# An agent-based approach to understand events in surveillance environments

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*Abstract*—**Intelligent surveillance aims at providing artificial systems in order to monitor and improve the security of public and private spaces. Since these environments are complex and the information is distributed through them, agent-based solutions represent a good approach when monitoring moving objects. This paper describes how an existing agent platform has been adopted and used to carry out intelligent surveillance. Within this context, agents implement a behavior-based model that is flexible enough to deal with the challenges that the surveillance tasks pose. The experimental results show how this agent-based approach can contribute to understand events in urban traffic environments.**

## I. Introduction

Intelligent Surveillance Systems [1] monitor environments by applying Artificial Intelligence (AI) techniques. The two key aims to reach by means of the use of these methods are the real-time automatic analysis of scenes and the obtaining of detailed and precise information that allows the artificial system to make decisions and anticipate future events. The use of intelligent surveillance techniques based on image processing and visual reasoning can reduce the human resources cost and solve the mentioned problems of tiredness and fatigue by supporting security staff. According to the knowledge generated by intelligent surveillance systems, there currently exist systems capable of detecting crowds [2], identifying suspicious or lost items [3], inferring anomalous behavior [4], or analyzing object trajectories [5] from visual information.

Intelligent Surveillance Systems are often deployed on top of a multi-layer architecture, where each layer performs a well-defined function and generates a set of results that is used as input for the rest of layers (see Figure 1). In this kind of architectures, AI techniques are generally applied to model, formalize, develop, and implement artificial systems capable of supporting the analysis of situations, learning from data, and making decisions consequently.

Research on the field of intelligent surveillance systems can be framed in some of these stages, but most work is focused on low-level stages such as segmentation and tracking, that is, the image processing mechanisms used to partition a digital image into multiple regions and to locate moving objects in a scene, respectively. In higher levels, research is commonly oriented to solve particular problems, such as detecting anomalous behavior or identifying suspicious or lost objects.

The detection and understanding of events by these high-level layers is essential to improve surveillance systems. Thus, previous experience and knowledge to monitor environments are required. This knowledge can generally be given by human experts in the security domain or learned from past situations. In order to acquire the expert knowledge and to learn from previous experience, knowledge acquisition tools and machine learning techniques can be respectively used. Knowledge acquisition tools require a human expert to explicitly define the domain knowledge. In the context of surveillance, this knowledge may involve the visual definitions of the physical zones that compose the monitored environment or the main characteristics of moving objects, such as size, shape, or color. On the other hand, machine learning techniques make use of automatic or semi-automatic algorithms to infer the domain knowledge needed to carry out the reasoning.

Besides employing AI techniques, last generation surveillance systems [1] are also characterized by the huge number of security devices distributed all around the environment. Therefore, the information obtained from the different surveillance sources is distributed so that we need to use a scheme that facilitates its fusion in order to provide an advanced surveillance. To address this problem and give support to the intelligent surveillance modules, we make use of a multi-agent architecture to deploy intelligent agents specialized in the different surveillance services required by the environment to be monitored. The use of a multi-agent architecture makes easy the design of a solution based on the intelligent management of distributed knowledge by offering a scalable and flexible system when integrating new concepts or elements that allow to provide a more sophisticated surveillance.

The rest of the paper is structured as follows. Section II reviews the evolution of intelligent surveillance systems and overviews some relevant proposals within this context. In Section III, the agent-based model used to monitor surveillance environments is introduced. Next, Section IV discusses how a multi-agent system was deployed to monitor a urban traffic environment where pedestrians and vehicles continuously move. Finally, Section V concludes the paper and suggests future research lines.

## II. Related Work

The problem of intelligent surveillance can be understood as how to process information from the environment in order to monitor activities traditionally done by the security personnel. The typical example is intelligent video surveillance, where the input is one or more video streams from cameras and the output aims at solving a concrete problem, such as crowd detection, face recognition, or even behavior analysis (for

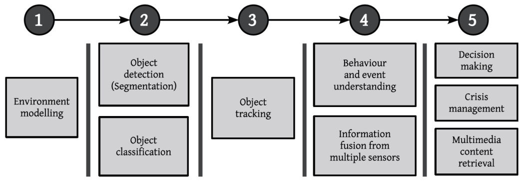


Fig. 1. Typical multi-layer architecture of a full surveillance system.

a complete survey see [1] and [5]), which involves visual reasoning. The remainder of this section shows an overview of relevant intelligent surveillance systems from two points of view: behavior analysis and agent-based approaches.

### A. Behavior Analysis from Visual Surveillance

One of the main research lines in cognitive or intelligent surveillance has been behavior analysis, which is often focused on detecting anomalous events. To date, however, research in this field has been almost exclusively concerned with the analysis of individual domains (vehicle traffic, parking, halls, etc) or aspects (paths, actions, movements, etc).

There exists a wide range of methods and techniques used for behavior analysis and understanding. Authors in this field use to choose people and vehicles to represent and understand behaviors. Another common issue is the analysis of paths followed by moving objects, which can be directly translated into the surveillance domain. The reasoning mechanisms are generally based on processing the visual information obtained from video cameras deployed around the monitoring environment. One of these techniques is Dynamic Time Warping (DWT), which allows to measure the similarity between two sequences that differ in time or speed [6].

Another approach consists in adopting a Finite State Machine (FSM), which is composed of states, actions, and transitions. Within the context of intelligent surveillance, the states represent the object situation on the environment, the actions represent moving object events, and the transitions refer to actions made by moving objects that have been recognized by the artificial system. Some applications of this technique involve the control of a robot monitored by a camera [7] or vehicle behavior understanding from aerial cameras [8]. On the other hand, the use of context-free grammars [9] has been also applied to intelligent surveillance in order to generate context-free languages used to recognize behaviors in a monitored environment [10].

Currently, one of the most widespread methods to deal with behavior analysis is Hidden Markov Models (HMM) [11]. Essentially, a HMM consists in a statistical model composed of a set of hidden states, the observable data, the transition probability, and the output probability. Research on video surveillance integrates the HMM to build artificial systems that help to automate the task of behavior analysis [12] [13].

There exists a significant number of research works focused on behavior analysis, such as discussed in [14] and [15]. Unfortunately, these work do not define scalable mechanisms for dealing with surveillance depending on different concepts, such as speed analysis, path analysis, or activity analysis.

### B. Multi-Agent based Approaches

As previously introduced in the introductory section, a multi-agent based approach fits very well to deal with the design of an intelligent surveillance system. Thus, agents give support to the distributed services that compose the whole system. One of the first approximations in the area of intelligent surveillance through multi-agent systems was to combine the information obtained from multiple cameras. An interesting work was introduced in [14], where the authors proposed a multi-agent architecture to get information of scenes from different points of view.

A more recent work is discussed in [16], which is mostly focused on using the multi-agent technology for coordinating the tracking of moving objects. This coordination is based on the exchange of high-level messages among agents that use a symbolic model to interpret situations.

Another solution to the problem of distributed intelligent surveillance may be adopting a general-purpose knowledge-based system to deploy concrete instances of that system for particular problems, such as a surveillance system. This is the approach followed in [17]. The paper presented an open and flexible architecture for a distributed knowledge-based system that can be applied to different problems. The architecture is based on multi-agent technology and the use of ontologies to represent knowledge.

## III. Agent-based model for event understanding

The agent model used in this work to monitor and understand events in urban traffic environments relies on the agent platform proposed in [18]. Basically, the agents of this architecture implement a behavior-based model so that the behaviors represent tasks to be carried out by the agents. From a general point of view, two kind of behaviors can be distinguished:

- **Simple**, which cannot be divided into other behaviors. Similarly, simple behaviors can be classified as follows:
  - *Cyclic*, which are continuously executed until the agent is destroyed.
  - *One Shot*, which are executed one single time.
- **Composite**, which are composed of other behaviors. Similarly, simple behaviors can be classified as follows:
  - *Sequential*, so that all their sub-behaviors are sequentially executed.
  - *Parallel*, so that all their sub-behaviors are concurrently executed.

Figure 2 shows the control flow of our agents according to the behaviors they implement. Basically, the agents maintain a pool of behaviors that are sequentially executed. If the pool is empty, then the agent becomes idle. On the other hand, if the agent is required to execute a new behavior, then this is queued up for executing.

Independently of the type of behavior that the agents implement, they typically will manage a knowledge base that will be

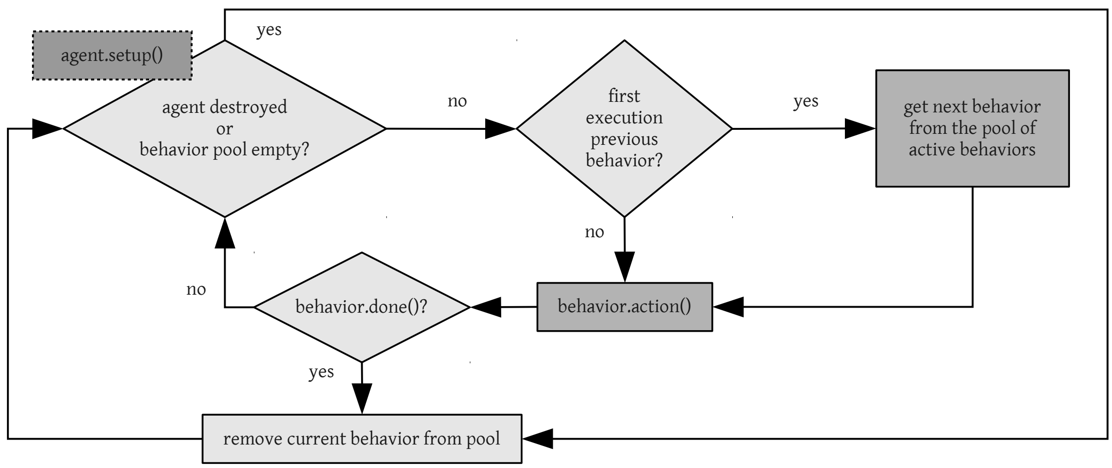


Fig. 2. Control flow of the agents, which relies on a pool of behaviors that are executed.

used to understand events and actions. In some of our previous works, these knowledge bases were acquired thanks to the help of a human expert [19] or learned by means of machine learning algorithms [20]. Now, the agents make use of these knowledge bases to monitor the environment but the flexibility gets increased thanks to this wide range of behaviors.

Within the context of urban traffic environments, the number of moving objects that should be monitored is usually large. The reader is encouraged to consider a crowded street with multiple pedestrian crossings to get an idea of a potential monitored scene.

From the point of view of monitoring, we chose to deploy a single software agent when a new moving object appears in the scene. Thus, each agent is responsible for a single moving object, using its knowledge base to determine whether its behavior is correct or not. When the object leaves the scene, then the associated software agent is destroyed and the used resources are freed.

## IV. Experimental results

This section discusses a specific urban traffic environment where a multi-agent system was deployed to monitor moving objects. Essentially, our goal was to determine if every moving object is on the physical area of the environment where it was supposed to be at all times. For example, pedestrians are not supposed to invade the road unless they use the pedestrian crossings. On the contrary, vehicles must not invade the sidewalks in no way whatsoever.

Figure 3 depicts some frames taken from a surveillance camera deployed in a Hungarian city. The second row of images shows visual information generated by the software agents: blue squares that delimit the surveillance areas and green points that represent the monitored moving objects[1]. In this particular case, the knowledge used by the software agents comprises the monitored areas, which are defined by using a graphical tool that simply generates XML files with the coordinates of each area. The frames captured by the surveillance camera were analyzed by using OpenCV. Plus, it is important to remark that the tracking results are not very good since there is no significant contrast between the road color and the pedestrians'.

For example, in Figure 3.d an agent was able to infer that the pedestrian represented by a green point in the center of the image does not behave correctly, since he/she is not over a pedestrian crossing or a sidewalk. Similarly, the pedestrian detected on the bottom right corner in Figure 3.f is crossing the street by using a forbidden area. Vehicles are also monitored by the agents but no anomaly was detected in the analyzed frames. Figure 3.e shows a number of vehicles that are detected by the software agents.

## V. Conclusions and Future Work

In this work we have discussed an agent-based approach that can easily be used in surveillance systems to increase the flexibility when monitoring aspects or events of interest. To carry out this task, the agents implements a number of behaviors that can adapt to the requirements of intelligent surveillance systems. These behaviors turn around knowledge bases, which can be defined by human experts or learned from previous experience. In order to increase the functional capabilities of intelligent surveillance systems, it is essential understand what moving objects do in the monitored environments. If this can be done in an artificial way with a high accuracy, the limitations of human monitoring (e.g. fatigue and tiredness) can be overcome.

We are currently integrating previous work on intelligent surveillance [19] [20] into the agent architecture so that every surveillance task is a behavior executed by an agent. After that, our intention is focusing our work on parallel behaviors to reach all the power of multi-core computing and increase the performance of our surveillance system.

[1]The full video is available at http://www.esi.uclm.es/www/dvallejo/wi-iat

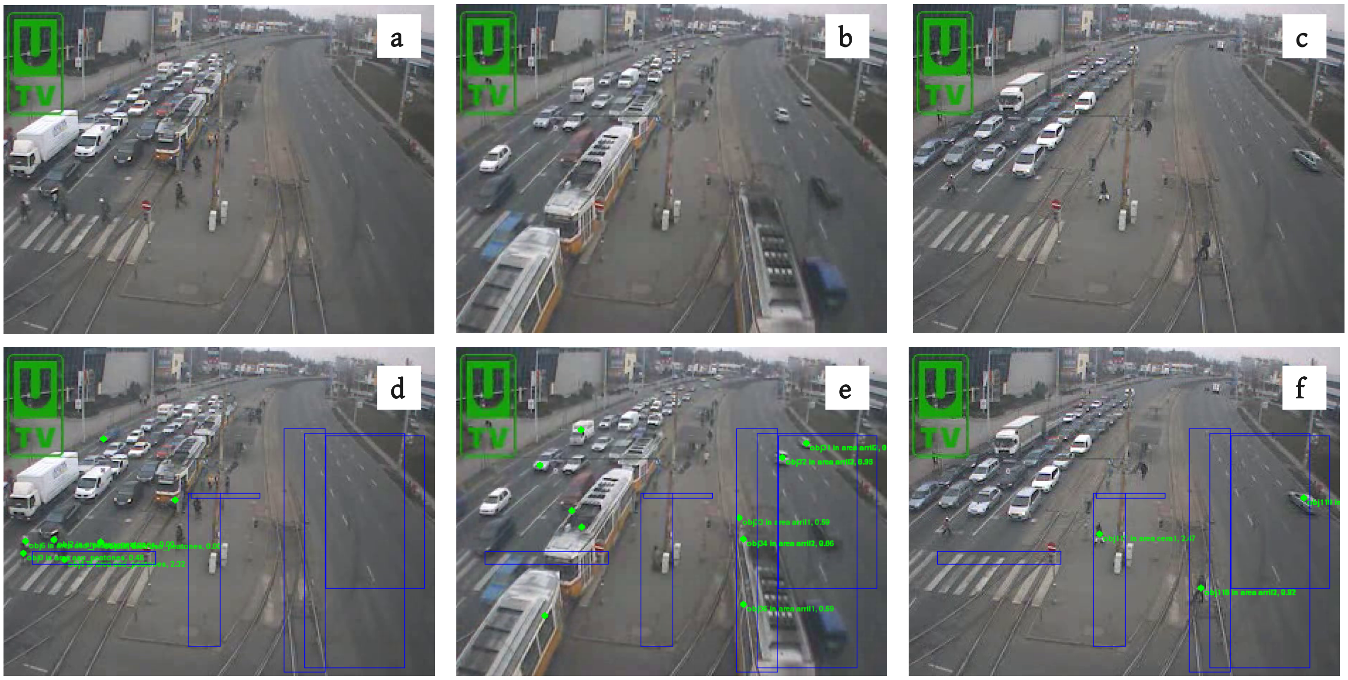


Fig. 3. **First row**: images captured by a surveillance camera in a crowed road. **Second row**: images analyzed by the agent-based surveillance system. The blue squares represent surveillance areas; the green points are associated to monitored objects. The text shows the area percentage covered by each object.


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