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An Efficient Knowledge Base Management Scheme for Context Aware Surveillance

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Abstract

We propose architecture for multi-agent systems to retrieve and classify features extracted from images and videos of smart cameras. To enable cooperative inference between agents on cameras, structured representation of agents' knowledge and abilities is required in the form of ontologies. Recognized features if properly structured and annotated, can be a useful source of information for context aware surveillance. This work builds a hierarchical inference data deployment structure and import related and required data to annotate rich data arriving from multiple sensor streams, in this case smart cameras. The annotation provides an impetus to the improvement of knowledge over time. Proactive deployment provides the main concepts and properties to model a hierarchical area ontology structure which can span a university campus or a city. We also define management policies to compare their performance for the wide area surveillance specifically.

Keywords: *Wide Area Surveillance Systems, Cooperative Smart Camera Network, Context Inference*

1. Introduction

Cooperation or integration among agents related to surveillance requires classification, recognition, inference for target. Information acquisition in complex environments addresses cooperation among agents for related knowledge. Cooperation among agents could increase the network traffic and need specific protocol. Networked multi-agent systems can be used for wide area surveillance where distributed cameras allow us to see a subject of interest from several different angles and different situations through the tracking path. This helps us solve some hard problems that arise in single camera systems with cooperative integrated inference.

For the surveillance of the wide area, agents built in networked sensors and smart cameras should collaborate through integration of recognized information. Recognized Information includes facial features, type of objects, environmental context and others. Distributed agents receiving heterogeneous data from various sources have autonomy and infer knowledge based on its ontology. For the continuous, higher level reasoning they collaborate with each other based on distributed global ontology. In this paper, we present a framework for the integration of knowledge supplied by a set of agents which are built in smart camera nodes. The agents are interconnected through a peer network. And non-leaf administrative agents in a geographic area hierarchy or in an administration hierarchy build a hierarchical structure according to their hierarchy. This framework guarantees the consistency and expressivity of the ontology used in the data integration process. In the process of reasoning each agent may process the consolidated data in order to generate inference based on its local and global ontology. Distributed and autonomous reasoning is scalable and efficient [1]. It helps security persons by giving appropriate decision or prediction based on huge ontology about situation it gathers.

Aiming at knowledge integration, we designed architecture for cognitive multi-agent systems that retrieve and classify recognized features and event alarms from agents on cameras, extracting higher context knowledge from it. To enable cooperation, it consists of explicit knowledge representation in the form of ontologies. The distribution of demands for specific items is often skewed, and the surveillance devices have different capabilities. For the efficient higher level reasoning such as continuous tracking over different regions, we propose a proactive deployment scheme for efficiency and interoperability. Implementation is going on into our distributed surveillance network environment.

The paper is organized as follows: Section 2 surveys related work of cooperative inference schemes. Our proposed modeling framework is explained in Section 3. Section 4 describes the adaptive surveillance data management technique. In Section 5, simulation results are presented and the performance is evaluated. We also show our implementation results in progress. Finally, Section 6 concludes with an outline of our future work.

2. Related Work

Several cooperative inference schemes on the smart cameras with different viewpoint are proposed with analogical peers. Ontology reasoning architecture [2, 3] can be used in many applications requiring images from multiple data sources to be combined in order to interpret the scene and understand the situation such as physical security surveillance [4], environmental surveillance, or disease surveillance [5]. For wide area physical security surveillance, monitoring systems are connected to communicate with each other [6, 7]. However, they do not adopt artificial intelligence technique like our ontology reasoning.

To ease merging of heterogeneous data, effort for the standardization for physical security is done by ONVIF (Open Network Video Interface Forum) [8], PSIA (Physical Security Interoperability Alliance) [9] define, recommend, and promote standards for IP-based security products. Besides ISO [10], BSI group [11] and other standard organizations enact standards for general aspects of physical security. Our system tried to meet the requirements of industry by providing functions recommended by standard organizations. Many of existed security surveillance system depend on the knowledge annotated by experts [12]. There are few of surveillance systems adopting ontology-driven technologies. [13] introduces artificial intelligence techniques only for the interpretation of objects. [14] uses ontology but does not build agents for web of data. Furthermore existing wide area surveillance system are closed system and do not provide surveillance information as a public web services.

To address these challenges, we advocate an adaptive hierarchical ontology deployment framework in which agents with limited knowledge co-exist and communicate for cooperative reasoning in an efficient knowledge base management policy.

3. Proposed Architecture

Cooperative inference such as object tracking requires the cooperation among local agents. Our wide area surveillance architecture is modeled as a hierarchy of agents as shown in Figure 1, consisting of national agents at the top, regional agents at the middle level, and local agents at the lowest level. At the lowest level, local agents built in smart cameras make leaf nodes. The lowest level agents having their own ontology with limited capacity can be directly connected to neighbor agents having related information and higher level agents of broader global ontology. Meanwhile, the users are directly connected to any level of agents. The rectangle mean origin agent which starts tracking and the ovals mean neighbor agents connected to origin agent directly. The lowest level server extract surveillance data such as facial features, type of object from raw image or video in their domain. Further low level context reasoning based on local ontology can be done at the leaf node agent.

Agents with ontology form a graph structure. They can communicate each other freely within access control permission to perform their own intelligent distributed inference based on ontologies of neighbor agents.

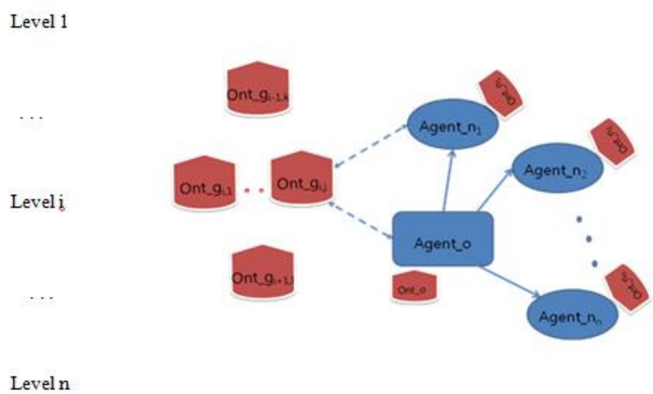

Figure 1. Hierarchical Infrastructure of Agents and Ontologies

We design an experimental system for a wide area surveillance covering Gyeonggi province area containing about 10 cities which can be extended to nation-wide surveillance. The design of architecture for the surveillance of the area consists of an integrated framework of networked RFID sensors and smart cameras. The surveillance device’s purpose is not only to take pictures, record videos and log location data, but also to analyze a scene and extract feature items and activities of interest to the security person. Also it is required to make decisions and suggest actions based on prediction by ontology reasoning. Various surveillance data, such as video, feature vector including biometrics, event alarms, originate from many kinds of input devices. Agents are distributed by geographic area hierarchy, they have their own knowledge base including context ontology, inference engine and communication protocol between agents for queries.

With a surveillance data distribution, even small agents, with the help of origin agents, can achieve very high hit rate locally, thus reducing significantly the bandwidth requirements of the network connection and the latency perceived by the users.

This paper assumes a proactive, rather than reactive, deployment and attempts to explore an optimal surveillance data management and service for wide area surveillance networks. By proactive data deployment, it means that the agents cooperate with each other in exchanging necessary information by fetch and broadcast the data before other agent requests it. To achieve this goal, the surveillance network is modeled as a multi-layered distribution network in the next section. And the system performance parameters for the surveillance network are derived. As a result, better usage of their limited data store space and network bandwidth for higher system performance can be obtained.

4. Knowledge Base Management Scheme

The image and the vision obtained by each camera depend on its position and orientation. Therefore they are different from those of other cameras observing the same scene. Various forms of the surveillance data including multimedia data and feature data are distributed over the knowledge bases of agents. The agents need to carry out the indexing and retrieval of the information distributed across the servers in an efficient manner. To aid the task, agents cooperate for seamless continuous tracking by exchanging information.

In the hierarchical surveillance network structure, agents cooperate with each other in such a way that the request not satisfied at the lower level is forwarded to a higher level in the structure hierarchy until it satisfied. As contrasted to this hierarchical request chaining, forwarding of request at the same level operates quite a different scheme on top of the surveillance network architecture.

With the proactive deploying of surveillance data, which we assume in this paper, agents gather information from neighbor agents. Based on the exchanged information, agents broadcast information to the subscribing agents before any other agent requests it. This service has no hierarchy among the agents and all agents maintain the same set of data.

We specify features of the forwarding surveillance data as an analytical model for evaluating the system performances. We define $D=\{1,2,\ldots,|D|\}$ as the whole set of surveillance data including recognized features of the target, and assume that the data in D are ranked in the order of their suspiciousness or importance. From the well-known results that the probability of the i-th data is collected is Zipf distributed [15], we have the probability function,

$$f(i) = \frac{\sigma}{i^{\alpha}}, i = 1,2,\ldots,|D| \tag{1}$$

where $\sigma = (\sum_{i \in D} 1/i^{\alpha})^{-1}$ and α is a constant close to 1.

Let n_k and λ_k be the total number of connected agents and the data request rate for agent k, λ_k is proportional to n_k.

If agents do not differ from each other in their preferences for data, the request rate of agent k for the data i, denoted by λ_{ki}, can be written as

$$\lambda_{ki} = \lambda_k f(i) = \beta n_k \cdot \frac{\sigma}{i^{\alpha}} \tag{2}$$

Using Bayes' theorem, searching a target of interest having d_t at time t, reduces to finding the maximum of the $P(d_t| D)$.

In order to determine the existence time in specific smart camera's view, the travel length which is the distance covered by a target and its velocity are needed. In this paper we consider a constant movement. This means that the velocity which is assigned to the target at the initialization of the movement remains constant during the travel. Given the random variable L of the travel length and the random variable V of the velocity, the random variable T of the existence time is defined by the following relation.

$$T = \frac{L}{V} \tag{3}$$

where L and V are assumed to be independent. To maintain the freshness and effectiveness of the data, we should update data adaptively in time T_j for target j. We use weight of surveillance data to describe its relative importance as compared to the other data in similar way as proposed in [16]. The higher the weight, the lower is the probability of the surveillance data being replaced. We also use a policy based on the size of the objects, in which the weight is proportional to the size of the data. Therefore the weight w is computed as following,

$$w = F^f S^s R^r \tag{4}$$

where F is the number of times the data is accessed, S is the size of the data and R is the time. The three exponents f , r and s are weighting factor.

From (1) to (3), Equation (4) can be written as,

$$w = \left(\beta n_k \frac{\sigma}{i^\alpha}\right)^f \cdot \left(\sum_{i \in D} S_i\right)^s \cdot \left(\frac{L_j}{V_j} \mathrm{P}(\mathrm{d_t} \mid D)\right)^r \tag{5}$$

where S_i be the size of the i-th surveillance data and L_j and V_j is the travel length and velocity of the target j. The value for f should be a positive number, meaning that more frequently accessed data is more likely to be found. The value of s can be should be a negative number, such that more small data is more likely to be stored. The value of r should be a negative number, meaning that more dynamic data is more likely to be stored. The absolute value of the exponents should be adjusted in accordance with the relative importance.

5. Experiment and Implementation Results

Experiments held with several agents, that treated the classes of surveillance data, produced promising results. We implemented our knowledge base management scheme on agents for cooperative inference by integrating ontologies. Each agent recognizes, filters and classifies images, extracting surveillance data such as feature vector, event alarm, *etc*. We incorporate the extracted raw data into knowledge base with context ontologies built using TopBraid composer. We defined data type as seen in Figure 2. Instances at data type property is imported from each agent in real time. Part of our context ontology is shown in Figure 3. We define many classes for the integrated inference.

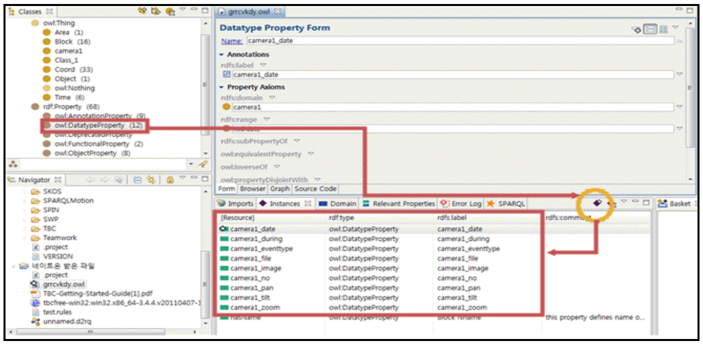

Figure 2. Example of Data Type Properties Defined

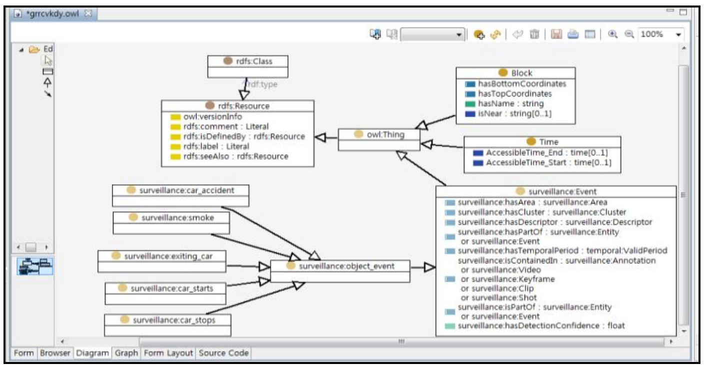

Figure 3. Example of Classes in Context Ontologies

We also implement various user interfaces. Web-based user interface shown in Figure 4 lists biometric feature data recognized on the right frame. On the left frame includes google map and marks for peculiar events. The event lists pop up is the results of the integrated inference. When we click each of the event items, it pops up related information. The target tracking through the communication between the independent agents is possible. They request and inquire surveillance data for a combined inference. In Figure 5, we show the mobile interface. Touch user interface is implemented to see the real time or stored video and for smart camera control.

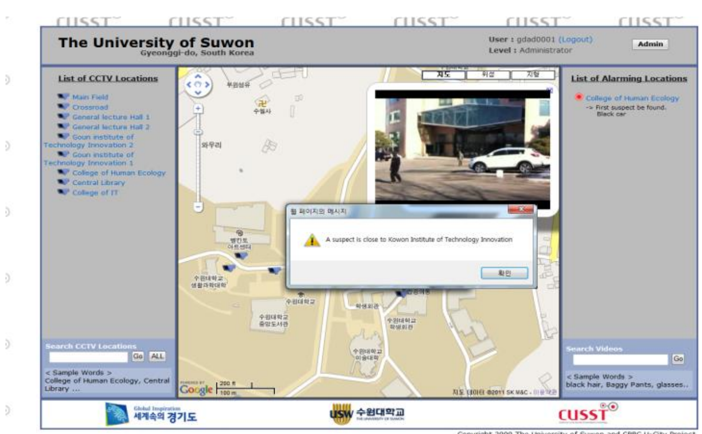

Figure 4. Web Interface with Google Map

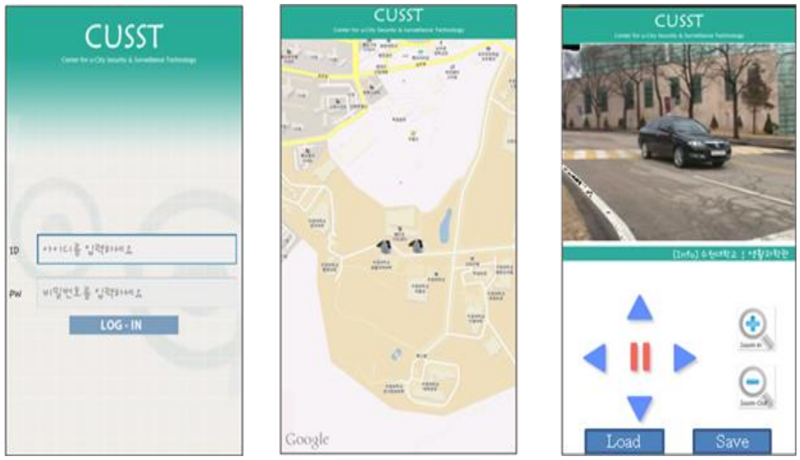

Figure 5. Mobile Interface for Security Persons

6. Conclusion

Context inference is widely used in distributed surveillance environment. This paper presents a cooperative knowledge base management framework for monitoring and tracking target from sequences of images obtained from multiple smart cameras. Based on this scenario, the problem becomes matching the target across different camera views, where the cameras' parameters and positions are assumed to be known a priori. To establish correspondence between consecutive frames from different cameras, agents built in cameras communicate and cooperate to recognize and inference. Agents deploy surveillance data such as extracted features or event alarm proactively to neighbor agents. For such a network, an efficient knowledge base management framework that a flexible deploying scheme which is adaptive to the actual device demands and that of its neighbors is proposed. Our scheme uses conformity to update and share data in a cooperative way. Simulation studies are conducted to evaluate the effectiveness of our flexible surveillance data deploying scheme. Implementation is also going on into our distributed surveillance network environment. Based on mathematical derivations, the proactive deploying of surveillance data and service policy maximizes the reasoning engine's potential for making decisions from operating the hierarchical structure distribution. The surveillance data deploying structure, where data are deployed in the order of hierarchy and in the direction of the target respectively, are formulated and optimal service policy is pursued in view of which neighbor agents to include in the system. Computational experiments are performed to investigate how the optimal deploying scheme and service policy responds to system parameter changes. Finally, implementation is discussed. More realistic data will be given in future work. Our scheme shows the efficiency of surveillance data deploying resulted in better context inference.

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