An RFID-Based Distributed Control System for Flexible Manufacturing System

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ABSTRACT

A modern flexible manufacturing (FMS) system typically consists of several distributed control systems, such as machining stations, assembling stations, material handling and storage systems. Employing new technologies and novel approaches on a FMS results to more flexibility, agility and re-configurability. The application of Radio Frequency Identification (RFID) technology in the manufacturing systems provides the basis for accomplishing more flexible and agile systems by utilizing real-time information of the components. Modeling an RFID-enabled FMS is necessary, so as to evaluate the design, measure the performance and translate the resulting models into operational applications. However, these processes are complex but very vital in implementation of the new technology. This thesis (a) presents the architecture for modeling an RFID-enabled flexible manufacturing system.(b) discusses the architecture devised to deploy RFID-enabled distributed control and monitoring system by means of a set of agents that are responsible for the realization of different control and monitoring tasks and cooperating with each other to enhance agility, flexibility and re-configurability of manufacturing system.

The primary focus is on, requirement analysis of the manufacturing system, design and development of RFID-enabled manufacturing system using Unified Modeling Language (UML) diagrams that ensure systems integration with more flexibility and re-configurability, using efficient algorithms and effective tools and applications for implementing RFID-enabled architecture for the FMS.

The RFID-enabled distributed control and monitoring system has been explored using a flexible manufacturing system (EMU- CIM lab) to demonstrate the feasibility of the proposed architecture successfully.

Keywords: Flexible Manufacturing (FMS) System, Radio Frequency Identification (RFID) Technology, Unified Modeling Language

ÖZ

Modern esnek üretim sistemi genellikle bir çok kontrol sistemlerinde oluşur ki,buna imalat istasyonları,montaj istasyonları,malzeme taşıma ve depolama sistemleri dahildir. Üretim sistemi sonuçları üzerinde yeni teknolojiler ve yenilikçi yaklaşım istihdamı daha fazla esneklik,çeviklikle sonuçlanır.Radio frekansı uygulama teknolojisi imalat sistemlerinde gerçek zamanı kullanarak geçiş ve esnek sistem sağlar. Üretim sistemi modellemesinde radio frekansı ile tanımlama özelliği gereklidir,böylece tasarım değerlendirildiğinde performans ölçer ve operasyon uygulamalarını çevirir. Ancak, bu yöntem karmaşık olsada yeni teknolojinin uygulanmasında hayati rol oynar. Bu tez, a) radio frekansı tanımlama özelliği ile esnek üretim sistemi için mimari modelleme sunar. b)radio frekansı tanımlama özellikli kontrol sisteminin mimari keşfi açışından tartışır ve izleme sistemi hangi farklı kontrollerin gerçekleşmesi için sorumlu, izleme görevleri ve çeviklik,esneklik üretim sistemini geliştirmek için işbirliğini anlatır.

En önemli odak noktası,üretim sisteminin tasarımı ve geliştirme analizidir.Radio frekansı tanıma özelliği ile üretim sistemi kullanarak birleşik modelleme dili diagramları temin eden sistem entegrasyonu ile daha fazla esneklik yaratır,verimli algoritmalar ve etkili araçlar ve radio frekansı tanımlama özelliği ile üretim sistemi mimari uygulamalarını anlatır. Radio frekansı tanımlama özellikli dağıtılmış kontrol etkin ve izleme sistemi başarıyla önerilen mimari uygulanabilirliğini göstermek için esnek bir üretim sistemi (DAÜ-CIM laboratuar) kullanılarak incelenmiştir.

To My Family

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I want to thank my supervisor Prof. Dr. MAJID HASHEMIPOUR not only for his supervisory, supporting and guiding for this thesis also for providing me the opportunity for researching, reading and writing. He has shown me the co working and also how can be a good engineer and manager.

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Besides I want to thank my alls friends that truly helped me in this thesis.

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INTRODUCTION

1.1. Introduction

The increasing diversity of the customer requirements and the attraction of the mass production efficiency shift the major manufacturing mode from mass production to mass customization. Unlike mass production in which finished products need to be stocked in inventory and wait to serve customer’s demands, mass customization considers fulfilling individual customer needs while maintaining near mass production efficiency (Tseng, 1997). Unique information is provided by each customer so that the product can be tailored to his or her requirements (Paul, 2001). This mode of manufacturing requires the production system to be very flexible and its control system adaptive to the rapid changing customer demands.

Classically a FMS contains centralized databases for product data model (PDM) and manufacturing data model (MDM). The PDM is an information models which contains information related to product (Chungoora & Young, 2011), while the MDM is an information model which holds information related to manufacturing facilities which is needed for the product manufacturing (GUERRA-ZUBIAGA & YOUNG, 2008). PDM and MDM provide an optimal scheduling plan for manufacturing control system in a centralized way (Barenji, Hashemipour, Barenji, & Guerra-Zubiaga, 2012). Centralized control system is effective mass production in which, when the product variety is low and when the volume of the product does not change much (Kamioka, Kamioka, & Yamada, 2007). However, the centralized control system is not flexible, nor agile for high-variety and low-volume production. Furthermore, this system does not have the ability for re-configuration in case of ad-hoc events.

While centralized control systems are no longer suited to mass customization mode, distributed collaborative control and scheduling (de-centralized) approaches have been proposed by many of the researchers. Early works, appeared from 1990s, started to introduce the auction based distributed control mechanisms in the manufacturing applications. Recently, multi-agent systems (MASs) for resolving centralized manufacturing control problems have drawn wide interest in many literatures (Zhou, 2003). It provides more flexibility and quicker reactions to the control systems in dynamic changing environment such as mass customization manufacturing environment.

Although a lot of research has been carried on in the area of de-centralized and agent-based auction control systems, very few have considered the implementation of such systems in a real time basis. With the emerging of real time information technologies such as RFID technology, this application opportunity has been enabled. Object (part, component, sub-assembly, etc.) in the manufacturing environment is an attached with an RFID tag which can carry the information such as its identification, attribute values and production status. The data can be read by an RFID reader and be forwarded to a subsystem such as PC, robot control system which will use the received data to decide the correct operation to be performed at the position to the object, without human intervention. The RFID reader can not only read and forward data, but also write to the tag which makes possible the documentation of any state changes of the object and therefore keeping track of the system’s status and predicting the future. Enabled by RFID technology, the control system could become more dynamic and flexible in tackling instant changes in the manufacturing systems.

1.1.Research Aims and Objectives

The aim of this research is to explore and investigate the idea of using intelligent distributed control system to a FMS with the help of RFID technology. By creating (a) new RFID-Enabled integrated architecture for structural modeling of the FMS that acts as a roadmap to re-designing the exist system aiming to meet the same objectives with higher performance, higher productivity, higher flexibility and lower costs (b) a novel agent-based de-centralized shop control system in which the agents will access, manage, and utilize the information carried with RFID tags, and intelligently anticipate, adapt and actively seek ways to manage the manufacturing procedure. This control system potentially will provide high flexibility and re-configurability for the system.

In achieving this aim, the major objectives of the research can be states as follow:

- Investigating the difficulties that exist in current control architecture of an exist system which can be potentially improvable by proposed idea.
- Design architecture for structural modeling of a novel RFID-enabled decentralized control system.
- Verifying the generate models with exist system.
- Implement the proposed RFID-enabled de-centralized control system in an educational flexible manufacturing shop
- Developed prototype software

1.2.Research Methodology

The proposed methodology contain three phases namely system requirement, design & development and, implementation (Figure 1). Furthermore, there exists verification process which connects both system requirement and design and development phases. System requirement and, design & development phases comprises of three different levels, namely; system level, data level, and sensor level. In the system requirement phase, the current system specification will be captured holistically and the difficulties which potentially need to be improved by RFID and agent technology will be highlighted. In design & development phase, the FMS is re-designed with the aim of overcoming the problems which are highlighted at previous phase. At this phase the FMS will be considered structurally at the system level. For the system level; the appropriate use case, class, object and sequence diagrams will be developed. The data level will be deliberated from structural points of view by employing the cell activity and development diagrams. The detail of employing RFID technology in FMS will be presented on sensors level by utilizing sequence, component and class diagrams. In the verification process, the designed structure will be verified with the exits system. Ultimately, the designed RFID-enabled FMS will be implemented from system to data and sensors levels. The proposed architecture will be explained using an example of a FMS which is composed of a cell and three stations. This FMS is placed on the Flexible Manufacturing System (FMS) laboratory of Eastern Mediterranean University (EMU) (Figure 2). The aim is to employ RFID-technology in the case study for distributed monitoring, control of stations and cell in a de-centralized way.

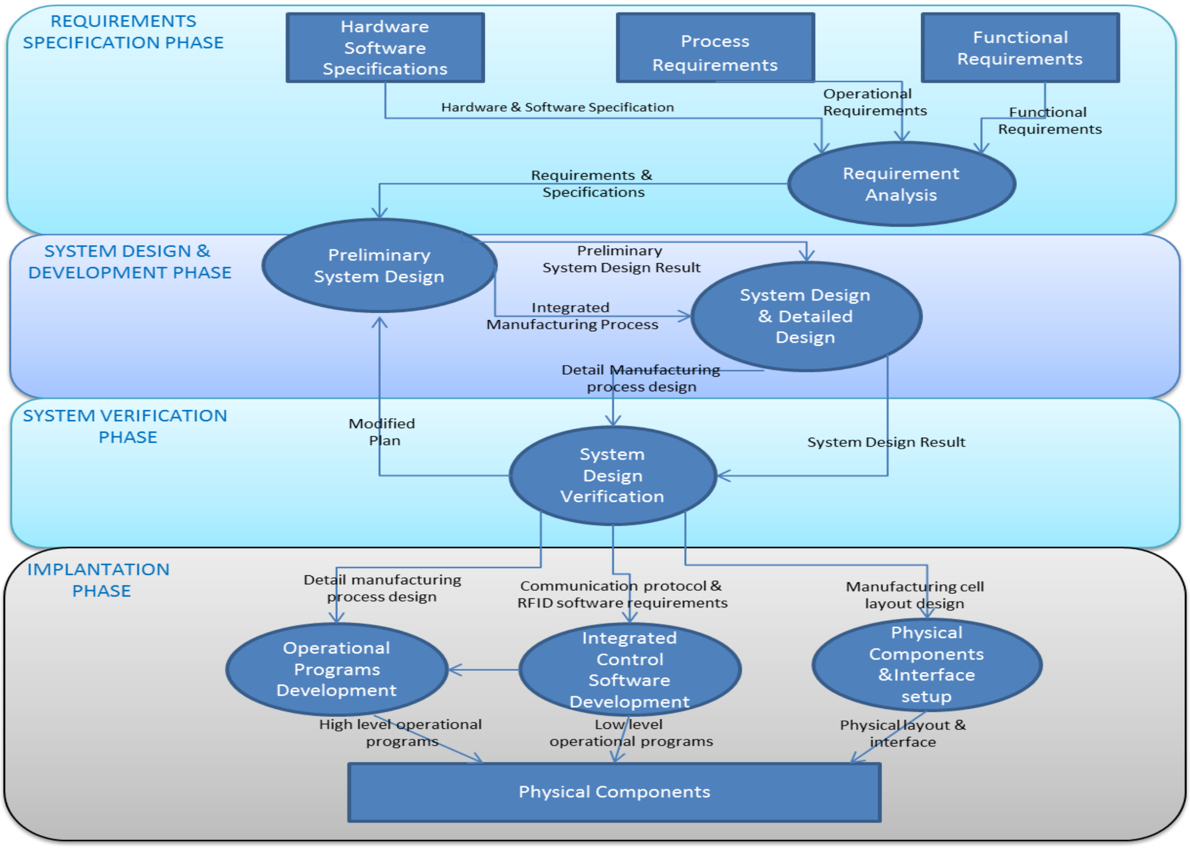


Figure 1: Proposed architecture for RFID-enabled FMS

Figure 2: FMS laboratory of Eastern Mediterranean University (EMU)

1.3.Structure of thesis

The remainder of this dissertation consists of four chapters that can roughly be divided in three parts, as was shown in Figure 3. In Chapter 2 (state of the arts) the control systems for flexible manufacturing shops will be explained in detail, the merits and benefits as well as shortcomings of the different control systems will be distill. Moreover, the working mechanisms of RFID technology as a new data-carrying system for shop control will clarify in part. Since, partially the aim of this dissertation is developing a new RFID-Enabled integrated architecture for structural modeling of the FMS; variety of approaches and tools for structural modeling of a business process will introduce in this chapter. Object oriented analysis system will selected as analyses approach for the dissertation. In chapter three, an RFID-enabled integrated architecture will introduce. For representing consistency of the proposed architecture using UML modeling language an educational manufacturing shop will being structural model. In Chapter 4, with the aid of multi- agent system, the generated UML models for the shop will be implemented. Chapter 5 contains concluding sentences and some endorsements for future works on this context.

Chapter 2

STATE OF THE ARTS

2.1. Flexible Manufacturing Control Systems

A flexible manufacturing system (FMS) is a manufacturing system in which there is some amount of flexibility that allows the system to react in the case of changes, whether predicted or unpredicted. This flexibility is generally considered to fall into two categories, which are further divided into numerous subcategories (Chi-Shih W, Sabah Randhawa, & Sheikh Burhanuddin, 1998). The first category, machine flexibility, covers the system's ability to be changed to produce new product types and ability to change the order of operations executed on a part. The second category is called routing flexibility, which consists of the ability to use multiple machines to perform the same operation on a part, as well as the system's ability to absorb large-scale changes such as in volume, capacity and capability.

With the rapid progress in the automatic object identification field, RFID technologies have had a tremendous impact on education, healthcare, manufacturing, transportation, retailing, services, and even war (Gunasekaran, 2006). In the field of FMS, (Johnson, 2002) presents a RFID application in a car production line. Pilot projects have recently been implemented and reported at http://www.autoidlabs.com/research archive/. Several relevant white papers have been prepared to provide a road map for developing and adopting Auto ID-based manufacturing technologies (Harrison). Based on RFID technologies, (Huang, 2008)build up a real-time manufacturing information system for controlling flows of information and materials of the entire shop-floor. (Zhang, 2008) develops a RFID-based smart Kanban system for work-inprogress (WIP) management. An innovative transport unit, called MT (Alejandro, 2009), has been developed for the grocery supply chain using active RFID tags. Some real life pilot cases adopted RFID technologies for real-time production management and control could also be found from ‘Productivity by RFID’ at http://www.productivitybyrfid.com and ‘Autom-ID Lab’ at http://www.autoidlabs.org.

Agent technology is a branch of artificial intelligence (AI) and has been widely accepted and developed in many applications of FMS for its autonomy, flexibility, re-configurability, and scalability (Sikora, 1998). (Krothapalli, 1999) adopts agents to concurrent design platform. (Giret, 2006) Present a multi-agent approach to analyze the holonic manufacturing systems. (Weng, 2008) proposes an agent-based service-oriented architecture for distributed shop floor scheduling. A multi-agent-based workload control for make-to-order manufacturing can be seen in Weng et al. (2008). Agent technologies have also been used by RFID-based systems to enhance their intelligence. For example, (Satoh, 2006) combines mobile agents to RFID-based location sensing systems. Recent progress of agent architecture and web services provide integrated solutions for solving the integration between agent and other heterogeneous systems. (Bellifemine, 2006) present the JADE framework (Java Agent Development Framework) to develop agent applications in compliance with the FIPA (Foundation for Intelligent Physical Agents) specifications for interoperable intelligent multi-agent system (MAS). (Shafiq, 2006) proposes a solution to make MAS compatible with existing Web Services standards. (Tapia, 2009) Describes a flexible user and services oriented multi-agent architecture called FUSION.

The literatures surveyed by the authors indicate that, also existing working attempts are valuable for employing the RFID and agent technology in a flexible manufacturing system. However, there is no empirical methodology for how a company should adopt RFID and agent technology to a flexible manufacturing system for achieving a robust de-centralized control system, since each manufacturing system has its own complexity. It has been suggested that extensive and heavy documentation, lack of a communication between the user and the system designer and implementer have been the major set-back in preventing an effective adoption for upgrading the exist system with a new technology (Hashemipour M, Erenay, O. , & Kayaligil, S, Virtual reality in requirement analysis for CIM system development suitable for SMEs, 2002). The structural and behavioral modeling approach has been principle tool used in requirement analysis and re-designing the manufacturing system and retrofitting the complex products (Abrishambaf , Hashemipour , & Bal, 2012). The structural modeling of a RFID-enabled FMS will be a good starting point for creating a robust communication link between manufacturing system designers, users and implementers.

2.2. RFID Technology

RFID (Radio Frequency Identification) is a means of storing and retrieving data through magnetic or electromagnetic field. An RFID system is made up of two components: RFID tag and RFID reader. An RFID tag is a data-carrying device and normally consists of a coupling element and an electronic microchip. A tag is categorized as either passive or active. A passive tag does not possess its own voltage supply (battery). It absorbs power from the RF field of the reader and reflects RF signal to the reader after adding information by modulating the received RF signal. An active tag possesses its own power supply.

Thus it can maintain data in RAM, a temporary working memory for microprocessor. Active tags usually have a bigger read range than passive tags and are suited to more applications. However, active tags have limited operational lifetime due to power constraint and are more expensive. An RFID reader can read and write data received from RFID tags. It operates on a defined radio frequency according to a certain protocol. A reader typically contains a high frequency module (transmitter and receiver), a control unit, and a coupling element to the transponder. In addition, many readers are fitted with an additional interface (e.g., RS 232 and RS 485) to interconnect with another system such as PC and robot control system.

As shown in Figure 3, the power required to activate the tag is supplied to the tag through the coupling unit (contactless) as is the timing pulse and data (Klaus, 2003).

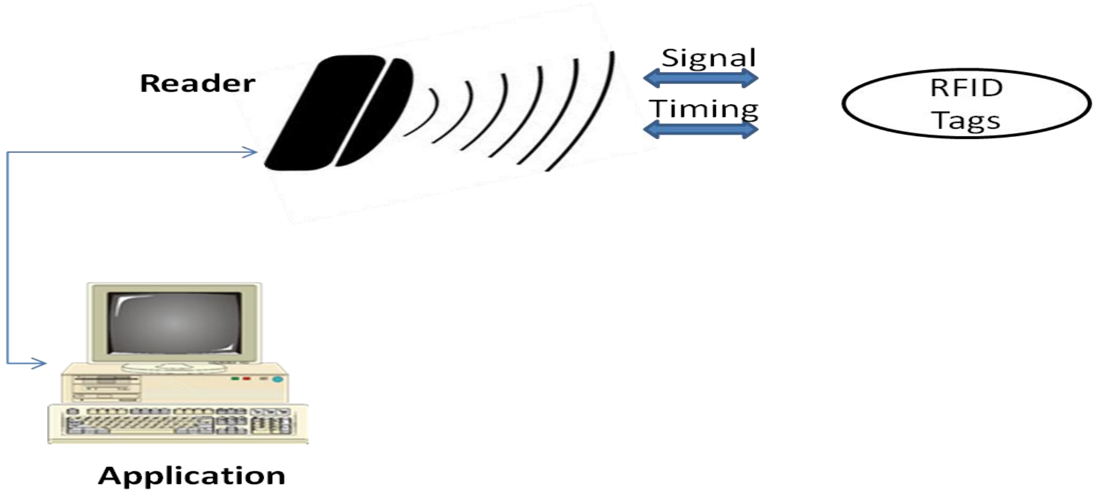


Figure 3: The Reader and the Tag Are the Main Components of Every RFID System

The characteristic of being contactless, which is achieved by using magnetic or electromagnetic fields for data exchange and power supply instead of galvanic contacts, gives RFID a broad range of applications from secure internet payment systems to industrial automation and access control.

2.3. Flexible Manufacturing System and RFID Technology

A flexible manufacturing system (FMS) is a manufacturing system in which there is some amount of flexibility that allows the system to react in the case of changes, whether predicted or unpredicted. This flexibility is generally considered to fall into two categories, which are further divided into numerous subcategories (Chi-Shih W, Sabah Randhawa, & Sheikh Burhanuddin, 1998). The first category, machine flexibility, covers the system's ability to be changed to produce new product types and ability to change the order of operations executed on a part. The second category is called routing flexibility, which consists of the ability to use multiple machines to perform the same operation on a part, as well as the system's ability to absorb large-scale changes such as in volume, capacity and capability.

Recently, RFID technology has been extensively applied in the fields of logistics, supply chain, warehousing, retailing, and transportation (Chow HKH, Choy KL, Lee WB, & Lau KC, 2006). In manufacturing system, application of RFID technology is still in developing stage. The process of applying RFID technology to the manufacturing system allows the opportunity for obtaining ideal and real-time information about the physical items involved in the system (Bin Wang, Zilong C, Ying Yan, Weiping Liu, & Zheng Wang, 2011). This information invariably may be used to improve efficiency of production and reduce cost associated with this production. Also, the production data for certain components such as operations, quality and time, can be written into RFID tags connected to the component thus allowing the system to be more decentralized and the production process more flexible (Günther O, Kubach U, & Kletti W, 2008).

A lot of research has been done on using RFID technology for flexible manufacturing system. For instance, Ruey-Shun Chen et al. (2010) employed the RFID technology to “hook” the physical objects in an enterprise to different business applications which traditionally are not easily integrated. (Wang JH, Luo ZW, & Wong EC, 2010)employed the RFID technology for an object tracking system to track the object movement for a flexible manufacturing assembly line. (McFarlane D, Sarma S, Chirn JL, Wong CY, & Ashton K, 2003) developed an RFID-assisted technology to implement automated identification, manipulating, and assembling of customized products in an experimental assembly line. (Liu MR, Zhang QL, Ni LM, & Tseng MM, 2004) developed the architecture of RFID-based distributed control system for a flexible manufacturing system.

The literatures surveyed by the authors indicate that, also existing working attempts are valuable for employing the RFID technology in a flexible manufacturing system. However, there is no empirical methodology for how a company should adopt RFID technology to a flexible manufacturing system, since each manufacturing system has its own complexity. It has been suggested that extensive and heavy documentation, lack of a communication between the user and the system designer and implementer have been the major set-back in preventing an effective adoption for upgrading the exist system with a new technology (Hashemipour M, Erenay, O. , & Kayaligil, S, irtual reality in requirement analysis for CIM system development suitable for SMEs, 2002). The structural and behavioral modeling approach has been principle tool used in requirement analysis and re-designing the manufacturing system and retrofitting the complex products (Abrishambaf , Hashemipour , & Bal, 2012). The structural modeling of a RFID-enabled FMS will be a good starting point for creating a robust communication link between manufacturing system designers, users and implementers. Furthermore, the structural modeling is an indicator for evaluating the design, measuring the performance and, translating the resulting models into operational applications

2.4. Structural Modeling, Approaches, and Tools

An important attempt during the design or redesign of a system is providing an abstract representation of the resources and activities on which the system is to be base for the design team. This abstract representation should be independent of how the resources and/or activates are configured and manipulated in the system. This effort refers as the design of a structural model. There exist two states for structural modeling of a system (a) structural modeling of a new system (e.g. developing a novel de-centralize distrusted manufacturing control system using Multi-agent approach) and (b) structural modeling for retrofitting an exist system (e.g. presented contribution). For the case of retrofitting of an exist system; the structural model is a term for the study the functionality of the existing system with the intention of re-designing the system using a new technology aiming to meet the same objectives with higher performance, higher productivity, higher flexibility and lower costs.

The process of designing a structural model for re-designing a system follows a stepwise procedure. The first step is to study the existing system for figure out the resources and/or activities that govern its structures. The resulting model referrers as “as is” model. With employing a new technology and understanding of the exits system structural model, the objective is to re-modeling functions based on the new technology to meet the business objectives. The resulting model of the enterprise is called the “to be” model. The structural model provides a representation of the entities (e.g. resources and activates) in the enterprise, the attributes of those entities, and the relationship that exist among entities.

The purposes of structural modeling is to design a conceptual schema of entities and their relationships in order to (1) facilitate the process of communication among the system stockholders (2) design a common model that will accommodate the different needs of individuals and organizations within the enterprise; and (3) establish a logical model that can be implemented.

In practice similar to software development, however two well-known approaches dominated for structural modeling: procedural approach and object- oriented approach.

These approaches cover the same aspects of the structural models, i.e. processes, activities and objects, by employing variety of tools. IDEF0 and data flow diagram (DFD) are two well-known tools for structural modeling using procedural modeling approach. Procedural approach for reengineering practitioners seems to realize that these techniques are too primitive and inadequate when using for serious, large scale business process reengineering.

The modeling approach for this research proposal will be based upon object-oriented. The main idea is that the world is considered to be composed of basic elements, which are called objects, e.g., a manufacturing system is composed of machines. One object is an entity that tightly binds both information (attributes) and operations (methods) on that information while hiding the implementation details. The abstraction of objects with common characteristics forms a class while the object is an instance of this class. The system is conducted via construction of objects and object relationship model, which reveals the inheritance, composition and associated relationship between classes. Inheritance describes the classification or the generalization between a superclass (parent class) and a subclass (child class) thus a subclass may inherit essential features from its super class. Aggregation indicates the whole-part relationship between two classes hence every structural link between two classes which does not fall in the former two relationships is named association (Thimm, Lee, & Ma, 2005).

Unified Modeling Language (UML) is a graphical modeling tool for object-oriented approach, which enables the system developers, analyzers and the stockholders to design and visualize the object-oriented systems. UML proposes a way to visualize a system's architectural blueprints, using different diagrams such as, use case diagram, class diagram, activity diagram, sequence diagram etc. This modeling tool has many advantages over other paradigms and existing modeling languages: (1) UML has been usually known as a modeling language for a widely ranges of industrial applications. (2) The software of most modern machines are modeled using UML (3) UML is combines techniques like; entity relationship diagrams, business modeling, object modeling and component modeling (4) UML is an information-rich representation; models can be tested for consistency, analyzed and translated into other representations.

Chapter 3

TOWARDS STRUCTURAL MODELING OF A RFID-ENABLED RECONFIGURABLE ARCHITECTURE FOR A FLEXIBLE MANUFACTURING SYSTEM

3.1. Introduction

Typically a FMS contains centralized databases for product data model (PDM) and manufacturing data model (MDM). The PDM is an information models which contains information related to product (Chungoora & Young, 2011), while the MDM is an information model which holds information related to manufacturing facilities which is needed for the product manufacturing (GUERRA-ZUBIAGA & YOUNG, 2008). PDM and MDM provide an optimal scheduling plan for manufacturing control system in a centralized way (Barenji, Hashemipour, Barenji, & Guerra-Zubiaga, 2012). The controllers for each subsystem of the FMS such as the one for stations, cells and factory, are hierarchically connected by host computer of the manufacturing system in a centralized method. Centralized control system is effective when the product variety is low and when the volume of the product does not change much (Kamioka, Kamioka, & Yamada, 2007). However, the centralized control system is not flexible, nor agile for high-variety and low-volume production. Furthermore, this system does not have the ability for re-configuration in case of ad-hoc events.

The Radio Frequency Identification (RFID) is an emerging technology which is newly adapted in a wide range of applications. This technology has many advantages such as long-distance contact, programmable, bigger storage and more flexible (Na, Zhiyuan , & Jie , 2010). Due to unique characteristics such as; waterproof, antimagnetic and, high temperature resistance, the RFID has become a very suitable technology for industrial applications (Kamioka, Kamioka, & Yamada, 2007). The use of RFID technology in manufacturing systems enables the possibility to obtain and/or transfer real-time manufacturing and/or product information of the component on the value adding chain (Kai-Ying Chen, 2012). Replacing dedicated wired sensors on a centralized manufacturing control system with the RFID-enabled control system may be considerable as an alternative for handling product complexity and process flexibility in a de-centralized way. This paper presents an RFID-enabled architecture for modeling several distributed control stations of a cell such as machining station, assembling station and material handling and storage systems. Emphasis in the design and development of this architecture has been on the use of UML diagrams, flexible interface design for monitoring the stations of the cell and real-time process control capabilities.

3.2. RFID-Based Integrated Architecture

The proposed architecture contain two phases namely system requirement and, design and development furthermore, there exist verification process which connects both system requirement and design and development phases. Each of these phases comprises of three different levels, namely; system level, data level, and sensor level. In the system requirement phase, the current system specification is captured holistically and the problems which potentially need to be improved by RFID technology are highlighted. In design and development phase, the FMS is re-designed with the aim of overcoming the problems which are highlighted at previous phase. At this phase the FMS is considered structurally at the system level. For the system level; the appropriate use case, class, object and sequence diagrams are developed. The data level is deliberated from structural points of view by employing the cell activity and development diagrams. The detail of employing RFID technology in FMS is presented on sensors level by utilizing sequence, component and class diagrams. In the verification process, the designed structure is verified with the exits system.

Case studies have often been viewed as a useful tool for the preliminary, probing stage of research methodologies, as a basis for the development of the ‘more structured’ tools that are necessary in surveys and experiments. This research strategy often emerges as an obvious option for researchers who are seeking to carry out a modest scale research project based on their workplace or resources. The case studies strategy is useful in providing answers to ‘How?’ and ‘Why?’ questions, and in this role can be used for exploratory, descriptive or explanatory research. Since the research question which aiming to be addressed in this contribution is “How to develop a structural model for an RFID-enabled flexible manufacturing system?” the case study strategy is selected as research strategy. The proposed architecture will be explained using a case study of a FMS which is composed of a cell and three stations. This FMS is placed on the Flexible Manufacturing System (FMS) laboratory of Eastern Mediterranean University (EMU) (Figure 5). The aim is to employ RFID-technology in the case study for distributed monitoring, control of stations and cell in a de-centralized way.

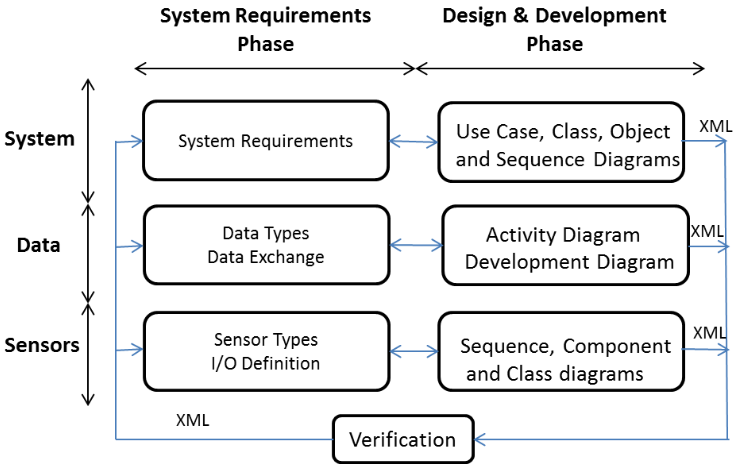


Figure 4: Proposed Architecture for RFID-Enabled FMS

Figure 5: FMS Laboratory of Eastern Mediterranean University (EMU)

3.2.1. System Requirement Phase

FMS laboratory of Eastern Mediterranean University (EMU) was designed for education and research purposes. The laboratory consists of three stations: Station 1 is a machine tending station, which consists of a CNC milling machine and a five-axis vertically articulated robot (SCORBOT - ER 9) designed to work in industrial training facilities. Station two is an assembly and quality control station, which has one “SCORA ER 14” Robot provided by “Intelitek”.This robot has a pneumatic gripper and works in connection with the peripheral station devices such as a ball feeder, gluing machine and laser-scan micrometer device (Mitutoyo). Station 3 is an automatic storage and retrieval system (AS/RS), which contains 36 cells for storage and retrieval and a robot with the capability of taking and placing the work pieces. A conveyer integrates the stations for performing material handling within the cell.

The two robots with multi-tasking controllers provides real-time control and synchronization of up to 12 axes, 16 inputs and 16 outputs, support both stand-alone applications as well as sophisticated automated work cells. The overall system is running with a supervisory host control consisting of a set of stations IPC's, a PLC for controlling the conveyor and a host computer that allows management of the cell orders, by employing the OPEN CIM software.

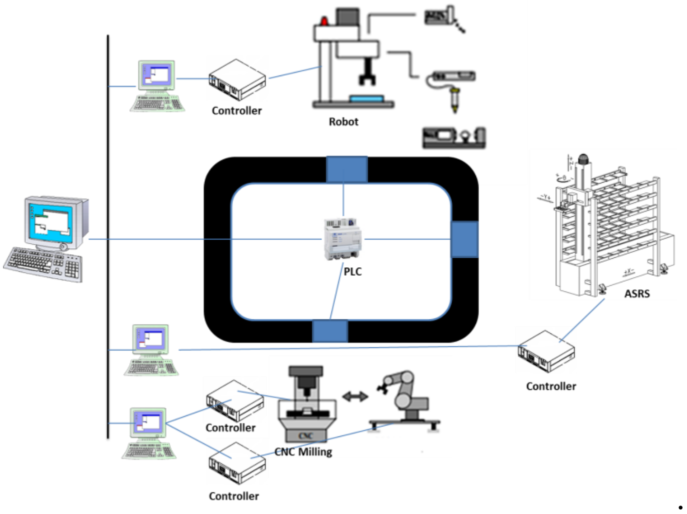


Figure 6: The Connections and Hierarchical Relationships Diagram of the FMS.

The problems that exist in current control architecture which can be potentially improvable by RFID technology are as follow:

- The manufacturing system is controlling by a central architecture which is locating on host computer thus all the decisions are issued by this control unit.
- The stations have not autonomous control unit for their operations.

- In the all stations of the cell the wired sensors are under usage.
- The system lacks the real-time reconfiguration and is not flexible in case of part variety.

3.2.2. Design And Development Phase

In this phase, the proposed integrated architecture for RFID-enabled FMS is presented at three levels namely; system, data and sensor. To begin with, at the systems level; a generic use case diagram and class diagram for the “RFID-enabled FMS” is presented and for each of the stations appropriate object and sequence diagrams are denoted. At data level, applicable activity and development diagrams are presented for the “RDIF-enabled FMS” and at the sensor level, the details of the RFID technology which employed to the FMS is presented in associated with sequence, component and class diagrams.

3.2.2.1. System level

The use of case diagram is an appropriate tool for creating opposite connection among users and stakeholders of a system. A wide range of modeling projects initialize with the use case diagrams to demonstrates what types of actions are happening within the current system or on the new system. Also, these kinds of diagrams demonstrates the structure and behavior of the entity at the highest level of abstraction and does not describes the subject in details, use case diagram is vital for displaying the relations among actors and use cases of the system. Figure 4 shows schematically, how the operator of the system can interacted with the Human Machine Interface (HMI). The upper rectangle of Figure 7 groups the use cases of the HMI namely monitoring and controlling. The link between the use cases and the operator symbols at the HMI rectangle indicates that operator is in charge of control and monitor of the system. Machining, Assembling, and ASRS are the main use cases of the system which are grouped and demonstrated on the lower rectangles; as indicated by the arrows with triangular heads, each has numbers of specializations, as indicated by ellipse within the rectangles. For instance, the ASRS use case contains action of; processing, storing, moving and sensing.

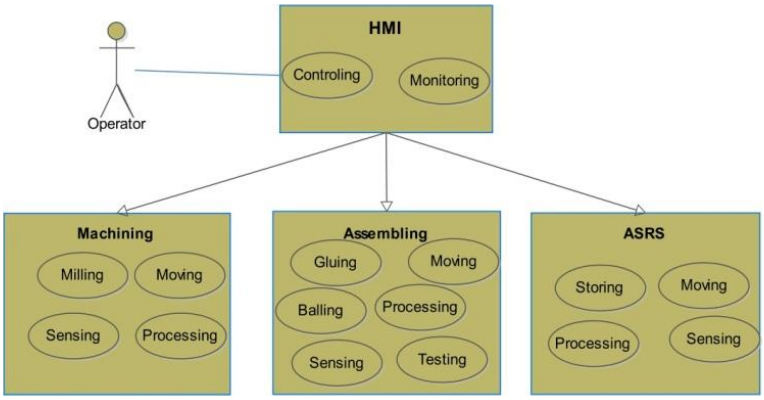


Figure 7: Human machine interface description

Class diagram is a static view of the system and are building block of an object-oriented modeling approach. For RFID-enabled FMS, a generic class diagram is developed for demonstrating the modules of system and sub-systems. It is sub-divided into classes and each class has connections with others. The generic class diagram of the FMS is depicted in Figure 8. The top part of the class diagram illustrates the hierarchical model of a shop. A shop can encapsulate numbers of cells and each cell may contain several stations. Based on the proposed class diagram: An RFID-enabled flexible manufacturing system can be defined as using a processor and data base for integrating a set of devices (e.g. machines, tools, and robots) and corresponding RFID-gate (e.g. tag, antenna, reader) that can be accomplished by those devices, as well as the applications about how these devices and sensors can effectively works.

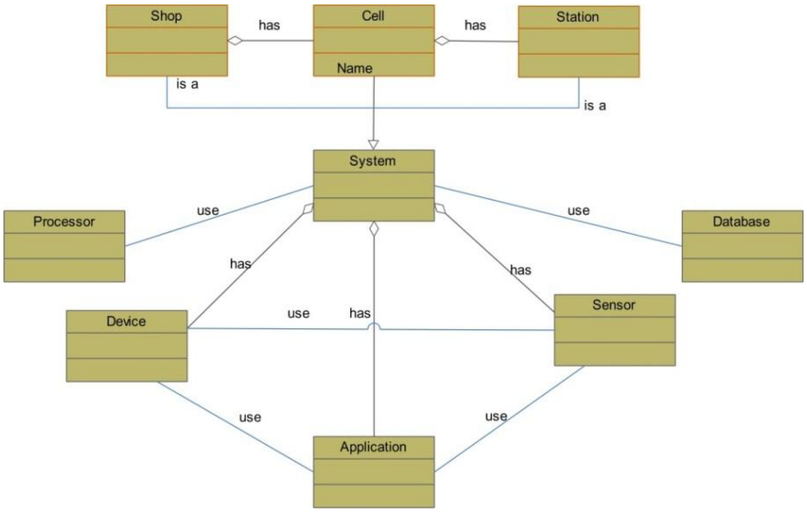


Figure 8: Generic class diagram for a manufacturing system (MS)

The UML object diagram demonstrates static aspects of the system building blocks. A station contains several resources that represent the mechanical and electrical components, and they are connected by means of an Industrial Personal Computer (IPC). All the stations in the shop form a network, which are connected to the HMI. Figure 9, 10and 11 illustrates the object diagrams of the machining, assembling and ASRS stations.

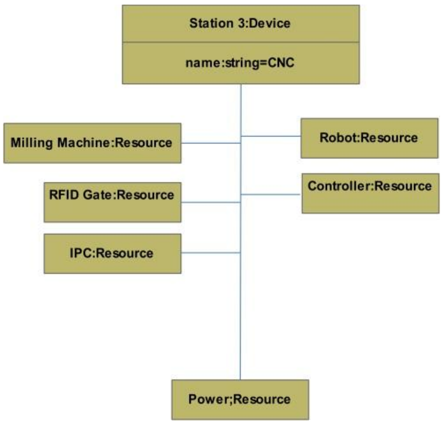


Figure 9: Machining station's UML object diagram

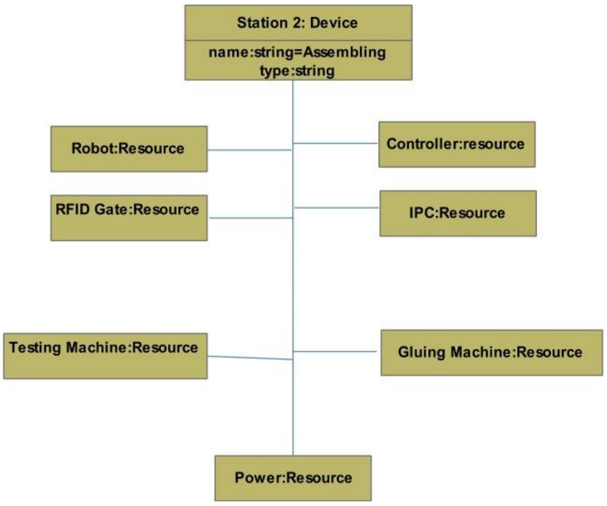


Figure 10: Assembling station’s UML object diagram

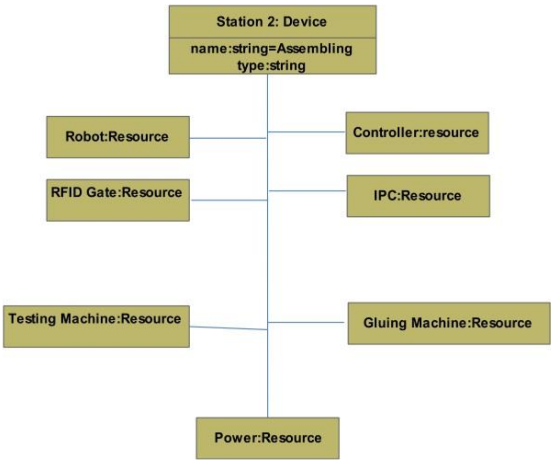


Figure 11: ASRS station’s UML object diagram

A station contains several devices, applications as well as a RFID-gate, which integrated with an Industrial Personal Computer (IPC) and they are connected to a data bus, the station’s UML sequence diagram will helps the analyzers and system developers to understand the dynamic behaviors of the stations. All stations in system integrated with the part’s information by receiving a message from the part’s tag in order to perform a service, the message will be broadcasted to the corresponding RFID-gate for further actions (e.g. open the gate). The station’s RFID-gate reads the part’s message, and based on its content, the proceeding operations will be performed. Several operations based on the scenario can be executed in the machining, assembling as well as AS/RS stations. Therefore simple operations for these stations are presented in Figure 12, 13 and 14. Any other operations which are received from the tag information can be designed and executed in a similar manner.

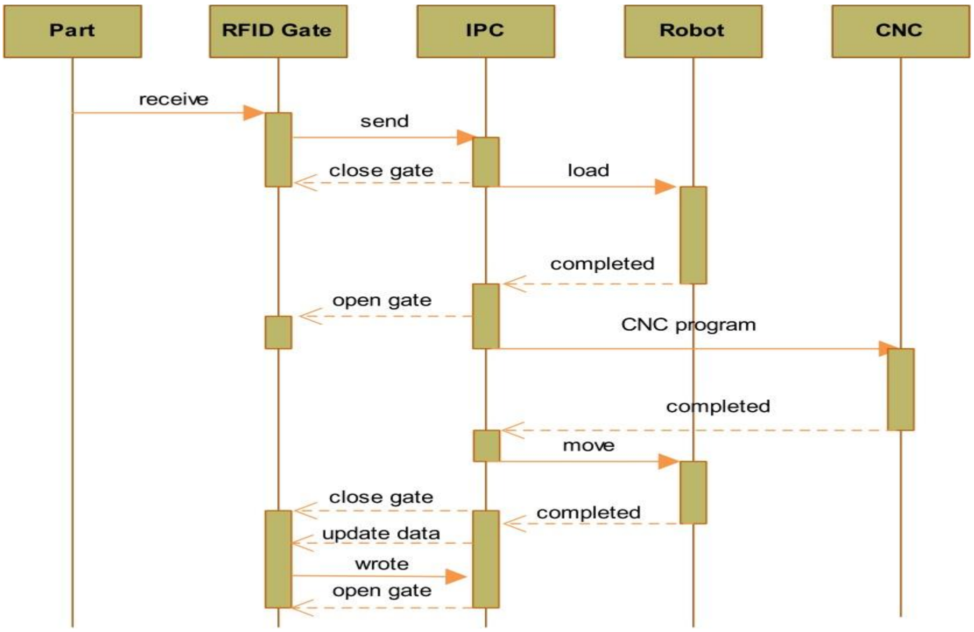


Figure 12: Machining Station’s UML Sequence Diagram

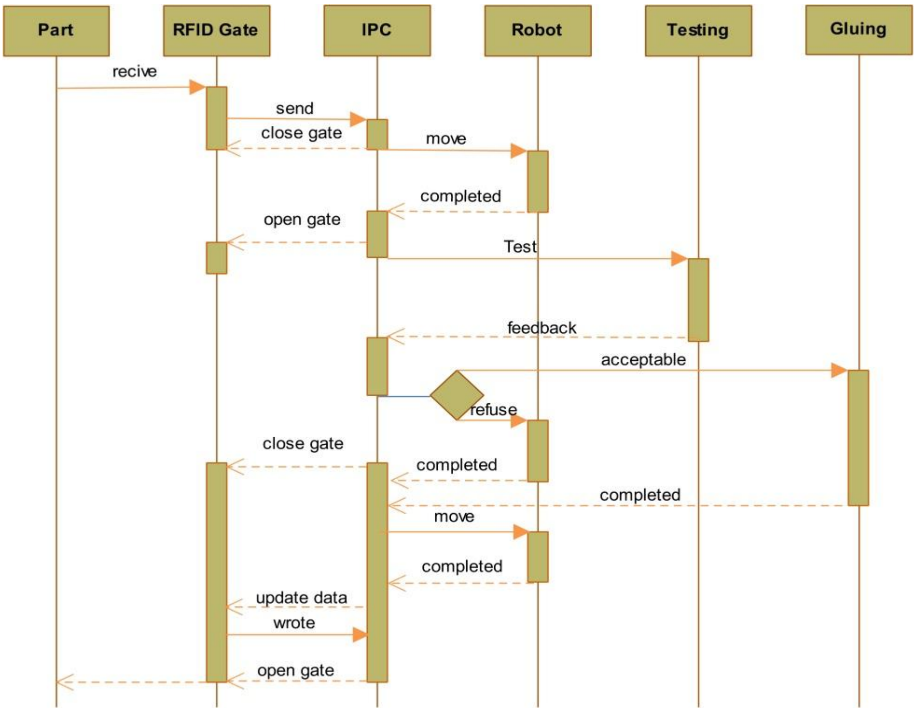


Figure 13: Assembling Station’s UML Sequence Diagram

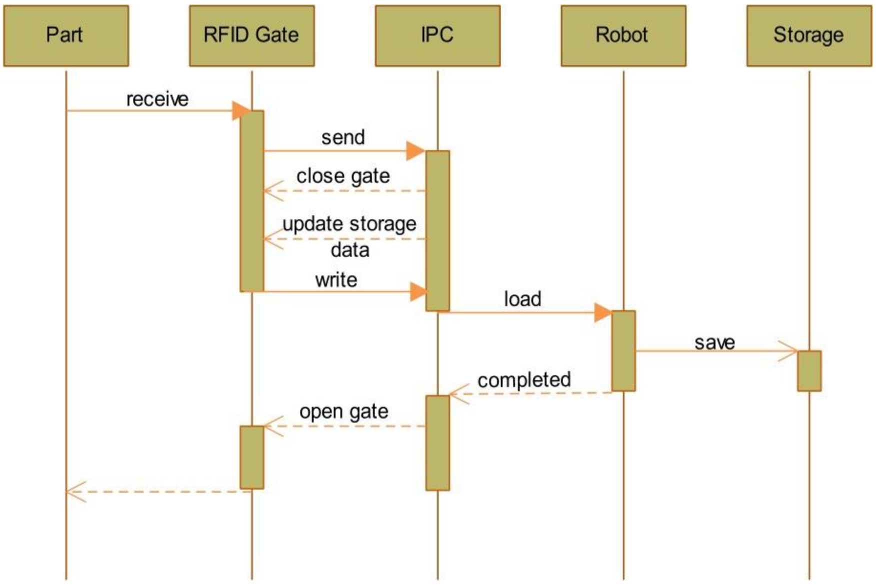


Figure 14: ASRS Station's UML Sequence Diagram

3.2.2.2. Data level

Data level presents the data flow as well as data connection among the cell components. This level contains structural as well as behavioral diagrams. The structural modeling of the system is depicted by activity diagram of the cell, while the development diagram of the cell represents the modeling.

The activity diagrams demonstrate the static aspects of the system building blocks. The UML activity diagram of the cell provides obvious graphical scenes for implementation as well as verification thus the activity model for the case study is conducted (Figure15).

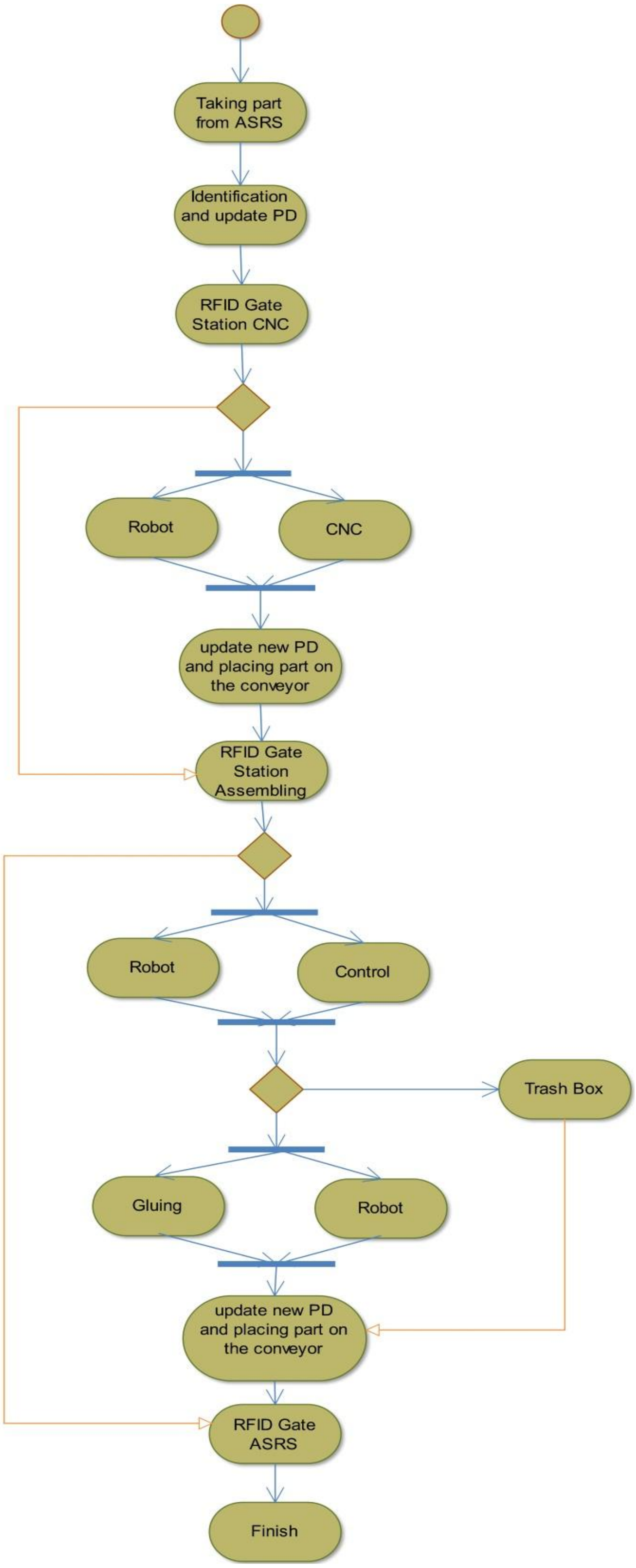


Figure 15: Cell UML Activity Diagram

This diagram is divided into three layers; machining, assembling and AS/RS station. In each layer an RFID-based gating system containing two antennas which are connected to the reader is integrated. The product development chain starts with a request from HMI to AS/RS. The AS/RS provides a raw material (part) to the conveyer. The RFID tag is attached to each part has lifetime information necessary for the production; meanwhile the gate updated the products related information to the tag.

The information includes but not limited to the following; universal identification number, parts number, station identification to be supplied for the component, processed status of station, delivery deadline time and order number etc. The RFID-gate of the machining station reads the information related to the part and implores the station's robot to pick the part up and put on the appropriate position (machine fixture). The RFID-gate also sends the process related information to the station IPC for requesting the machine controller for the machining process. When the processes finished the robot takes the part from the machine and puts on the conveyer, meanwhile as the part passes the station RFID-gate, the information related to the part is updated. The same actions would be completed at the other station and the finished product is stored on the suitable position of the AS/RS. Several operations based on the scenario can be executed at each of the stations.

UML development diagram demonstrates the implementation view of the stations. However, deployment diagram identifies the implementation view of the cell. Figure 16 presents the deployment diagram which addresses the static realization of the cell. In this figure, each station consists of several components and the station is communicated via a wireless communication link. The information of the part is shared among the other stations before it is forwarded to the HMI. HMI has the capability of processing as well as transmitting and receiving hence can be connected directly to the Internet for remote controlling via TCP/IP protocol.

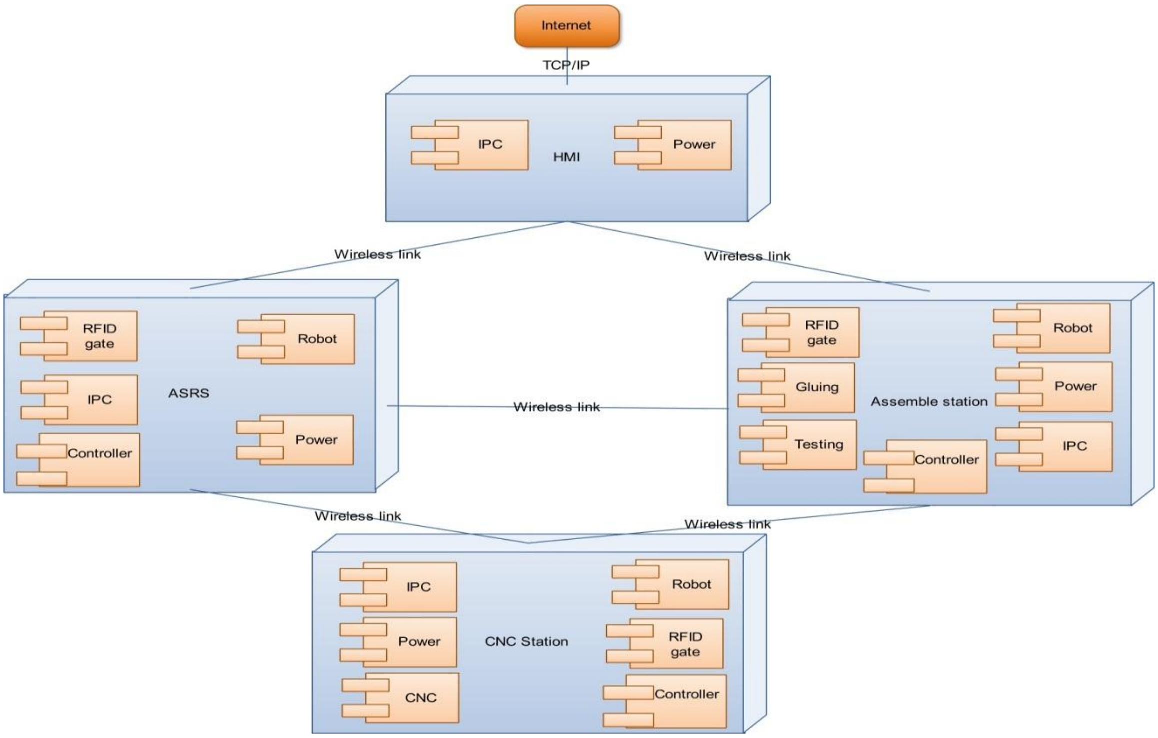


Figure 16: UML Deployment Diagram of the Cell

3.2.2.3. Sensor level

Utilizing RFID technology to the manufacturing system enables the possibility to obtain real-time information about the products which are involved on the add value chain. This information would be used to improve the system productivity, agility and flexibility. Furthermore, it is vital to form a reconfigurable manufacturing system. Information which is stored on the tag of the part can be associated with the component for allowing the system to be more decentralized and the process of production more flexible.

Schematically, an RFID system is composed of tag, antenna, and reader. Data is collected on the tag while the antennas read and/or write tag's data and send to reader. The reader decoded the data and then it is communicated to computer for treatment (Figure 17).

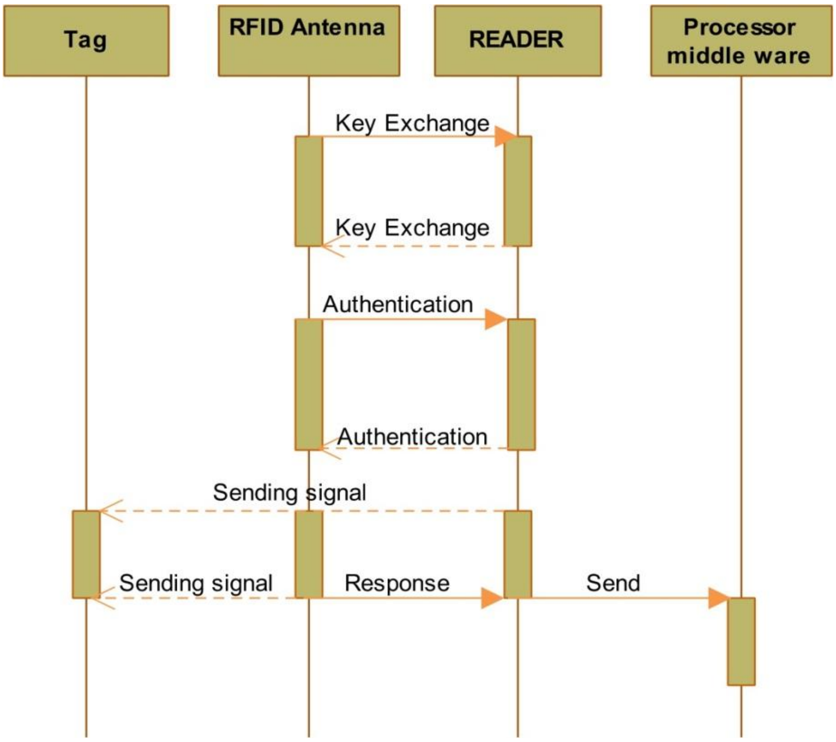


Figure 17: The Relationship between the RFID Antenna and the Reader

In the proposed manufacturing cell, the station's RFID gate is used for not only scanning parts but for updating the tag information and for station loading/unloading as well. The parts are transmitted to the stations according to the next stations ID. Thus the conveyer can forward the parts to the appropriate RFID-gate for loading or unloading the part to the desired station. Each station receives components from the RFID-gate, and then the station IPC do some operations on the part and finally sends them to the following conveyor. When orders changes, first, the revised information is sent to all the relevant station IPC from HML. Afterwards each RFID-gate reads each tag of the component through a tag reader/writer before it is supplied to the

Station. The station's IPC compares the tag information with the order change information (received from HMI) to decide whether the corresponding component should be processed by the station or passed. The component diagram for a RFID-gate is illustrated on Figure 18.

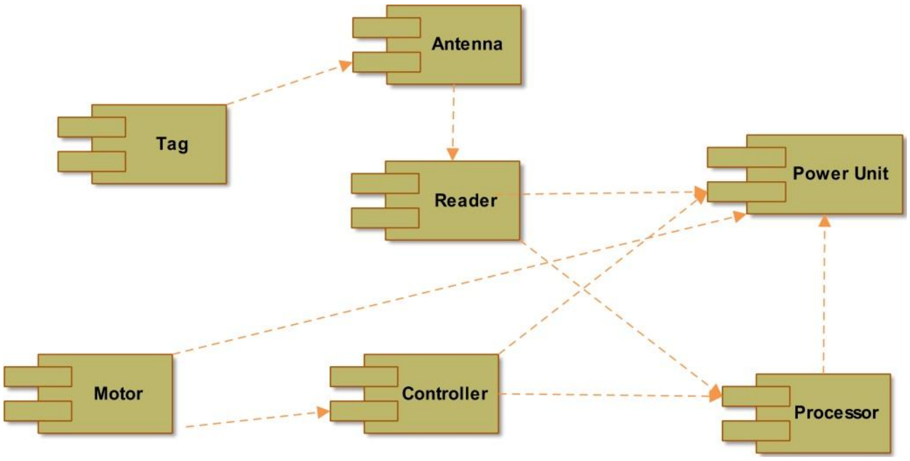


Figure 18: RFID-Gate Components Diagram

The part tag enables the RFID-gate to switch and route mutually connected conveyors automatically to enable the component be transported to the desired station.

3.3. Verification Process and Generalization

The focus of the verification process is on the generation of data files using the developed UML diagrams form the "system requirements" and "design and development" phases, then compering the generated data files with the system requirements. The information collected from the joint operations between "system requirements" and "design and development" phases, represented in a data file in the extensible Mark-up Language (XML) file format. XML supports the development of the structure data entities that contain a high level of the semantic content, which is both human and machine interpretable. This is widely used as a file format for manufacturing system data and information modeled using UML and manufacturing simulation software. In the verification process, XML is the encoding mechanism for the exchange of the file between the “system requirements” and “design and development” phases, and is hereafter referred to as cell data file.

As the RFID-enabled FMS models are executed, the collected information from the “design and development” phase is transformed into manufacturing data files. The manufacturing data file is the main actor of the matching environment. After the consistency rules are applied, the related manufacturing data file is ready for the matching environment.

The environment that captures the differences of the two manufacturing data files is called the verification environment. Discrepancies between operational representation by “system requirements” and informational representation by “design and development” can be easily captured in the verification environment. The overall information requirements of the cell can be specified by analyzing the difference between “system requirements” and “design and development” with requirement analysis environment. The verification environment can be seen in Figure19.

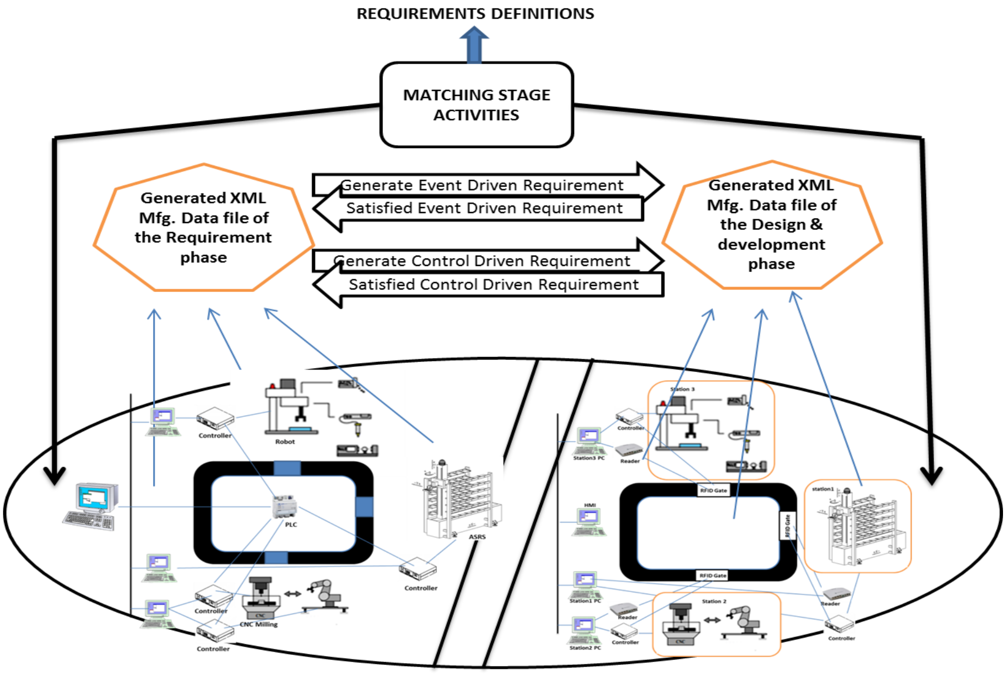


Figure 19: Verification Environment

For applying the proposed integrated architecture to the other manufacturing cells the following steps have to be considered:

- Highlighting the manufacturing resources which are exist on the stations of the cell as well as the processes that are realizable at each of the stations.
- Developing an appropriate use case diagram for the desired cell; the actor of the cell is “operator” and the main use case of the cell is “HMI” which is in charge of control and monitoring of the cell, each of the stations manifest a sub-use case for the cell.
- Expanding the cell’s class diagram using the proposed generic class diagram.
- Developing the stations object diagrams; do not put out of your mind to place an RFID gate as an object to the station’s object diagram.
- Developing the stations sequence diagrams based on the realizable manufacturing process and manufacturing resources of the station. Highlight the station’s RFID gate actions at the diagram.

- Developing the cell activity and deployment diagram based on previous steps.

The sequence and component diagrams at the data level are employable for any manufacturing cell.

Chapter 4

IMPLEMENTATION

4.1. Introduction

Nowadays business globalizations affect the manufacturing enterprises to provide new products with cheaper prices, high quality and faster delivery in order to sustain competitive advantage in the turbulent market. Flexibility, agility and re-configurability are three paradigms which are proven as hazards to enterprise efficiency and profitability and playing a robust roll in this goal. Thus, enterprises are seeking methods for upgrading the manufacturing control system in order to achieve more flexibility, high agility and with reconfiguration abilities. In the manufacturing industry, centralized control system is a common method which is employed on flexible manufacturing systems (FMS). The controllers for each subsystem of the FMS such as the one for stations, cells and factory, are hierarchically connected by a host computer in a centralized method; all the decisions and process are taken place on the host computer. Centralized control system is effective when the product variety is low and when the volume of the product does not change much (Kamioka, Kamioka, & Yamada, 2007). However, this method is not flexible, nor agile for high-variety and low-volume production. Furthermore, this system does not have the ability for re-configuration in case of ad-hoc events.

Currently, a great deal of effort has been spent on development new types of manufacturing control system, which capable to make production systems more flexible, agile and re-configurable. A Distributed Control System (DCS) configured from a set of autonomous controllers that comes together to control a FMS in order to achieve more flexibility, agility and re-configurability, and whose cooperation is supported by computer networks. Flexibility and responsiveness of DCS are mainly characterized when the right data are delivered to the right user at the right time. Furthermore, the ability of the system adaption based on product data model (PDM) as well as manufacturing data model (MDM) is other issues for realizing a reconfigurable DCS. In distributed manufacturing control, acquiring the real-time state data of every product accurately is an important attempt for promoting flexibility, re-configurability and agility of a manufacturing enterprise.

Evidently, traditional collection of data (e.g. barcode technology) is of low efficiency and has a high probability of producing error. The merging of, Radio Frequency Identification (RFID) technology provides an opportunity to realize accurate and just-in-time data acquisition. In an RFID-enabled manufacturing system, a tag is attached to every product, tags contains state data of the product. RFID reader is capable to read and/or write the tags data when the tag is in the readable range of the reader. These data can be transferred to a computer and stored in PDM for querying and processing. This chapter addresses design and implementation of architecture, specifying those components needed to provide an integral solution as well as those mechanisms required to deploy an RFID-enabled distributed control and monitoring system of a manufacturing shop.

This section describes our prototype implementation of a RFID-enabled FMS. The implementation consists of three phases: (a) Operational programs development (b) Integrated control software development and (3) Physical components and interface setup. It does not support implementation of the proposed integrated architecture present in chapter 3.

4.2. RFID-enabled distributed control and monitoring system: System overview

In this section, we will present detailed introduction to the proposed DCS for a flexible manufacturing shop. We summarize technological issues that must be respected by hardware systems for a successful RFID-enabled DCS implementation. We consider an educational FMS lab (Eastern Mediterranean university CIM lab) with three flexible stations which are integrated by a conveyer.

The illustrated UML development diagram (Figure20) demonstrates the implementation view of the flexible manufacturing cell located at Eastern Mediterranean university CIM lab. This diagram addresses the static realization of the cell with three stations as; AS/RS station, CNC station and assembly station. Each station consists of several facilities and the stations are communicated via a wireless communication link moreover the facilities within each station are connected through wired communication links. The information of the part is shared among the other stations before it is forwarded to the shop monitoring system (SMS). SMS has the capability of monitoring as well as transmitting and receiving hence can be connected directly to the Internet for remote controlling via TCP/IP protocol.

At the desired shop, each piece (RFID tags are attached to the piece) holds unique product capability list. The product capability list is stored in the tags. Two RFID gate, which are used to transfer data from (or to) the tags attached to the pieces into the machining and assembling stations as well as loading/ unloading of the pieces into the stations are placed near each of the stations. Another RFID gate is located at the loading/unloading point of the AS/RS. This gate is used to read or write data from the piece’s tag to the station that it is going to enter. The gate antenna reads acquired data from tags and then transfers it to the station’s reader.

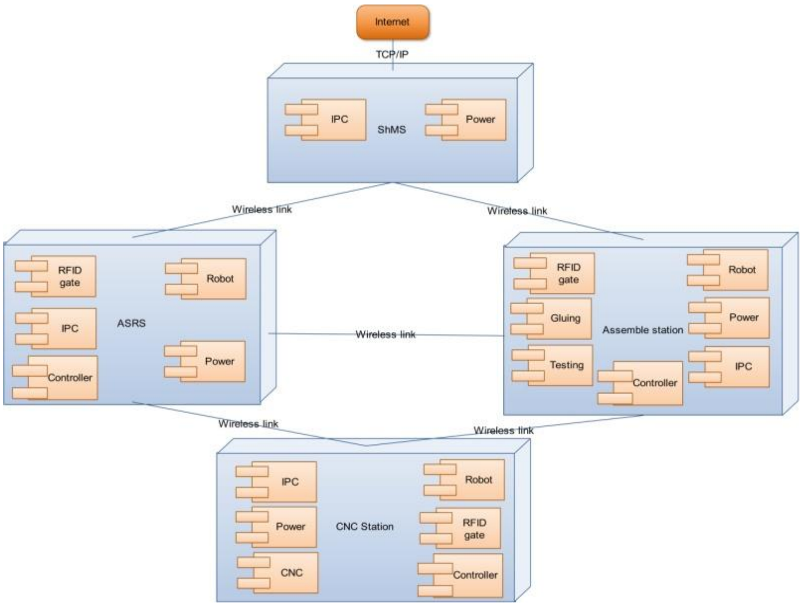


Figure 20: UML Deployment Diagram of the Cell

Each RFID gate configured from the two antennas, RFID reader and a manipulator for piece preventing process at conveyer. The RFID gates is used for not only scanning pieces but for updating the tag information and piece loading/unloading to the desired station as well. Also the manipulator which is installed at each RFID gate realizes the loading/unloading process of the piece from conveyer to the station. When a part is transmitted to the station (using conveyer in this system) based on information of the product capability list, the RFID gate loads the piece to the desired station. Each station receives pieces from the RFID-gate, and after the station add some capability on the piece the RFID gate sends them back to the following conveyor.

The current RFID-based distrusted manufacturing control system for the FMS contains the following components:

1. 30 RFID Active tags (FC909T active RFID tags).Each tag is attached to a component.
2. An RFID gate for each station which holds antenna, RFID reader, and manipulator.
    - Antenna (Motorola's AN480) which is installed on front of each station for sensing the parts
    - RFID reader (Motorola FX7400). Each reader is installed near to station’s IPC
    - Manipulator- which is used for preventing components on the conveyor from loading/ unloading process at the stations.
3. 3 IPC (PC/Microsoft Windows XP), which runs on the station control software and by which piece state data is received from the reader and stored in the database, and RFID gate is controlled.
4. HMI (PC/Microsoft Windows XP), which is used for monitoring the real time state of the productions.
5. Data server, application server and web server (2 PC/windows XP).

The hardware architecture of our system is depicted in Figure 21.

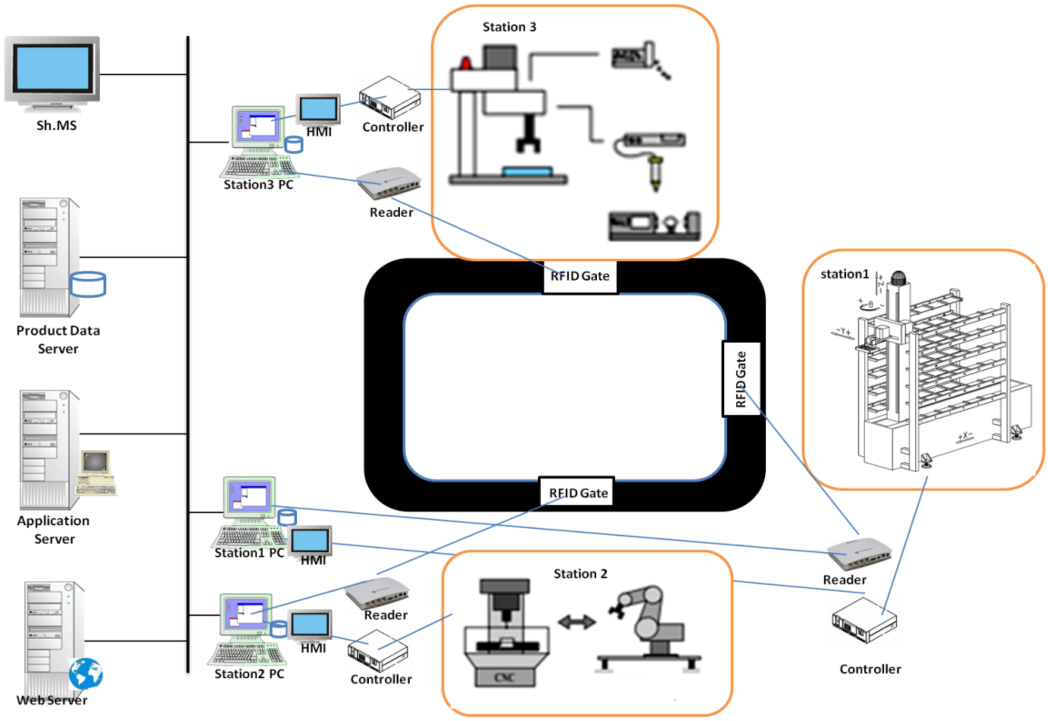


Figure 21: RFID-Enabled Control Architecture for the Flexible Manufacturing System

4.3. Multi-agent system architecture

Based on the physical compounds and connections of the RFID-enabled distributed control system identified in Section 4, multi-agent system is chosen to develop the application for realizing distributed control and monitoring system at the shop. It aims to implement, the RFID-enabled distributed control and monitoring system for the multidisciplinary stations or facilities which are involved on the product capability list. In this section, we present an overview of the multi-agent system architecture firstly, and then we will explain each all the agents as well as engineering tools exist on the proposed architecture.

The proposed multi-agent system is designed as a network of software agents which interact with each other and the system actors. These agents categorized as; Shop Management Agent, Agent Manger, Shop Monitoring and Command Agent, Station

Control Agents, Station Monitoring Agents, Agent Machine Interface and, Manufacturing Resource Agent. In addition to the exist agents at the architecture, two groups of database exist on the architecture, shop database and station's database. Furthermore ontology (capability-based knowledge model) required for multi-agent system for proper communication between the agents. The architecture is designed to integrate all the software agents with databases as well as ontology. The shop multi-agent system architecture and its hardware configuration are illustrated in Figure 22.

Next, the functionalities of the main software agents in the proposed multi-agent system are described as follows:

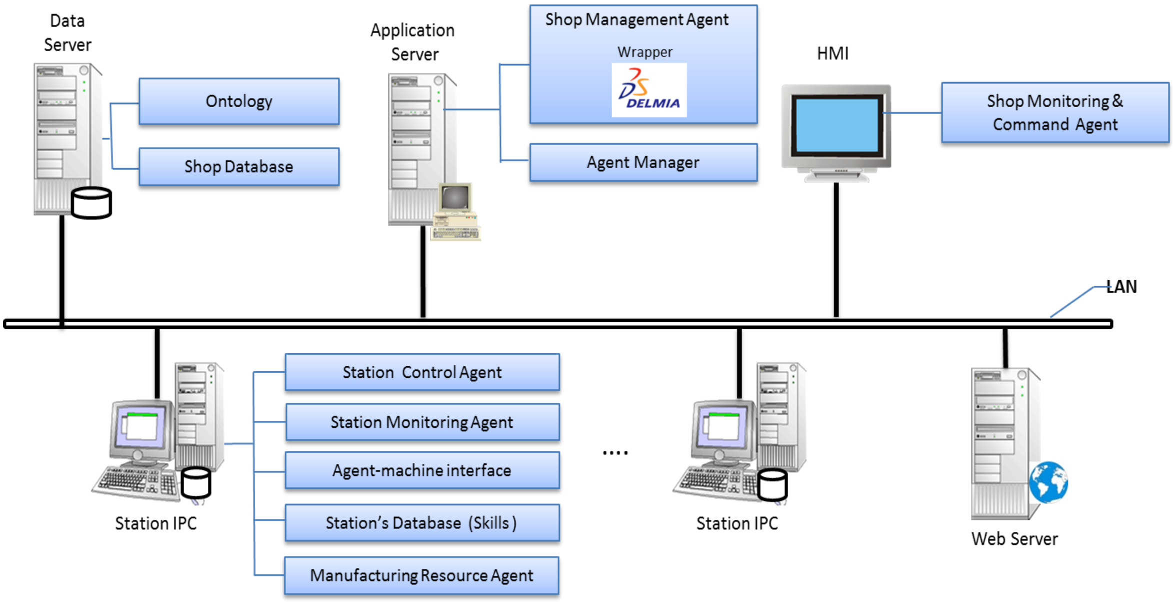


Figure 22: Multi-Agent System Architecture

Shop management Agent is responsible of assisting a shop manager to define a new product for the system, specify the initial manufacturing parameters, decompose product capability for the system. It has a user interface for assisting the shop manager for making necessary changes while the plan gets more detailed and the higher levels of the plan need to be updated. This agent is also responsible to send the generated product capability list to the AS/RS's RFID gate for writing the information on a desired piece's tag. This agent linked with DELMIA engineering software to perform key manufacturing tasks.

Agent Manager is responsible for controlling the utilization and availability of all agents by maintaining an accurate, complete and timely list of all active agents through which agents residing in the system are capable of cooperating and communicating with each other.

Shop Monitoring and Command Agent is responsible of obtaining and displaying the real-time state of raw materials, in-process products, and finished products as well as the status of the stations. Also it serves to act as a port for incoming commands form the shop supervisor manually in case of any ad hoc events and new product setup.

Station Control Agent, the station control agent realizes the process of selecting suitable capabilities from the product capability list for the station, and requesting capabilities from basic agents to do a job. Also, station control agent can update state data regularly at the station's database, and can send control instructions to shop database.

Station Control Agent, the information reflecting manufacturing state in station is displayed by the station monitoring agent a history of the station's process is stored in the station database.

Manufacturing Resource Agent, represent specific manufacturing components, such as robots, conveyors, machinery, etc. that are identified to encapsulate all the capabilities, interaction behaviors (collective capabilities), and internal status that characterize these type physical components.

Agent-Machine Interface is the agent that is directly connected to the physical controller. It acts as a kind of device driver to the Manufacturing resource agent. For each different controller there should be one agent machine interface.

All the agents are connected by a local network (LAN) via which they communicate with each other through asynchronous message passing. For the expediency of the Shop Management Agent and the Agent Manager run on an application server; the Ontology operates on data server which is also responsible for maintaining the shop database, the Station Control Agent, Station Monitoring Agent, Manufacturing Resource Agent, the Agent Machine Interface additionally station's database operate on the station's IPC.

4.4. Station Control Agent

Although various multi-agent systems have been developed in the domain of distributed control system for FMS, station control as a base component for RFID-based distributed control systems has yet to be formally specified, implemented, integrated, and tested.

Figure 23 illustrates the architecture of the "Station Control Agent" and its interactions with "Agent Machine Interface" and other engineering tools and agents. The station control agent is a kind of semiautonomous and service-oriented agent.

The station control agent lunches when a tag (piece) is place on the station’s RFID gate. Detail processes are described below:

Step 1: Each tag holds the product capability list which is written to the active tag at AS/RS‘s RFID gate, based on information from shop database.

Step 2: The product capability list is loaded in “Station Control Agent” from the RFID gate. The SCA receives this information through the “Reader Middleware Agent” and send to the complex skill unit.

Step 3: The “complex skill” unit verifies the received product capability list with the capabilities which are realizable on the station and decides to do any further action or not. The station’s capability list is available at “Station database”.

Step 4: If the piece is the station’s desired: the “Complex Skill” unit will select appropriate capabilities from the product capability list.

Step 5: The “Complex skill” unit with the assist of knowledge model (ontology) for each capability assigns: the information related to manufacturing resources and processes as well as the strategy about effectively and efficiently use of these resources and processes.

Step 6: The “Control System” unit requests relevant services from the “Manufacturing Resource Agent”, if the MRA accept services the “Control System” stores the manufacturing resource information on the station database.

Step 7: the “Control System” unit sends appropriate command through the “Agent machine interface” to the “Manufacturing Resource Agent” for doing specific job (as an example: station’s robot take the compound from the conveyer and puts on the CNC milling machine table and start to milling process on the component).

Step 8: As soon as the job started on the station, the “Manufacturing Resource Agent” sends feed back to the “Control System” unit through the “Agent Machine Interface”. Once the “Control System” unit receives the feedback from the manufacturing resources controllers, the “Control System” sends this information to the “Station Monitoring Agent” for reflecting manufacturing process and storing on the station database.

Step 9: Meanwhile, the manufacturing process of the desired component finished, the “Station Monitoring Agent” sends the history of the component state to the shop database.

In case of any constraint conflicts on the station, the station controller sends back related feed back to the “Station Control Agent” for further decisions and re-configuration. The “Station Control Agent” has a real time data exchange with the other agents (e.g. manufacturing resource agent) as well as tools (e.g. shop data base) of the system.

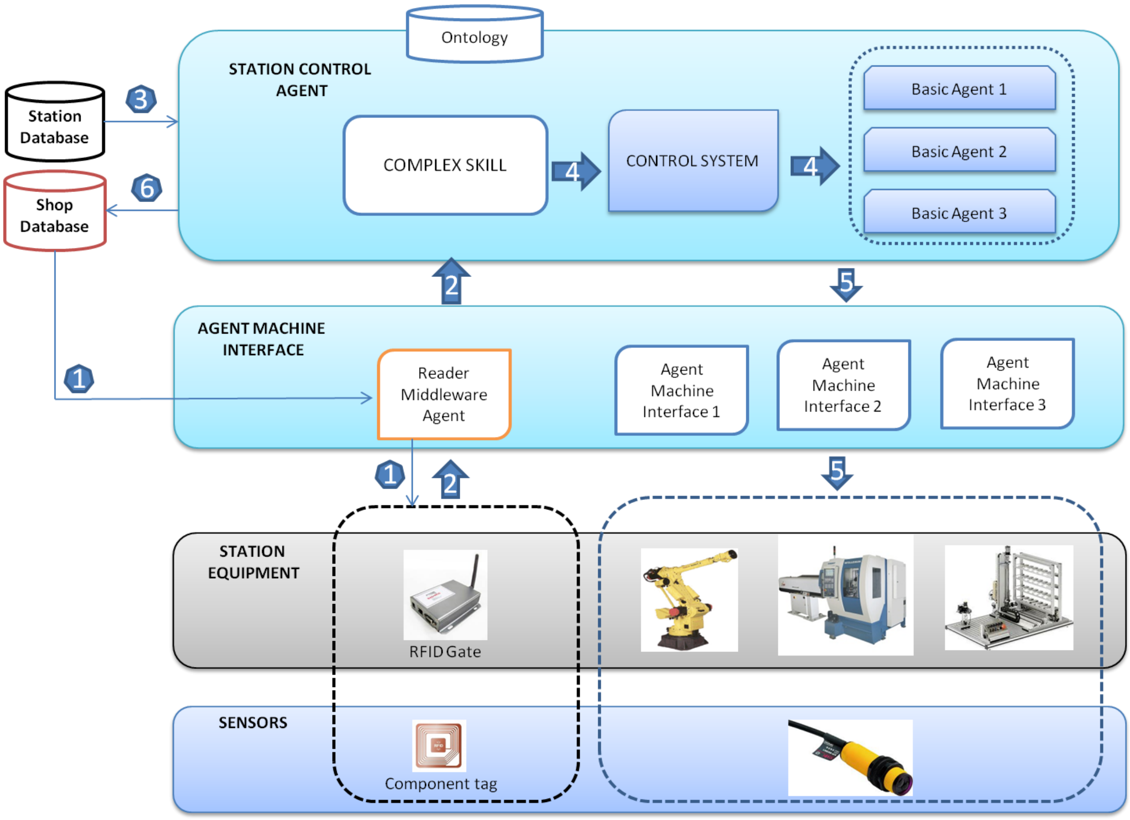


Figure 23: Station Control Agent” And Its Interactions with Other Agents on the System

4.5. Manufacturing Resource Agent

Manufacturing Resource Agent represent specific manufacturing components, such as robots, conveyors, CNC machine, etc. that are gentrified to encapsulate all the capabilities, interaction behaviors (collective capabilities), and internal status that configures these type of physical components.

An MRA whenever requested to execute one of its published capabilities by a controller agent or another MRA issues the necessary commands to the AMI that is connected to its physical controller. The MRA architecture is represented in Fig. 24. An important characteristic of the MRA agent is that it is a generic agent in the sense that no new code is necessary to create different MRA. They are only different at configuration level, mainly at skill level. Different MRA possess different skills.

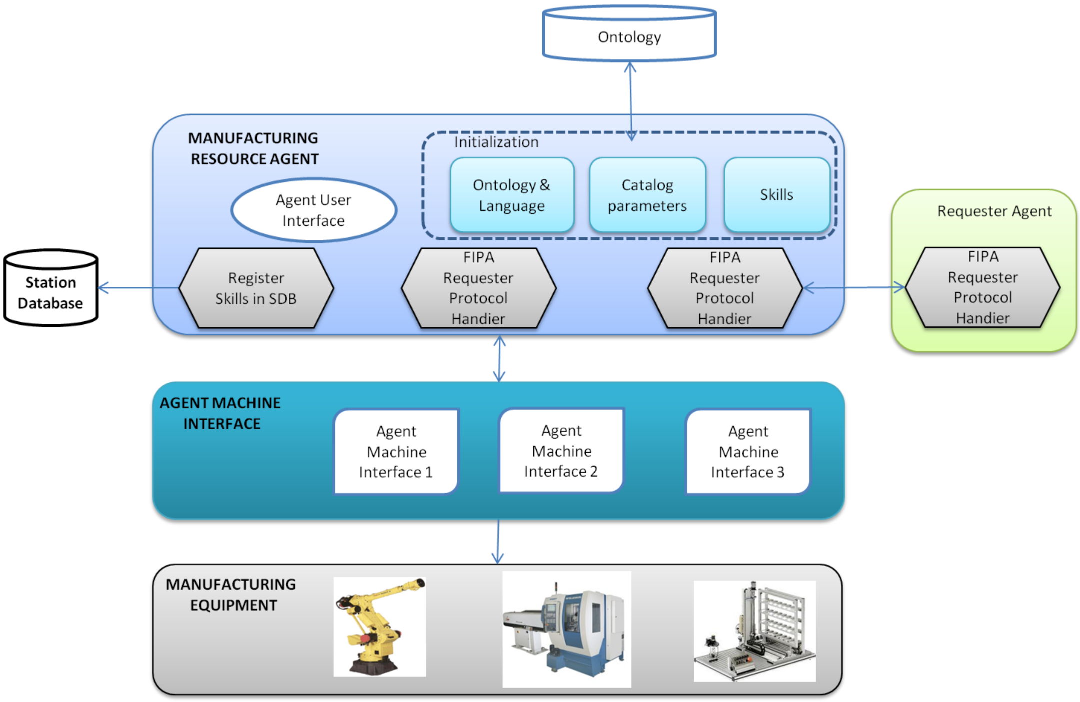


Figure 24: Manufacturing Resource Agent

4.6. Ontology (knowledge model)

For proper communication between the agents in multi-agent system ontology have to be defined. It has to mention that the defined ontology for the current work is more a knowledge model than a real ontology. However, the term ontology is used by most multi-agent environments and, therefore, it will also be used here. Capabilities refer to the company's ability to use its resources. In that, capability is a chain of business processes and routines which manage the interaction between its resources. In the proposed capability-based ontology, the capabilities within the production system is identified and the relationships of the main elements namely resource, process and knowledge are established. In current work the author's definition for capability is:

Manufacturing capability can be described as a set of information embedded by all available resources and corresponding processes that could be performed by those resources, as well as the knowledge about how these resources and processes can be effectively, efficiently and economically used.

Fig 25 illustrates a generic manufacturing capability model in the top-level diagram. Manufacturing capability model composed of all the main classes and their relationships promotes the realization of a single conceptual capability model. In manufacturing capability model, a facility comprises of one or many resources, processes and knowledge. Among these, there exist associated relationships. The key role of the associations between classes shows that resources perform processes, and knowledge constraints of one another that are both resources and processes. Any event of a process is related to one or many instances of the resources features that specify the pre-condition and post-condition of that particular process. Any resource feature can be achieved by one or multiple different processes. Knowledge is partially imposed upon the use of resources and processes.

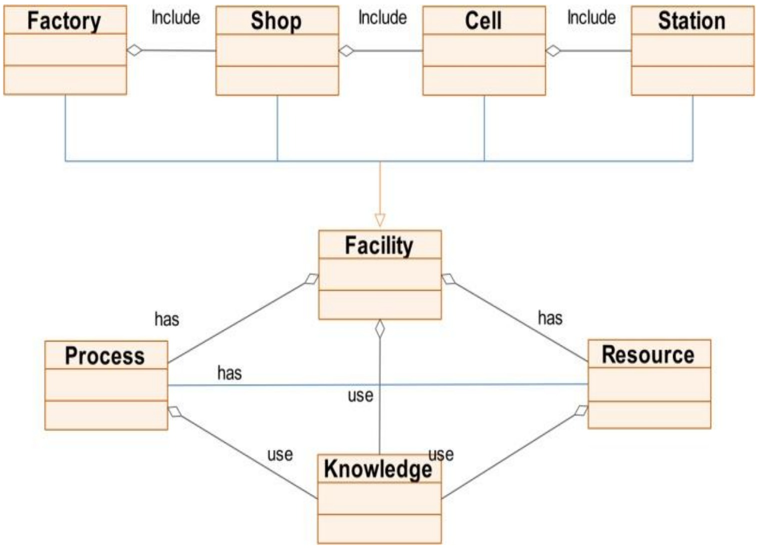


Figure 25: Manufacturing Capability General Model (Adapted From)

The main elements of the manufacturing capability model is decomposed and sub-modeled for the desired flexible manufacturing system at shop and station level for generating knowledge model.

As an example, Figure 26 illustrates the resource modeling of the assembling station using logical UML object diagram. UML object diagrams are used to render a set of objects and their relationships. The purpose of using the object diagram can be summarized as “forward and reverse engineering” object relationships of a system, static view of an interaction, understanding object behavior and their relationships from practical perspectives. The object diagram of the station involves the robot, RFID gate, testing machine, controller, IPC and gluing machine. The material flows between the stations and are completed using a conveyer. Each of the stations involves several resources, the material flow between the station’s resources are realized by station’s robot. Similar to the shop level the data flow at stations level is integrated by station’s IPC.

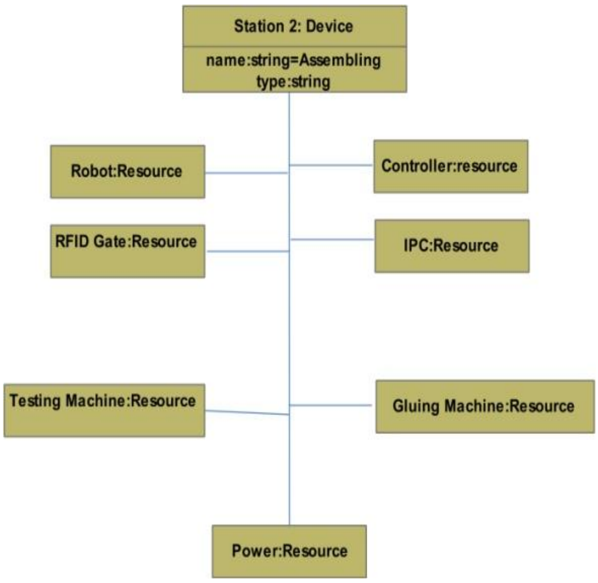


Figure 26: Object Diagram of the Shop

UML activity and sequence diagrams are outlined for representing the manufacturing processes of the shop and stations. The activity diagram is used for graphical representation of work flow of the system, which is backing up for selection, repetition and concurrency. An activity diagram consists of many shapes, connected with arrows. The most important shapes in use here are; oval, diamond, bar, filled circle and encircle filled circle. The oval represents a process, while the diamond represents a decision, the bars represents the starting or ending of simultaneous processes, the filled circle states the starting process while encircle filled circle the ending of the process. All this can be seen in Figure 27 where all the steps and processes for the shop are clearly shown and demonstrated.

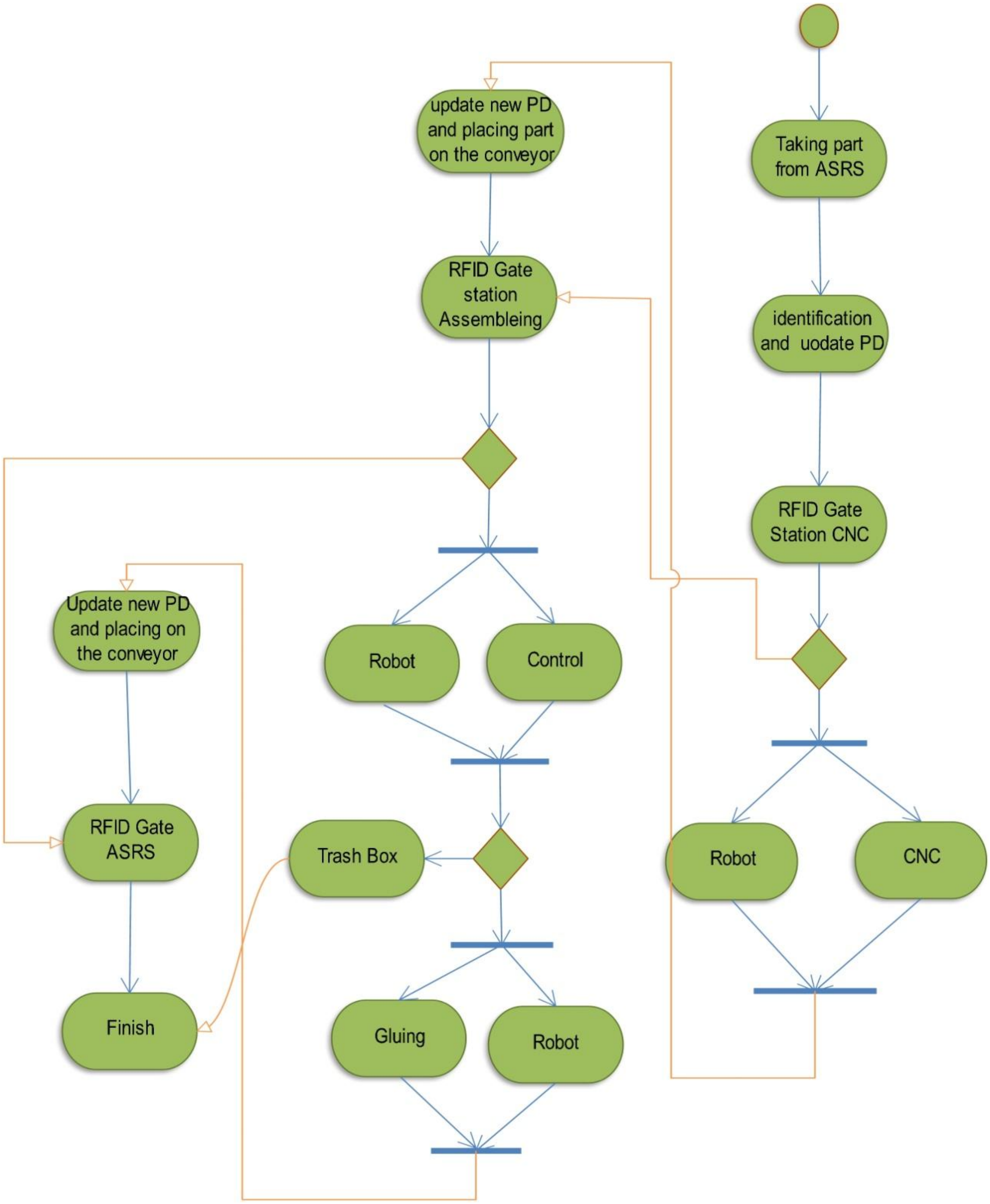


Figure 27: Shop's Activate Diagram

Sequence diagram is a type of dynamic work flow diagram which shows how processes work together and what the demand is. It is a creative plan as well as a message on how to work on the system telling the sequence to follow. The sequence diagram describes the levels of communication in the system. It represents the activities and processes related to each scenario followed by the sequence of messages to be performed on each scenario depending on their need or specification. The sequence diagram of the assembly station as an example is represented in Figure 28. These rectangles illustrate a manufacturing process and each of the columns demonstrates a manufacturing activity. Depend on the sequence of the processes, arrows connect the processes, the processing duration is bolted on the column based on the duration.

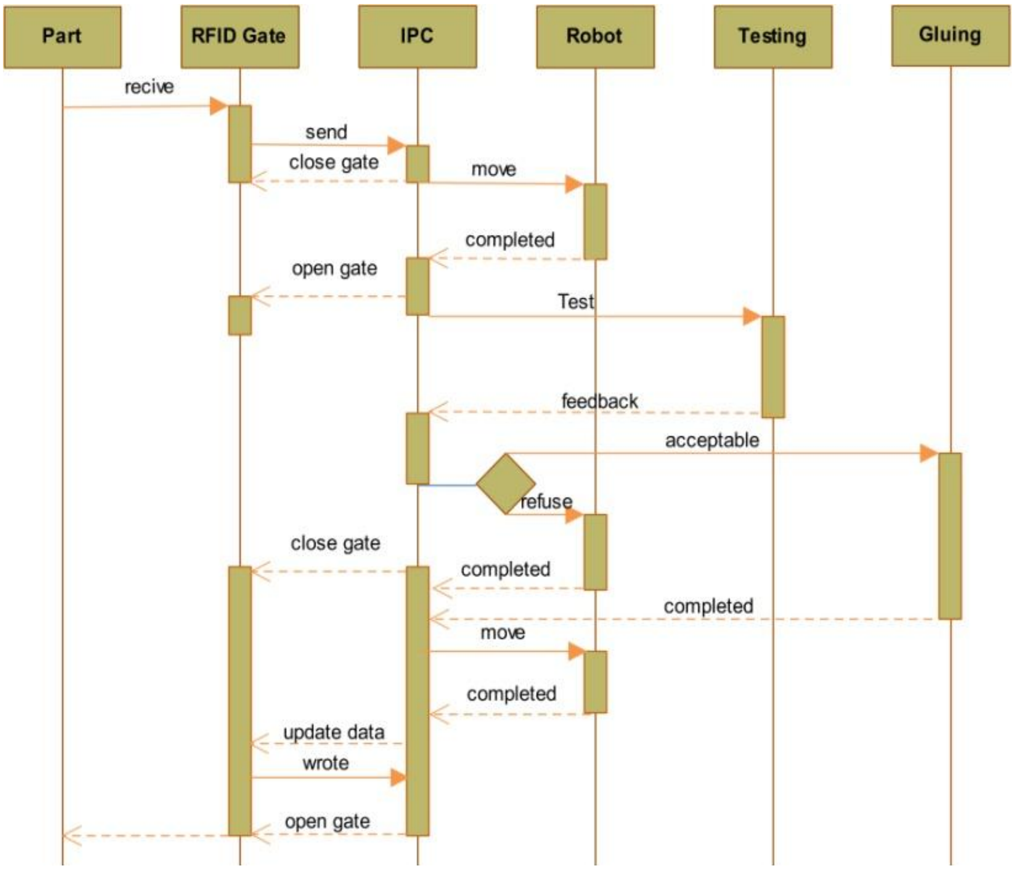


Figure 28: Shop Sequence Diagram

Manufacturing knowledge is an important part of the intended capability-based ontology since it contains all the processes and resources knowledge identified in the manufacturing shop. Therefore, it is necessary to follow a structure that allows the access and storage of the wide range of manufacturing knowledge. To define these, knowledge structures is necessary to explain what process and resource knowledge the manufacturing facility has and how they can be represented. Some examples of collected knowledge are presented to clarify the definitions of knowledge representation used in this work. Graphs, texts, tables, diagrams, formulas are some of the examples for explicit knowledge. While pattern, storytelling, video-clips and sketches are instances for tacit knowledge and implicit knowledge is concluded from performance of a person. Knowledge related to manufacturing processes and manufacturing resources are structured using different types of knowledge namely: explicit process knowledge, tacit process knowledge, implicit process knowledge, explicit resource knowledge, tacit resource knowledge and, implicit resource knowledge.

As it is shown on Figure29 the manufacturing knowledge class is depicted by a super54class redefined to organize separate types of knowledge and using this knowledge to access the facility knowledge. A super class named types of knowledge is defined to organize the current knowledge types in a manufacturing facility. Explicit, tacit and implicit knowledge are considered subclasses of this superclass. The explicit knowledge described is divided into table, graph and procedure subclasses. In a similar manner, the tacit knowledge can be divided into sketch, pattern, video clip and storytelling. Implicit knowledge is considered in the implicit knowledge class. Figure 11 shows an explicit, tacit, implicit type of knowledge structure to represent facility another main class entitled as Types of knowledge.

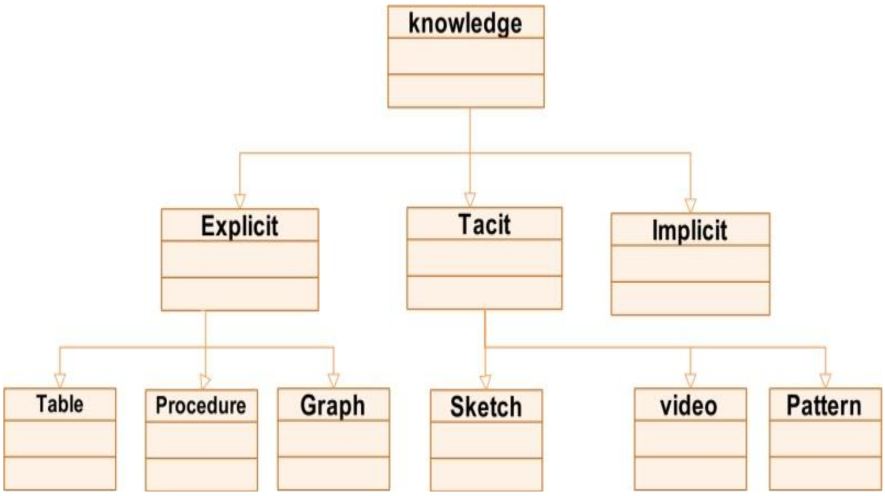


Figure 29: Explicit, Tacit and Implicit Types of Knowledge Structure, (adapted from (Guerra-Zubiaga & Young, 2008)).

4.7. Implementation

4.7.1. Agents and engineering tools

The system was implemented using *C#* and the *.Net framework*. The *.NET Framework* is a runtime execution environment that manages applications that target the *.NET Framework*. It consists of the common language runtime, which provides memory management and other system services, and an extensive class library, which enables programmers to take advantage of robust, reliable code for all major areas of application development.

Microsoft SQL Server database management system is employed for development of the shop and stations databases. In addition, for transferring logical UML models in to physical database (*SQL Server*) on ontology development *.NET developer* is used. This ontology development tool provides a user-friendly environment to create and update ontologies since it is possible to integrate an *SQL* database project file with an ordinary *C#* programs.

The source codes for the used Reader “Middleware Agent” are available at the producer’s website (http://www.motorolasolutions.com) where the *C# .NET* codes is selected for current work. All codes for “Shop Management Agent”, “Agent Manager”, “Station Control Agent” and, “Manufacturing Resource Agent” applications were developed on *C#*. While, “Shop Monitoring Agent” was established by *SWISH Max 4* software using *C* programming language. The “Station monitoring Agent” which is placed on HMI is developed by PM *designer 2.0* software using Macro Language. The “Agent Machine Interface” which is placed on HMI is developed by PM Designer V1.2 using Macro Language.

4.7.2. Interaction

The cooperation between all the agents implies a robust interaction schema that supports information exchange and deals with error situations to avoid deadlocks and abnormal stopping situations. All the agents that are developed with C# codes are interacted with *Microsoft SQL Server (e.g. station database, Ontology)* by the SQL DB Provider component. Also these agents are interacted with “Shop Monitoring Agent” by Shell Shockwave ActiveX component. Furthermore for creating connection between the “Station Control Agent” and HMI using RS232 port the System IO Ports component is used.

XML tags for data connection string between C# and SQL server.

```
<connectionstrings>
   <add name="ResourceInfo" connectionstring="
   Data Source=myserver\sqlexpress;Initial Catalog=true;
   User ID=sa;Password=*****"
   providername="System.Data.SqlClient" />
```

```
</connectionstrings>
```

XML tags for data exchange between C# and SWISH MAX software.

```
"<invoke name=\"GetDataFromAPP\" returntype=\"xml\"><arguments>"+
          "<string>"+ Value1 +"</string>" +
          "<string>"+ Value2 +"</string>" +
          "<string>"+ Value3 +"</string>" +
                      .
                      .
                      .
          "<string>"+ Value N +"</string>" +
          "</arguments></invoke>"
```

The UML sequence diagram in Figure 13 stands for a normal request for station RFID gate Robot made by a piece to the station robot agent from one origin (Input Controller) to a destination (Output Controller). If some controller is occupied, the piece remains on the queue and another request is chosen.

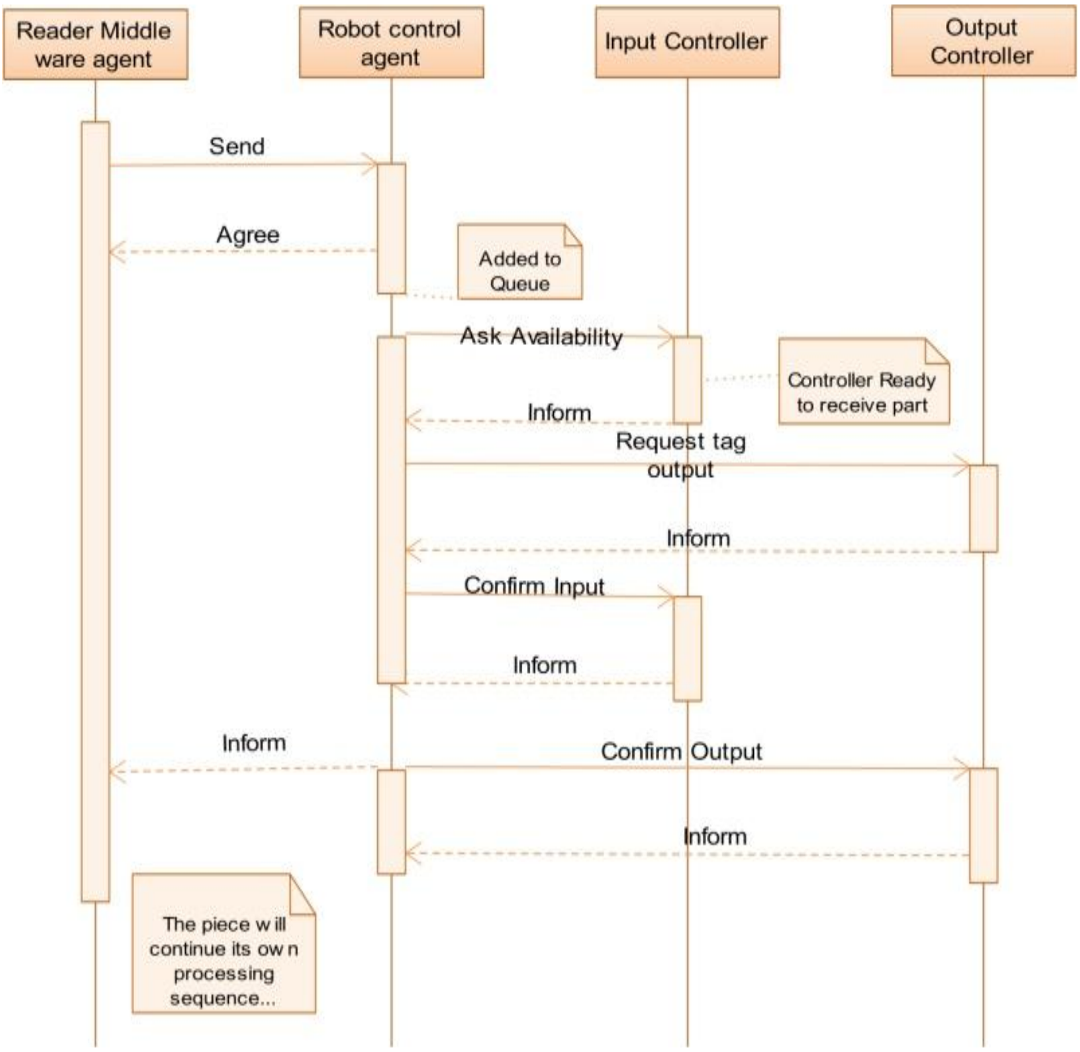


Figure 30: UML Sequence Diagram for RFID Gate

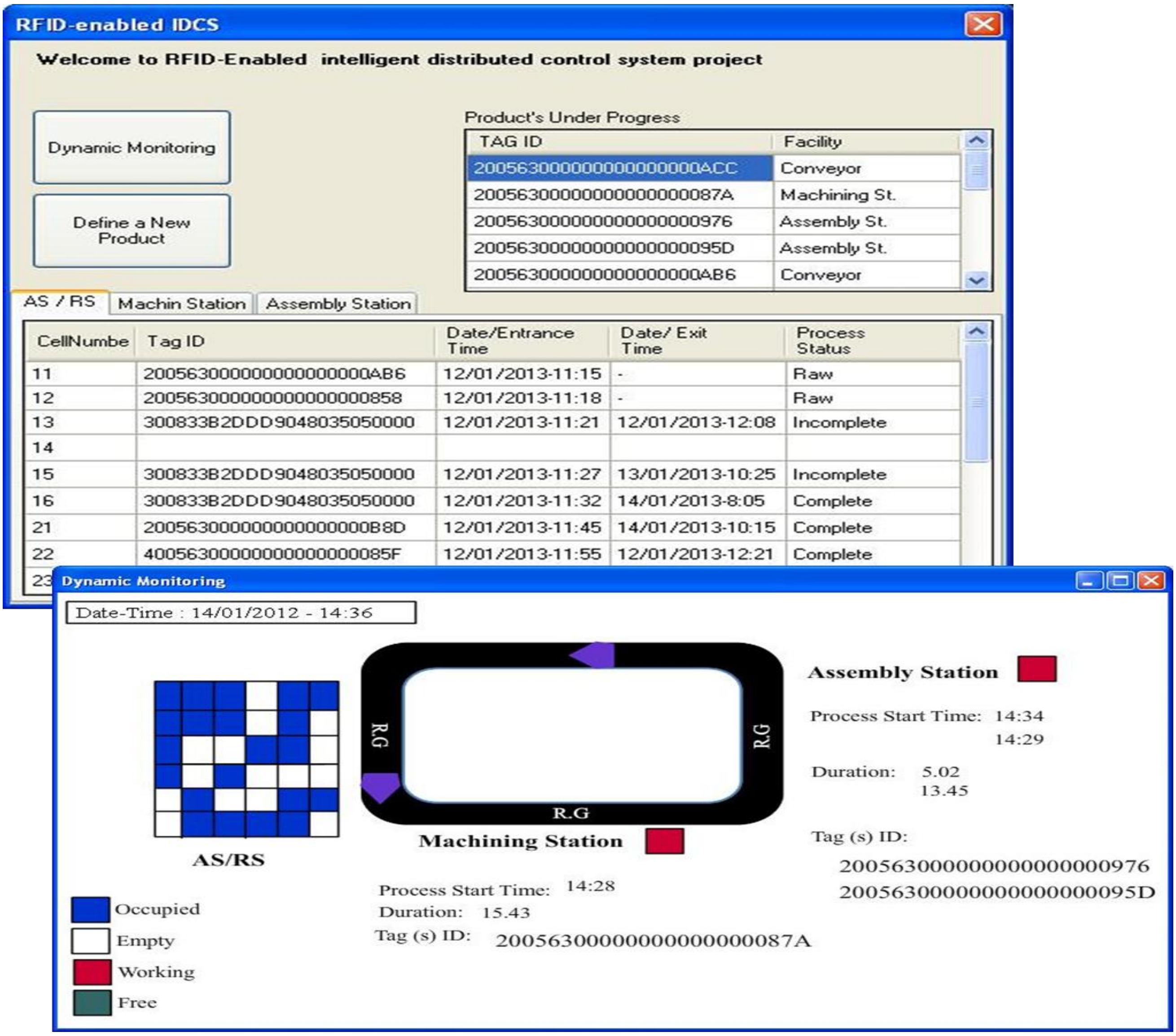
Chapter 5

CONCLUSION

5.1. Conclusion

In this thesis, the architecture for structural modeling of RFID-enabled IDCS has been presented. This architecture is aimed to overcome some of the short comings of the current flexible manufacturing system to give flexibility and re-configurability. The proposed architecture contains three phases, namely system requirements and design & development and implementation. The result of design & development phase goes through a verification process to check the consistencies. The developed models at design & development phase are effective in communicating the re-deigned system and its integration to users with less knowledge on implementation details; also these models are vital for developing implementation specific procedure and interfaces. The models suggested in the design & development phase can be adapted to a variety of FMS systems and to easily incorporate changes and extensions to the system as needed. For applying the proposed integrated architecture to the other manufacturing cells the following steps have to be considered:

Figure 31:HMI Monitoring System



Welcome to RFID-Enabled intelligent distributed control system project

Product's Under Progress

TAG ID	Facility
200563000000000000000ACC	Conveyor
20056300000000000000087A	Machining St.
200563000000000000000976	Assembly St.
20056300000000000000095D	Assembly St.
200563000000000000000AB6	Conveyor

CellNumbe	Tag ID	Date/Entrance Time	Date/ Exit Time	Process Status
11	200563000000000000000AB6	12/01/2013-11:15	-	Raw
12	200563000000000000000858	12/01/2013-11:18	-	Raw
13	300833B2DDD9048035050000	12/01/2013-11:21	12/01/2013-12:08	Incomplete
14				
15	300833B2DDD9048035050000	12/01/2013-11:27	13/01/2013-10:25	Incomplete
16	300833B2DDD9048035050000	12/01/2013-11:32	14/01/2013-8:05	Complete
21	200563000000000000000B8D	12/01/2013-11:45	14/01/2013-10:15	Complete
22	40056300000000000000085F	12/01/2013-11:55	12/01/2013-12:21	Complete
23				

Date-Time : 14/01/2012 - 14:36

AS/RS

- 🟦 Occupied
- ⬜ Empty
- 🟥 Working
- 🟩 Free

Machining Station 🟥

Process Start Time: 14:28
Duration: 15.43
Tag (s) ID: 20056300000000000000087A

Assembly Station 🟥

Process Start Time: 14:34
14:29
Duration: 5.02
13.45
Tag (s) ID:
200563000000000000000976
20056300000000000000095D

Figure 32 : Shop monitoring system

- Highlighting the manufacturing resources which exist on the stations of the cell as well as the processes that are realizable at each of the stations.
    - Developing an appropriate use case diagram for the desired cell; the actor of the cell is “operator” and the main use case of the cell is “SHMI” which is in charge of control and monitoring of the cell, each of the stations manifest a sub-use case for the cell.
    - Expanding the cell’s class diagram using the proposed generic class diagram.
    - Developing the stations object diagrams; do not put out of your mind to place an RFID-gate as an object to the station’s object diagram.
    - Developing the stations sequence diagrams based on the realizable manufacturing process and manufacturing resources of the station. Highlight the station’s RFID-gate actions at the diagram.
    - Developing the cell activity and deployment diagram based on previous steps.
    - The sequence and component diagrams at the data level are employable for any manufacturing cell.

At the implementation phase of the proposed architecture for RFID-enabled IDCS a multi-agent framework is developed. All the software agents are defined and explained in detail for achieving the research aims. The RFID-enabled IDCS developed in this research work is currently working at the flexible manufacturing system laboratory of Eastern Mediterranean University at Cyprus, where visitors can see that RFID-enabled IDCS is advantageous in terms of fast scalability and flexibility. Some experiments have been done to verify the feasibility of the developed control system. The different tests made with different product operation list proved that in terms of product variety there are no limitations from the control points of view and the control system is intelligent. Also, using shop monitoring system the real-time location as well as orientation of the parts within the cell is reachable. Furthermore the station’s HMI monitors the status of the machines at the desired stations. The AS/RS’s HMI have the capability to show each of the parts status.

Since there is no similar station at this cell (all the stations are unique), furthermore, the conveyer which is used on EMU-FMS lab can take limited numbers of part simultaneously; the author was not able to test the re-configurability of the system experimentally but the intelligence of the control system is an indicator that the system have the re-configuration capability.

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