Multi-Agent System for Management and Monitoring of Routes Surveillance

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Abstract. This paper presents a multi-agent system for security control on industrial environments. The system uses a set of wireless technologies and software agents which integrate reasoning and planning mechanisms. It has the ability to obtain automatic and real-time information about the context to schedule the security guards activities. The combination of technologies enables users to interact with the system in a simple, natural and intuitive way.

Keywords: Industrial Security, Agents, Surveillance Routes Calculation, Monitoring, Radio-Frequency Identification.

1. Introduction

In recent years there has been an expansion in the industrial sector, especially in developed countries. In such an important and growing sector, it is necessary to establish security policies to manage risks and control hazardous events, providing better working conditions and an increase in productivity.

Recent studies [4] have revealed that at least 3% of the working shifts time is spent because of the lack of time control systems that supervise the real working time. Implementation of time control systems have a good influence in productivity, since the workers optimize their potential and enhance the process where they collaborate.

Multi-agent systems and intelligent mobile devices architectures are suitable to handle complex and highly dynamic problems in execution time. Agents and multi-agent systems are successfully implemented in areas such as e-commerce, medicine, oceanography, robotics, etc. [2][3].They have been recently explored as supervision systems, with the flexibility to be implemented in a wide diversity of scenarios, including industrial sector. The current application of multi-agent systems in real-time environments is an area of increasing interest. In general, the multi-agent system represents an appropriate approach for solving inherently distributed problems, whereby clearly different and independent processes can be distinguished. The use of wireless technologies, such as GPRS (General Packet Radio Service), UMTS (Universal Mobile Telecommunications System), RFID (Radio-frequency identification) , Bluetooth, etc., make possible to find better ways to provide mobile services and also give the agents the ability to communicate using portable devices (e.g. PDA's and cellular phones) [10]. Nowadays, there is a great growth in the development of agents-based architectures, evolved in part because of the advances on intelligent environments and computational networks [10].

This paper presents the application of a novel hybrid artificial intelligence (AI) system to manage and monitor surveillance routes for security guards on industrial environments. The system uses a set of wireless technologies: Wi-Fi, GPRS and RFID. These technologies, increase the mobility, flexibility and efficiency of users, allowing them to access resources (programs, equipment, services, etc.) remotely, no matter their physical location.

The rest of the article is structured as follows: in Section 2 a case study is defined, describing the development of a multi-agent system designed to solve some of the problems that affect the industrial sector. Sections 3 and 4 present the main characteristics of the system, describing its architecture and the surveillance routes planning mechanism; and, lastly, the evaluation is presented and the results obtained are analysed.

2. Multi-Agent System for Industrial Security

A multi-agent system has been designed to allow scheduling and distribution of surveillance routes among available security guards in order to provide better control over the activities performed by the staff responsible for overseeing the industrial environments. The routes assigned are automatically and real-time monitored to ensure the accomplishment of the security guards working shifts. The system interacts with users through a set of mobile devices (PDA's) and wireless communication technologies (Wi-Fi, GPRS and RFID). These technologies and devices work in a distributed way, providing the users a flexible and easy access to the system services.

Depending on the security guards available, the working shifts and the distance to be covered in the facilities, the agents in the system calculate the surveillance routes. A supervisor (person) can set the possible routes, defining the areas that must be supervised, which can be modified according the scenario or changes in the environment. The system has the ability to re-plan the routes automatically considering the security guards available. It is also possible to track the workers activities (routes completion) over the Internet.

Radiofrequency Identification (RFID) is a key technology in this development. RFID is an automated data-capture technology, relying on storing and remotely retrieving data. It is most frequently used in industrial/manufacturing, transportation, distribution, and warehousing industries, but there are other growth sectors including health care [11]. As can be seen in Figure 1, the RFID configuration for the system presented within this paper consists of a mesh of tags distributed all over the building. Each tag, named "control point" is related to an area which must be covered by the security guards. Each security guard carries on a PDA with a RFID reader to register the completion of each control point. The information is sent via wireless technology to a central computer where it is processed.

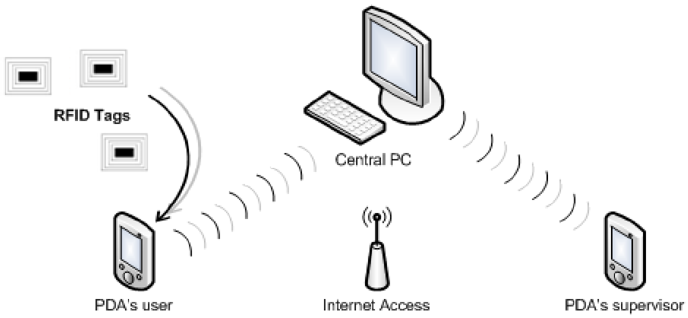

Fig. 1. Basic Monitoring Schema

The case study has been successfully implemented in a real environment. Sections 3 and 4 present the main characteristics of the system, describing its architecture as well as the surveillance routes planning mechanism.

3. Multi-Agent Architecture

The core of the hybrid system presented in this work is a multi-agent architecture specifically designed to facilitate the development of ubiquitous environments. The basis of the multi-agents systems is the cooperation of multiple autonomous agents [2]. Multi-agent architectures comprise plenty errors recovery, with the ability to initialize or end separate agents without the need to restart the entire system. The developed system presented on this paper has these features, so it is possible to initialize multiple services on demand. The agents' behaviour is affected when it is necessary to schedule a new surveillance route. Besides, the system store continuously its status information, so it can be restarted and recover the last backup information. The analysis and modelling of the system has been done using a combination of the Gaia methodology [12] and the AUML language [1]. Once defined the system structure, shown on Figure 2, it is possible to appreciate that the system is composed of five different kinds of agents:

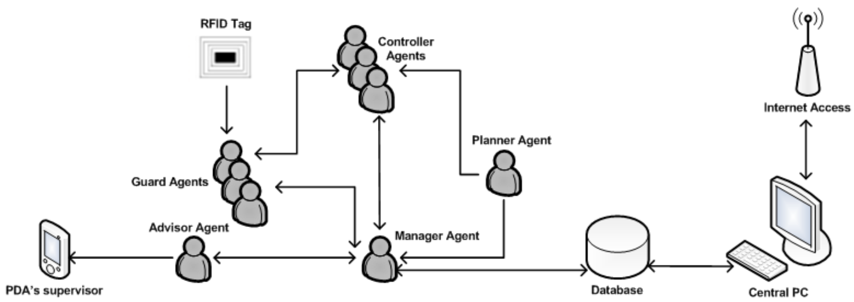

Fig. 2. Multi-agent architecture describing the system structure

- *Guard Agent* manages the portable RFID readers to get the RFID tags information on every control point. Communicates with Controller Agents to check the accomplishment of the assigned surveillance routes, to obtain new routes, and also to send the RFID tags information via Wi-Fi.
- *Manager Agent* controls all the rest of agents in the system. Manages the connection and disconnection of Guard Agents to determine the available security guards available. The information is sent to the Planner Agent to generate new surveillance routes. Manager Agent also receives incidences (omitted control points, route changes, new security guard connected/disconnected, security guards notifications, etc.) from the Controller Agents and Guard Agents and, depending its priority, informs the Advisor Agent. Manager Agent stores all the system information (incidences, time, data, control points, route status, etc.) into a database. Information can be accessed via Internet.
- *Planner Agent* generates automatically the surveillance routes. The routes are sent to the Manager Agent to distribute them among the security guards.
- *Controller Agent* monitors the security guards activities by means of the control points checked. Once a surveillance route is generated by the Planner Agent, the average time to reach each control point is calculated. The Controller Agent also handles the associated route incidences and sends them to the Manager Agent.
- *Advisor Agent* administers the communication with the supervisors (person). Receive from the Manager Agent the incidences, and decide if are sent to the supervisor. Incidences can be sent via Wi-Fi, SMS or GPRS. If a communication problem is detected, the incidence is sent back to the Manager Agent and stored.

4. Surveillance Routes Planning Mechanism

The system, in particular the Planner Agent, makes a route planning, delivering the control points between the security guards. For surveillance routes calculation, the system takes into account the time and the minimum distance to be covered. So it is necessary a proper control points grouping and order on each group. The planning mechanism uses Kohonen SOM (Self Organizing Maps) neural networks with the k-means learning algorithm [8] to calculate the optimal routes and assign them to the available security guards. Once distributed control points, it sends distribution of the points each agent controller, which calculates the route to be followed by every security guard. Neural networks allow the calculus of variable size data collections, and reduce the time and distances to be covered. In addition, the control points can be changed on each calculation, so the surveillance routes are dynamic, avoiding repetitive patterns.

The mechanism starts spreading the control points among the available security guards. Then, the optimal route for each one is calculated using a modified SOM neural network. The modification is done through a FYDPS neural network, changing the neighbourhood function defined in the learning stage of the Kohonen network. The new network has two layers: IN and OUT. The IN layer has two neurons, corresponding the physical control points coordinates. The OUT layer has the same number of control points on each route [6][9].

Be $x_i \equiv (x_{i1}, x_{i2}) \quad i = 1, \cdots . N$ the i control point coordinates and $n_i \equiv (n_{i1}, n_{i2}) \quad i = 1, \cdots, N$ the i neuron coordinates on $\Re^2$, being N the number of control points in the route. So, there are two neurons for the IN layer and N neurons for the OUT layer. The weight actualization formula is defined by the following equation:

$$w_{ki}(t+1) = w_{ki}(t) + \eta(t) g(k,h,t)(x_i(t) - w_{ki}(t)) \qquad (1)$$

Be w_{ki} the weight that connect the IN layer i neuron with the OUT layer *k* neuron. *t* represents the interaction; $\eta(t)$ the learning rate; and finally, $g(k,h,t)$ the neighbourhood function, which depends on three parameters: the winner neuron, the actual neuron, and the interaction.

A decreasing neighbourhood function is considered with the number of interactions and the winner neuron distance.

$$g(k,h,t) = Exp\left[\left(-\frac{|k-h|}{N/2}\right)^{\frac{\underset{\substack{i,j\in\{1,\cdots,N\}\\ i\neq j}}{Máx}\{f_{ij}\} - \sqrt{(n_{k1}-n_{h1})^2 + (n_{k2}-n_{h2})^2}}{\underset{\substack{i,j\\ i\neq j}}{Máx}\{f_{ij}\}}} - \lambda \frac{|k-h|t}{\beta N}\right] \qquad (2)$$

λ and β are determined empirically. The value of λ is set to 1 by default, and the values of β are set between 5 y 50. *t* is the current interaction. Its value is obtained by means of β N. $Exp[x] = e^x$, where *N* is the number of control points. f_{ij} is the distance between two points *i* and *j*. Finally, $Max\{f_{ij}\}$ represents the maximum distance that joins those two points. Each parameter of the neighbourhood function can be 0 or 1. The neighbourhood function radius value must be close to 0 to update just the winner neuron.

To train the neural network, the control points groups are passed to the IN layer, so the neurons weights are similar to the control points coordinated. When all the process concludes, there is only one neuron associated to each control point. To determine the optimal route, the *i* neuron is associated with the *i*+1 neuron, from i=1, 2, …, *N*, covering all the neurons vector. A last interval is added to complete the route, associating the N neuron with the *i* neuron. The total distance is calculated adding the distances between two points. The learning rate depends on the number of interactions, as can be seen on the following equation:

$$\eta(t) = Exp\left[-\sqrt[4]{\frac{t}{\beta N}}\right] \qquad (3)$$

The neurons activation function is the identity. When the learning stage ends, the winner neuron for each point is determined, so each point has only one neuron associated. The optimal route is then calculated following the weights vector. This vector is actually a ring, where the n_1 neuron is the next n_N neuron. Initially considering a high neighbourhood radius, the weights modifications affect the nearest neurons. Reducing the neighbourhood radius, the number of neurons affected decrease, until just the winner neuron is affected. The learning stage is stopped when the distance between two points cannot be optimized any more.

The initial number of interactions is $T_1 = \beta N$ in the first stage. When $t = \beta N$, the weights of the possible couple of neurons are changed from the neurons ring obtained. If the distance is optimized, the number of interactions is reduced to continue the learning. In the Z phase, the total number of interactions is:

$$T_Z = T_{Z-1} - \frac{T_{Z-1}}{Z} \tag{4}$$

The objective of these phases is to avoid the crossings. Once all interactions are concluded, the distance obtained is analyzed to determine if it is the optimal distance. So, the recoil in the number of interactions is reduced each time, obtaining a maximum number of interactions, although the value is variable. Figure 3 shows the routes planned by the Controller Agent for one and two security guards, with the grouping of checkpoints done by the Planner Agent.

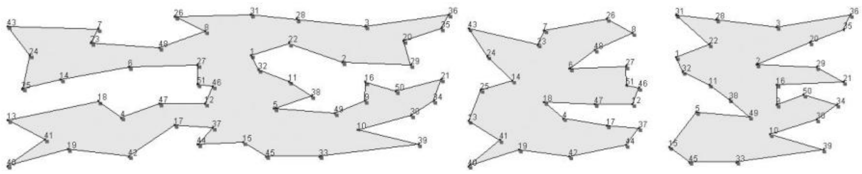

Fig. 3. Routes for one (left) and two (right) security guards.(175, 79 and 76 minutes)

5. Results and Conclusions

The hybrid system presented in this paper has been implemented and tested over real and controlled scenarios. The main scenario used for tests has been an environment where was introduced a variable number of control points. In addition to vary the control points, the number of guards switches between the different tests. They were conducted with a maximum of 4 people with the role of security guard.

Each control point contained an RFID tag that would be activated by the PDA's security guard. Information obtained at each control point was sent a central computer via Wi-Fi. The aim of the tests was to check viability from the combination of technologies (wireless technologies such as RFID, software agents and planning mechanism) in the chosen environment, in a scenario reduced and controlled.

The main input data used by the system were: (i) the number of control points; (ii) the distance between the control points; (iii) the average time to go from one control point to another, (iv) the number of guards available to calculate routes.

The results obtained have shown that it is possible to find out the necessary number of security guards depending on the surveillance routes calculated by the system. For example, Figure 3 (left) shows that the calculated route for a single security guard is relatively large for an 8-hour workday and it can visit once. By adding a new security guard, the new routes, as shown in Figure 3 (right), can be completed over 2 and a half times in 8 hours.

To evaluate the system efficiency, a comparison after and before the prototype implementation was done, defining multiple control points sets and just one security guard. The results of times and distances calculated by the users and the system are shown on Table 1.

Table 1. Time and distance calculated for security guards and multiple control points sets

Security guards	Control Points	Users		System	
		Time (min)	Distance (m)	Time (min)	Distance (m)
1	15	39	1285	28	944
1	20	64	2124	44	1451
1	25	76	2535	53	1761
1	30	79	2617	63	2088
1	35	96	3191	77	2551
3	100	357	11900	253	8415

The system provides optimized calculations, so the time and distance are reduced. A complete working day shift can be fixed according the system results, for example, if the route calculated is too long or the time exceeds eight working hours, a new guard must be incorporated.

Extending these results, Figure 4 (left) shows the average number of estimated security guards needed to cover an entire area, which consisted on a mesh from 20 to 100 control points, with an increment of 5 control points. The results are clear, for example, for 80 control points, the users estimated 4 security guards, but the system recommended only 3.

As shown on Figure 4 (right), the differences are bigger when there are 3 security guards and 100 control points to determine the level of accuracy compared with the users' predictions. The reason is that the system calculates the optimum route for each security guard and not for the entire control points set.

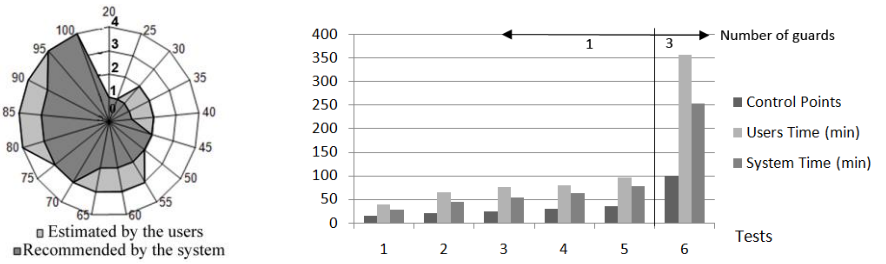

Fig. 4. Average number of estimated security guards (left) and time calculated by the users and the system with different number of control points (right).

The results obtained so far are positive. It is possible to determine the number of security guards needed to cover an entire area and the loops in the routes, so the human resources are optimized. In addition, the system provides the supervisors relevant information to monitor the workers activities, detecting incidences in the surveillance routes automatically and in real-time.

The use of wireless technologies, such as Wi-Fi, RFID, or GPRS provides an adequate communication infrastructure that the agents can use to obtain information about the context. With this information, the system can adapt services and interact with users according a specific situation in an easy, natural and ubiquitous way to solve some of daily life problems.

The system presented can be easily adapted to other scenarios with similar characteristics, providing a simple but powerful tool to optimize human resources and monitor the staff activities. However, this system is still under development, continuously adding new capabilities and services to have the enough robustness to implement it on other scenarios.

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