Object-Oriented World Model for Surveillance Systems

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To survey large areas or buildings, it is necessary to install an extensive amount of sensors. In conventional surveillance systems, all signals from various sensors, such as cameras, microphones, RFID detectors and light barriers, have to be evaluated manually by human operators, which is cost-intensive and error-prone. Present approaches for a more automated surveillance mainly focus on the automated exploitation of a single sensor signal, enabling the system to notify the operator of primitive events. The most critical threats however, such as terrorism and industrial espionage, can only be detected and avoided, if information from multiple sensor signals is fused together.

Therefore, an approach to represent the relevant information extracted from sensor signals, fused into a single comprehensive, dynamic model of the monitored area is presented. The proposed object-oriented world model (OOWM) is part of the semi-autonomous surveillance system NEST, developed at Fraunhofer IITB. The main focus of this research project is to migrate from a sensor-centered view to a task- and object-centered view, with the aim to focus the system on the application-relevant information.

The OOWM is preconfigured with static prior knowledge, such as the spatial data of the area or building to be supervised. Dynamic information is collected by arbitrary signal exploitation algorithms (e. g.

person tracking) and fused into a consistent representation inside the world model by means of Bayesian fusion.

As an obvious benefit, the resulting object-oriented representation of the dynamic situation provides the operator with a tool to easily overview the situation, detect critical situations early and initiate appropriate countermeasures. Furthermore, the world model is a key component to enable an easy and seamless integration of new sensors and to develop high-level algorithms that are able to execute surveillance tasks autonomously.

Introduction

In today's state-of-the-art surveillance systems the exploitation of information is coupled to the sensors. Every sensor hast to be evaluated and monitored by humans. The most prominent example is CCTV. The video stream is displayed at a screen matrix, allowing a subset of the available video cameras to be selected for observation. These CCTV systems are inefficient and have a very low detection rate because several video streams have to be monitored in parallel. Little by little semi-automatic exploitation techniques become available, for example video based movement detection, but are still sensor centered. These systems have a high demand on computational resources, as the available sensor data has to be processed, whether it is relevant or not. Regarding the number of sensors necessary to cover an area of interest, this approach leads to an intractable demand on computational resources.

The presented approach focuses on the surveillance tasks and security relevant objects. The key component of such a system is the *object-oriented world model (OOWM),* providing a dynamic representation of the situation. It contains consolidated and consistent interpretations of the processed sensor data, containing relevant information on the supervised area. An object-oriented data model in combination with Bayesian data fusion assures a methodically founded technique to ensure consistent and up-to-date information in the model. Prior Knowledge like CAD data of the building to be supervised or information about security relevant objects and persons can be integrated and handled by the model effortlessly.

The OOWM acts as information hub for all system components and provides a decoupling of sensor exploitation and situation detection. Thus it can handle complex tasks described on a semantic level that need several cameras or even different types of sensors. Additional surveillance scenarios or novel sensors and algorithms can be integrated with little effort as the system architecture clearly separates the relevant information from the physical sensor.

The OOWM is part of the NEST surveillance system, being developed at the Fraunhofer Institute for Information and Data Processing IITB [1].

Architecture

The overall NEST system architecture is based on a service-oriented design. The OOWM is an active part of the architecture, providing interfaces for the submission of observations by sensor data exploitation components as well as query and subscription interfaces for high-level components. To ensure the validity and consistency of the OOWM and protection of the outgoing data concerning privacy policies, the model representation itself is confined by these interfaces inside the OOWM *Core* (Fig. 1).

Sensor services deliver observations extracted from raw sensor data over a sensor observation bus. A sensor service is not necessarily bound to a single sensor as it can subsume several physical sensors. The observations are channeled into a network of fusion modules which provide consistent consolidation of the incoming data. Such fusion algorithms are able to establish a consistent interpretation even in the situation of multiple and conflicting observations.

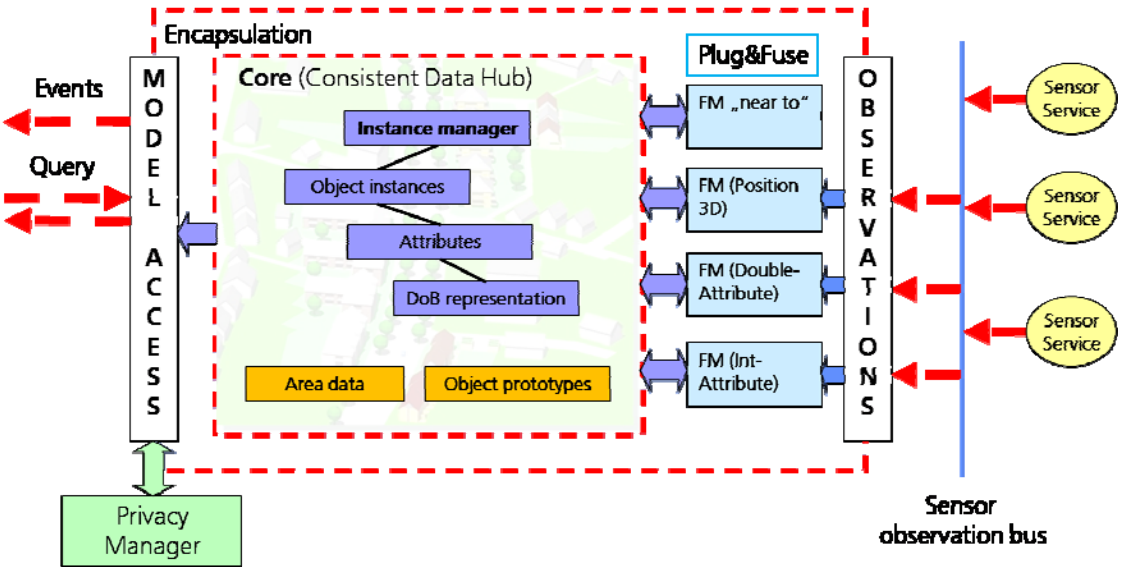

Fig. 1: Object-oriented world model (OOWM) architecture

An *instance manager* inside the *Core* is responsible for all dynamic objects “living” in the OOWM. Newly detected objects are instantiated and updated by the fusion modules when new observations are available. The objects are described by their attributes which are modeled as degree of beliefs (DoB) [2].

The OOWM also contains prior knowledge like spatial data of the area and object prototypes. The objects in the world model are linked dynamically to these prototypes according to best matching attributes.

Queries from high level services are handled on a semantic level by the *model access service (MAS)*. The occurrences of important events are signaled by the *MAS* to high level services, which are able to subscribe to the certain categories of events (e. g. events concerning a specific object instance or a relevant area).

Information Representation

The OOWM *Core* initially contains the prior knowledge which is configured by the administrator of the system. The prior knowledge is comprised of spatial data of the site to be surveyed, for example rooms, doors, elevators, stairs, etc., usually derived from CAD data. Object prototypes are preconfigured to cover the main typical object types which can be expected in the surveyed area and are relevant to the surveillance tasks. The object types are universal descriptions of certain classes of objects of interest (e. g. human, suitcase, etc.) for the surveillance tasks. Their characteristic attributes are represented by prior DoBs.

Physical objects which are detected by the system and relevant for the surveillance tasks are represented in the OOWM Core by object instances. They can be described only by their attributes (e. g. size, shape, color etc.), without determination of the object type at instantiation time. This data model overcomes limitations of the classic object-oriented inheritance scheme, which makes it difficult to change object types at runtime. Thus the type of object which has to be instantiated does not need to be known beforehand. The type of object is dynamically estimated and updated based on matching of the attribute characteristics of the object prototypes. Fig. 2 illustrates the loosely coupled association between instances, types and attributes of objects by the application of DoBs.

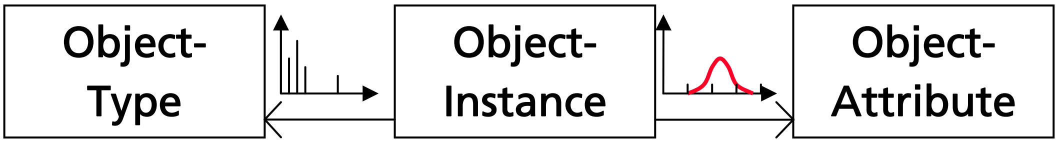

Fig. 2: Data model

All associations between object instances and its attributes are modeled as DoBs. As object instances represent physical objects in the real world, the object instances are associated to the spatial prior data and to each other at least by spatial attributes (e. g. 3D coordinates).

The most complete and exact uncertainty model in terms of probabilistic modeling is the joint distribution over all object instances and their attributes asserting that dependency between all variables in the model is always expectable. However this DoB representation is computationally not traceable because of the high complexity and dimensionality. On the other hand the simplest DoB representation is a deterministic model which uses facts with no measure for uncertainty, leaving no possibility to fuse several and possibly conflicting observations.

Between these extremes uncertainty modeling can be realized on different levels of complexity, regarding both independence assumptions and approximations of the distribution:

- Instance independency model - To reduce complexity, it can be assumed that object instances can be interpreted independently, reducing the representation to the cumulative distribution over all attributes of each single instance.
- Attribute independency model - To further reduce complexity, attribute values are assumed to be independent; the cumulative distribution can be expressed as a function of marginal distributions.
- Approximation of the distribution - The complexity of the distribution and fusion algorithms can be reduced by applying a parametric representation e.g. with a mean value and a standard deviation, which is a Gaussian distribution according to the Maximum Entropy principle[3].

The OOWM Core currently implements an attribute independency model, as it is computationally traceable and accounts for the most prominent sources of uncertainty. To justify this approach, however, it is planned to evaluate the cost/benefit of added accuracy introduced by modeling the correlation between attributes, in an experimental setup representing typical surveillance scenarios.

Information Fusion

Based on the uncertainty representation mentioned in the previous chapter, incoming observations are handled by a plug-and-fuse concept. Fusion methods, either of general nature (e. g. Bayesian fusion of observations of a continuous one-dimensional variable), or adapted to the specific dynamic behavior of an attribute over time (e. g. Kalman-Filter), are encapsulated into fusion modules. Fusion modules, which implement the OOWM interface definition, can be easily plugged into the system by adding them to the OOWM configuration. If a new observation is delivered to the OOWM, the instance manager selects the most suitable fusion module based on its meta-description, able to fuse the new observation with the respective object already present in the world model. The Bayesian fusion algorithms consider the information in the model as prior information, while the newly measured information is interpreted as likelihood. Considering that attributes of the objects may change over time, a propagation model increases the respective uncertainties over time, in case the attributes were not observed. The extent of the increase depends on the type of attribute and is handled by the responsible fusion module. For example the uncertainty of the position of a person may increases more rapidly than the uncertainty of its body height.

A very important aspect influencing the quality the fusion is data association, i.e. to determine which instance in the world model is associated to an observation of an object in the real world by comparing their attributes. If the sensor is not able to identify and to measure attributes at the same time, it is necessary for the OOWM to determine the correct object instance by itself. Therefore a maximum likelihood estimator in the *instance manager* is implemented to decide which object to associate with an incoming observation. This observation is then fused on attribute level with the chosen object instance.

If no matching object already exists in the world model, a new object is instantiated. All observed attributes are initialized according to the given observation in conjunction with the uncertainty provided by the sensor, while unobserved attributes can be initialized with default values and non-informative DoBs for their uncertainties. The use of fusion modules allows for an effective way to add new sensors with more complex uncertainty representations and new types of observable features to the system by simply adding a new fusion module without recompiling the whole OOWM system.

The architecture also allows for special fusion modules assigned to supervise security critical situations, which are described on a higher semantic level. For example one module could be assigned to check if an object of the type "luggage" is abandoned and to posts an event if this situation occurs.

To prevent cluttering of the world model by false-instantiations or instances of objects which are no longer present in the surveyed area, an adequate mechanism to decide when to remove instances has to be implemented. A plausible method is to add an attribute to every dynamic object describing an existence/relevance DoB. By evaluating this DoB, the instance manager can destroy/forget objects that became irrelevant or unlikely to be still present in the surveyed area. The DoB is increased if positive evidence i.e. an observation of the object is received. The decrease of the DoB has to be coupled to the relevance and type of an object to ensure reliable surveillance. The incorporation of an existence DoB can be additionally used for delayed instantiation of new objects to cope with spurious observations due to sporadic occurring sensor errors.

Information Dissemination

High-level services that are able to execute surveillance tasks autonomously extract the information on an object-oriented, semantic level form the world model. The necessity to deal with sensor data and reconfiguration on the availability of new sensors becomes obsolete for these services. They can gather information by querying the *model access service (MAS)* interface or subscribing to events created by the OOWM.

As all services requesting information are channeled by the *model access* module, privacy policies can be easily enforced by a *privacy manager [4]* linked to the OOWM.

Conclusion and Outlook

Tomorrow's surveillance systems will be required to deal with complex surveillance tasks, which have to be continuously adapted to changing threats. Integration of new advances in sensor systems must be easily realizable. Most importantly, the systems must be equipped with a high level of automation to perform at acceptable efficiency and provide a high detection rate. This can only be achieved if information acquisition at the sensor level and the interpretation of sensor information for threat detection at the semantic level are decoupled. The object-oriented world model (OOWM) describes an approach which represents the relevant information extracted from arbitrary sensor systems fused into an object-oriented and probabilistic model, forming the basis for the application sensor-independent, task-oriented algorithms for the detection of critical situations. In the near future, the system concept will be extended to be able to autonomously task available sensor systems, based on the information requests of situation detection algorithms. The system is currently implemented and evaluated as a part of the semi-autonomous surveillance system NEST, developed at Fraunhofer IITB.

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