Multi-agent Control Architecture for RFID Cyber-Physical Robotic Systems: Player/Stage Simulation

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Multi-agent control architecture for RFID cyber-physical robotic systems

Initial validation of tagged objects detection and identification using Player/Stage

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***Abstract*—The objective of this paper is to describe and validate a multi-agent architecture proposed to control *RFID Cyber-Physical Robotic Systems*. This environment may contain human operators, robots (mobiles, manipulators, mobile manipulators, etc.), places (workrooms, walls, etc.) and other objects (tables, chairs, etc.). The proposed control architecture is composed of two types of agents dispatched on two levels. We find at the *Organization level* a *Supervisory agent* to allow operators to configure, manage and interact with the overall control system. At the *Control level*, we distinguish the *Robots agents*; to each robot (mobiles, manipulators or mobile manipulators) is assigned a *Robot agent* to carry out operations. We simulated *RFID readers* with *fiducial finders* and *RFID tags* with *fiducials system* using *Player/Stage*. *Fiducial tags* are attached to all the objects of interest of the environment; *fiducial finders* are installed on the robots (*Robots agents*) to be able to detect and identify each tagged object in the robots vicinity. Finally, obtained data are sent to the *Supervisory agent* to be saved and organized into a centralized database available for all the robots of the system.**

Keywords—Cyber-physical system; Fiducial interface; Multi-robot systems; Player/Stage; RFID.

I. INTRODUCTION

Autonomous robotics is becoming increasingly a very active research field; it is facing a rapid growth in the complexity of needs and requirements for robots able to coordinate their actions while carrying out multiple tasks [1]. Robots are generally used to carry out objects manipulation tasks in hazardous environments (chemicals, explosives, etc.), hardly accessible environments (space exploration, underwater, etc.), harmful environments (nuclear, toxic, high-/low-temperature environments, etc.), etc.

For the realization of such tasks, the *Multi-robot system* (*MRS*) decision-making is generally based on information gathered through proprioceptive and exteroceptive sensors equipping the robots. To be able to safely interact and more effectively accomplish robotic tasks, current trends implement a new information exchange mechanism between the robots and their environment through new sensors deployed inside this environment.

In relation to this context, the scientific evolutions occurred in this last decade have attributed more intelligence to the environment objects, and defined new control architectures for robotic systems primarily based on tags (or sensors) integration within distributed and communicating objects of interest. All these sensors deployed inside the environment in the robots proximity, define what is called a communicating environment. This new convergence between robotic applications, communication infrastructures and interaction with the environment makes robotics research topics redefined in favor of taking into account these recent developments.

In parallel to these developments, robotic control systems have recently evolved into embedded and cooperative control systems called *Cyber-Physical Systems* (*CPS*). *CPS* represent a new generation of developed concept of autonomous systems of perception, analysis and control of real physical world with tightly integrated computational, physical and communication processes [2] [3]. They combine a physical system with embedded information processing system such that the resulting system has novel capabilities that could not be achieved by either the physical or the computational entity alone [4]. Unlike traditional embedded systems, a full *CPS* is generally designed as a network of computer elements that interacts with physical inputs and outputs instead of autonomous interacting devices.

Cyber-Physical Robotic Systems (*CPRS*) consist of a set of autonomous/intelligent robots with the ability to cooperate and communicate with the various entities present in the environment to perform tasks. The ability of robots to intelligently interact with the real world is based on embedded computing, communication, real-time control and perception of the world around them to (*i*) automatically perform tasks, usually recognized as arduous, repetitive, impossible or dangerous for humans (substances analysis inside of volcanoes, nuclear power plants, space/depths of ocean, etc.). (*ii*) get better efficiency especially in everyday life such as domestic household, elderly or medical healthcare, medical surgery with robots able to perform operations, medical instruments detection and identification, etc.

In robotics, the ability to detect, identify and localize, at any time, fixed/dynamic objects in the environment is a very important issue. There exists a set of methods, technologies, approaches and devices that can solve this problem. They mainly include *GPS*, *Zigbee*, *Ultrasound*, *Wi-Fi*, *Near Filed Communication* (*NFC*) and *Radio Frequency IDentification* (*RFID*) [5] [6]. Subsequently, information collection, processing, correct interpretation and saving require more effective tools to extract, manage and use data.

In this article, we focus on RFID technology which is relatively a new element for automatic identification. It uses radio frequency to identify tagged objects when they pass near RFID reader. In this context, our work aims to:

- Propose a distributed multi-agent architecture to control RFID CPRS. The proposed scheme consists of two types of agents (*i*) the *Supervisory agent* is responsible of coordination and synchronization between the *Robots agents*. (*ii*) the *Robots agents* are assigned to locally control the physical robot and to carry out operations.
- Simulate RFID cyber-physical infrastructure in unknown indoor environment that may contain operators, robots, places, obstacles, known and unknown objects using *Player/Stage* simulator.
- Simulate *RFID readers* of the *Robots agents* with *fiducial finders*, *RFID tags* with *fiducials* attached to all the environment elements so they can be read by these sensors.
- Organize all data collected by the *Robots agents* into a centralized database by the *Supervisory agent*. This database is accessible by the *MRS*.

Besides this introduction, this article is organized into four sections. Section two presents RFID technology, its main advantages and drawbacks. Section three describes in details our proposed RFID CPRS control architecture, and presents the proposed solution for tags detection and identification. Section four presents and discusses the main obtained results while performing tests validation to prove the effectiveness of the proposed solution. Finally, section five concludes the paper, summarizes our major contributions and gives some future works.

II. Radio Frequency IDentification

In general, RFID technology is widely used in *CPRS*. It consists of an automatic identification technology and data capture that allows different entities to be uniquely identified. In recent years, it is possible to equip almost all objects of the environment with small RFID tags at very low cost. These improvements make this technology very attractive to be incorporated in robotics field. Indeed, these tags and sensors provide rich information and data that can be very useful to robots, to help them carrying out their various tasks (navigation, mapping, people tracking, etc.) or used as a support for accurately localize robots inside the environment, detect obstacles and eventually know their nature (fixed/mobile, doors, objects, etc.), robots (mobiles/manipulators/mobile manipulators), etc.

Advances in manufacturing have produced miniaturized radio transponders called RFID tags that can be attached or integrated into very small objects [7]. Each tag has a unique identifier and small-size memory (64-2048 bits) to allow storing data [8].

RFID technology allow to identify an object, to follow its path, to know its characteristics and to quickly have accurate, reliable and consistent information through a tag, that emits radio waves, attached or incorporated into objects. Suitable devices, called RFID readers, can access RFID tags by radio, either for read or write operations. Tags capture energy and transfer stored data/store data accordingly using the power scavenged from the signal coming from the RFID reader [9]. As depicted in Fig. 1, RFID system consists of the following components [7]:

- *RFID tag (Transponder)*: it is an electronic identification device which consists of a chip with an antenna.
- *RFID reader (Base station)*: it aims to identify the transponder. Recent RFID readers are divided into short-range and long-range readers depending on the distance within they can access RFID tags. Such a distance may vary from few centimeters up to several meters.
- *Data processing system (Computer system)*: it consists of a computing infrastructure used to collect and exploit data.

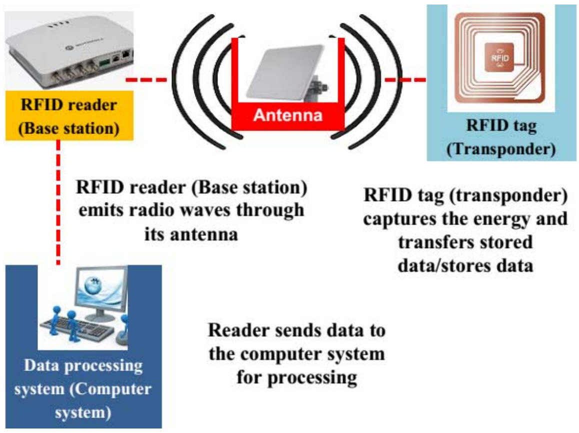

Fig. 1. Principle of *RFID* technology

A. RFID technology advantages

RFID technology has numerous advantages given as follows [10] [11]:

- Many RFID tags can simultaneously and automatically be read by RFID readers in the vicinity leading to enhance real-time objects tracking.
- No line-of-sight is required between RFID tags and readers for information reading; tag placement is less constrained with high positioning flexibility.
- RFID tags offer higher reading rates of contained information.

- RFID tags can be re-written with new information and as such are re-usable and updatable with new information about the object to which they are attached to.
- RFID tag has a much greater data capacity; it can store large amounts of data additionally to a unique identifier.
- Long-life service; tags are less sensitive to adverse conditions (dust, chemicals, physical damage, etc.).
- High writing and reading speed.
- Possibility of secure access to content.

B. *RFID technology drawbacks*

On the other hand, RFID technology has some drawbacks [10] [11]:

- RFID technology proves to be unreliable in mediums like metals or liquids where RFID tags fail to be read.
- Significant percentage of RFID tags fails to function properly (about 20–30% of tags).
- RFID tags can suffer from orientation problems as sometimes these tags do not interact with the readers when both are misaligned with respect to each other.
- RFID technology is expensive even though prices are decreasing. For the use of RFID tags, a particular adopter has to first install RFID reader(s) and computer networks for assessing information in the RFID tags. This leads to an expensive installation cost.
- Depending on the field of application, it may become necessary to prevent unauthorized persons from reading or writing data stored on or transmitted from tags. To this end, encryption must be ensured at all interfaces where data could be intercepted or transmitted.
- Interrogation (and standards) on the impact of electromagnetic waves on humans health.

III. DESCRIPTION OF THE PROPOSED SOLUTION

In this section, we describe in details the proposed distributed multi-agent control architecture of RFID CPRS. The section describes also our solution for tags detection and identification in the robots vicinity.

A. *The multi-agent RFID CPRS control architecture*

The multi-agent RFID CPRS control architecture is based on that previously proposed in [12]. It is organized into two levels communicating via a wireless network (Fig. 2):

- *Control layer*: this layer gathers the different *Robots agents* controlling and managing the physical robots. To each robot of the MRS is assigned a *Robot agent* dedicated to decision-making and operations execution. This level communicates with the *Organization layer* by sending data/reports and receiving requests.
- *Organization layer*: it consists of an interface (the *Supervisory agent*) between the control architecture and the MRS. This level communicates with *Control layer* by sending requests and receiving information on tasks/operations execution.

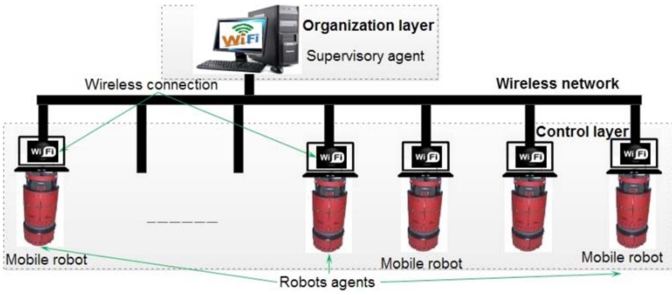

Fig. 2. The distributed multi-agent control architecture for RFID CPRS

One of the most significant tasks for mobile robots is detection and identification of objects in a dynamic environment. In addition, getting information related to each object present inside the environment and saving them into a database is a very important issue. This information could be very useful for accurate robots navigation, localization, etc. For example, the robots could infer to be close/far away to corresponding places, etc.

B. *The proposed multi-agent approach for RFID tagged objects detection and identification*

The algorithm of detection and identification of RFID tagged objects we proposed and implemented is split into two parts running in parallel. The first part is carried out by the *Supervisory agent*; the second part is executed by the *Robots agents*. The two algorithm parts are describes in what follows:

1. *Supervisory agent*

This hybrid agent is responsible of the coordination and synchronization between the entire *Robots agents*. The whole process starts by receiving, from the human operator, the request to detect and identify the tagged objects of the environment (REQUEST message) within the number of the robots team (R_{Max}). After that, the *Supervisory agent* creates the required number of mobile robots, sends them an INITIALIZE message and waits for their responses. When the *Supervisory agent* receives the INITIALIZED messages from all the active mobile robots team, it replies by sending them the DETECT message. Just after receiving this new message, the *Robots agents* start moving inside their environment. Thereafter, each time the *Supervisory agent* receives a DETECTED message within the ID of the detected tagged object, its current coordinates and the detection time, it looks-up for the tag ID into the centralized database and gets all the object information. After that, the *Supervisory agent* requests accessing the ".txt" log file. Finally and when getting access, robot ID, object ID, detection time and object information are all written into this file by the *Supervisory agent*. This procedure continues until detecting the entire tagged objects or the human operator decides to end the process.

The diagram shown in Fig. 3 summarizes the overall behavior of the *Supervisory agent*.

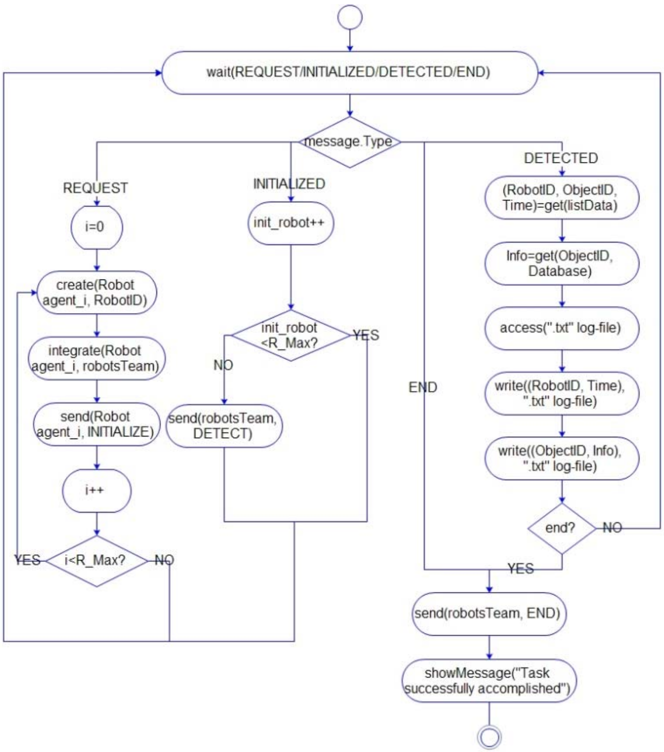

Fig. 3. Behavior diagram of the *Supervisory agent*. **create(Agent, ID)** creates an *Agent* with *ID* to locally control a mobile robot. **integrate(Agent, Team)** integrates a new *Agent* into the *Team*. **send(Agent, Message)** sends *Message* to *Agent*. **get(listData)** receives *listData* from the operator, another agent, a sensor equipping a robot or from the knowledge database. **access(File)** blocks the execution until getting rights to access *File*. **write(v_1, …, v_n, File)** writes v_1, …v_n into *File*. **showMessage(Message)** displays *Message* on the screen of the human operator.

2. *Robots agents*

After receiving the INITIALIZE message from the *Supervisory agent*, the *Robot agent* will create the required sensor for detecting and identifying tagged objects and initialize their parameters (*fov*: *field of vision*, *range* …). Once done, it sends INITIALIZED message to the *Supervisory agent* to inform it about the success of these actions. This last agent replies by sending DETECT message to all the active *Robots agents* of the control system. Thereafter, each *Robot agent* randomly moves inside its environment and starts detecting and identifying objects present in its surrounding environment. At each iteration and when the RFID reader (installed on a mobile robot) detects a tag within its range, the *Robot agent* localizes itself, calculates the current position of the detected tagged object and sends these data (DETECTED message) to the *Supervisory agent* to insert them into the ".txt" log file. This procedure continues until receiving END message from the *Supervisory agent*.

The diagram shown in Fig. 4 explains the global behavior of a *Robot agent*.

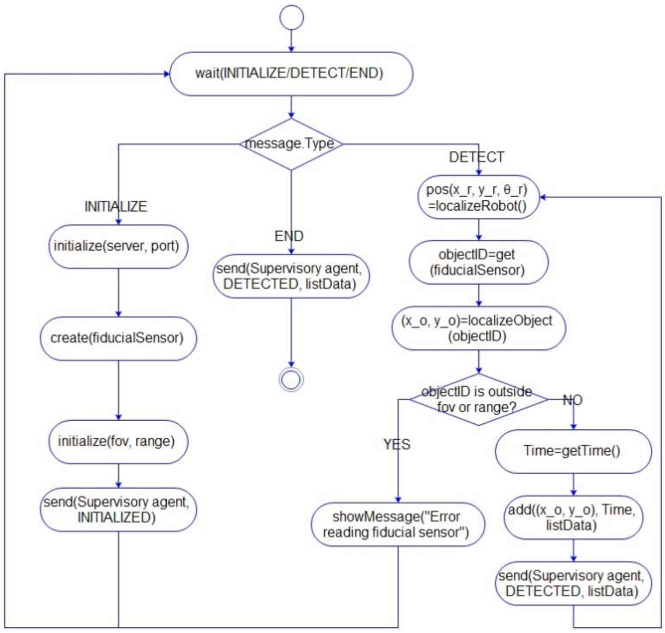

Fig. 4. Behavior diagram of the *Robot agent*. **initialize(field$_1$ … field$_n$)** initializes *field$_1$…field$_n$* of the *Robot agent*. **create(sensor)** creates a *sensor* to equip the mobile robot. **localizeRobot()** returns the actual position (x, y, θ) of the mobile robot. **add(v_1, …, v_n, listData)** adds v_1, …v_n to *listData*. **localizeObject(ID)** localizes the object with *ID* into the workspace of the robot. **getTime()** gets the current time when the object is detected.

C. *Centralized database*

Fig. 5 describes the different classes of the proposed centralized database. This latter has been implemented using MySQL the open-source relational database management system.

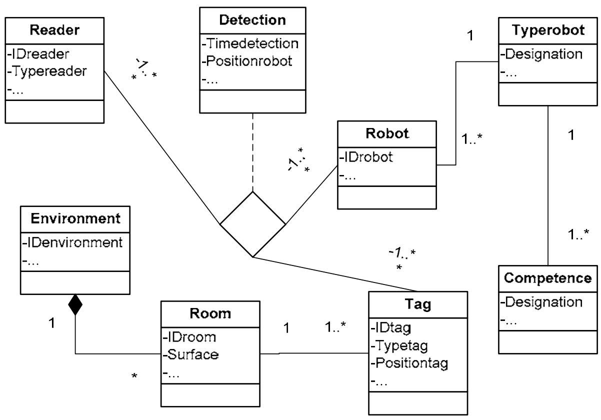

Fig. 5. Class diagram of the proposed centralized database

IV. SIMULATION RESULTS

We implemented a C++ program using the fiducial system of *Player/Stage* for tagged objects detection and identification.

A. *Player/Stage simulator and fiducial interface*

Player/Stage is a 2D simulator created at the *South California University* [13] which allows simulating a robots population. It simulates a large number of equipment including cameras, lasers, grippers, fiducial, blob-finder, etc. so that each sensor has its own interface. In this work, we have used *Player-3.0.2* and *Stage-3.2.2*.

It is not possible to integrate RFID system in *Player/Stage* simulator; it has neither interface nor detection/identification model of various objects in the environment. For this reason, we have used *fiducial interface* that shares the same characteristics as a RFID system.

Fiducial interface is a system that uses *fiducial finder* (reader) to detect *fiducials* (tags) located within its *field of vision* and *range*. They represent the distance and angle between the tagged objects and the robot equipped with this sensor [14]. Fiducials (tags) are generally known as markers, which can be added to objects. With fiducial interface, a tag consists of a fixed point in an image attached to an object, where each *fiducial* has its own identifier. On the other hand, *fiducial finder* localizes the fixed point to detect the tag and get its own identifier [14].

B. Simulation of the ground floor of the DPR

We have simulated a population of mobile robots in the ground floor of the DPR of the CDTA research Center. This environment, of about 32x22 meters square, is described in Fig. 6. All the operators, robots (mobiles, manipulators or mobile manipulators), entities (obstacles, objects, etc.) and places (doors, walls, workrooms, corridors, etc.) are tagged with RFID tags. Tagging such an entity (operators, robots, places or entities) involves sticking an RFID tag on it.

In this paper, tagging an object with fiducial consists of adding a colored fixed point in the image of the environment (as shown in Fig. 6), and making a database entry mapping the tag ID to all the object information.

C. Validation of tags detection and identification approach

Using *Player/Stage*, we performed a series of simulations with different numbers of mobile robots randomly navigating inside their environment. Robots are equipped with *fiducial finders* having a maximum detection *range*=09 meters and a field of vision *fov*=180°.

In the first scenario, we considered one (01) mobile robot only (r_0). The second scenario considers three (03) mobile robots (r_0, r_1, r_2). In the last scenario, we simulated ten (10) mobile robots (r_0 ... r_9). Robots are randomly dispatched inside their environment; they progressively detect and identify the different objects rather than the other mobile robots themselves (as shown in Fig. 6).

Table 1 summarizes the obtained results. The number of identified tags represents the sum of the new detected tags (tags that have not been detected yet by any mobile robot) by all the robots at each interval of detection time (few seconds).

TABLE 1: RESULTS OBTAINED FOR TAGS DETECTION AND IDENTIFICATION

scenario	**Time of detection**											
	t_0	**t_1**	**t_2**	**t_3**	**t_4**	**t_5**	**t_6**	**t_7**	**t_8**	**t_9**	**t_{10}**	**Total tags**
01 robot	0	**3**	2	1	1	2	2	**3**	1	2	2	19
03 robots	0	8	9	7	7	9	10	**14**	13	**14**	11	102
10 robots	0	18	18	20	17	15	15	**24**	19	20	21	187

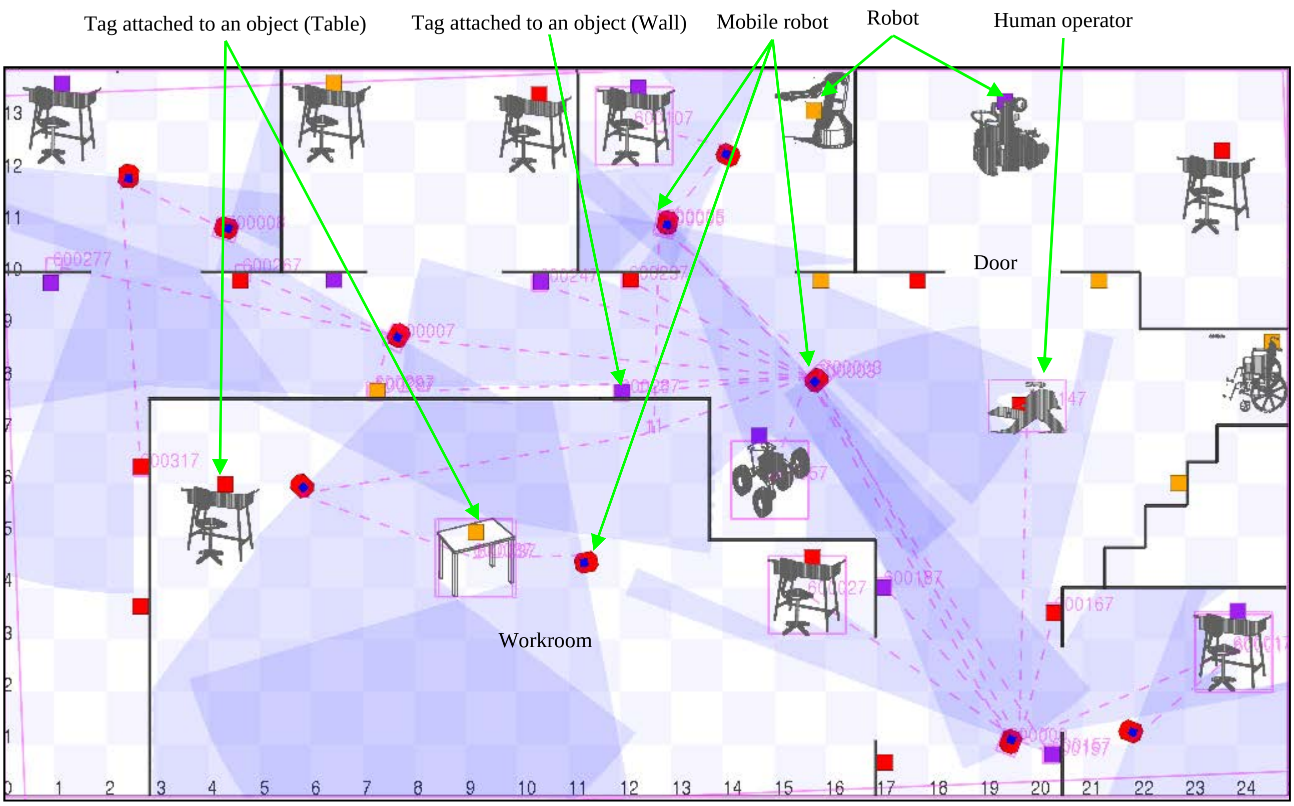

Fig. 6. Scenario with a MRS of ten (10) mobile robots (r_0 ... r_9) evolving inside the simulated considered environment in *Player/Stage*

During the execution of the first scenario, we noted that the maximum number of detected tags at each time interval is less than or equal to three (03) tags. For the second scenario, the maximum number of detected tags at a time interval is less than or equal to fourteen (14) tags. In the case of the last scenario (a population of ten robots), we noticed that the maximum number of detected tags at a time interval is less than or equal to twenty-four (24) tags.

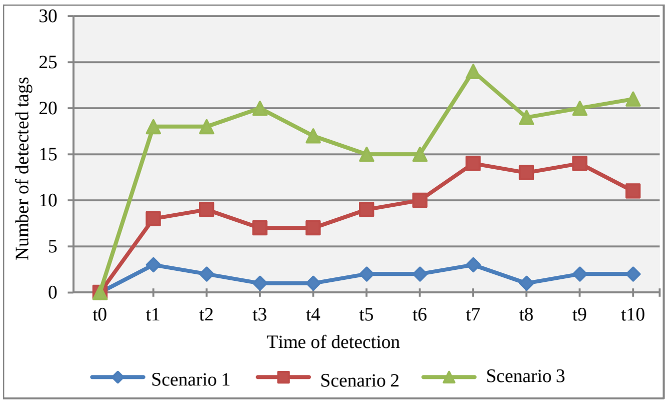

Fig. 7. Comparison between the obtained results for tags detection and identification

As shown in Fig. 7, the number of detected tags in the first scenario was very low compared to the two other scenarios. Indeed, the simulation of a single mobile robot does not allow collecting a large number of new tags; the results of this scenario are not sufficient as the solitary robot requires much more time to get enough information about its environment. On the other hand, we found that accessing the ".txt" log file was easy and does not require any particular treatment.

Regarding the two other scenarios (second and third), we were able to achieve better results and the number of detected tags was really higher. However, accessing the ".txt" log file was too long and requires considerations and management of access rights. Even worse, as there were collisions between the different mobile robots, we found that the mobile robots velocities have significantly decreased compared to the first scenario.

V. CONCLUSION

This paper described and validated a distributed multi-agent architecture proposed to control *RFID CPRS*. The proposed control architecture consists of two types of agents dispatched on two levels. The *Supervisory agent*, at the high level, coordinates and synchronizes the overall *Robots agents*. In addition, a *Robot agent*, at the low level, is assigned to locally control each physical mobile robot and to carry out operations.

For the validation of the proposed control scheme, a RFID CPRS is deployed in indoor environment that may contain operators, robots, places and other objects. To this end, we simulated the RFID system by a *fiducial system* using *Player/Stage* simulator, so that a set of *fiducial tags* is attached to all the environment entities. In addition, mobile robots were equipped with *fiducial finders* to be able to detect and identify each tagged object. Obtained data are saved and organized, after that, into a centralized database. We were able to assimilate the various objects in an unknown indoor environment with a MRS, collect enough information about this environment and update the centralized database after each new detection.

As perspectives of this work, we envisage to apply the proposed approach on real RFID hardware in different indoor environments so that each robot will be equipped with a real RFID reader while taking into consideration the nature of tagged objects. The proposed approach will also be applied on other applications such as MRS localization and mapping, etc.

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