Decision-Theoretic Sensor Resource Management

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Abstract – Sensor resource management is usually formulated as an optimization problem under uncertainty. We use a decision-theoretic model to show that the objective function should not be just tracking or target identification performance. Instead, it should represent the expected value of the outcome from using the collected data. This outcome depends on how the collected data and fusion results are used in making other resource management decisions such as weapon to target assignment. We argue the need for considering the integrated sensor/weapon management problem and propose a decomposition to make the solution feasible.

Keywords: sensor management, fusion, decision theory, integrated sensor/weapon management

1 Introduction

Sensor resource management is important for data fusion because it collects data to support other data fusion functions. Most sensor management algorithms focus on improving the performance of the lower level fusion functions in the Joint Directors of Laboratories (JDL) Data Fusion Model [1, 2]. In particular, improving tracking and target identification performance are the most common objectives. In the JDL data fusion model, sensor resource management is part of Level 4, process refinement, and uses information from the other levels, such as target location, identity and intent from Levels 1 and 2. By assessing the impact of the threat, Level 3 fusion provides priorities on the different targets. However, the data fusion model does not deal with the actual goal of sensor resource management.

The ultimate goal of sensor management is to support better decisions, and not just better sensor data or better fusion results because better information by itself has no intrinsic utility. Since fusion results are used to make weapon or other decisions that impact outcome such as the survival of own assets or destruction of threat, we need a framework for representing the relationship between decisions, uncertainty, and utility. Decision theory provides such a framework. This talk presents a decision-theoretic model of sensor management in the form of an influence diagram [3]. We show how the different levels of the JDL data fusion model are represented in this model. We also show that predicting the impact of sensor collection requires knowing the future weapon management decisions. This argues for a tighter integration of sensor and weapon resource management. However, since the integrated problem is difficult to solve, approximate solutions are needed. One approach is to use nominal policies or strategies to decompose the two problems.

The rest of this paper is structured as follows. Section 2 presents the decision-theoretic framework for sensor management. Section 3 discusses the decomposition into sensor and weapon management problems.

2 Decision-Theoretic Model

In a decision-theoretic formulation of sensor resource management, sensor decisions are selected to optimize an expected utility in the presence of uncertainty. Figure 1 shows an influence diagram for such a model for the first two time steps. The threat state may represent the position/velocity and type of multiple targets as well as their intent. Own state includes the location and status of the assets. Outcome includes both status of threat and own assets. Thus the value to be maximized may reflect either threat destruction or own asset survival.

Figure 1: Influence Diagram for Sensor Management

In Figure 1, threat estimate is generated by Level 1 and 2 fusion. Predicting the outcome given the own state and threat estimate is impact assessment (Level 3). However, predicting outcome requires more than just own state and threat estimates. One also needs to know how the threat estimate is used to generate other response decisions (e.g., weapon) that affect the threat state and own state and eventually the outcome. Weapon decisions affect the threat state while moving away from a threat affects the own state. Figure 2 shows an influence diagram that includes the response decision. It is similar to the sensor influence diagram in [4]. In order to solve the sensor resource management problem, the response decision has
to be provided by an external algorithm (weapon resource manager) or an approximation computed internally by the sensor resource manager.

Figure 2: Influence diagram with weapon decisions

3 Problem Decomposition

The sensor and response resource management problems are tightly coupled as seen in Figure 2. Consider weapons as the main response resource. Weapon management prioritizes targets and decides which targets to shoot at and the weapons to use. Sensor management does not need to observe targets that are not of interest to the weapon manager. Similarly, the weapon manager needs to know future sensor data availability in order to plan weapon actions. Thus, the optimal approach to sensor management is to solve the integrated sensor/weapon resource management problem. However, each problem by itself is difficult enough to be solved exactly [4 - 6]. Thus, we need a way of providing an approximate coupling between the two problems. One approach is to assume that nominal policies are available at each planning interval. A nominal weapon policy specifies the mapping of threat estimates (and own states) into weapon decisions. This is equivalent to specifying the weapon decisions in Figure 2. Similarly, a nominal sensor management policy specifies the sensor decisions. Given the nominal policies, the integrated resource management problem decomposes into independent sensor and weapon management problems as shown in Figure 3.

Figure 3: Decomposition with nominal policies

Finding good approximate nominal policies is crucial in making this approach work. Since the nominal policies have to be updated at each planning time, they should be efficient to compute. One approach is take the weapon manager’s output as the reference and use sensitivity analysis to look at the benefit of getting additional information for tracking and target identification. This value of information will be provided to the sensor manager as the objective of its optimization problem. Note that this objective is different from just information gain because the latter is not related to the expected value of the outcome.

Similarly, the current sensor management policy can be used to compute the predicted track quality and target identity probability in the future. This information is provided to the weapon manager to specify the nominal data that will be available. Figure 4 shows the information exchange between the weapon and sensor resource managers. Basically, the weapon resource manager provides an objective function for the sensor management problem while the sensor manager specifies the available information for the weapon management problem.

Figure 4: Interface between sensor and weapon resource management

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4 Conclusions

Sensor resource management requires knowing the value of the information generated by fusion from the collected data. This value of information is generally different from information-theoretic measures since it depends on how the information is used to make response decisions such as assignment of weapons to targets, or taking other defensive actions. The decision-theoretic approach models the relationship between information, decision and value and involves both sensor and response resource management. While the integrated resource management is difficult to solve exactly, it is possible to decompose the problem into sub-problems by defining appropriate interfaces. In addition to techniques of solving the decomposed weapon and resource management problems, research issues for sensor management include how to compute the value of information efficiently, and predicting the performance of sensor decisions.

References


