertise in all the various sensors that the UAV carries, so that he may select which to use, and when.

Figure 5 illustrates the new proposed paradigm for operating UAV sensors. The operator selects between 'super modes' involving predetermined coordination of sensors. The burden of managing the sensor collaboration is now shifted to the mission executive computer. Sensor operation can be truly simultaneous, integrated, and inter-dependent. The operator can now focus his attention on the mission rather than sensor management. No one sensor is necessarily supreme. For example, sometimes an EO/IR sensor may 'drive' the radar, and sometimes the radar may 'drive' the EO/IR sensor. This will be mission driven, as a choice among super-modes. Down-linked data may only be an executive summary of findings, not necessarily all the data from all the sensors involved (but still could be). Alternatively, one sensor may provide merely annotation for another sensor's product. These might be super-mode options. Some additional points are made here in no particular order.

- The Mission Executive Processor is introduced as intending to coordinate sensors within super-modes. However, as processing horsepower increases, we can begin to consider moving exploitation functions into this subsystem. More processing horsepower yet might allow us to introduce cognitive functions, such as target or activity recognition, or recommendations for follow-up ISR collections and interrogations.
- The Mission Executive Processor will ultimately drive individual sensor mode requirements, as well as hardware and software interfaces. This processor will define plug & play standards. Whoever controls this function has the high ground for defining ISR instrument function and functionality.
- The Mission Executive Processor is portrayed as residing on the aircraft with the sensor suite. We believe this to be optimal. However, while alternatively sub-optimal, it may still be useful if this function resided in whole or in part in the ground control station. Ground-residence would not offer any data bandwidth reduction, and may actually increase it, but may nevertheless provide a convenient retro-fit or demonstration route.

4 SUMMARY & CONCLUSIONS

We observe that technology already exists to extend the state of the art in sensor coordination, thereby improving situational awareness of ISR payload operators. This is facilitated by ortho-rectifying imagery using DTED information. This in turn allows projection to other image perspectives. Modern processors can do this in real time. This in turn allows projecting radar data (e.g. SAR, SAR products, and GMTI detections) into EO/IR images and FMV. Furthermore, this facilitates enhanced usage and utility of the radar system, because the radar might be slaved to the EO/IR system. The automated coordination of a suite of sensors on a UAV is a natural progression of current technology. The concept of a Mission Executive Processor was introduced to perform this role. The ideas presented herein are a major step towards system cognition.

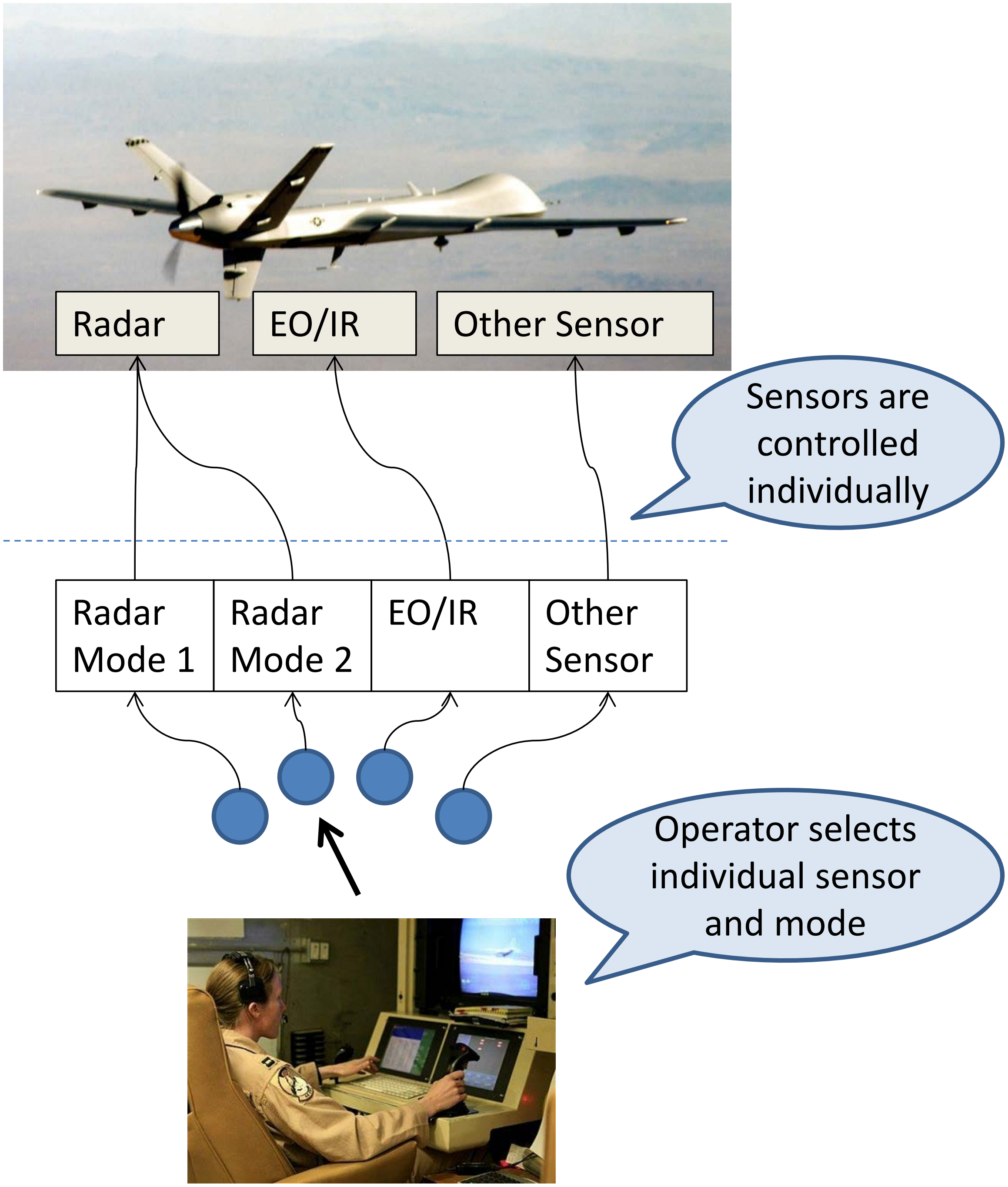

Figure 4. Current paradigm.

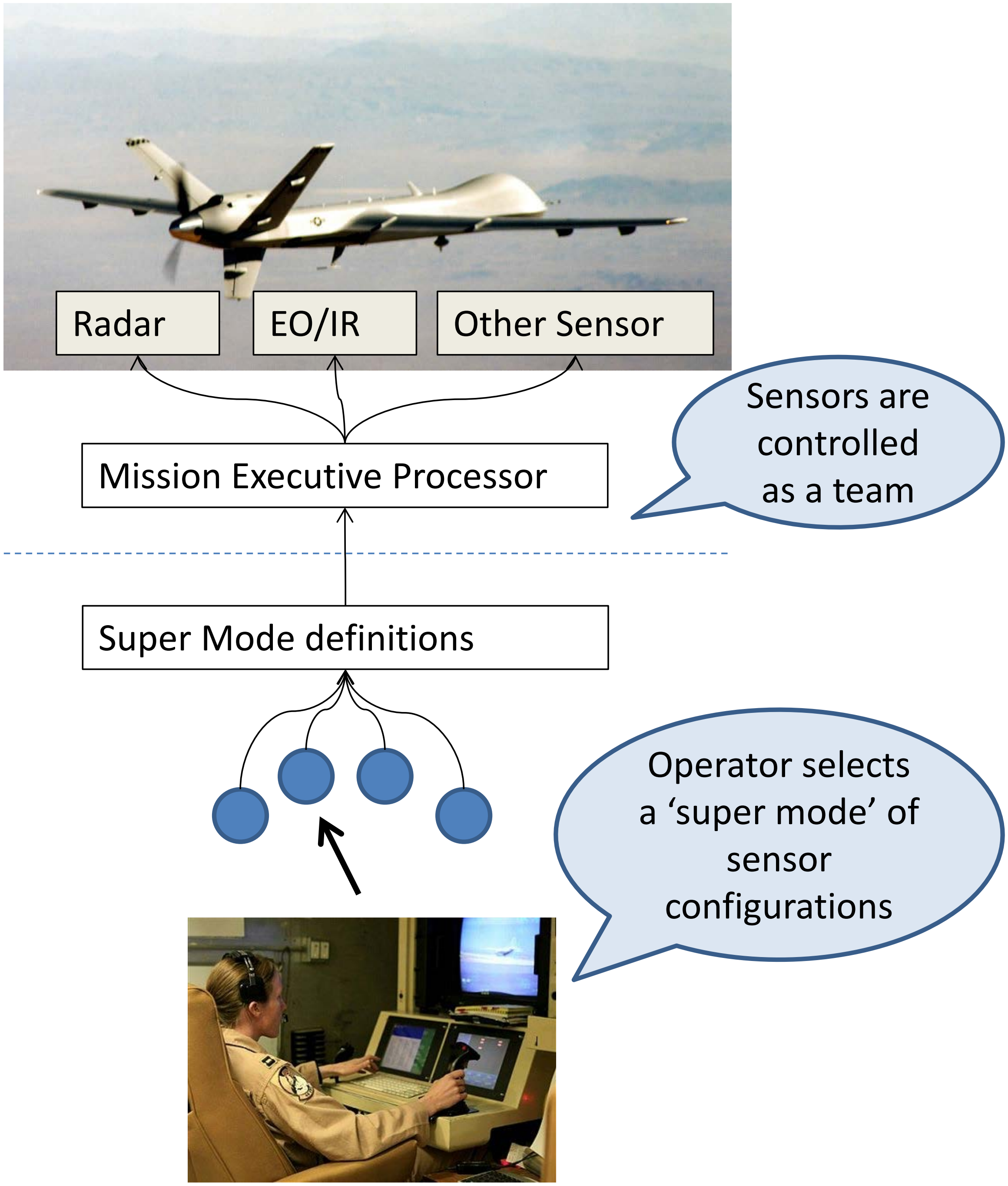

Figure 5. New proposed paradigm.

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