Perception Management: An Emerging Concept for Information Fusion

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Abstract

The state-of-art of sensor management has been advanced to the extent where high-level information plays an increasingly important role. Since situation state and associated request for information are device independent, a question arises as whether the term (sensor management) is sufficient enough to encompass the functions on the information level. Recognizing the essential need of intelligent agents to perceive the environment to take appropriate actions, this letter proposes the concept of perception management. It refers to controlling the process of data acquisition from the external world to enhance percepts obtained. The content of perception management is outlined and its relationship with sensor management is also discussed.

1 Sensor Management: Advancing to the Information Level

Control of sensing resources to enable efficient and coordinated observations plays an important role in modern multi-sensor systems. It serves the purpose of process refinement within the JDL data fusion model [1]. The term sensor management [2] was created to refer to the generic aspect of controlling and allocating the usage of sensor resources to enhance fusion performance.

With the increasing sophistication of real applications, however, the scope of sensor management has been extended considerably to beyond merely controlling and scheduling physical devices in response to estimated object states. As there is a close coupling between estimation and control in multi-sensor data fusion systems [3], high-level information about the state of the environment is highly valuable for directing the control to proceed in an efficient course in a perplexing environment. We believe that adaptive management (of observation actions) also involves analysis and reasoning on the information level (encompassing situation and impact assessment) to make situation dependent decisions for exploring what is truly needed or relevant. This opinion of ours coincides with recent endeavours by many researchers towards information-oriented management functions, including:

- proposal of an additional mission manager [4, 5] above the sensor manager. In appraising the current mission situation, the proposed mission manager is envisaged to recognize the lack of information and raise requests for additional data to the sensor manager;
- prioritizing various information requests with reference to the current mission and situation analysis [6, 7, 8, 9];
- selecting sensing actions (including resource allocation) for maximised information gain [10, 11, 12];
- selecting desirable viewing locations and directions to improve the utility of gained information [13];
- deploying extra sensing resources to enhance the quality of fused information in dynamic environments [14, 15, 16].

Obviously, due to resource constraints, it is not realistic to continuously perceive everything in the envi-

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ronment. Control and management of data acquisition under constrained devices and communication channels seem crucial for effective and efficient information processing. Information-oriented observation (data gathering) exhibits strong relevance to *active perception* [17] in artificial intelligent systems. It contributes to the improvement of perception in that it restricts the focus to the most critical or interesting events or aspects, facilitates better situation awareness, as well as helps avoid overwhelming storage and computational burden in a data rich environment.

2 Perception in Intelligent Systems

In biology, perception is understood as "the mental interpretation of physical sensations produced by stimuli from the outside world" [18]. Here "mental interpretation" could be interpreted as a process of constructing an internal model of the environment.

There is an obvious analogy between the needs of biological beings and artificial intelligent systems to perceive the environment to perform appropriate actions. This has encouraged the exploration of machine perception.

Perception is an important concept in the research field of computer vision. Active perception, referring to modeling and control for perception, has been recognized as effective means to reduce problem complexity.

In agent theory, an agent can informally be described as some entity, artificial (e.g., robotic) or natural (e.g., mammal), that is capable of perceiving its environment and acting upon it (a tentative definition inspired by [19]). In agent theory, the term perception is frequently used and is widely recognized as an essential part of the agent model. Normally, the notion of perception is represented by a mapping $f : \Omega \rightarrow P$, where Ω is the set of environment states and P the set of percepts (i.e., outputs of the perception process) [20, 21, 22, 23, 24, 25, 26]. Figure 1 illustrates a common model of the agent perception-action cycle.

Robotics, being an application domain of both agent theory and computer vision, naturally inherits the term perception. This fact is made instructively clear in [27] where a robot system combines computer vision technology and an agent architecture for self-localisation. Furthermore, a chapter in [28] has been devoted to an extensive discussion about robot perception. Other works that recognize the need for perception include [29, 30, 31, 32].

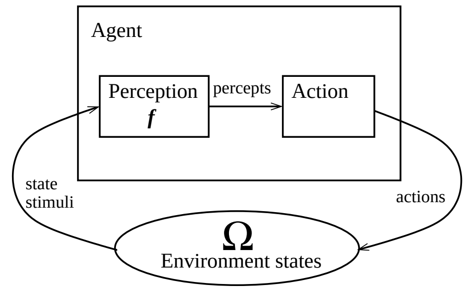

Figure 1: In the agent perception-action cycle, the perception process produces percepts of the environment states. The percepts are fed to the action process which generates the actions the agent applies to the environment.

3 Perception Management

In Section 1, we presented some indications of an ongoing expansion of research for sensor management. We feel that the term "sensor management" is no longer sufficient to encompass the recent and future research in which the data acquisition is driven by the outcomes of situation and impact assessment (functions in the JDL model [1]). A similar opinion, doubting the appropriateness of sensor management to capture the nature of this fast developing area, was expressed in [33].

A study of the literature on data acquisition reveals that several different terms have been used to name the process. However, none of them seems to meet the requirements presented here. Terms such as *resource management* and *asset management* are too general since they include resources which are of no use for perception. The term *collection management*, which has also been used, is a bit ambiguous since it may refer to either a collection of items or the process of collecting.

Section 2 provides support for the term perception, which is well established in various fields of research. Perception was also incorporated into the data fusion model in [34], treating situation awareness as percepts of the environment. Since the perception discussed here is active, we naturally need a mechanism to manipulate it. This, combined with the just mentioned limitations of the sensor management concept, encourages us to propose a new concept, *perception management*. The name inherits its first part, "perception", from its affinity with the notion of perception used frequently in related fields of research. The second part, "management", reflects its close relation to sensor and resource management.

Perception management would be an appropriate concept referring to controlling and improving data acquisition from the external world to obtain information with greater content, higher utility, and lower uncertainty. This concept also implies and acknowledges that data acquisition is an integral part of an artificial intelligent system due to its close relation to the agent metaphor.

In our view, activities for perception management can include but are not limited to the following:

- reasoning about information requests with respect to the underlying mission and situation;
- ranking the importance of various information requests and resolving the conflicts between them;
- real-time distribution and adaptation of perception tasks through, e.g., cooperation or negotiation among decision agents;
- management of other data acquisition resources, in addition to sensor devices, that can also support the perception process (e.g., in a command and control system, additional resources may include human observers or news agencies);
- planning of sensor external actions (e.g., controlling the motion of a mobile platform carrying sensors) to support the purpose of perception with increased scope and utility of gained information;
- pro-active deployment and planning of resources according to predicted situation tendency, to get first-time information of an event which is likely to happen in the upcoming period.

Perception management would be a generic concept emphasising the ultimate purpose of data fusion (i.e., acquiring percepts) without necessarily paying particular attention to details of concrete sensor devices. The motivation for doing this is the awareness that information and associated (information) requests are sensor and device independent, and at the information level it is knowledge and information processing systems that play a key role in working out required outcomes. In comparison, the term sensor management leaves one with the intuition of it involving only utilisation of sensor devices. Therefore, this old term seems weak in capturing the nature of management functionality at high levels.

At present, we are contemplating two different alternatives of the interrelation between sensor and perception management. We are not yet confident whether to include sensor management in perception management or treat it as a separate and independent concept.

In favour of the former alternative is the fact that perception is often considered to be responsible for all levels of information processing including dealing with data directly from sensors. Hence, perception management should, by this consideration, also include the functionality of sensor management. Figure 2 roughly describes this relationship from a resource accessibility point of view.

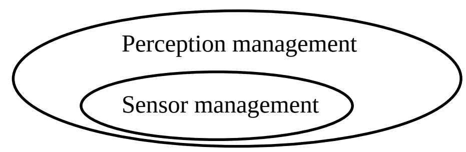

Figure 2: A coarse sketch of the relationship between the two types of management. Perception management is in this alternative considered to encompass sensor management.

In case the latter alternative is more appropriate, we have yet to discern a clear boundary between the two concepts. According to our current understanding, one of the major functions of perception management should be to figure out a schedule of perception tasks to be served by sensor management. In this sense, perception management works above sensor management and offers a driving force to sensor management, as illustrated in Figure 3.

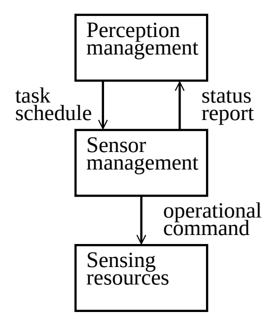

Figure 3: One may envisage a boundary between sensor management and perception management. Herein, perception management offers a driving force to sensor management.

Although sensor and perception management have different foci (the former mainly reconfiguring devices, the latter serving information needs), perception management does not overlap with the lower levels of the JDL data fusion model. It refers to resource control (as opposed to the lower JDL levels which deal with assessments), and, thus, would be entirely contained within the process refinement level of the JDL model (just as sensor management). Since process refinement is currently not clearly distinguished from sensor management, perception management contributes to a better understanding of it by well reflecting its true versatility.

Even though extension of traditional sensor management to encompass the emerging aspects mentioned may not be entirely ruled out, attempting to do so may risk spoiling or weakening the notion of sensor management, today well established in a wealth of literature (including [35, 36, 37]). Indeed, the established sensor management term is inherited from the multisensor data fusion and target tracking field, sometimes making it awkward in a more general context. Hence, we believe that the introduction and investigation of the new concept of perception management will be beneficial for further advancement of information fusion technology on the process refinement level.

Finally, it bears emphasising that the concept of perception management is proposed to refer to the external aspect of perception (i.e., sensations of the environment). But it does have an indirect, yet important, effect also on the internal process of data interpretation by controlling data streams and offering the most useful data to be processed.

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