Sensor management—Control and cue

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Abstract - ***This paper presents the role of sensor management with respect to sensor system and the fusion process. The important roles and functions of sensor management are discussed. Multi-level classification of the sensor management is presented. The control and cueing aspects of sensor management are explored. An experiment is set to demonstrate sensor manager controlling electro-optical (EO) sensor's moving direction and sensor cueing process to track a target. A fuzzy controller is used in this experiment. The fusion system used an interactive multiple model (IMM) algorithm to give the estimated target direction.***

Keywords: Sensor management, Tracking, Fuzzy controller, Cueing process.

1 Introduction

Sensor Management is an important technology area for modern tactical sensor systems and multisensor fusion systems. Sensor management is discussed in [2, 5, 10, 7, 4] and is also considered as part of the multisensor fusion process.

The task of sensor management work is challenging due to [8, 7]

- Insufficient resources
- Limited sensor capabilities
- Highly dynamic environment
- Varied sensor capabilities and performance
- Limited processing capabilities
- Unplanned sensor failures
- Data fusion requirement.

In [11, 9], the author highlighted the need for the pilot to be occupied with other activities than sensor control. Thus, the aircraft must have a sensor manager that is able to select, prioritize, specify, distribute and schedule tasks for the sensor suites mounted in the flying platform. Besides this scenario, we also see many other scenarios such as sensors on land vehicle [3] or multi-site sensor systems where there are need of sensor management system (SMS) to aid the complete operation of the sensors.

We view the SMS working hand in hand with the data fusion process and the sensor systems. The following diagram shows the complete working loop of the sensing system framework.

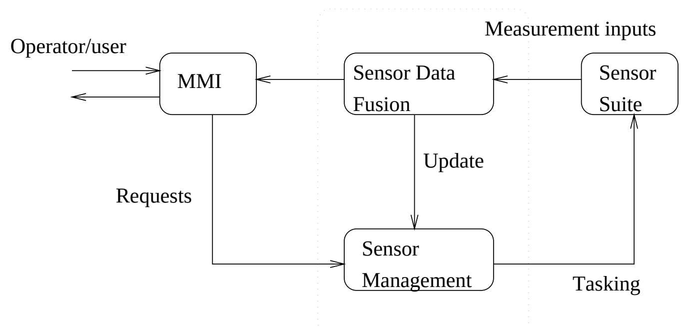

Figure 1: Sensing System Framework.

The goal of SMS can be defined as to manage, coordinate and integrate the sensor usage to accomplish specific and often dynamic mission objectives. Examples of mission objectives are

- to identify low flying target at area A.
- to track target at area B.

The mission objectives should be predefined and can be set in two modes automatic or manual. We define the automatic mode as the mission objectives already preset in the system and the manual mode as the mission objectives entered by the operator in real time.

In fulfilling these goals, the sensor management in effect will help to improve the process of data fusion.

While it is true that sensor management was borne from the task of performing resource allocation and scheduling of task, with the current advances in sensor technology, its role and function have expanded. We can classify its role and function in a more systematic and well-defined structure.

The paper is organised as follows. Section 2 discussed the roles and function of sensor management in a multi-level approach. Section 3 discusses the sensor management in the control aspect. Section 4 demonstrates the sensor management using a fuzzy controller and a cueing process. We conclude at section 5.

2 Multi-level Sensor Management Based On Functionality

The sensor management can be classified based on its functionality [10, 1]. Most of the discussions on sensor management have been centred on the architectural design such as centralised, decentralised and hierarchical (micro and macro) design [12]. However, the discussion on this design can be further improved or better understood if we can breakdown the different levels of sensor management based on functionality. As in the data fusion process, the sensor management can also be classified into the following 3 levels:

- Level 1 - This is the lowest level of work in sensor management involving individual control of each sensor such as direction, pointing, change in frequency, power level etc. For example, directed radar where the tracking of the target can be guided by a SMS. The SMS is then a controller to the sensor system. Such SMS can be built closely coupled with the sensor system and the fusion process. The goal of this SMS controller is to reduce the error based on the fusion input. We will discuss this in greater detail at the next section.

- Level 2 - This is the medium level sensor management. At this level the SMS focus more on the sensor tasks and different modes of the sensor with respect to the operation needs. SMS will work out the method to prioritise the tasks and determine when and how a mode should be activated. Besides these, the SMS can also look at some basic function of sensor to sensor switching. Hence at this stage we look at
  - Sensor task scheduling.
  - Sensors cueing (sensor handing over, target acquisition by another sensor aiding).
  - Sensor modes/functions (sensor's own modes changing process).

- Level 3 - This level can be seen as higher-level sensor management. Each sensor in the sensor suite could only detect a limited amount of information. But the sensor manager can direct several sensors in an integrated fashion or sensor mix to supply information to the fusion process. The total information will provide greater content than information from a single sensor. Examples of the tasks at this level are
  - Dynamic sensor placement (e.g. to provide good coverage)
  - Effective/optimal sensor mix (e.g. to minimise the emission)

  Sensors can be placed on a moving platform such as ground vehicle or fighter aircraft. SMS can coordinate, manage or suggest positions for the sensor and its platform to be located to best view the target, provide better coverage and etc, based on information such as the digital terrain map.

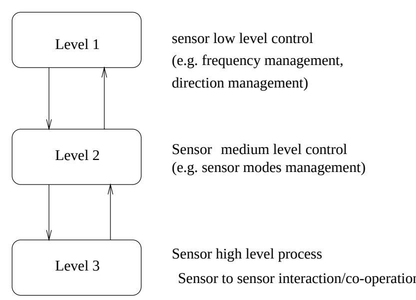

Figure 2: Sensor management levels based on functionality.

Figure 2 shows the concept of the sensor management level. We may not have exhausted all possible tasks in each level. Note that the discussion of the sensor management levels are intended for better understanding and convenient categorisation of the various SMS's functionality. It is not intended as a prescription for designing a system.

3 Sensor management - Controller and Cueing

As highlighted at section 2, level 1 of sensor management process involves controlling of the sensor action. Hence, conventional and advance control techniques may play a part in sensor management's work at this level.

However, the process of control in SMS is not trivial [6]. Depending on the system involved; the SMS can be complicated by many factors such as

- Moving platforms.
- Geographical differences in sensor locations.
- Complexity in the fusion process.
- Complexity and different types of sensor systems.

The task of the controller can have many different functions or roles such as controlling the

- Sensor directions/pointing to best locate/identify the moving target.
- Sensor mode and when to switch mode.
- Sensor power level.

All the control tasks have the same objective, namely to improve the fusion process in tracking and identifying the target. Figure 6 shows an example of a possible SMS behaving as a controller in a closed-loop form with the sensor system and the fusion process.

With SM providing command and control to the sensors, the sensor system will provide the data fusion system with measurements or track data, and in turn the data fusion algorithm will provide the SM with fused track data.

However, the SMS is certainly more than just a controller. As discussed in section 2, there are different levels of process in the SMS. One of this is the sensor cueing process.

Here, we define sensor cueing as taking the following two forms, namely:

- sensor hand over or
- target acquisition with another sensor aiding

The SMS may cue a sensor to hand over its current tracking target to another sensor due to, say,

- another higher priority target entering its trackable region, or
- when the target is about to leave its trackable region.

The issue here is that SMS has to co-ordinate the handing over to ensure a smooth transition and to reduce tracking or identification error. On the other hand, cued target acquisition [1] process involves the SMS selecting which sensor to acquire the target and disseminating to that sensor information required for such acquisition. For example, the SMS may cue one of its radars to acquire range information of a target that is being maintained primarily by an EO sensor (bearing only).

Sensors vary greatly in their ability to detect the presence of targets or the onset of particular target behaviour. Therefore, sensor management may improve the response time of a sensor by proper cueing process, hence obtaining information from another sensor. Multiple sensors performance modelling or some expert rules can be used for cueing to ensure no lost of target information.

In the next section, we demonstrate the SMS as a complete system based on what we have discussed in this section.

4 Simulation Results

In this experiment, we considered a 20km (probability of detection 0.90) ground-based EO sensor with field of view (FOV) of 15 degrees, and capable of panning movement of 120 degrees.

Without the SMS, a normal EO sensor tracking a target will probably move at a fixed panning rate, following the heading of the target.

In this simulation, the target moves in constant velocity ($20m/s$) from 0 to 20th seconds and then accelerated ($5m/s^2$) from 21st to $50th$ seconds and decelerated ($-5m/s^2$) from 51st to 90th seconds. Mid-way through the deceleration process, the target makes a right turn (65th to 73th seconds). An IMM filter is used in the fusion process to track the target. The estimated target state is then sent to the sensor management system.

4.1 Fuzzy controller

The fuzzy controller used in the SMS has two inputs namely error (k) and error ($k-1$), where error (k) represents the bearing error, in degree, of the sensor boresight to the target at the kth time step. Note that this error(k) is obtained by taking the estimated bearing of the target minus the sensor boresight bearing.

The choice of error (k) as one of the input variables is intuitive. Nonetheless, most similar fuzzy control systems might use the rate of change of error or Δ error (k) as the second input variable, where Δ error(k) = error (k) - error ($k-1$). The time change from k to k-1 is 1 second in this simulation. From the above equation, it is clear that both pairs of error (k)/ Δ error(k) and error (k)/error ($k-1$) contain the same amount of information and thus will provide equivalent inputs to the system. Our choice is based on simplification reason.

The crisp value of error (k) and error ($k-1$) are mapped into five fuzzy sets labelled in linguistic terms of VL(very low), L (low), M (medium), H (high), and VH (very high). The meaning of each linguistic term is determined by the specific membership functions, which are defined by triangular functions on the universe of discourse of error (k) and error ($k-1$) respectively. Figures 3 and 4 show the input universe of discourse and the specific membership function.

The output of this fuzzy system is the panning rate (degree/sec) for the sensor, and its universe of discourse is divided into thirteen fuzzy sets labelled in linguistic terms of VL (very low), MVL (mid-very low), L (low), ML (mid-low), M (medium), MH (mid-high), H (high), MVH (mid-very high), VH (very high), $MVVH$ (mid-very very high), VVH (very very high), $MVVVH$ (mid-very very very high), and $VVVH$ (very very very high). The membership functions are also triangular.

Figure 5 shows the output universe of discourse and the specific membership functions.

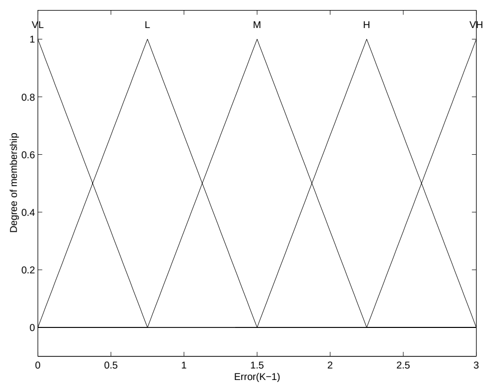

Figure 3: Partition of the input universe of discourse for error (k).

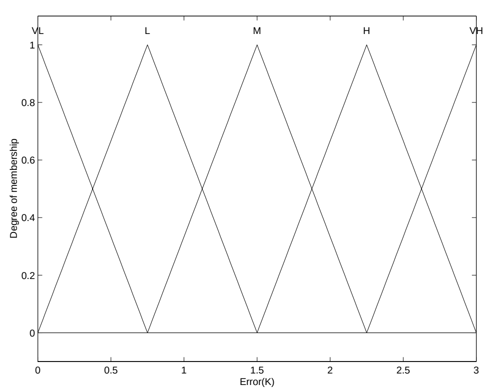

Figure 4: Partition of the input universe of discourse for error (k-1) .

The fuzzy system has a total of 25 IF-THEN rules, as summarised in table 1. A sample of these rules is given below.

- IF error$(k-1)$ is L AND error(k) is M THEN panning rate = VH.

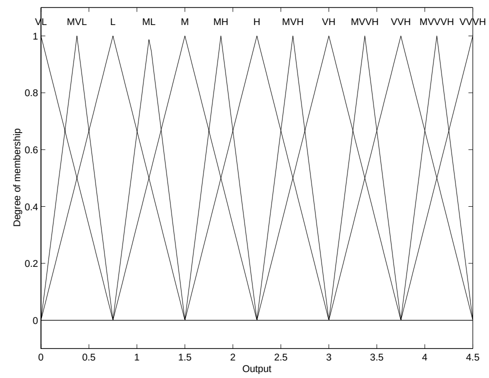

Figure 5: Partition of the output universe of discourse.

- IF error$(k-1)$ is H AND error(k) is L THEN panning rate = ML.
- IF error$(k-1)$ is M AND error(k) is VL THEN panning rate = MVL.

e$(k-1)$\e$(k)$	VL	L	M	H	VH
VL	MVL	ML	MVVH	MVVVH	VVVH
L	MVL	ML	VH	VVH	VVVH
M	MVL	ML	VH	VVH	MVVH
H	MVL	ML	MVH	MVVH	MVVVH
VH	MVL	L	H	VH	VVH

Table 1: The 25 fuzzy rules

where e(k) and e$(k-1)$ are the error(k) and error$(k-1)$ respectively. We use the centre of gravity approach for defuzzification process.

The complete closed-loop diagram is as in figure 6. The desired goal or the set point of the SMS is to achieve zero error.

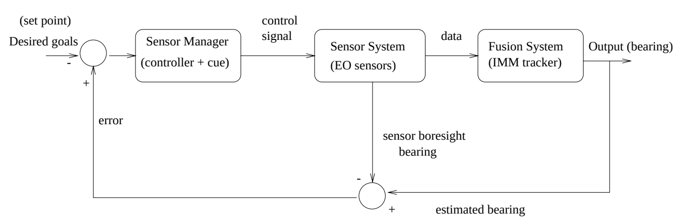

Figure 6: The complete closed-loop diagram.

4.2 Example 1

In the first simulation, we considered one sensor. Figure 7 shows the target moving profile and the sensor position and FOV.

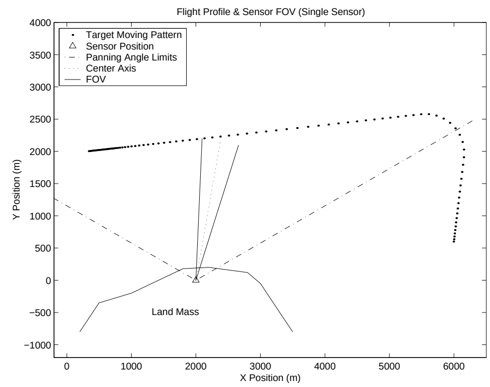

Figure 7: Target moving profile and the sensor field of view (FOV).

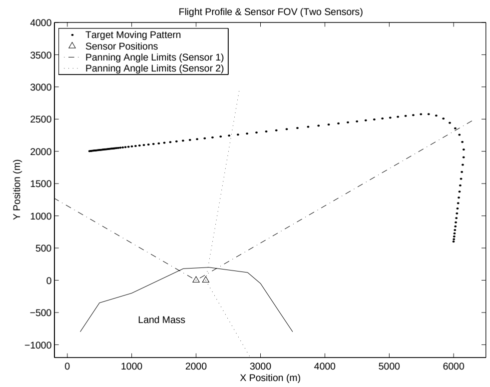

Figure 9: Position and coverage of the two sensors.

Figure 8 shows the results of the sensor tracking error with respect to the target track with and without the sensor managed by the SMS.

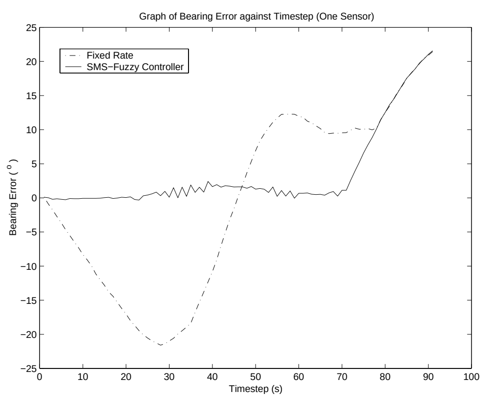

Figure 8: Error results of one sensor.

With fixed panning rate of about 1 degree per second, the sensor lost track of the target by the 11th time step and only managed to pick it up again on the 42nd before losing it totally after the 51st. On the other hand, with SMS, the sensor managed to keep track of the target throughout the first 76 time steps. Note that due to the limited panning angles of the EO sensor, regardless of whether SMS is in use, the sensor will not be able to sense the target beyond the 76th time step. This led us to the next example where 2 EO sensors are used for a better coverage.

4.3 Example 2

In this example, we introduce an additional EO sensor to the previous example. Cueing process is added to the SMS on top of the fuzzy controller. The position and coverage of the two sensors are as shown figure 9.

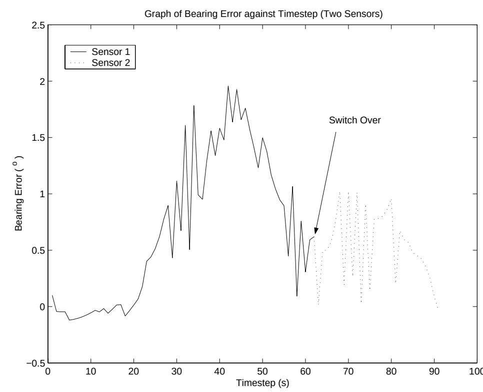

Figure 10: The error results of the two sensors with SMS.

Theoretically the sensor management cueing modules will command the next sensor to take over when the target is within the sensor FOV.

Cueing process is based on a simple rule statement as follows:

IF
Sensor 1 is within 10 degrees of it's panning limits and Target is within Sensor 2's FOV,
THEN
cue Sensor 2 to take over the tracking process from Sensor 1.

Alternatively,

IF
another target is entering the trackable region of Sensor 1, and Sensor 1's current target is within Sensor 2's trackable region,
THEN
cue Sensor 2 to take over the tracking process from Sensor 1.

Figure 10 shows the error output of the two sensors controlled by the SMS. The switch over occurred at the 62nd time step. Note that the errors correspond to the target moving pattern.

5 Conclusions

We have presented the various classification and roles of sensor management. The roles of sensor management as a controller were also discussed and demonstrated in the simulation studies.

The sensor movement with the fixed panning rate will not be able to adapt to target changes and neither could they do a proper switching between sensors. However, the sensor controlled by properly designed SMS, such as the fuzzy controller and the cue process, can adapt to the change in the target and detect the target.

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