TAMPERE UNIVERSITY OF TECHNOLOGY

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Gesture-based Human-Machine Interaction in Industrial Environments

Master of Science Thesis

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ABSTRACT

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The traditional human-machine interaction systems for manufacturing processes use peripheral devices that require physical contact between end user and machines. This physical contact causes an alteration of the elements that constitute the system due to the transmission of undesirable particles such as oil, chemical substances and pollution. This Master's thesis gives a solution for this issue which is based on the integration of a device used by game industry in entertainment applications that enables human-machine interaction through a non-physical contact modality. Several purposes are offered by the market such as kinect sensor and leap motion controller (LMC). However, the solution used in this thesis was focused on a hand gesture-based device called "LMC", which promising features that make it an attractive tool for future solutions in the industrial domain. The obtained result was the integration of this gesture sensor with different technologies that enables the interaction via hand gestures with a monitoring system and also a robot cell which is part of a manufacturing system.

PREFACE

This thesis is the arduous final result of a personal goal set many years ago once I planned to live in Finland for the first time. It was supported by many people in different ways and for sure I will keep them in mind for long time because of the importance of this achievement in my life.

Firstly, I would like to thank to my parents for their advices and support over the years, their example of love and effort will live in my heart.

I want to thank you, Laura and Maya. You are my life, your love is my strength. I hope the future will keep us together.

I want to thank my sisters, Mafe and Gaby, their example and courage were my guidance to walk forward in this process.

I would like to thank also Pr. Jose L. Martinez Lastra for giving me the opportunity of participating in the Master's Programme in Machine Automation. In addition, I would like to express my gratitude to all to the staff of the Fast Laboratory for their help.

Finally, thank also to Hilkka-mamma, Eija, Suvi, Mikko and Tapsa, and my friends Luis Enrique, Luis Miguel and Fernanda for helping me to take this step a forward.

CONTENTS

TERMS AND DEFINITIONS

API	Application Programming Interface
CSS	Cascading Style Sheets
DPWS	Device Profile for Web Service
HTML	Hipertext Markup Language
HTTP	Hipertext Transfer Protocol
IU	User Interface
JPEG	Joint Photographic Experts Group
JSON	JavaScript Object Notation
LAN	Local Area Network
LED	Light Emitting Diode
KDK	Kinect Development Kit
LMC	Leap Motion Controller
NPM	Perceptron neural networks
PC	Personal Computer
PLC	Programming Logic Controller
RTU	Remote Terminal Unit
SCADA	supervisory control and data acquisition
SOAP	Simple Object Access Protocol
ST	Structure Text
URL	Uniform Resource Locator
USB	Universal Serial Bus
VGA	Video Graphics Array
VR	Virtual Reality
WAN	Wide Area Network
XML	Extensible Markup Language

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1. INTRODUCTION

In this chapter is presented to the reader a background related to the thesis work, moreover, a clear definition of the problem to solve and justification. Finally, the work description is defined by the proposed objectives, methodology and assumptions and limitations.

1.1 Background

In spite of the prolonged recession that has crossed the frontiers in Europe, the evolution of the global economy continues and according to Mckinsey Global Institute in [1], the manufacturing sector plays an important role because it accounts for 16 percent of global GPD and 14 percent of employment. In addition, Mckinsey Global institute estimates that 1.8 billion people will enter the global consuming class over the next fifteen years, and worldwide consumption will nearly double to 64 trillion. To reach these goals, the developing countries aim to implement in the industrial sector innovations focused in material composition, information technology, production process and manufacturing operations in order to obtain new products, renovate the existing ones and contribute to a new dynamism in the sector.

On the other hand, during the past few years, the video game industry has grown faster than other industrial sectors. This fact is due to the expansion of the gaming industry not only in entertainment development but also in educational, artistic and work solutions. Through gaming industry, the interaction between human and machine has evolved from conventional peripheral devices such as mouse, joystick, key board, and microphone to the use of emergent electronic gadgets with non contact gesture sensors. These novel peripheral devices may enhance human machine interaction systems in manufacturing process.

The gesture sensor is based on the interaction between user and machine through the recognition of human movements, this interaction may be via non-physical contact modality. Gesture-based sensor recognizes corporal gestures from fingers, hands, arms, face and body of the user. Examples of gesture sensors devices are Microsoft Kinect camera and Leap Motion Controller (LMC) among others. Kinect and LMC devices track the movements of the body and hands through deformation of a 3D mesh projected by infra-red light. In contrast with Microsoft Kinect, Leap motion controller tracks gestures made only by hands, fingers and held hands tools with an accuracy and robustness proper of an industrial device.

The leap motion controller is characterized by its open-source code, and it allows the development of applications in many different areas. This gesture-based sensor will provide potential solutions in the manufacturing sector to problems in tasks where the use of non-physical interaction between user and machine was inconceivable.

1.2 Problem Definition

In manufacturing processes, the traditional human machine interaction systems involve intermediate devices whose input data or commands are based on physical contact by pressing buttons, rolling balls, moving levers or touching screens. Usually, this physical contact sometimes cause problems such as contamination in industrial harsh environments, through the transmission of undesirable particles of the surroundings such as oils, pollution, or chemical substances to peripheral devices of the control and supervisory systems. For instance, maintenance workers of production line have to repair equipments and interact with control and supervisory systems where its physical contact is common and contamination for transmission is occurred. In addition, another problem that lies in the use of the current peripheral devices in many manufacturing processes is the complex structure based on dozens of buttons or commands to interact with machines. It complicates the interaction between user and equipment and in some cases it involves unnatural movements to enter commands from the user side. The last but not the least, the working conditions in industrial environment are often unsuitable for people with disabilities due to the lack of suitable devices for interacting with the systems.

These previous problems can be addressed by the new breakthroughs in human machine interaction technology, which has given rise to reliable devices with high accuracy and robustness. These devices are currently applied to entertainment domain, however, they could be used in more demanding fields such as manufacturing, mining, maintenance systems, for instance. This novel technology can provide a solution for inherent drawbacks attached to the use of conventional devices that are employed for human computer interaction.

1.2.1 Justification

In the last years, a number of human-machine interaction devices have been introduced into the market, it enables a wide range of different and novel applications. However, the video game industry has been targeted as the main application arising from the use of most devices in spite of their advantageous features that can be employed in more demanding environments than those corresponding to the entertainment field. In computing, novel interaction methods are ushered by devices that allow non physical contact between user and machines through the vision based technology. Among these gadgets, the LMC stands out due to its sub millimetre accuracy and high robustness as claimed by Weichert [2] and Guna [3]. In addition to this, its small size, low price and easy integration with other systems as a result of its open source license make the LMC a very attractive alternative for human-machine interaction applications.

In recent research carry out by Garcia [4] a real time 3D monitoring system for an assembly line located at Fast Lab in Tampere University of Technology was put forward. This system receives events that occur in the shop floor and shows them in 3D animations, moreover, it enables to supervise a physical process using 3D cad models, created for design, and novel technologies such as a game engine application called Unity 3D. This game engine and LMC share extensive documentation to integrate and develop applications using both platforms simultaneously. Admittedly, new challenges emerge nowadays due to the need of using the LMC to improve the interaction of the workers in an industrial environment, an issue that could be tackled by integrating the LMC with a manufacturing application tool to control and visualize information obtained from the process.

1.2.2 Problem Statement

Human computer interaction is addressing to new ways of developments that gives the user more freedom to face the use of intermediate devices; leap controller is an example of such a new approach. To such an end, this thesis explores how the leap controller may improve the work experience between worker and machines in the manufacturing environment. To address such a challenge, it is necessary to head for the performance of the LMC. The interaction between human and machine using the LMC permits to avoid the physical contact between the user and the machine through the capture of the fists, hand and finger movements of the user; which solves one of the problems aforementioned: the contamination of the environment. Although the maintenance personnel keep substances in their hands from previous physical contact with equipments, the interaction with the supervisory system can be free of touch, even when the worker uses gloves. Other advantages are associated with the use of simple and natural dynamic gestures with hands such as swipe and circle gestures to interact with web browser interfaces through coding them. In addition, the use of LMC to capture sign gestures can be interpreted by computers like commands of execution of specific task without the need of intermediate devices which requires physical interaction.

1.3 Work Description

1.3.1 Objectives

The main objective of this thesis is to contribute in the field of user interaction for control and monitoring of industrial systems. The application will consider the different kind of users that interact with control and monitoring systems in the industrial domain and it will help them to perform their tasks by providing new interaction modalities (e.g. gesture) and visualization technologies (e.g. 3D models). To such an end, it is necessary to define the following list of specific objectives:

1. Analyse the advantages and disadvantages that come with the use of computer peripheral devices based on gesture interaction and propose a practical approach that considers its use in a real time monitoring system.

2. Implement an application that allows the interaction with a real time monitoring system by hand gesture-based device.

1.3.2 Methodology

The implementations of the proposed work are based on the following steps:

- Perform extensive reviews on the following topics:
  - Determine a state of the art of monitoring systems for the industrial domain.
  - Define different types of media for human machine interaction systems.
  - Define human gestures and classify these for human machine interaction systems.
  - Define different interaction modalities and visualization technologies for control and monitoring systems.
  - Carry out investigation on different gesture applications and new visualization technologies (e.g. 3D)
  - Investigate the available commercial devices for providing novel interaction to users and define their main advantages.
- Definition and development of an application based on gesture interaction for different users of a monitoring system as well as new visualization technology (e.g. 3D models).
- Integration of gesture-based application with a manufacturing system. The monitoring system should be integrated with a test-bed system that consist

on a production line with 10 robotic cells controlled by web service enabled devices. The monitoring system has to display the run-time information of the line and provide interaction to the users with their hands to access more detail information available in the 3D model.

1.3.3 Assumptions and Limitations

The assumptions and limitations took in consideration in order to design and implement the gesture-based application for interacting with a 3D monitoring and manufacturing system are described in the next points:

1. The 3D models that represent a system placed on Fast laboratory are converted to suitable format used for game engine Unity 3D.
2. The integration of a gesture-based device with a monitoring system must be done with a real time monitoring system based on game engine unity3D. The compatibility of both technologies is primordial.
3. A retrofitted architecture based on web server enable devices displaced on testbed fastory line mark the standards to interact with the physical system.

1.4 Thesis Outline

Chapter 2 presents a literature review of monitoring systems based on context-awareness for manufacturing domain, human-machine interaction media, definition and classification of hand gestures for human interaction, commercial input devices for the recognition of gestures and application in different domains using LMC device. Chapter 3 describes the proposed architecture and methodology approach that was followed to design and implement gesture-based applications. Chapter 4 depicts the developed implementation and its characteristics. Chapter 5 shows the obtained results, an assessment and suggestions for future works. Chapter 6 provides the conclusion of the thesis work.

2. LITERATURE REVIEW

In this chapter is presented the literature review of topics which their clear understanding is considered fundamental to develop next phases of the thesis work. In the section 2.1 is described the advantages of industrial monitoring systems based on context-awareness compared to traditional supervisory systems. Moreover, some examples of solutions applied on industrial environments are depicted. In the section 2.2 is presented different types of media in human- machine interaction. In section 2.3 is presented a definition and classification of gestures in order to interact with computer systems. The section 2.4 presents a classification of input devices for the recognition of gestures. In the section 2.5 is presented examples of current commercial devices to track hand and body gestures, and besides, describes two evaluations about the performance of LMC device in demanding environments, and finally, examples of its application in different domains.

2.1 Industrial Monitoring Systems based on Context-Awareness

In the last few decades, there has been a significant evolution in the manufacturing processes due to its large scale influence on world's economy [5]. Moreover, there is much competition in the global market due to the fast growing trend in technological developments; the technology breakthrough creates opportunities for improvement in the different fronts of manufacturing.

A solution for the enhancement of industrial monitoring systems by utilizing context awareness has been presented in [6]. This proposal lays on collecting information from monitoring systems along with the context of the industrial process; which is then, used to generate notifications with relevant, user-specific information. The purpose of comparing the context data with the current monitoring systems output is to provide adequate information to the right user, thus preventing the user from receiving irrelevant data and, therefore optimizing user performance.

The proposed solution enhances the monitoring system by focussing on context awareness and is based on three major components: a Context Engine, a Proactive Decision Engine and an Adaptive Human Machine Interface (HMI) Definer. Each component has its own functionality and all combined tackle a set of specific requirements like robustness, high relevant information delivery, easiness to operate, quick context sharing, best presentation selection, best modality and flexibility. The

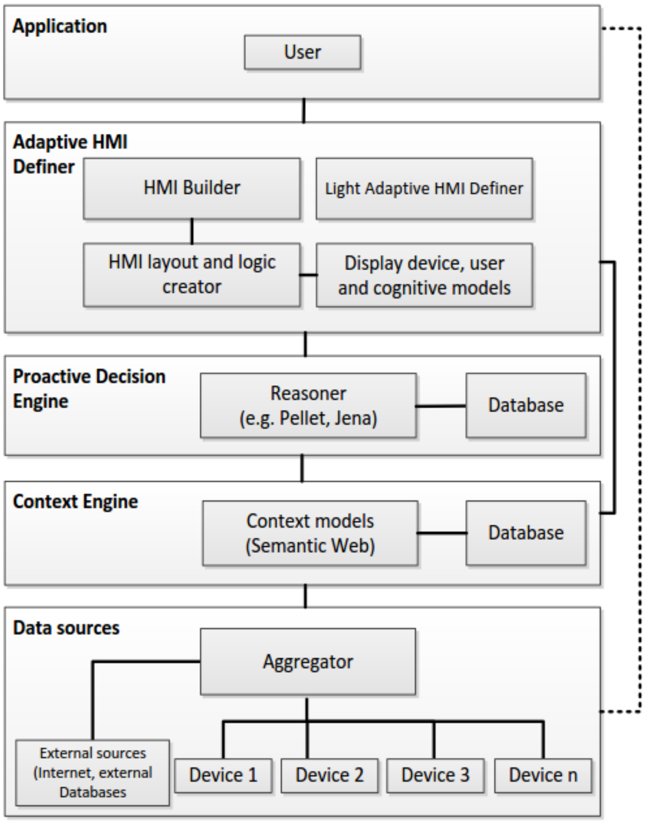

Figure 2.1: Components of context-aware industrial monitoring system in [6].

Context engine is at the primary layer; its role consists on mapping context data from sensors and devices, updating and ensuring that the latest context model is maintained in a repository accessible to the proactive decision engine. At the proactive decision engine, context data obtained from the repository is operated based on set of rules which are triggered when changes to the system are detected or conditions are satisfied. It maintains a list of events containing information to be shown to users. The adaptive HMI engine deals with the way information is built and displayed based on parameters such as user role and device.

New web technologies enable straightforward developing context-aware industrial monitoring systems. The research reported in [6] recommends the use of semantic web technologies as equally put forward by [7], where the most commonly used one is ontology applied to create specific models in the context engine component.

The system presented on Nieto´s research in [6] was illustrated using a simple industrial scenario, a discrete manufacturing line. The context information sources considered were production data, device user, location, weather condition of the environment, display devices and time. These parameters have to be shown to three different user roles: manager, supervisor and maintenance personnel, in various modalities and presentations depending not only on the relevance of the information related to the task of each users; but also, on the device being operated by the users.

The solution provides desired improvements like more flexibility in the monitoring system, increased user efficiency and, direct access to needed information reducing the required number of steps and time. Additionally, combined with the use of new display technologies such as a 3D model and AR , this solution provides comprehensive and accurate information.

A few solutions related to monitoring systems based on context-awareness are described in the next paragraphs:

MOSES The MOSES system presented in [8] is a mobile work clearance management system focused on avoiding accidents in complex, large industrial environments. This system enhances occupational safety for the maintenance personnel using similarly as fire fighting peer-structure such as siren system and utilizes low-cost passive RFID tags to sense positions of tools and add information for maintenance performance.

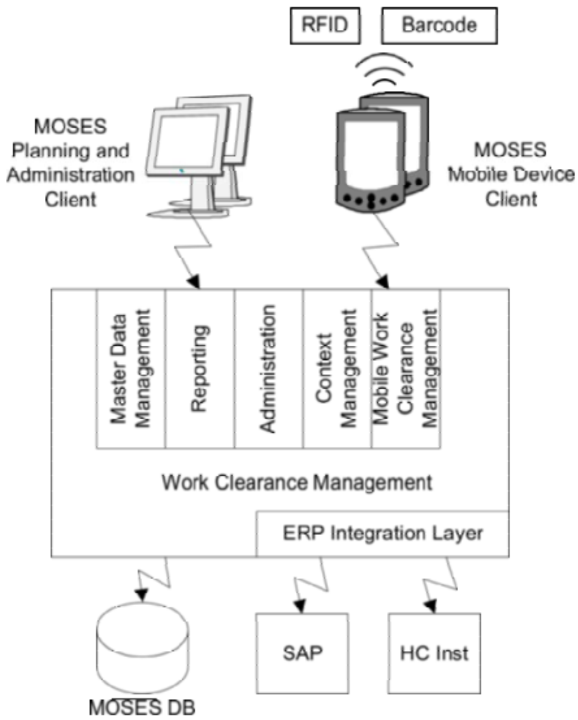

Figure 2.2: Architecture of MOSES system in [8].

In the MOSES system the contextual data is gathered, integrated and distributed by peers into the network. This contextual data is fed of data by the planning stage. The solution based on MOSES improves the work clearance process getting more secure and nimble, although maintaining the collaboration characteristic of the real process. Some drawbacks have been noticed in MOSES such as failed connection between mobile devices and server that hamper the use of latest data; also the flow of technical information sent to devices has to be controlled to avoid overloading the user.

SAGE The Semantic Ambient Generic Extensible framework presented in [9] proposes a solution that compel small and medium size enterprises to find methods to respond quicker to continuous market changes. This generic framework also called "SAGE" is based on human actor as main focus of whole manufacturing working environment. It relies on an ambient intelligent logic that establishes an sensitive and responsive environment to human requests.

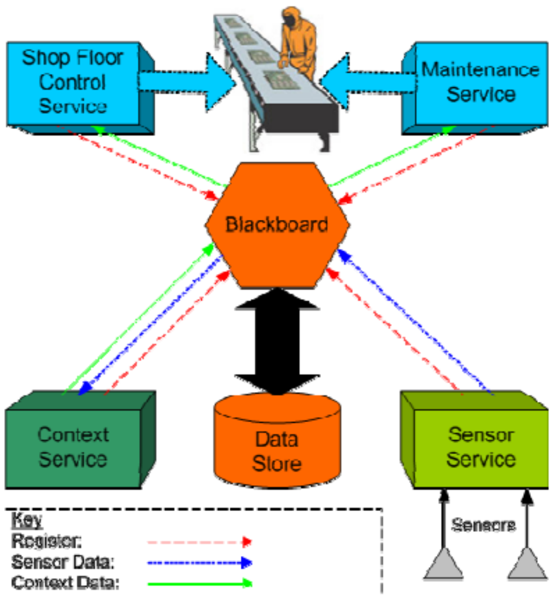

Figure 2.3: Generic framework of core components and extesible services of SAGE system in [9].

As [9] points out, the main objective of this approach is to provide decision support to small and medium enterprise user, achieving maximum efficiency in manufacturing processes. This framework incorporates technologies used in ambient intelligence and semantic web fields in order to overcome the drawbacks from deterministic and predictive solutions. Unlike to current solutions where vital parameters to counteract unpredictable nature of the market are not covered; this system supervises in real time key resources of the shop floor such as employees, stock and machinery. In addition, purpose reports management documents that content critical information of the context to the decision-making process.

SMART FACTORY The solution called Smart Factory presented in [10] is based on the concept of "Smart Environment" transferred to a manufacturing landscape. This concept explained by Mark Weisers is described in [10] pag. 115 as "physical world, which is closely and invisibly interwoven with sensors, actuators, display and computer elements, which are seamlessly embedded in daily life objects.

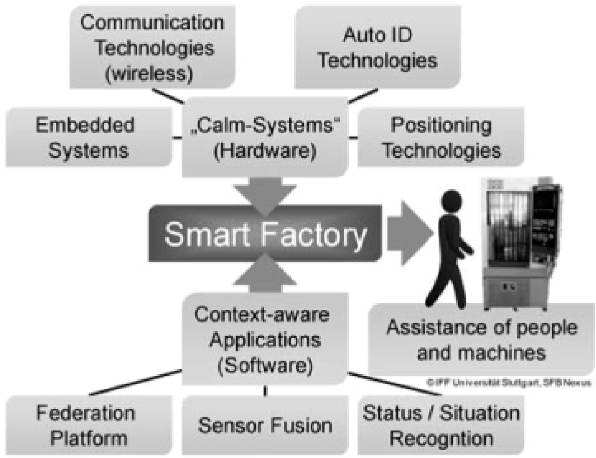

Figure 2.4: Smart factory technologies in [10].

They are connected with each other by network". Smart factory approach seeks to resolve current challenges in the market originated by globalization and highly customized products that along with short product life cycles causes the decrease of batch size and forces companies to increase flexibility in manufacturing. According to [10] current market solutions involve Enterprise Resource Planning (ERP), Manufacturing Execution Systems (MES) and applications to tackle the complex problems caused by continuous market changes and higher requirements in flexibility. These solutions do not offer satisfactory results because they imply the use of many different specialized software systems and any failure may impact the whole system. The Smart Factory system assists people and machines in the manufacturing tasks based on context-aware information on the factory. The position and status of tools through electronic sensors are examples of context information used by the SMART FACTORY approach. This information is delivered and used on different levels of the factory, such as shop floor and advanced manufacturing execution systems, to make the right decisions. The results given in [10] demonstrate that smart factory approach can handle continuous changes in production using decentralized information and structured communication for an optimal management of the production process.

As a brief summary, the monitoring system based on context-aware information optimizes the flow of data that is provided to the user, it enables the reduction of time consumption because of the use of only relevant information for the user.

In some of these systems the integration of mobile devices and internet network technologies play an important role in the scheme of the development.

2.2 Human - machine interaction

The interaction between the human and machine involves the use of devices that enable communication between them. These devices are based on different types of media, which serve as channel to transmit information from the system or machine to user and from user to machine, see Figure 2.5. According to Agah in [11], since the point of view of machines, transmitted information from machine to user requires the use of an output device, and in the other direction, the transmission of information from user to machines requires the use of an input device.

The human machine interaction in several domains takes into account the development of input and output peripheral devices performed in computer science. For instance, the conventional peripheral devices such as keyboard, mouse, screens, computer pens, track ball and other similar devices are used between human machine interaction.

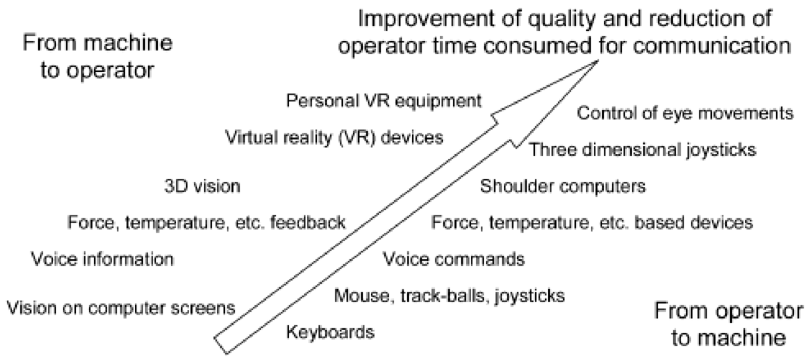

Figure 2.5: Human-machine interaction media in [12]

In the next paragraph, the main media used for human machine interaction are presented:

- **Visual display (machine to human)** is the most common medium of interaction between human and machine. This medium presents four possible types of visualization: real image, virtual image, combined image and data.
  - Real image displays a real environment to the user.
  - Virtual image displays a computer representation of the environment to the user.

  - Combined image displays a mixed representation of real and virtual image to the user, where usually the virtual image part represents a prediction of the real image part, in order to find the differences between them and calibrate the system.
  - Visual data represents information in graphical format in order to make it more understandable to the user.

- **Audio display (machine to human)** Medium that enables a system or machines the communication with users through sounds captured of the environment, virtual sounds created by computer or sounds that represent data or information.

- **Voice (human to machine)** Medium that enables the execution of commands by machines through the recognition of them in user´s voice.

- **Force (human to machine)** Medium that enables the system to perform recognized commands through forces applied by the user. For instance, the user controls a robot by manipulation of remote control that consist of buttons and levers.

- **Force feedback (machine to human)** System generates forces that represent performed task and are recognized by the user.

- **Body/head/hand/eye movements (human to machine)** Medium based on the tracking of body motions from the user. It is one of the promising communication methods due to the growth of tools that present reliable results. This thesis presents in more detail this medium of interaction man-system by hand gesture recognition of manufacturing systems.

2.3 Gestures

2.3.1 Definition and Classification of Gestures

Gestures are complementary elements of the human communication in many cultures, they enable social interaction and add valuable information to speech communication. The use of human gestures as way to interact with machines has become more popular due to the recent evolution of novel technologies and computer science. Indeed, as Karam points out in [13], researches in human gestures field which have gained most relevance are those based on the use of gestures through the interaction of humans and machines. Techniques of computer interaction through gestures have been originated from concepts of multidisciplinary research on human gesturing; involving areas like anthropology, cognitive science, linguistic and psychology. The definition of gestures, according to Mitra et al in [14] is "Gesture are expressive, meaningful body motions involving physical movements of the fingers, hands, arms, head, face or body with the intend of: 1) conveying meaningful information or 2) interacting with the environment".

Human gestures can be classified in two categories according to the parameter of bodily motion over a short time span. Static gestures are defined by fixed expressions that keep the state and location over a time span without any movements involved, while dynamic gestures refer to sequence of expressions connected by motions over a short time span. More types of gesture classifications have been attempted and these are related to physical characteristics of gestures within computer literature. Quek et al in [15] have proposed a framework for classifying gestures in computer interaction domain; this framework defines three approaches for gestures: manipulation, semaphores and gesture speech approach. An extension of Queck´s framework is proposed by Karam and Schraefel [13], where they include deictic and language gesture approach. In computer literature, there are many different terms to name similar motions or gestures referred in Queck and Karam works, for instance, according to Karam et al [13], gesticulations are also named pantomimes or natural gesture. For this reason, in this thesis is considered vital to follow a framework that clarifies terms for the styles of movements. Karam and Schraefel [13] categorize gesture types in five classes: deictic, manipulative, semaphore, gesticulation and language gestures, see Figure 2.6.

- ***Deictic gestures***, also called "pointing gestures" are defined to point at an entity of indicated spatial location of an object within a context. Deictic gesture is also implicit in other form of gestures where entity object is marked and then manipulated. The first example of this type of gesture is dated from 1980, which Bolt presents as "put that there" in [16]. Karam and Schraefel in [13] point out that deictic gesture is used to point at and identify objects in virtual reality applications.

- ***Manipulative gesture*** is defined by Quek in [15] as motion to control an entity by applying a tight relationship between gesturing object being controlled and actual movements. In addition, Quek indicates that manipulative gestures are presented in two and three dimensions on desktop applications. For example, mouse or stylus devices are used to manipulate an object in a two dimensional context, while mimic motions are used in three dimensional environment as virtual reality interfaces.

  According to Rubine in [17], one of the characteristics of the manipulative gestures is to provide parameters to the system that indicate the intent of the users request to move, relocate or physically alter the digital entity. Research presented by Bolt in [16] suggests that clicking or dragging an object is not considered a gesture; however, pointing at an object and then pointing at different location to move the object, it is.

- ***Semaphoric gestures*** are described metaphorically as gesturing system because it applies the same technique of a semaphore system to inform using flag, light signals. Semaphoric systems use stylized dictionary of static and dynamic gestures to communicate with machines. This is one of the most widely applied styles in the literature; even the concept of using signs or signals to communicate information has been a minuscule part of human interaction. Semaphoric gestures involve static poses like hand gesture, for instance; when the fist is held closed and the thumb is extended up, that means approval. Moreover, these gestures involve dynamic movements like waving motion using a hand to greet somebody. Finally, stroke motions have been part of semaphoric gestures, these motions are used for example to control back and forward commands in a web browser.

- ***Gesticulation gestures*** are the most natural gesture style , they are commonly used in combination with speech communication, this type of gesture has recently gained a great deal of attention in the literature and is currently considered a challenging area in gesture research. In contrast to semaphoric gesture, gesticulation gesture is not pre-recorded, it is based on computational analysis of expressions within the context of the topic of the speech.

- ***Language gesture*** is based on the linguistic domain where gesture refers to individual signs that combined grammatical structures, which are lexically complete. According to Zimmerman et al in [18] work in this area was originally based on static gestures such as finger spelling. However, during the last thirty years, more complex algorithms and methods have been developed and implemented to recognize complex words, concepts and structures of sentences.

Gestures makes part of human communication with the environment and their taxonomy and standardization by different disciplines gives multiple advantages for the continuous use in exigent domains, and beside, it helps to develop interactions more intuitive between humans and industrial systems.

Features of human gestures have to be sensed in order to recognize them through machines, characteristics such as movements (velocity), position (angle, rotation) have to be measured by input devices in order to categorize its style of movement.

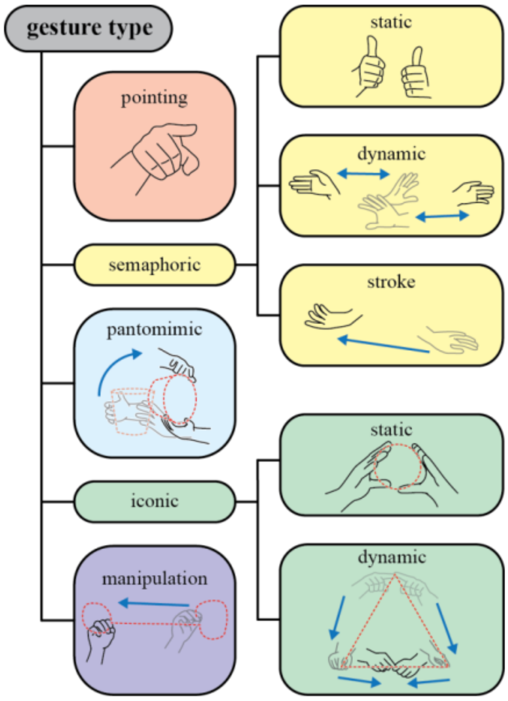

Figure 2.6: gestures classification in [19]

2.4 Recognition of Gestures - Input Devices

The recognition of hand gestures requires the use of input devices, these devices allow the capture of hand movements for the analysis by machines through the interaction between human and computers systems. According to Karam and Schraefel work [13], they present a classification of devices focused on the technology in terms of its ability to enable the gesture. This classification shows a general overview about the different styles of devices used in the past 40 years rather than exhaustive list of the possible technologies used for gesture based interactions. The classification of Karam suggests the distinction between perceptual and non perceptual inputs and further includes individual technologies in these categories.

2.4.1 Non-perceptual input

Non perceptual input involves peripheral devices that capture the gestures through physical contact, these technologies have been used for gesture input over the past 40 years.

2.4.1.1 Light Pen and Mouse

The light pen device was one of the first peripheral gesture-based devices for interaction with machines. This gadget shows the location of an object on the screen.

This tool performs with Sunderland´s sketchpad device that was used as a graphical communication system, see Figure 2.7. The mouse works through commands translated from gestures or strokes. This tool has become an alternative to direct manipulation devices in the interaction with the computers. According to Karam and Schraefel work [13], Pen and mouse are one of the oldest and most commonly used form of gestures reviewed in the literature. These devices perform simpler and faster to provide commands or actions to the human machine interface.

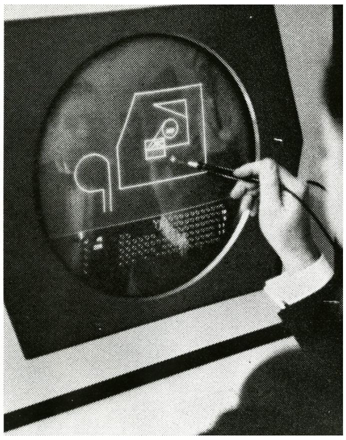

Figure 2.7: Sunderland's sketchpad in [20]

2.4.1.2 Touch and pressure input

The touch and pressure input is an optional form of interaction to the use of intermediated devices such as mouse or light pen, this input technology is direct and it enables a more natural style of interaction with the computer. The first applications of touch and pressure sensors were to mobile and tablet computer devices although these input sensors have a wide field of performing from desktop monitors to small mobile screens and large interactive surfaces. Gestures used in these devices have a similar performance compared to them which are naturally executed on surfaces.

2.4.1.3 Electronic sensing

- ***Wearable or body mounted*** The first methods in order to recognize hands, arms movements for interaction with machines involve electronic sensors. The magneto -electro sensor also called "polhemus sensor" is able to track objects through variables related to their space, position and orientation data. The use of this kind of sensor is not only a recent trend, polhemus sensor was and still is one of the primary devices used to sense object movements attached directly to the user. Current areas of application are adaptive technology and navigation for virtual environments, however their high cost and complexity in everyday operation impact negatively the overall performance. The integration of polhemus sensor with wireless technologies improve the capabilities despite they are attached to the user.

- ***Gloves*** The Z-gloves and Data-gloves were the first manufacturers referenced in literature. The Z-gloves allows individual movements, that are more flexible and accurate to fingers, wrist and hands than devices based on polhemus type sensor. These gloves made out of cotton and fitted with sensors allow to track finger bending, positioning and orientation, besides they give a tactile feedback through vibrate mechanism included. The use of these gloves in Zimmerman´s system involves virtual reality (VR) applications and manipulation of computer generated objects and interpretation of finger spelling. This device gained significant attention in gesture research in the 1990's due to the immersion with VR, autonomous agent control interface, telematic robotics and 3D graphic manipulations and navigations.

- ***Sensor embedded objects and tangible interfaces*** Sensoring embedded objects are another form of input gesture-device, these devices involve the manipulation of physical objects with sensors embedded in them. These devices are included in tangible or graspable interfaces. The manipulation of these objects is known as gesturing and their form of interface with the computer translate movements or manipulation into deictic, manipulative and semaphoric gestures.

- ***Tracking devices*** The use of infra-red tracking devices, as gesture transmitter, is another form of gesture-based interaction. The demonstration by worldbeat system in 1997 shows the transmission of gestures using infra-red batons to a tracking device to control a miniplayer. Camera tracks infra-red beam and its gestures, it translates movements to predetermined actions or behaviours. In addition, deeper researches in this area showed that pointing devices based on infra-red tracking, transfer data or control devices remotely in a smart environment. The interaction of this system requires the use of infra-red transmitters and receivers, and its performing is similar to the remote control. The use of the infra-red transmitter is also used in computer vision area and it will be described in the next sections.

2.4.1.4 Audio input

The audio sensor is an alternative of input compared with the pointing and selection gestures. Audio sensing is used in large public displays, and it detects the location of a knock or tap gestures. Although this form of sensing takes advantage of the audio perception of the computer, this is quite limited in the type of gesture detection. Another implementation of audio sensors is based on the registration of audio caused by finger and hand movements through a sensor attached to the wrist of the user. The user has a physical contact with the device in order to perform the gesture, for this reason it is categorized in non perceptual input although audio is inherent to perceptual input technology.

2.4.2 Perceptual input

Perceptual input involves peripheral devices that recognize gestures without any physical contact of the user with intermediate devices such as gloves or mouse, perceptual technology sensors are capable to measure data from the user such as physical location, actions or speech. This sensor can be visual, audio or motion sensors.

2.4.2.1 Computer vision

Computer vision for human gesture recognition is the major technological advance in human-machine interaction. Krueger´s system in [21] is one of the first applications that involved video to capture hand gestures for interaction with machines. The technique that is used in Krueger´s system mixes user image, obtained by a camera, and objects on the display and allow their contact or interaction. This technique is used by other system like FaceSpace system, this system interacts with the user through desktop screen, it receives gestures from the user and give feedback over top of the monitor display. The recognition of all gestures is based on computer vision and some common problem caused by lighting make more difficult to recognize some movements. The uses of led transmitters in combination with cameras increase the sensitivity, however, it does restrict the type of gestures that can be used for interactions.

2.4.2.2 Remote Sensors

Remote sensors enable to recognize body gestures using the transmission of the electric field to a ground and stationary receivers. This technology is applied to detect human presence and movements using full body movements tracking. In addition, the use of these sensors for the tracking of finger movements replace the use of the mouse instead of their placement on desktop screens.

Different input devices for recognition human gestures are collected in the Table 2.1, there were classified in two methods of used (Non-perceptual and Perceptual) based on the its physic's contact with the end user.

Input device	Non-perceptual	Perceptual
Light Pen and Mouse	x	-
Touch and pressure devices	x	-
Wearable or body mounted devices	x	-
Gloves	x	-
Sensor embedded objects and tangible interfaces	x	-
Infra-red Tracking devices	x	-
Audio input	x	-
Computer vision	-	x
Remote Sensors	-	x

Table 2.1: Input devices for recognition of gestures.

2.5 Commercial Solutions

The next section describes the commercial devices based on perceptual inputs, they recognize body and hand movements through the use of infra-red camera, sensors and powerfully algorithms.

2.5.1 Kinect Sensor

Kinect sensor is a perceptual gesture recognition device launched by Primesense that provides two input modalities for the interaction between human and machines: body gestures and sounds, see Figure 2.8. According to Tashev in [22], the evolution of this sensor enabled its use from entertainment to more exigent applications such as health care, physical therapy, educations among others.

Figure 2.8: Kinect device in [22]

The first toolbox for design and integration of Kinect sensor to human machine applications is KDK, which includes drivers, tools, IU's and code samples, moreover, algorithms to recognize body, facial gestures and voice. Through the KDK the user can have access to raw data from cameras and microphones, it allows to the user to process audio, speech and images in order to track and recognize gestures of bodies and facial in order to track its location.

The Kinect sensor's hardware is based on depth sensor, color VGA video camera and multi-array microphones; according to [23], its performance measuring the depth is based on a process of triangulation, where infra-red sparkle points are projected into the scene creating a pattern, this pattern is captured by a depth camera and correlated versus a reference model.

Accuracy analysis performed in [23] indicates the random error depends of the distance of the measured object with the sensor, if the distance raise, the error also raise and it arrives at maximum of 4 cm, see Figure 2.9.

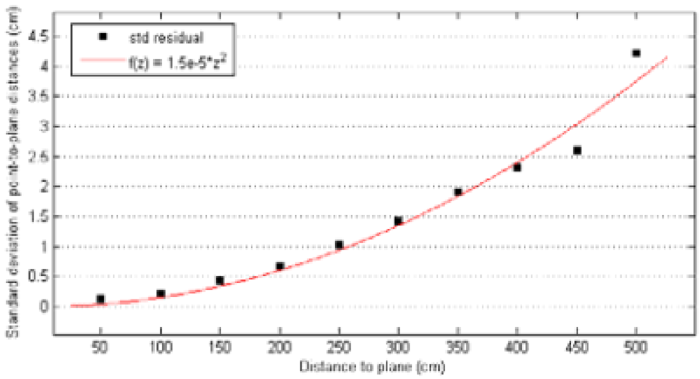

Figure 2.9: Standard desviation of plane at different distances by Kinect sensor in [23]

2.5.2 Leap Motion Controller

Leap motion controller sensor is a perceptual input device released by Leap motion Inc, see Figure 2.10. It tracks from the user movements of hands, fingers and tools held in user's hands and also recognize predetermined gestures.

Figure 2.10: Leap Motion Controller device in [24]

This device contents a simple hardware based on two cameras and three infra-red LEDs that creates a projected work environment characterized by a field of interaction of 150 grades and a maximum distance of 1 meter. The potential of this device is related more with the algorithms to capture the movements than hardware components. This tool provides an API for different platforms that enables the user to create and design interfaces for interaction.

2.5.2.1 Precision of the Leap Motion

Leap motion is a gesture-based sensor which captures the position in Cartesian spaces of predefined objects like fingers, hands and pen. The evaluation of this sensor in terms of accuracy, repeatability and robustness is vital to determine the suitability for a possible replacement of professional devices in industrial environments. Even though the first focus of application of the leap motion controller was entertainment applications, its characteristics such as sub-millimetre accuracy, small size free space and low price make attractive its use in other areas.

In the literature two evaluations that analyse the accuracy and repeatability of the LMC were found that were done by Weichert [2] and Guna [3]. They use two different methods based on two different reference systems such as optical and mechanical set-up. Guna evaluates in [3] the consistence and accuracy of the LMC using as reference system a high precision optical tracking system Qualysis. This system consist of eight oqus 3+ high speed cameras and track manager software. The regular use is in industrial, bio-mechanics, media and entertainment applications, due to fast and precise tracking. In Guna´s evaluation two scenarios of measurement were defined. The first scenario consisted in the measurement of 37 stationary points in space for a long period of time. Guna concludes from the static measurements that the LMC has a high accuracy in the space of work just above sensor and lost this property at the leftmost and rightmost positions. In addition, along the x plane the accuracy of the controller is higher compared to y- and z- plane, and finally the variation of the accuracy change significantly depending on the distance of the measurement and azimuth angle. The measured points were chosen systematically into the controller sensory space and market through a passive reflexive maker and the reference system and controller system tracked the object simultaneously. The second scenario was based on tracking a distance between two marker points defined through of tool with V-shape. These points were moving freely around the controller sensor space. Guna notices that Leap motion is less accurate for dynamic than static tracking, therefore the accuracy vary significantly at different position space in static measurement. In addition, the leap controller lost accuracy when the object tracked is placed on distances higher than 250 mm above the controller.

The analysis concluded that consistence and accuracy of leap motion is spatially dependent, it determines that LMC is a limited device for systems which demand precise tracking. Furthermore, the area of the controller which gives high accuracy is relatively modest however these shortcomings do not make unsuitable the LMC as an alternative interaction device.

Wheichert in [2] presents another analysis of the Leap controller. In order to obtain its accuracy and robustness, Wheichert uses a novel mechanical reference system based on an industrial robot that provides a repeatable accuracy of less than

0,2 mm. This accuracy margin is due to the fact that Wheichert accounted on the involuntary movements of human muscles known as tremor.

The measurement set up consisted of LMC and an industrial robot, it measured simultaneously the position of a pen tip attached to the robot. The LMC is placed on the plane in range of the robot TCP and the static world coordinate system of both systems were linked through the pen tip point. The measurements were preformed through two scenarios like Guna analysis, static and dynamic, in these scenarios pen tip is moving into a regular grid of a plane (xy-, xz-, yz plane) through a discrete positions on a path. The speed of the robot was reduced to a minimum in order to avoid mechanical oscillation, as well as the ambient conditions such as temperature and lighting were constant in values like 23 grades of Celsius and 250 lumens in order to avoid numerical deviation. The evaluation was based on 5000 measurements of LMC, which gives results of the accuracy for instance in static scenario less than 0,2 mm and appreciating the higher accuracy in X axe, see Figure 2.11.

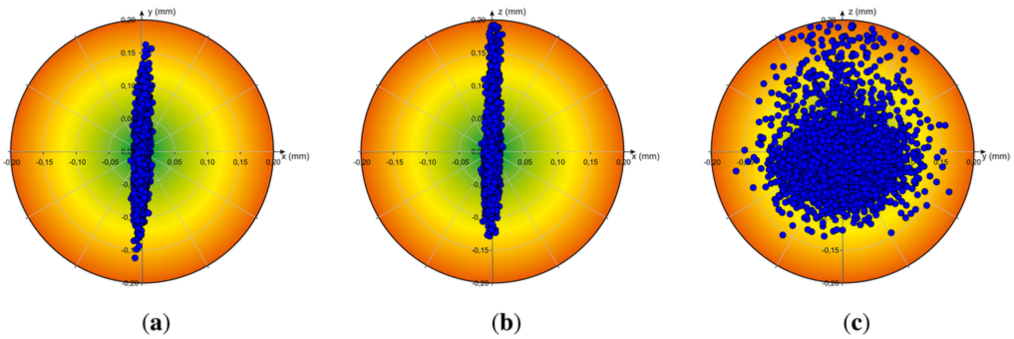

Figure 2.11: Deviation between a desired 3D position and the measured positions for a static position, (a)xy-Variation, (b)xz-Variation (c)yz-Variation in [2]

Wheichert concludes that the position of the tracked object has a direct influence on the quality of the gesture recognition. Furthermore, in the evaluation different radios of pen tip were attached in order to analyse the leverage of the size however the results conclude the non observable influence in this case. Wheichert affirms that the theoretical accuracy was not achieved in real conditions but the results are prominent compared to similar controllers in range of price like microsoft Kinect.

2.5.2.2 Applications in different domain using Leap motion controller

The leap motion controller presents important enhancements within the gesture recognition area due to its features; such as small size, high performance and low price, that make it a suitable tool for the industrial domain. In this section three implementations of the LMC in different domains such as healthcare, sign communication and care service delivery fields will be presented.

- **Visualisation healthcare information**

  The contamination of tools, patients and environment is an usual challenge in the medical domain. Contamination is frequently produced by physical contact between healthcare personnel and contaminated surfaces. A scenario in which contamination could take place is a surgery, where medical staff interacts with patients and monitors to visualize information relative to patient. This interaction between personnel and equipment is usual through touch screens and peripheral devices such as mouse, joystick and keyboard. According to [24] the use of leap motion controller provides a potential solution to deal with this issue because it allows the interaction and manipulation between human and machine without any physical contact. One of the most important tasks reported in [24] is the integration of gesture sensor as leap motion controller with the medical image processing application called "OsiriX", see Figure 2.12. This integration was successfully achieved due to two fundamental features: open source license in both systems and low requirements in programming to work with gesture sensor.

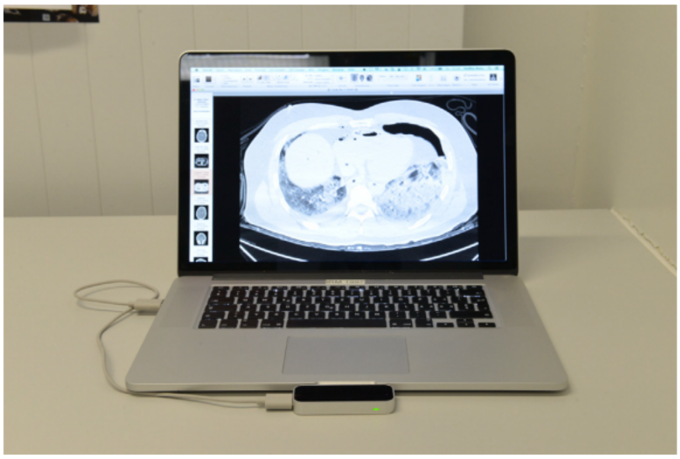

Figure 2.12: Original image of Visualization of Healthcare Information in [24].

  The association of the leap motion controller with the application OsiriX allows browsing over different images and studies of patients. For browsing through these data, different hand gestures were implemented. Swipe gesture was used to change between several documents of the same patient and, zooming was achieved through moving open right hand away or toward the sensor.

- **Recognition of sign language**

  Communication is vital for human beings because it helps to know, feel, meet, orient and express feelings. Besides, communication facilitates relating with other people and understanding their ideas and feelings. In order to avoid the exclusion of hearing impaired people in the society, it's necessary to apply technologies that make easier the interaction between hearing impaired people and those who do not know sign language.

LMC is also seen as a tool for sign language communication, according to [25], this sensor is a reliable option to facilitate communication with hearing impaired people. In contrast to current approaches as sensor-based systems, the use of leap motion controller does not require the use of complex electronic gloves that make sluggish and unnatural the interaction. In addition, the environment conditions given through the use of leap controller are more lenient than image based system approach.

The solution described in [25] is focused in Arabic sing language recognition by hand and finger tracking through the use of leap motion controller. The approach has been developed to recognize twenty-eight Arabic alphabet signs, see Figure 2.13; these are static gestures and performed by a single hand. Twelve of twenty-three features given by LMC were vital to perform the application and include finger length, finger width, average tip position with respect to x, y and z-axis, hand sphere radius, palm position with respect to x, y and z-axis, hand pitch, hand roll, hand yaw.

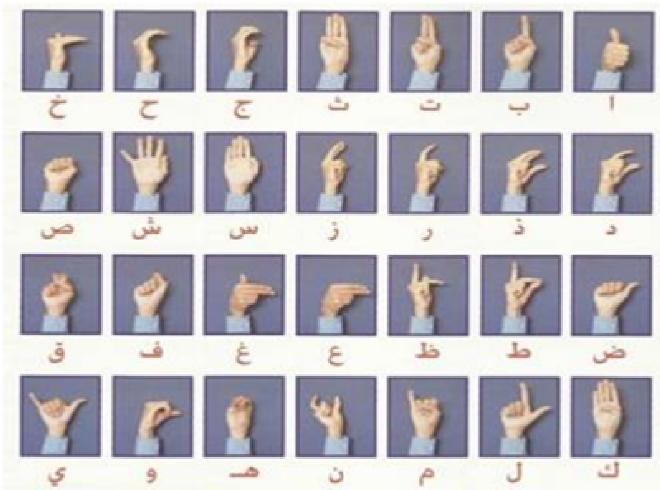

Figure 2.13: Gestures recognized from Arabic alphabet signs in [25].

The right definition of each sign gesture required the analysis of ten samples of each one. This definition is based on the mean value obtained from relevant characteristics given by LMC. It is due to the variation on the recognition of same letter performance by different user. In addition, other important part in the approach was the classification of these characteristics in signs using two different performances, Nave Bayes Classifier (NBC) and multilayer perceptron neural networks (MLP). According to [25], in contrast to Nave

Bayes classifier, the use of MLP performance presents an accuracy of 99.1 percent. This improves in 0.08 percent NBC purpose.

- **Enhancement of ageing and impaired people surroundings**

  The average age of the European people is raising, Bassily and et al [26] says, "Statistics predict that by 2035, half of the population in Germany is going to be older than fifty, every third person even over 60". This data forecasts many problems caused by the ageing of the population such as lack of independence for elderly people in performing daily living activities and low rate of young people to work. For these reasons, researchers in many fields have been searching for solutions through disruptive technologies like the use of robot arms. The use of robot arm technology has the objective of assisting elderly people in performing activities in familiar surroundings and also collaborating with handicapped people to execute a task. The handling of robot technologies through peripheral control devices like joystick; sometimes presents difficulties in the usability, due to the presence of numerous buttons and required control of the order of each step. LMC plays an important role to tackle this complexity; since it allows the control of the robot technology by a method more suitable to human communication.

  The application is based mainly on three fundamental hardware components as leap controller, Jaco arm robot and Arduino Uno microcontroller. Their complete integration allows interaction with more components such as sensor and actuators in order to make the application more robust. The coordinate system of robot arm and leap motion are not the same. One relevant achievement accomplished in this case was changing the rotation of both coordinate systems in order to synchronize them. In addition, the use of leap motion to control robot arms technology by elderly people could present drawbacks due to diseases like Parkinson. However, the solution described in [26] has implemented a filter in the algorithm to avoid undesirable movements originated by tremor of hands. This application presents different kickoff scenarios such as the bedroom terminal, where the main objective is the assistance to elderly people by providing the right medication at the right time, it avoids common problems related to mixed up medication, see Figure 2.14. Another case is the kitchen terminal scenario where the system allows the user to have help in preparing the raw material and utensils to cook.

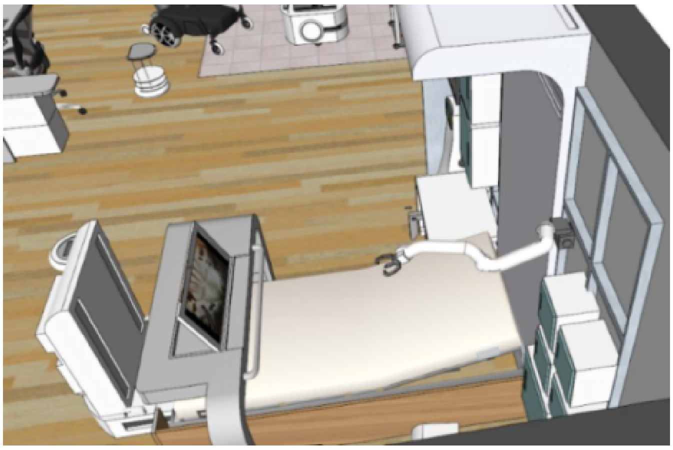

Figure 2.14: Example of bedroom Terminal in [26].

As a brief summary, the gaming industry has been a substantial influence in the transformation of peripheral devices by offering a new trend with the arrival of gadgets that allow an interaction human- machines without physical contact. Several options can be found in the market such as Microsoft Kinect and LMC, each one with interesting technical features and reasonable prices. This thesis focuses on hand gesture sensor called LMC because its high accuracy, size and easy integration make it an attractive tool for future solution in the industrial domain. In addition, the feasible use of LMC in different domain, such as entertainment, is demonstrated in three applications that solve problems in different fields.

3. METHODOLOGY

This chapter describes the proposed architecture system for the integration of the LMC device in a manufacturing and novel monitoring system, moreover, here is depicted the followed steps to understand the performance of each technology involved in the process.

3.1 Proposed architecture system

The integration of the LMC peripheral device into a manufacturing environment involves the use of different technologies that provide services between themselves keeping hierarchical relations in various levels.

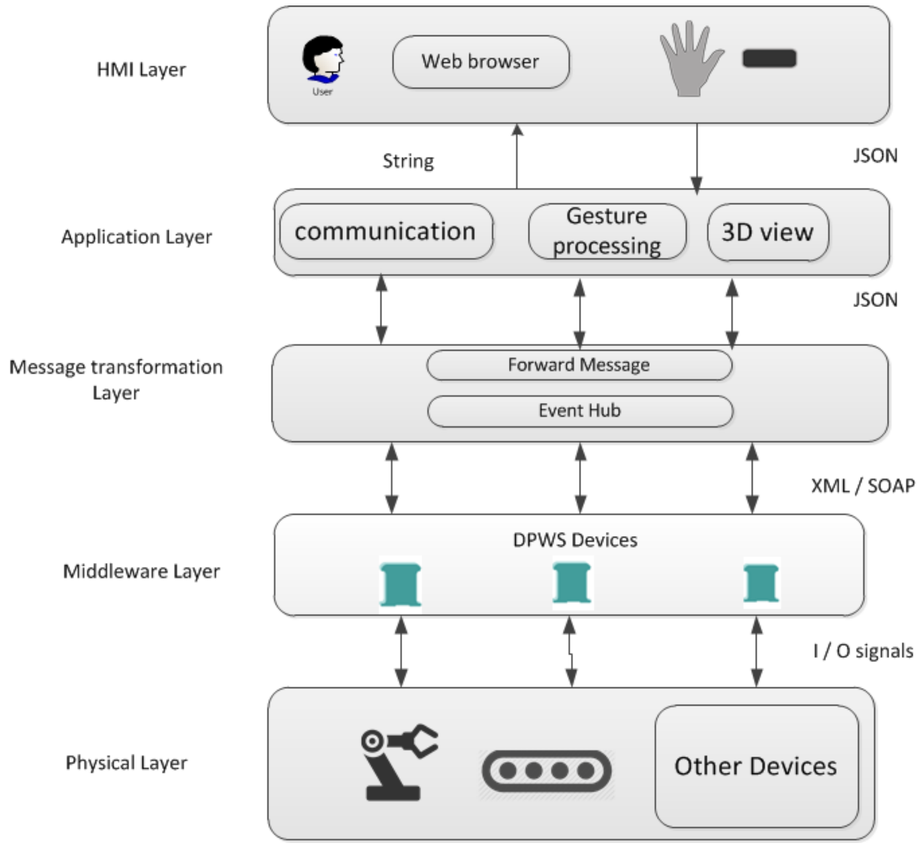

Figure 3.1: Layered architecture of proposed system

The proposed architecture is presented in Figure 3.1, it represents the flow data interaction between the technologies which are involved in the LMC integration, it keeps a layer approach structure. This architecture consists of five layers:

- ***Physical layer:*** It contents the shop floor devices placed on the manufacturing system such as robot, conveyor, buttons.
- ***Middleware layer:*** It contents the smart remote terminal units that gather the events occurred on the shop floor and report them to a high level layer through XML/SOAP messages.
- ***Message transformation layer:*** It includes a software application that convert the events from XML to JSON format and forward these to higher level applications.
- ***Application layer:*** It contents the modules that process the information occurred in the shop floor and analyse the data tracked by LMC device, moreover, it enables to connect process and users through WAN and LAN networks.
- ***HMI layer:*** It enables the end user to visualize and interact with the manufacturing process via web browser and gesture-based peripheral device.

3.2 Followed approach

The integration of a developed monitoring system with other novel technologies is part of the achievements to accomplish in this thesis. For this reason, the first step from the followed methodology is based on understand how this system works and what contribution is giving into the final solution.

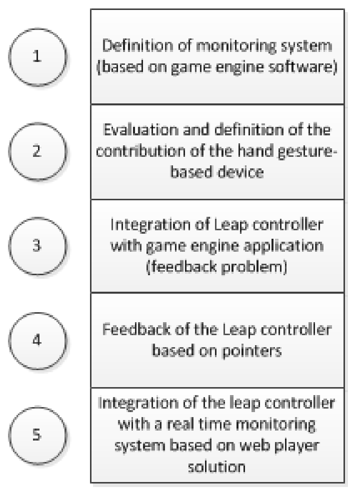

Figure 3.2: Followed approach

Other achievement in this thesis is related to the integration of a novel technology based on hand gestures recognition with the defined monitoring system. As a second followed step, it supposes to realize an analysis about the currently use of this kind of device in order to find the contribution of this technology in the final solution. In addition, the third step followed is the integration of both technologies, monitoring system and hand gesture-based. The fourth step included to search a solution which gives an human-machine interaction more friendly due to the results obtained in the previous integration. As the final followed step, the addition of the novel hand gesture-based technology into the system that receives real-time data from manufacturing process was achieved.

3.2.1 Definition of the monitoring system

The objective of the 3D monitoring systems is to provide enhanced information of the supervised process. The 3D monitoring systems contribute with more realistic graphics than 2D monitoring system like supervisory control and data acquisition (SCADA). It allows to recognize needs and detect problems easily in the monitored process. The traditional 3D monitoring systems are based in two techniques, Java3D and video cameras systems. According to [4], these techniques increase the complexity of the systems and reduce the flexibility and modularity of them. The video monitoring systems are based on supervising the process through cameras. In a common production line, this technique requires a high bandwidth consumption because of the quantity of data demanded to transfer the images from cameras. It causes problems to access and visualize the process and also the quality of image is not reliable.

The thesis presented in [4] proposes a new approach for 3D real time monitoring based on a game engine. The author explains that game engine technology offers remarkable features which may be applied in 3D monitoring systems such as rendering engine for 3D graphics, the use of physics engine to simulate physics laws, scripting, animate, communication, sound and releasing to several platforms. Moreover, according to the author in [4], game engine technology is so powerful that its applicability field should not be restricted only to video game industry.

An advantage of this approach is the new use given to 3D models of machines, there were used previously on design phase, because in manufacturing environment objects such as robot, cell, conveyor or pallet models, could be reused to simulate performing tasks on the monitoring system. In [4] is presented a 3D real time monitoring system based on game engine software like unity3D. This system supervises a manufacturing line located in FAST laboratory at TUT composed by ten robot cells interconnected between them by conveyors. Currently, the unity3D is one of the most powerful game engine oriented in 3D graphics, this platform offer vast features mentioned previously and related with game engine technology.

3.2.1.1 Unity3D

Unity3D is a game engine software, which main purpose is to give a vast number of tools to create and interact with 3D virtual environments. This technology enables to represent each component or asset in 3 dimensions and manipulate them. Unity3D works based on scenes, where the elements placed there follow certain behaviours traced through scripts. The scripts may be written in two different languages CSharp and JavaScript.

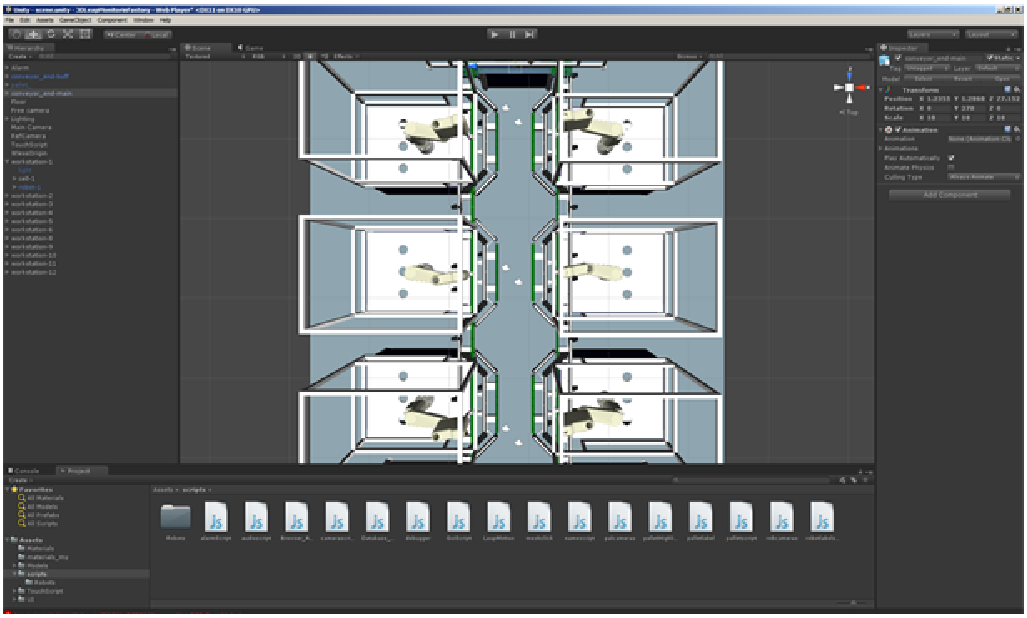

Figure 3.3: Unity 3D

Unity works under different licenses (depending on their rights) and provides the user with the option to create applications for different platforms. For instance, Unity basic and Pro license enable publish application in Web player such as windows and Mac OSX. Furthermore, there are licenses addressed to mobile devices such as IOS, IOS Pro, Android and Android Pro licenses. Also, licenses to publish for consoles are offered.

In the next list there are presented the strength characteristics that made unity3D more attractive to be considered as an option to create applications for monitoring systems in the industrial domain.

- It allows to create graphic animations to different platforms using only an editor and scripts.
- It allows to develop on-line games that enable the exchange of data with external devices and applications.
- It allows to develop applications for mobile devices.

- The intuitive layout makes it easy to create and develop the application.
- The extensive on-line support and complete documentation.

Once the advantages of using the game engine technology on the development of 3D monitoring system were reviewed, the next phase was to understand how the platform works. Unity technologies provides extensive documentation and tutorials to help users to understand the Unity 3D's operation. For that reason, in this thesis the explanation related with this software will be focused in particular points which mark the future integration of unity with new technologies.

3.2.1.2 Building robot scene through the unity editor

As it was briefly described earlier, the FASTory is a manufacturing line composed by 10 robot cells interconnected between them through conveyors. Each robot cell accomplishes a particular assembly task. In this part, it will be described how to build up the robot scene and revised the basic operational principles of the Unity 3D.

The use of unity as a tool to develop manufacturing applications require accomplish certain steps that involves 3D model representation, animation and communication. According with [4], the first step is the import of 3D models that represent the manufacturing equipment and devices. In the FASTory line, the initial models are designed in CAD format and these are not recognized by Unity3D. However, Garcia explains in his thesis [4] the process followed to convert CAD files on the format that works in the unity editor. At this process, it must also be taken in consideration the use of intermediate software called Blender.

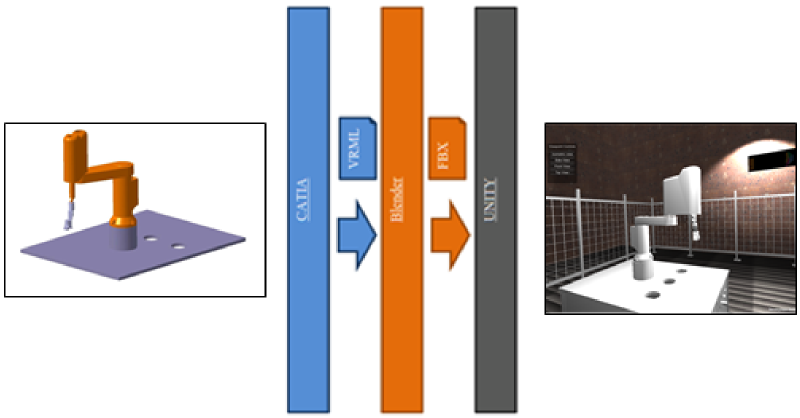

Figure 3.4: Conversion of the format of the 3D model

The unity project is based on the creation of scenes, which in turn are based on the importation of assets. An example of assets are the 3D models imported to unity. These 3D models are added to the scene clicking and dragging them from the project view to the hierarchical or view scene. The 3D models are part of the scene as game object elements and they are placed there according to the real manufacturing arrangement. The game object is the key element of unity and according to [4], "Game object includes a vital component called Transform which enable to set the position, rotation and scale of every object in the 3D space". Once the game objects are placed on the scene, these can simulate real movements or behaviour through the use of scripts. For example, each arm of the 3D model that make part of the robot in the workstation at Fastory is represented by game objects and its behaviours are described through scripts written in JavaScript language.

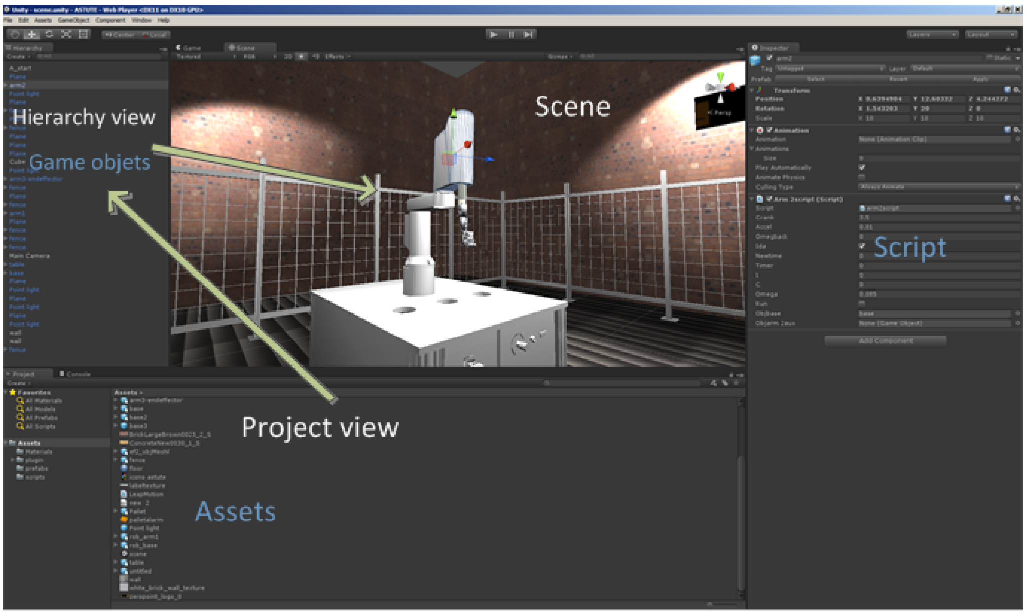

Figure 3.5: Description Unity editor

3.2.2 Evaluation and definition of the contribution of the hand gesture-based device

The familiarity acquired by the users through years of use of intermediate devices to interact with machines, presents an apparent limitation with the emergence of new displaying technology. That is why, according to [27], in recent years it has been a tremendous push in research toward novel devices and techniques that will address this human computer interaction choke-point. However, for more than 40 years, the industry sector has not been interested to apply the results obtained by researches into commercial systems. According to [28], the situation is changing due to the great incursion of gesture-based devices along with the fact that the sale of these products have marked a step forward for the use of a commercial gesture interface. Microsoft company plays a huge role about the interest gained by the industry in the gesture-based technology due to the eight millions of kinect devices sold in the first two months they were available. In addition, the novel gesture-based device called Leap motion, which despite of its size and simple shape presents better performance in accuracy and robustness than microsoft kinect and similar technology existed.

The new devices such as leap motion offers to the users new experiences of interaction with machines and new thoughts proves this, as said by the leap motion's vice-president in [28] "People are carrying around technology wherever they go".

In the next list there are presented the strength characteristics that made LMC more attractive option for integrating this device with applications in the industrial domain.

- Its high accuracy in tracking hand movements.
- Its wide option of development platforms provided by API.
- It enables an easy integration with other systems because of its open source license.
- Its small size.
- Its low cost.

3.2.3 Integration of the Leap Motion Controller with game engine application

This section explains the steps that are needed to make a unity application that interact with leap motion controller. Basically, the started kit of the leap motion for unity was the guide followed to understand and develop all the procedure needed. This guide enables to the user or developer to learn how to create behaviours in an application and interact with the leap controller data via game objects in Unity3D using instructive examples.

The user should complete preliminary tasks based on software requirements to run unity3D and leap motion technologies. This requirements involves download the SDK for leap motion related to the version demanded; in this thesis for example, the SDK used was for windows (x64) and the unity 3D desktop for student version. Once Leap controller is connected physically and all the drivers are installed for the version required, the calibration of the sensor required and explained in the Leap motion platform documentation should be performed.

The objective of the first application developed in this thesis, besides learning about both technologies, was to create the first interaction with a virtual reality scene in a manufacturing environment. For this reason, the chosen scenario was the robot cell from FASTory line, where through the use of the leap motion is enable the navigation inside the scene based on two hands gestures, these were a two open hands and a two close fists. This scene has analogy with flying scene from the started kit, see Figure 3.6, which enables to immerse in a cityspace environment and fly there based on the same gestures.

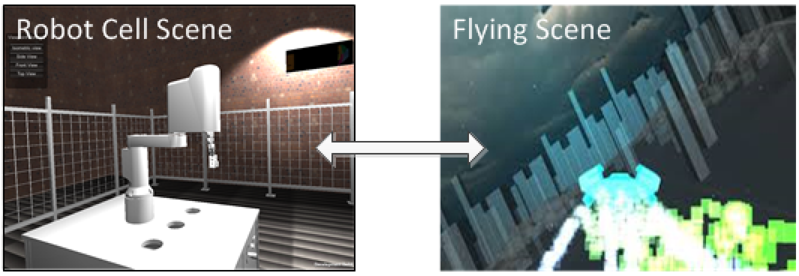

Figure 3.6: First analogical scene

Before explaining the connection of all components that are required to integrate the leap motion device with unity3D, it is necessary to define the functionalities of several classes involved in the project. One of these is the Leap Hand Controller class, which assigns all the data related to hand and finger movements to the appropriate unity hand element of the scene, also this controller hold hand settings for the unity Hand.

The unity Hand class represents a virtual hand through a game object, it contents the absolute position/rotation of hand and fingers in the unity world. Through Unity Hand class the user finger's are detected and assigned to the respective game object into the unity scene. The hand type class holds and updates the data tracked and collected by leap device with the game objects associated, see Figure 3.7.

The animation on the unity scene is performed by the Leap Fly class, where, once the leap controller is instantiated, it waits for a gesture, that in this particular case, is defined by the appearance of two hands in the zone of tracking of the leap motion controller. The user starts to fly in forward direction through a two open hands gesture and in backward direction when the number of fingers in the user hands is less than three fingers, making a fist, see Figure 3.8.

Once the scene was built with all the 3D models that presents a real robot cell workstation from Fastory line; the setting up of the unity 3D and leap motion connection require to stablish the communication between a virtual hand in unity scene and leap hand, this connection push all the data frame about the movements of user's hands tracked by LMC, in order to achieve this, the game object called "Leap controller multiple" combine two class elements, Leap Hand controller and Unity Hand classes. In addition, the Hand Type Multiple class is added as child of each unity hand elements (right and left hands) to represent the different hand states which may be in.

Other game object which take place in the unity scene is flight animation, it

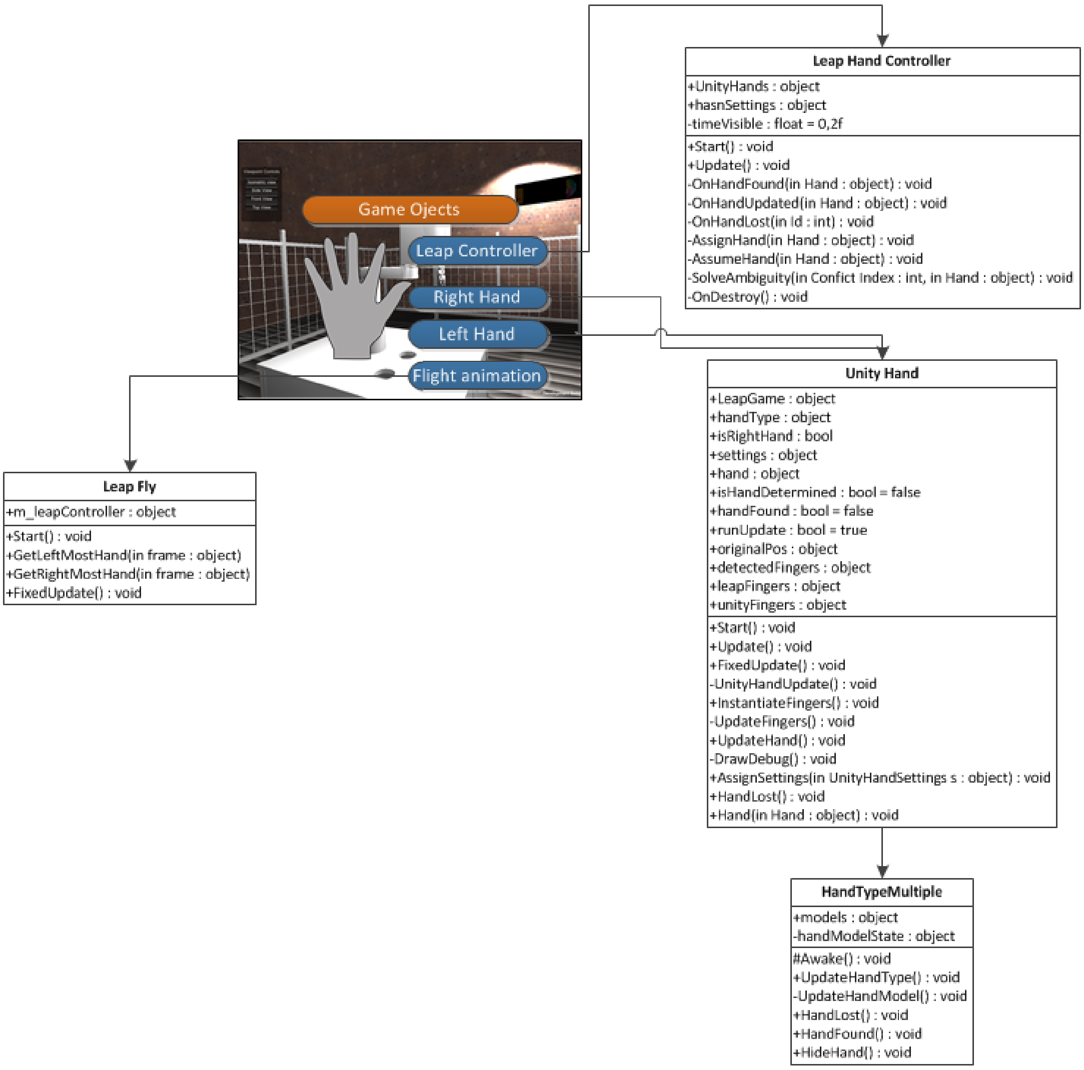

Figure 3.7: Elements of Tekes application

contents the Leap Fly class, which determines the flight behaviour. The main camera of the scene is attached to flight animation game object with the objective of giving a first person interaction view during the navigation.

The initial positions of the right and left hand game objects must have relation with the position of the main camera, it is important in order to have control and a first person interaction during the scene.

3.2.4 Feedback of the leap controller based on pointers

The previous step through the creation of the Tekes application introduce to the user in the integration between LMC and Unity3D, also it provides an interaction via leap motion device with an unity application. However, this application does not give any graphical representation such as feedback to the user and it causes sometimes lack of control related to the scene. In order to solve this problem, a new

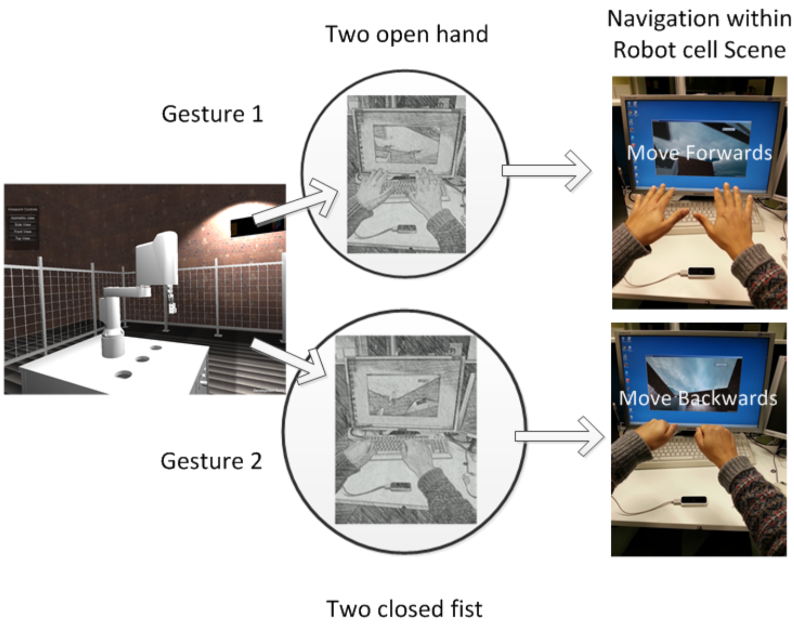

Figure 3.8: Tekes gesture-based application

scene was added, it involves virtual pointers which correspond to the finger positions of the user.

The second application developed in this thesis is the Astute gesture-based application. It links two scenes that allow different gestures in the interaction between the user through LMC and the unity3D application. The creation of several visualizations and interactions into an application is possible due to the option given by unity3D technology to create more than one scene and link them, see Figure 3.9.

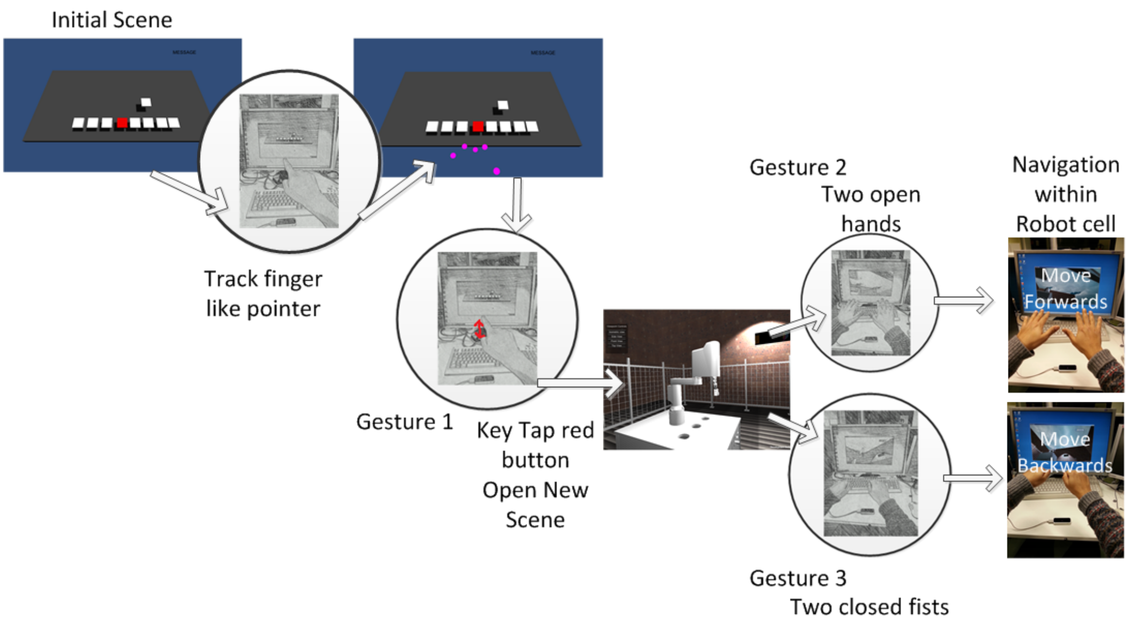

Figure 3.9: Astute gesture-based application

The initial scene represents a keyboard based on several virtual buttons; the interaction with the buttons is through a key tap gesture and it combines the continuous representation of the fingers by pointers and the virtual collision with the button. This application has analogy with Leap DJ scene example, see Figure 3.10, which enables to interact with a music mix board using virtual touch with buttons and slide bars. The first scene is linked with a second application through the gesture of key tap a button, the second scene is based on the tekes application explained in the previous section.

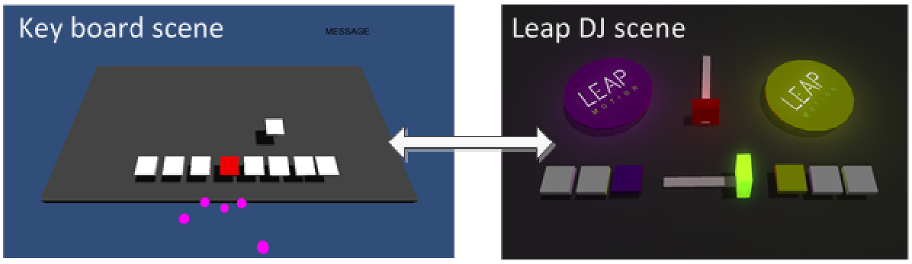

Figure 3.10: Second analogical scene

The initial view of the astute application may connects and shows the data tracked by the leap hand through the attachment of the Leap unity bridge class via game object in the scene. Moreover, it updates movements from user's fingers and shows them adding fingertips objects through a simple class called Leap finger collision dispatcher into the scene. The virtual interaction between the user and the buttons is defined by Leap button region class, which linked with leap button class and another behaviours classes such as rigidbody, boxcollider and mesh renderer enables to recreate the real action of pressing down the button. Each button added in the scene may attach Leap button region class, leap button class and the previous behaviours classes explained via game objects.

3.2.5 Integration of the leap controller with a real time monitoring system

Once the connection between Unity3d platform and LMC is done and the user has updated feedback from his owm hand movements into the application, the next step in this thesis is the integration of LMC with the Fastory monitoring application. This application is hosted in the Esonia server in TUT. To achieve the integration it is necessary to define how the current architecture of the whole manufacturing system is included with the monitoring application.

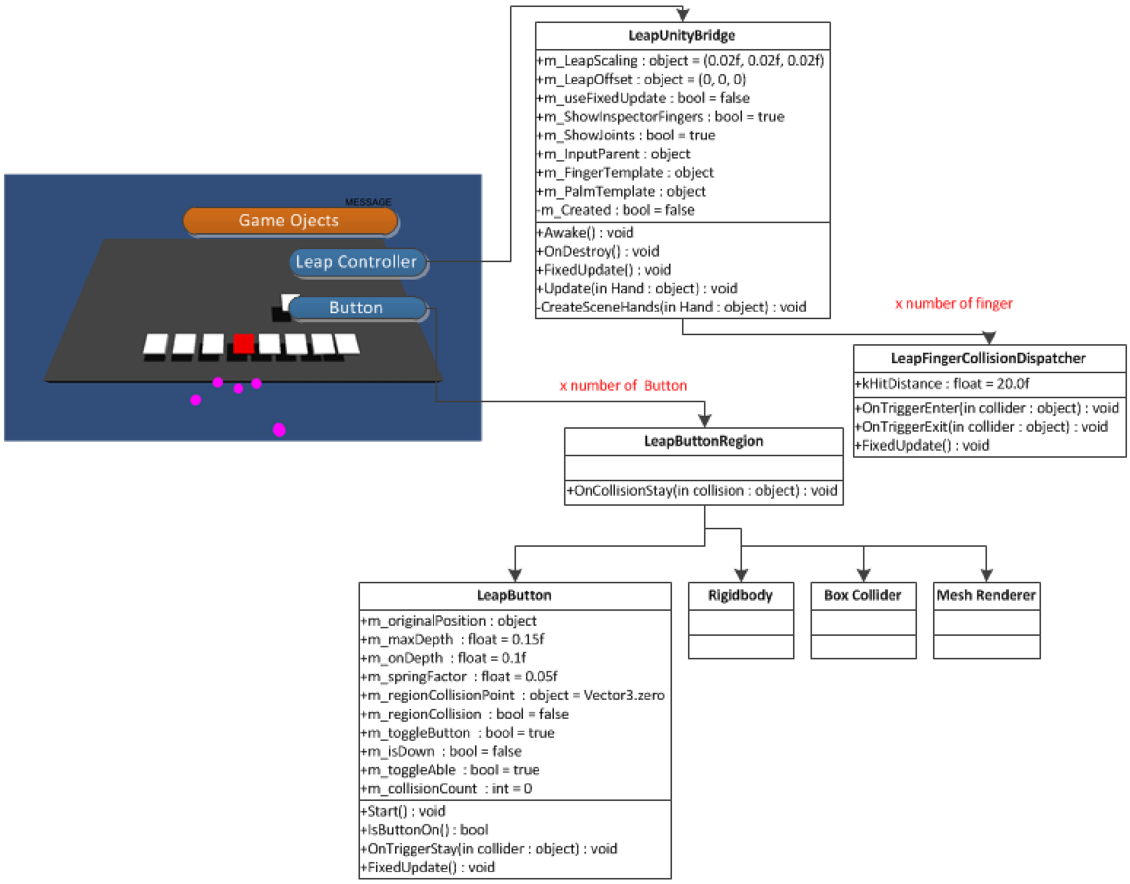

Figure 3.11: UML class elements of astute gesture-based application

3.2.5.1 Description of testbed

The testbed called FASTory is a manufacturing line that produces draws of mobile phones. It is used for educational research at Fast laboratory. The Fastory line forms a rectangular closed loop shape using eleven robot cells or workstations interconnected between them through conveyors. Each workstation realizes a particular drawing operation and the final product is result of the work of several workstations. In case of one product,there is no need to be draw by a particular workstation, the product passes through a second conveyor called "bypass", which divert the traffic of the pallets. Each workstation at FASTory contains a scara robot that draws a part of particular model mobile phone.

Each produced model has particular characteristics based on the colour of frame, screen and keyboard and it implies the presentation of many scenarios that increase the complexity of the process in order to obtain a more customizable result. According to Gonzalez in [29], the original purpose of the FASTory was to assemble parts of mobile phones instead of drawing these parts; the change of the functionality does not cause large modifications in the hardware employed originally. In fact, some hardware such as conveyors and robots work in similar manner than the original

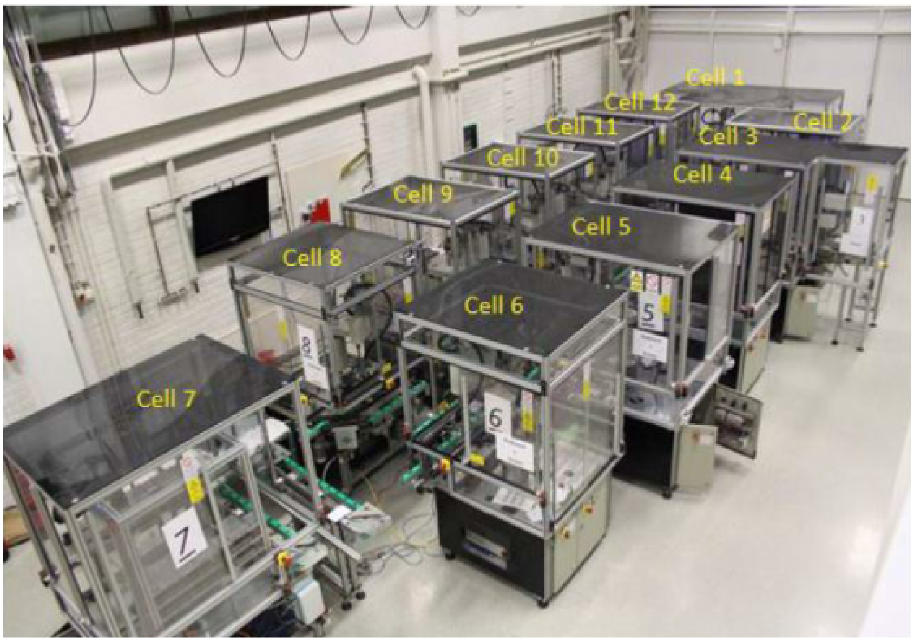

Figure 3.12: Fastory in [30]

purpose. However, the replacement of the traditional central controllers (OMRON PLC) by smart RTU retrofitted the architecture of fastory line to distribute control structure, see Figure 3.12.

The smart RTU used in FASTory is the S1000 from Inico tech. Its use in the FASTory process aims to transform the system communication from hierarchical layout that involves different layers to a decentralize layout constituted by just one layer. This device is defined by Minor in [31] as "a compact controller device with a DPWS communication stack ". The smart RTU device recognizes an IEC 61131-3 standard programming language such as Structured Text (ST), and enables to publish events through WS-Eventing push mode. Furthermore, this device communicates through high level applications such as web service messaging and use the RS232 serial communication port and digital I/O to physical connection with robot Scara in fastory line.

3.2.5.2 Data flow in the monitoring application through Event-driven paradigm

The events produced in FASTory are reported by the monitoring application hosted at Esonia server. These events are represented by animations of 3D models there. These representations show for example the robot performance in a particular workstation or supervise the travel sequence of a particular pallet through the manufacturing line. When a robot starts an action, the event is reported by the smart RTU attached to it. The RTU device sends to Fastory server a XML message via fastory

LAN network that inform the activity and the location occurred; then the Fastory server forwards this event in JSON message format to an end point such as the fastory monitoring application via WAN network. In the monitoring application, the events received in JSON format are translated to string format in order to be understood by the scripts attached in Unity3D platform to the game objects of the scene that represents the manufacturing line, see Figure 3.13.

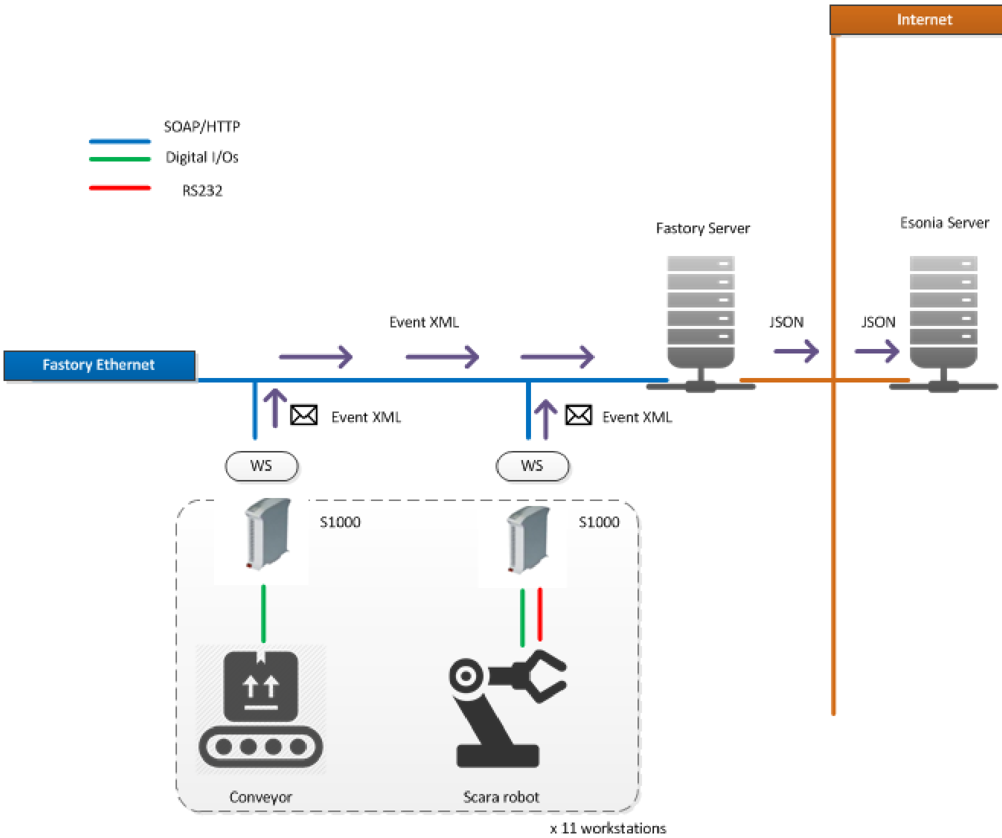

Figure 3.13: Data flow of events in the monitoring application

- **XML/SOAP message**

  The smart RTU device use a message extensible mark-up language, in short XML, to send data to the Fastory server via Ethernet LAN through SOAP protocol. This message's format represent the data in semi-structured and self-described form. According to Delamer in [32], "It was designed to overcome the shortcomings of other existing data formats by employing technologies that had been instrumental in the success of the World Wide Web".

  The monitoring application receives messages of events occurred in the manufacturing line by de S1000 device. These messages keep the SOAP standard and contains information of actions such as the robot calibration performance or pallet location, see Figure 3.14. To receive these events by the monitoring

XML Message

```
<?xml version="1.0" encoding="UTF-8"?>
<s12:Envelope
  xmlns:s12="http://www.w3.org/2003/05/soap-envelope"
  xmlns:wsa="http://schemas.xmlsoap.org/ws/2004/08/addressing">
<s12:Header>
<s12:Body>
<EquipmentChangeState xmlns="http://www.tut.fi/fast/robot"
dateTime="2012-07-11T12:37:24.43"
currentState="READY-PROCESSING-EXECUTING"
previousState="OFF"
eventId="ItemTransferZoneDep"
palletId="5"
recipeNum="1"
toolId="1"
cellId="6"
devType="robot"/>
</s12:Body>
</s12:Header>
</s12:Envelope>
```


Figure 3.14: Example of XML/SOAP message sent from S1000 connected to scara robot in [33]

applications, the application must subscribe to the smart RTU device and the number of subscriptions could be more than one per device.

- **JSON message**

  The JavaScript Object Notation message, in short JSON, is the type of message forwarded by Fastory server to WAN network, this kind of message is used in Fastory architecture because of it is common used in web service platform due to it lightweight format and easy generation and parsing by machines.

  The events occurred on the manufacturing line come to the monitoring line web application hosted in Esonia server in JSON format,see Figure 3.15, then through JavaScript method it is parsed and translated to string commands that are understood by unity3D module.

JSON Message

```
//start robot
{"EquipmentChangeState":{"@eventID":"xx","@transID":"2","
@src":"robot","@cellID":"3","@eventName":"ItemWorkComplete",
"@condition":"NORMAL","@currentState":"READY-PROCESSING-
EXECUTING","@previousState":"READY-PROCESSING-EXECUTING","@
palletID":"13","@recipeNum":"9","@toolID":"2","@dateTime":"2000-01-
08T03:47:19.690"}}
```


Figure 3.15: Example of JSON message Forwarded by Fastory server

3.2.6 Leap - enabled application in Javascript

The leap motion controller gives different options for their integration on several frameworks, one of those is the unity3D, which has been presented in the section

3.3. In addition, LMC enables to create Leap-enabled application in a browser environment through LeapJS.

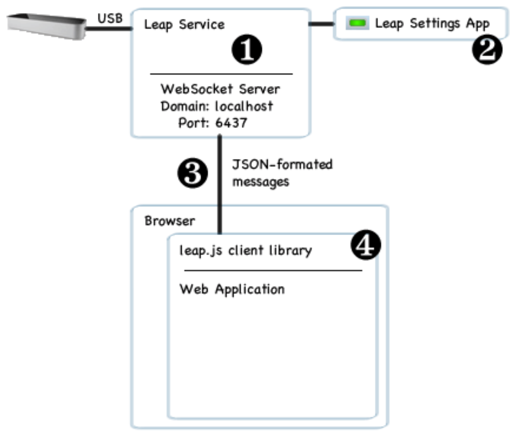

Figure 3.16: Leap-enable web applications architecture from [34]

LeapJS is the javaScript framework, it works through the API´s modality called "Websocket Interface" that follows the RFC 5741 Standard for Websocket protocol. According to on-line documentation in [34], the localhost at port 6437 enables connect a leap motion device with a web application. The connection provides messages that contains tracking information from the user hand, these messages are formatted in JSON. To complete the connection between leap device and leap enabled application the use of the client JavaScript library is necessary. The set up of the websocket server is through the leap motion control panel.

one advantage of the use of LMC through its JavaScript framework is the easy integration with other web applications, such as the monitoring application used in the integration of this thesis and published by Unity3D via web browser.

4. IMPLEMENTATION

This chapter describes the components of the architecture system for the integration of the LMC device in a manufacturing and novel monitoring system, moreover, here is defined the performance of the application prototype, describing each module that make part of it.

4.1 Overall system architecture

Based on the layered architecture described on the section 3.1. This section presents the components which are part in the final implementation for the integration of the LMC with a manufacturing environment. The following elements were selected:

- ***Testbed fastory line:*** A manufacturing line composed by eleven robot workstations connected by conveyors (scara robot).
- ***Smart RTU:*** InicoTech S1000 enables communication with devices placed on testbed fastory line.
- ***Forward application:*** a javascript application that convert the events from XML to JSON format and forward these to external servers, it is hosted in Fastory server.
- ***Application prototype:*** a javascript application that contents the three modules (LMC, Unity3D and COM).
- ***User interface:*** through user interaction with a LMC peripheral device and browser, user can visualize and interact with the manufacturing line.

The architecture of the system is presented in the Figure 4.1. The core of the system is the application prototype hosted in Esonia server, this application process the events occurred in the shop floor and analyse the data tracked by LMC device, moreover, it enables to the end users to connect remotely to manufacturing system through WAN network and visualize the events occurred there in real time. In addition, using a LAN network connection, the end user can interact with the manufacturing line via hand gesture.

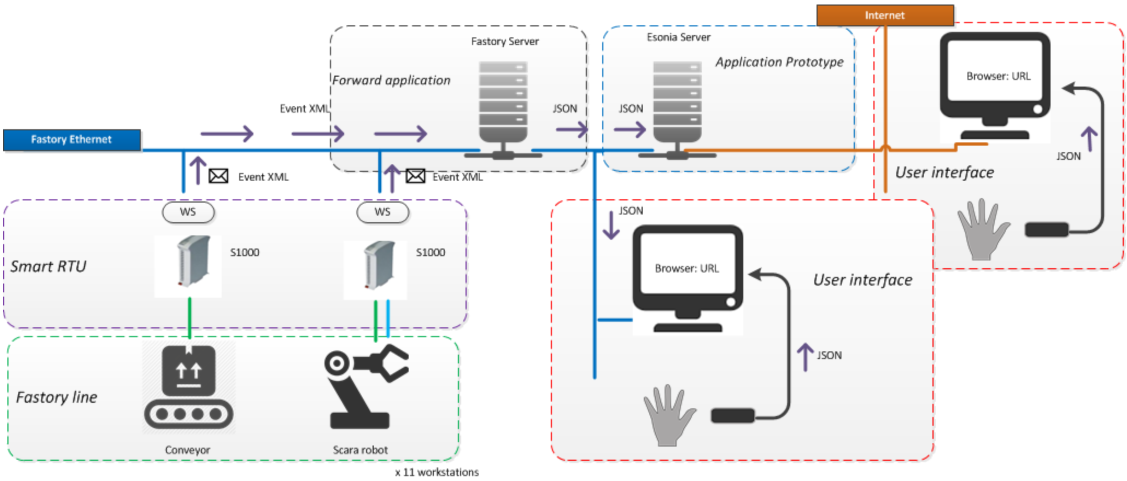

Figure 4.1: Architecture of the system

4.2 Definition of the application

The application presented in this thesis is based on the integration of several technologies such as game engine, web application and gesture-based interaction device.

This application enables the interaction with a monitoring process via non-physical style. In addition, it allows turn-on remotely robot workstation from monitored system via hand gestures. The application described in this thesis contents three interfaces (see Figure 4.2), which are index menu (1), 3D monitoring (2) and maintenance view (3). The navigation into the application is done by the use of two predetermined hand gestures such as circle and swipe. Moreover, the application receives events with data from the FASTory and represent it in 3D model animation. This application can be used remotely downloading the plug-ins needed to visualize unity3D web browser app and leap-enable JavaScript app.

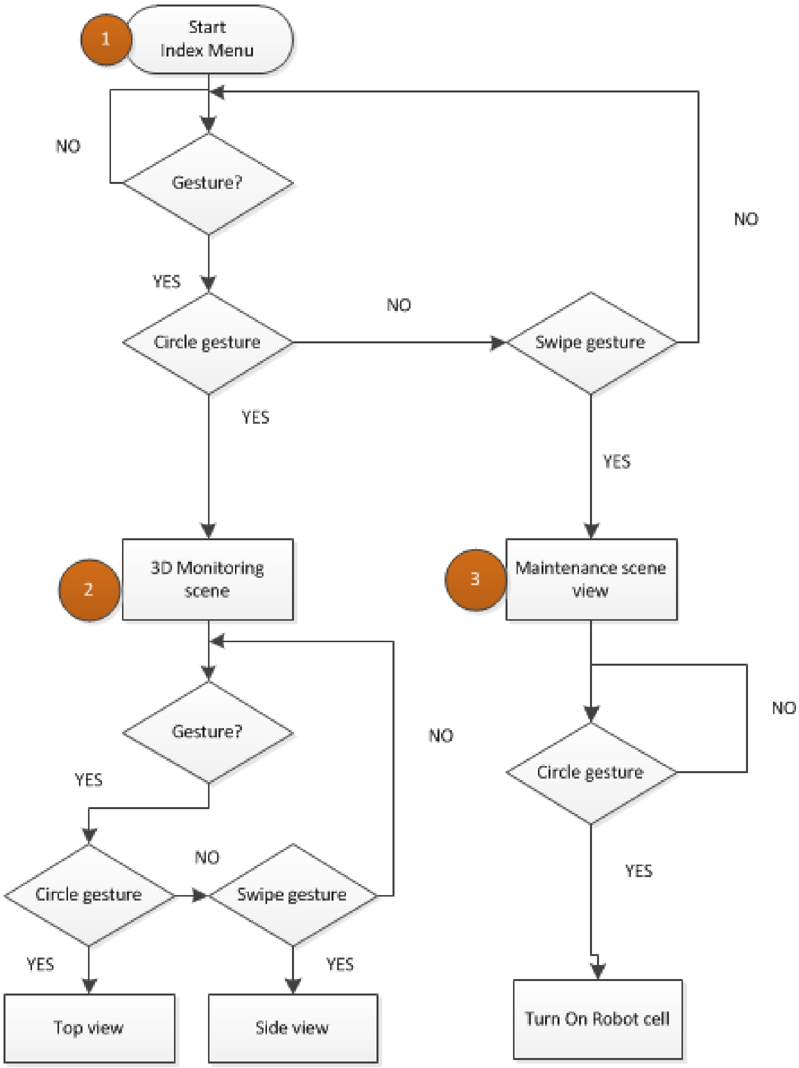

Figure 4.2: General flow chart application

4.3 Index menu

Index menu scene is the first screen view that the end user have with the Non-physical interaction application. In this part of the application two pictures are presented in the upper right corner of the screen, these pictures describe in images gestures recognized by LMC, it gives instructions about how the end user must interact with the system.

Index menu gives a feedback to the user through text format messages from the hands and fingers positions and gestures. This information is tracked by the leap motion device and received by the application in JSON format. These messages are parsed by a method in in JavaScript and extracts data information such as number of frame, number of hands, number of fingers, type of recognized gestures, etc. In addition, this screen view enables the user to move toward two different scenes using circle and swipe hand gestures, see Figure 4.3. The swipe hand gesture open a 3D

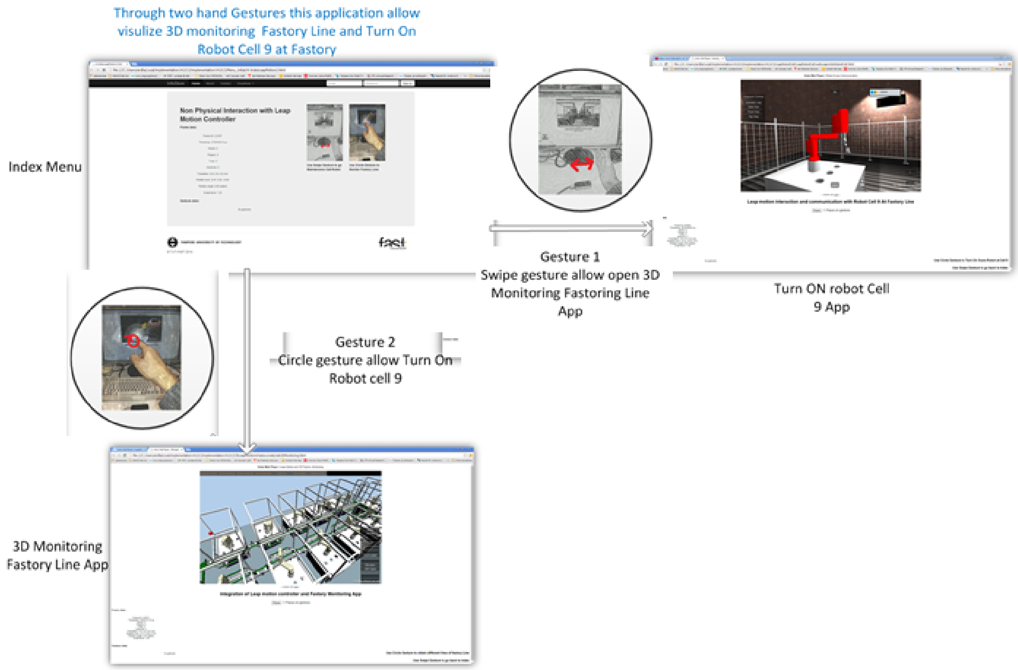

Figure 4.3: Index interaction

monitoring view while circle gesture open a maintenance workstation view. The leapjs API provides the information of JavaScript classes needed to connect the application with the LMC, recognize predetermined gestures. However to open a new web browser, JavaScript API be use. The most important method used in this part of the application involves to parse JSON messages to allow the evaluation of data obtained in each frame of hand tracking. Moreover, it enables to determine when the predetermined gesture occurs to perform the action conditioned for it.

4.4 Monitoring scene

In the monitoring scene are integrated the previous supervisory application based on Unity3D with a LMC. In addition, through the use of circle and swipe gestures the end user can interact with the monitoring view via LMC tracking. Circle and swipe gestures enable change the visualization of the monitored manufactured scene, on top and side view, see figure 4.4; and also these actions allow to visualize in more detail the performance of the manufacturing system.

The application in this part displays data in two formats, the events from the manufacturing line are presented in animation of 3D models and the tracked data from hand movements in text format. The structure of the web application is showed in the figure 4.5, it describes the path that follow the messages from monitored process and the LMC. In addition, As the figure 4.5 shows, the web application is composed by three modules: communication, unity view and LMC.

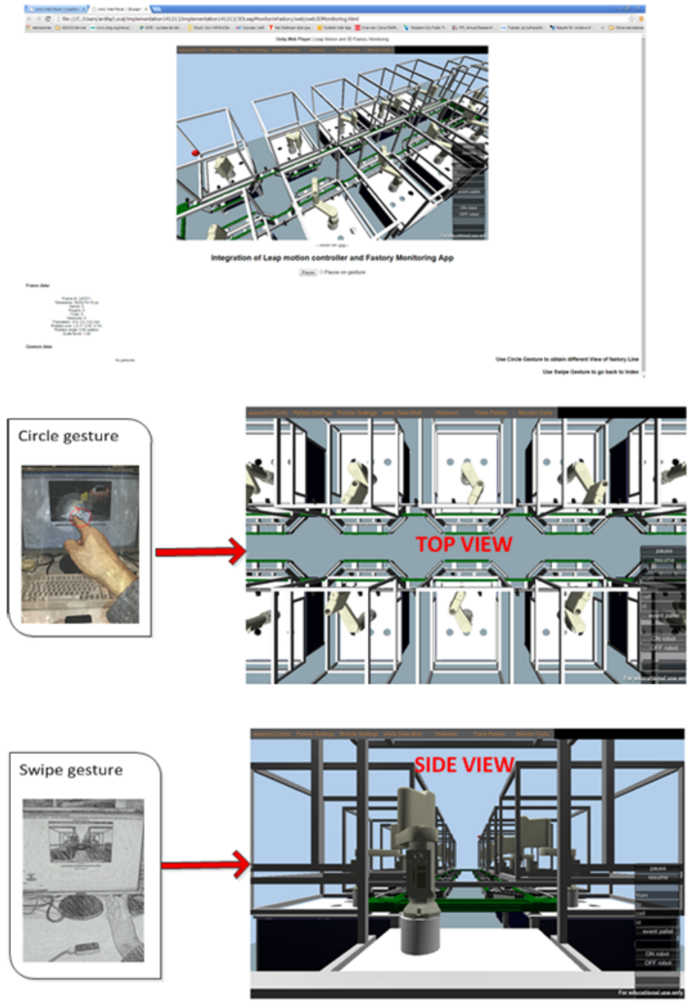

Figure 4.4: LMC Interaction in monitoring scene

4.4.1 LMC module

The LMC module receives JSON messages (1) from the LMC device and parse them, see Figure 4.5. Once the message is parsed, it is displayed in text format into the web browser in order to give feedback of the hand movements to the end user. In addition, in this module is placed the method that recognize the circle and swipe gestures. When these gestures are distinguished the data related to the gesture is displayed in the browser. Moreover, this method sends a message (2) to the unity 3D view module through a function: " u.getUnity().SendMessage("Main camera", "viewscene", "Message")". This function send a string message to a function that is attached to an object placed on the 3D scene. The parameters in this case are: message with a string value between 0 or 2, destination function is "viewscene" that is attached to "Main camera" game object. The connection of the LMC module with the unity3D view module was performed through the creation of the new function (viewscene) in the unity project that contains a switch statement which gives a particular focal coordinates to the main camera such as top or side view. The flow chart that describes the functionality of the module is placed on the appendix A.1. Classes and methods involved in this module are presented in the appendix B.1.

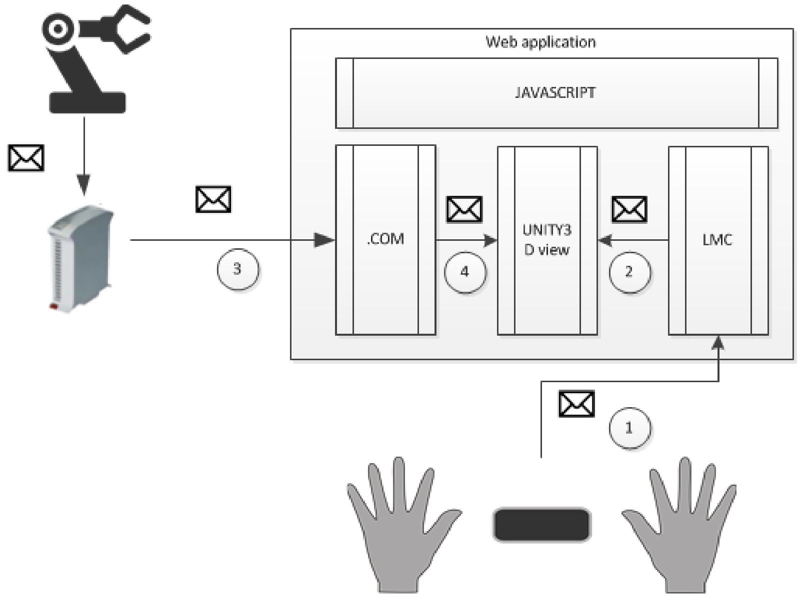

Figure 4.5: Data flow events from FASTory

4.4.2 Unity3D module

The unity3D module shows the graphical representation in 3D models of updated status from remotely manufacturing process (Fastory Line). The web content of this part is created by unity3D via web browser publication. To visualize this content is necessary to download and install the version required of unity web player, in this thesis was used the windows version. Moreover, this module understands the messages received by LMC and the remotely manufacturing system through functions attached to game objects that as part of the scene, this functions interpret the content of the messages and executes the commands associated such as working animation of a robot workstation.

4.4.3 Communication module

The communication module performs the subscription of the web application with the fastory server, this server forwards events occurred on the Fastory line. In this module the JSON messages are received and converted to string format (3), then these are forwarded (4) to the unity3D module. The subscription is done to the URL: `https://130.230.141.246:8082/FastPush/events`. The connection between the web application and fastory server is asynchronous because the data received do not affect browser display before this is analysed.

4.5 Maintenance scene

Maintenance scene presents a 3D representation of the robot workstation number nine placed in Fastory line, in addition, information in text format from the hand and finger position tracked by leap device, see Figure 4.6. This scene enables the end user to turn on robot through a simple hand gesture: circle gesture. As the monitoring scene, this scene is composed by three modules such as communication, LMC and unity3D.

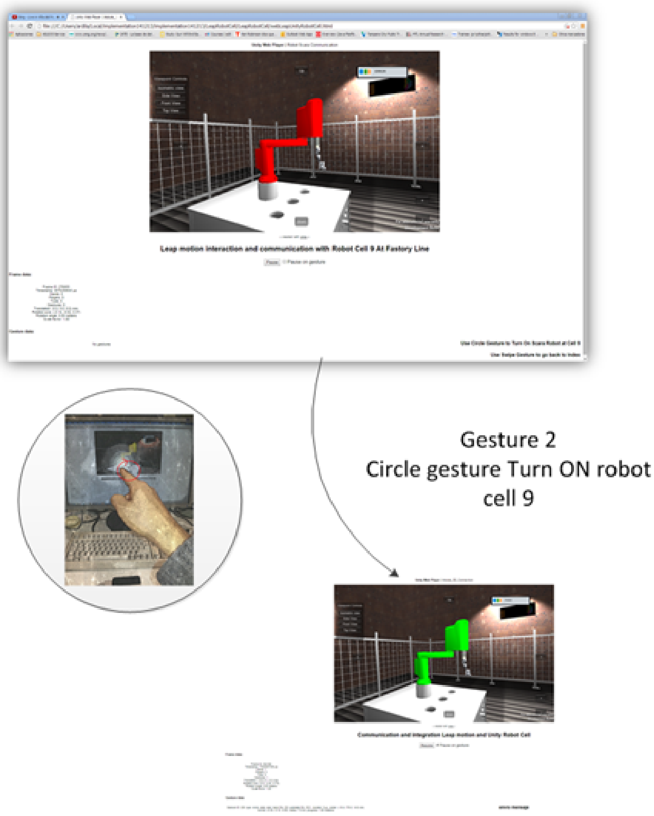

Figure 4.6: LMC interaction with maintenance scene

4.5.1 LMC module

This module performs in the similar way that the previous described in the monitoring scene. In addition to receive JSON message from leap device (1) and parse them, this module has connection with the unity3D and communication modules, see Figure 4.7.

Once is recognized the predetermined circle gesture that is captured by the leap device from user´s hand, two messages are sent (2) and (3); one message is performed by the method u.getUnity().SendMessage() and addressed to the unity3D module, in particular, to the function getrobotdata attached to gameobject A-start. This message (2) turn animation of the robot on in Unity scene. At the same time, the function sendMsgToRobot() is executed (3), and a second message (4) is addressed to the smart RTU attached to the robot scara of the workstation number nine that follow the XML/SOAP standard. This message realize a similar task performed by first message in the unity module, turn robot on remotely in the workstation nine. The flow chart that describes the functionality of the module is presented on the appendix A.2. Classes and methods involved in this module are presented in the appendix B.1.

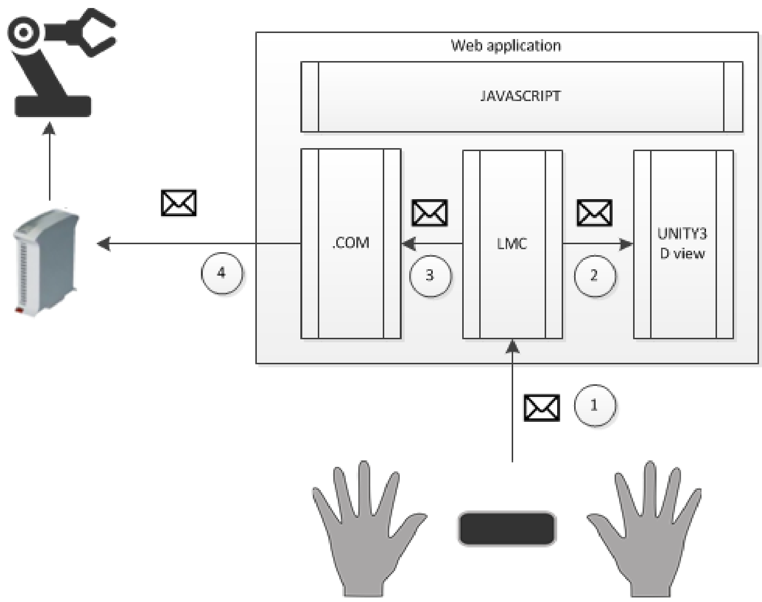

Figure 4.7: Data flow turn robot on operation

4.5.2 Unity3D module

The unity3D module contents a graphical representation of 3D model of robot scene from workstation number nine placed on fastory line. This information is created in unity3D and published there through the option of web browser publication. To visualize this content is necessary to download and install the required version of unity web player, in this thesis was used the windows version. In this module a scenario of applicability is simulated, the scene displays a robot workstation with status fail, such as, the robot is stopped and each arm of the robot is showed in red colour.

Once the failure is repaired, the application enables to turn on the robot and the characteristics of the scene are changed, the scene switches their status from error to working. The working status displays the robot with green colour and robot follows the sequence of work (animation).

XML Message

```
var soapMsg='<s12:Envelope xmlns:s12="http://www.w3.org/2003/05/soap-envelope" xmlns:wsa="http://schemas.xmlsoap.org/ws/2004/08/addressing">\
  <s12:Header>\
    <wsa:MessageID>urn:uuid:8b04aba0-31a9-11e3-bf8b-194c52899d5b</wsa:MessageID>\
    <wsa:Action>http://www.tut.fi/fast/robot/RobotPortType/calibrateRobot</wsa:Action>\
    <wsa:To>$msgData[wsEndPoint]</wsa:To>\
    <wsa:ReplyTo>\
      <wsa:Address>http://schemas.xmlsoap.org/ws/2004/08/addressing/role/anonymous</wsa:Address>\
    </wsa:ReplyTo>\
  </s12:Header>\
  <s12:Body>\
    <replacePaper xmlns="http://www.inicotech.com">\
        <EndEffector_Mode xmlns="http://www.inicotech.com">1</EndEffector_Mode>\
    </replacePaper>\
  </s12:Body>\
</s12:Envelope>\
```

Figure 4.8: XML/SOAP message turn robot on

4.5.3 Communication module

The communication module connect with the smart RTU through a HTTP POST request. Once is accepted the connection, this module send a XML/SOAP message that turn on remotely the workstation number nine through a circle hand gesture. The message is addressed to the URL address `http://192.168.9.1:80/dpws/ws02` associated to the S1000 of workstation nine. To turn on remotely the robot, the PC terminal must connect to the Ethernet Fastory network.

5. RESULTS AND DISCUSSION

The result of this thesis is the integration of a LMC with a manufacturing system through a software application using web browser platform. This application enables to interact with a developed monitoring application and physical robot workstation at FASTory via hand gestures. The followed approach included was to understand the performance of the different technologies involved such as game engine Unity 3D, LMC, smart RTU S1000, web browser, et al, and find the contribution of each in order to integrate and implement these together in an application prototype. The final application demonstrates the easy interconnectivity of the different technologies employed, moreover, the feasible implementation of the LMC as a tool in a manufacturing environment giving good contributions to the area.

5.1 Testing

The task of the next testing consists of checking the functionality of the application and the integration of the different technologies involved. This is based on the following steps:

1. Verifying the requirements needed(hardware / software) to launch the developed web page application.
2. Confirming that the application recognizes predetermined gestures tracked by LMC and realizes tasks associated to them. Moreover, the application gives feedback of the user's hand position.
3. Verifying the integration of the LMC device with an existed monitoring application. Monitoring system has to receive data from manufacturing line and show the generated events graphically. In addition, using predetermined gestures the user can interact with the monitoring system changing the visualization of the scene.
4. Confirming the integration of the LMC with a manufacturing line. A robot cell, of a manufacturing line will turn on once a predetermined gestures tracked by LMC are recognized by the application.

The performance of the application requires the placement of its files on a PC server with access to fastory LAN and WAN networks. In addition, to obtain a well performance of the application, the user must accomplish the following steps:

1. Download leap motion software setup (Mac or Windows version).
2. Plug the leap motion device into the USB port.
3. Calibrate leap motion device following the instruction of setup.
4. Install unity player (Mac or Windows version).

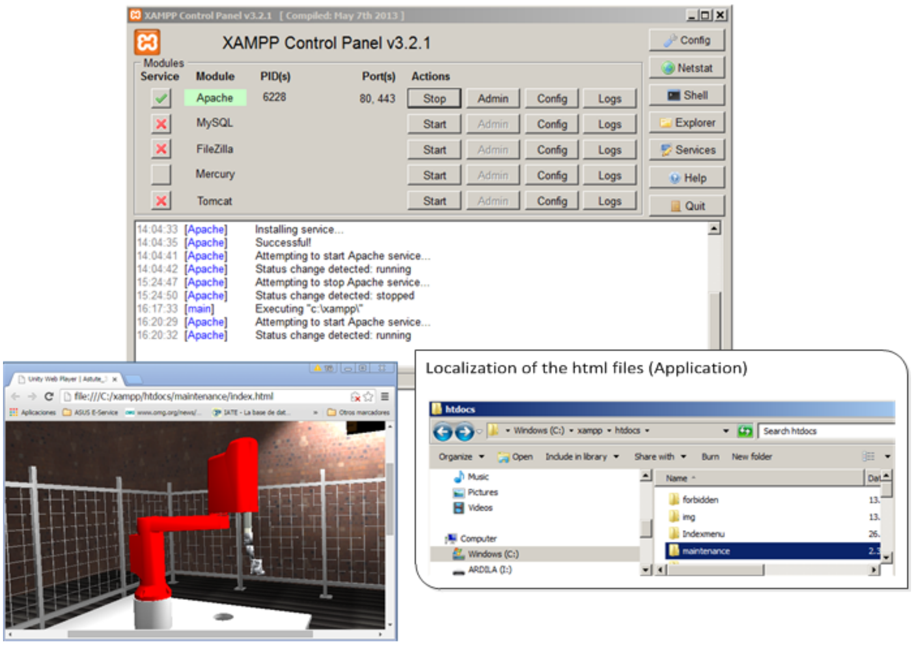

Figure 5.1: Application placed local server

Once the previous requirements are done, the web application runs in a web browser through writing the URL where is placed the user interface. In this demonstration they are placed on a local server installed in a terminal PC using Xampp web server application, see Figure 5.1. In the Xampp application were placed three folders that contents the interfaces which are based the application prototype and each folder contents HTML, CSS, JPG, UNITY3D files and library required.

The final application consists of three interfaces such as index menu, monitoring view and maintenance view, which recognize circle and swipe hand gestures as commands of execution.

A final demonstration about how the application works is presented on video and placed on the URL `http://youtu.be/3PKc-W2HvK0`, however, in this section is depicted a sequence that gives a graphical explanation of their functionality through testing.

5.1.1 Testing of index and monitoring interfaces

Index menu is the first interface in the application presented to the end user. This interface gives the first instructions about how to navigate in the application. Moreover, it provides information about fingers and hands positions. In the sequence depicted in Figure 5.2 a hand gesture (circle gesture) executed by the user above LMC device is displayed and this gesture enables to open a second interface called monitoring view (see frame four). The second interface represents graphically events occurred in the manufacturing line placed at FAST laboratory.

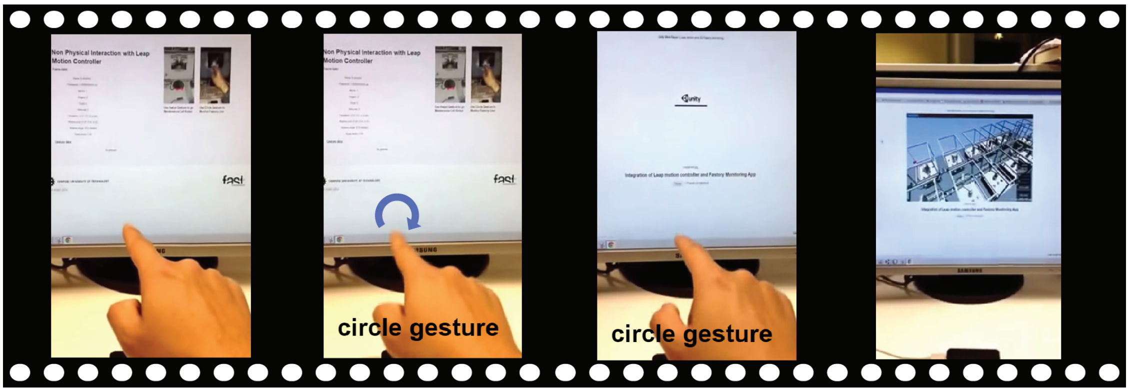

Figure 5.2: Interaction Index menu - Monitoring scene

In order to simulate these events, an application known as "advanced rest client", was used to send messages XML/SOAP such as presented in Figure 4.8. Two messages were sent to Esonia server with the objective of reproducing the turning on of two robot workstations and confirming that the monitoring view gathers these data, this is showed in the picture 5.3. The circle and swipe hand gestures enable to visualize (top and side perspective) the complete system in different views in order to obtain more details.

Figure 5.3: Interaction Index menu - Monitoring scene

5.1.2 Testing of index and maintenance interfaces

In the index menu, trough a swipe hand gesture above LMC device it is enabled to open the maintenance interface to the user, see figure 5.4. This interface enables to turn on robot workstation number nine using a simple circle gesture (frame 2). This part of the application must access to the fastory LAN network in order to interact physically with the workstation number nine.

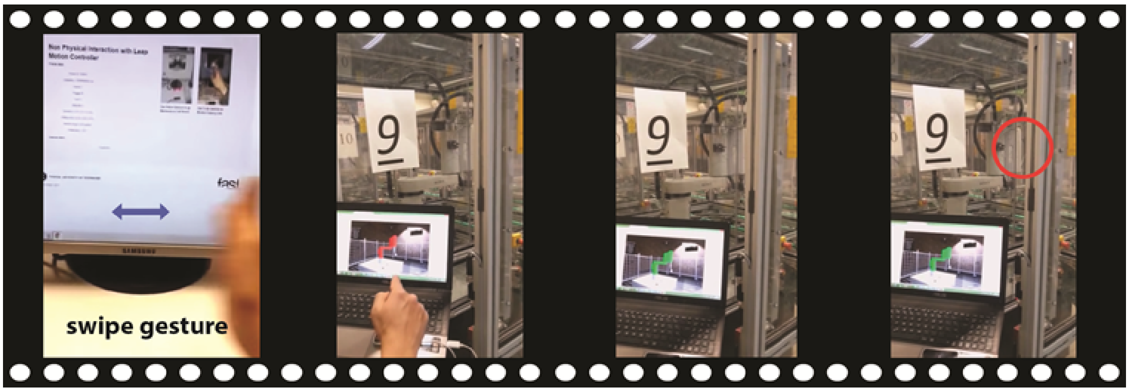

Figure 5.4: Interaction Maintenance scene

5.2 Assessment

The final application prototype worked well during the testing. The gestures performed by the user are recognized and processed through the application due to the predetermined identification characteristic given by the LMC device.

The feasible interaction of the LMC to the real time monitoring and manufacturing system was demonstrate. Moreover, it shows the compatibility of technologies with previous focus in entertainment application working in an exigent environment such as the industrial domain. In addition, its contribution in front of a possible scenario of use in a manufacturing environment.

The interaction with the systems based on two simple dynamic gestures could be easily expanded with more gestures (dynamics and statics) that executes actions inside of applications, it can transform the prototype in a more complex application.

This application can be used to demonstrate new technologies of interaction with a testbed FASTory line and systems attached to it.

5.3 Future works

The final solution in the integration of the LMC in the industrial environment gives a promising results. However, these outcomes can be improved. The LMC is a tool that has continuous updates given by the manufacturers, it means that the version two of the API gave notable improvements respect to the previous related to new classes for implementations. It enables to the next developers to pay attention on updates and analyse if these modifications can be applied to the betterment of the application prototype presented here.

In addition, the new boom of VR technologies on industrial environments and its easy compatibility with the LMC device enables to develop and integrate a new module into the application. This module can be addressed to integrate both technologies in the manufacturing environment.

6. CONCLUSIONS

The development of input/output peripheral devices performed in computer science has enriched the different forms of interaction between humans and machines. These improvements have contributed to build solutions in areas less rigorous than industrial domain such as interactive entertainment field.

The application prototype presented in this thesis demonstrates the promising contribution of the LMC device as a tool of interaction in a stringent field such as the industrial domain adding new assets through the non-physical hand gesture recognition by manufacturing and monitoring systems. For instance, maintenance personnel reduce time in the execution of tasks.

Even though the performance of the leap controller is limited to indoor locations (its high performance can be diminished by pollution and lighting of open and luminous spaces); LMC is an attractive device to incorporate in manufacturing environments due to low requirements in programming for the user, small size, low price, high accuracy and easy integration with other systems because of its open source license.

On the other hand, defining the LMC as a tool that offers straight intuitive interactions is not well accurate, as the user requires previous description of movements and a brief training period to interact with this technology. However, its manipulation does not require intermediate devices and it allows quick adaptation because the user only needs his/her own fingers and hand for interaction.

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A. APPENDIX: FLOW CHART

A.1 flow chart monitoring interface

This flow chart describes the module LMC of monitoring interface.

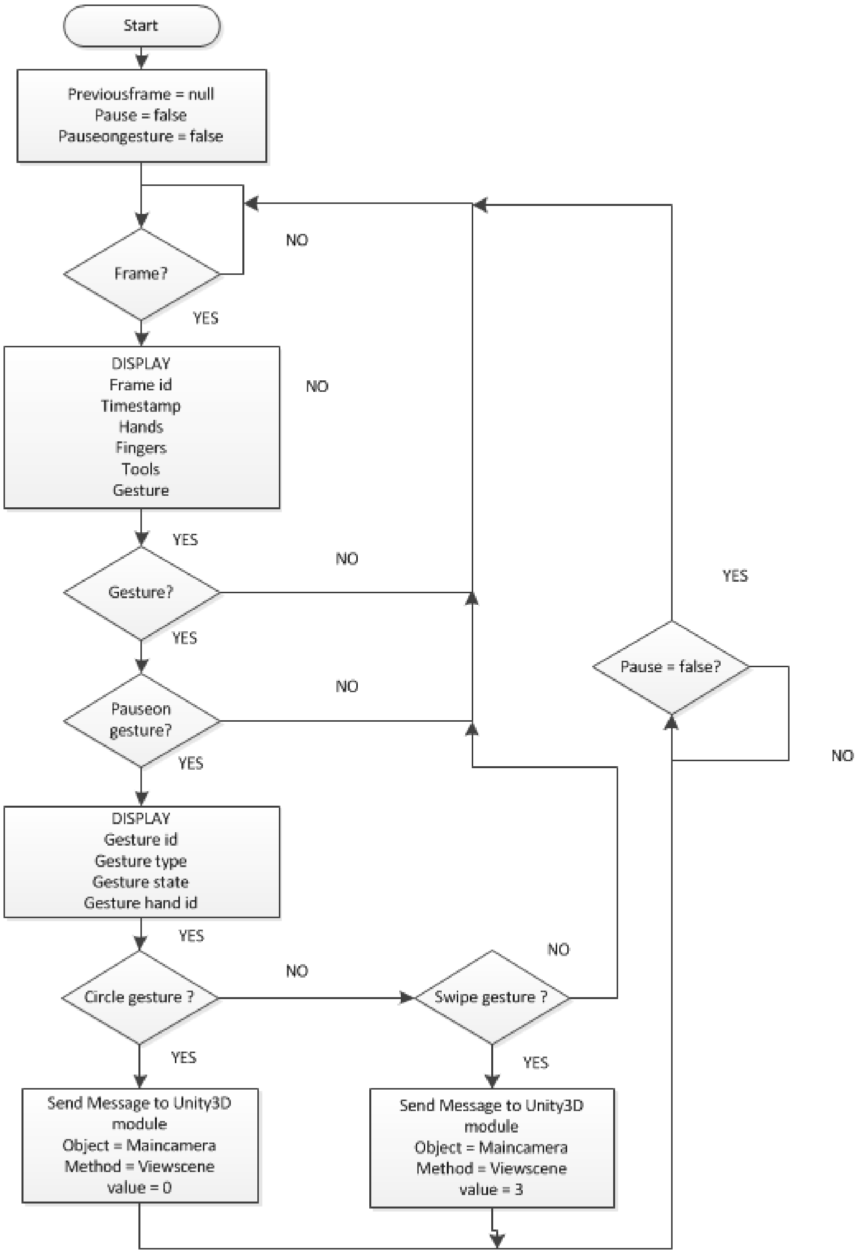

Figure A.1: flow chart in monitoring application

A.2 flow chart maintenance interface

This flow chart describes the module LMC of maintenance interface.

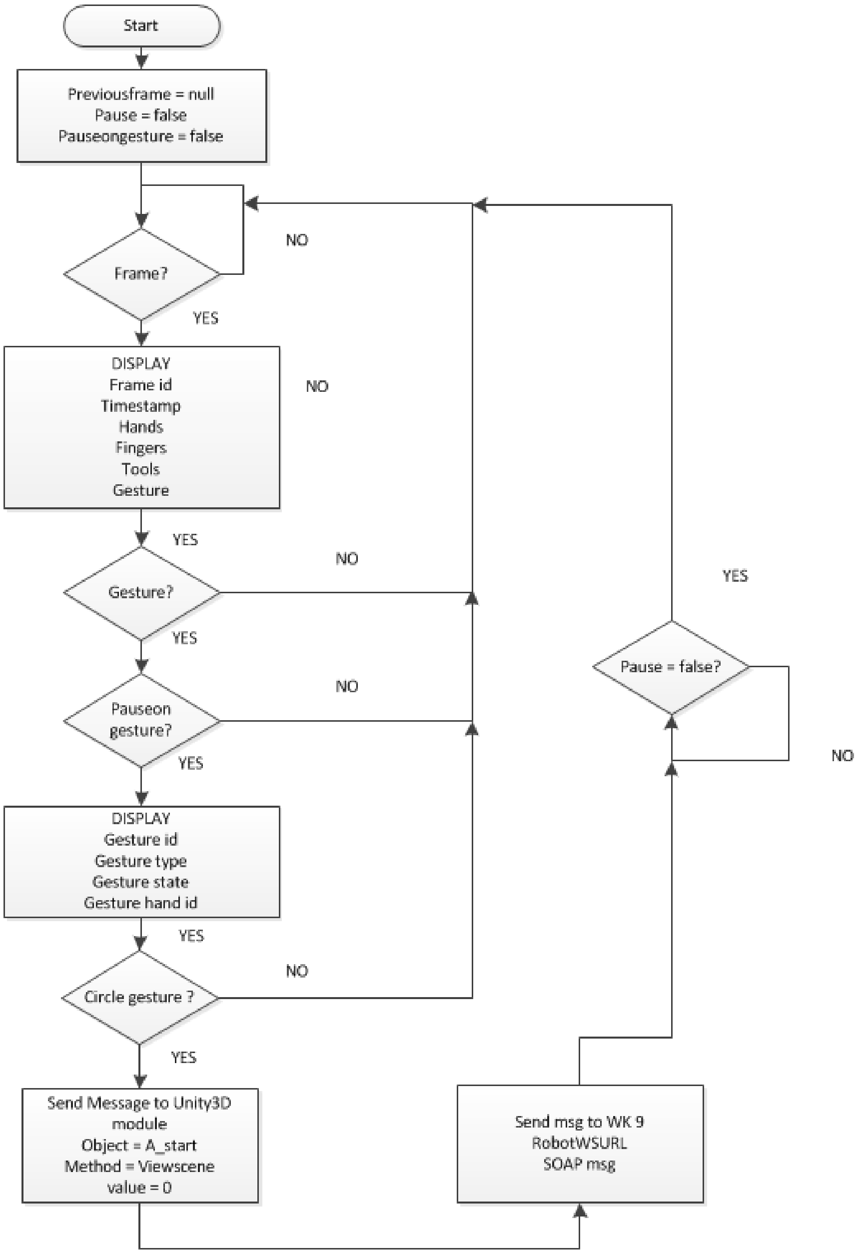

Figure A.2: flow chart in maintenance application

B. APPENDIX: UML DIAGRAM

B.1 UML diagram of LMC module

This UML diagram describes the module LMC in both interfaces, monitoring and maintenance.

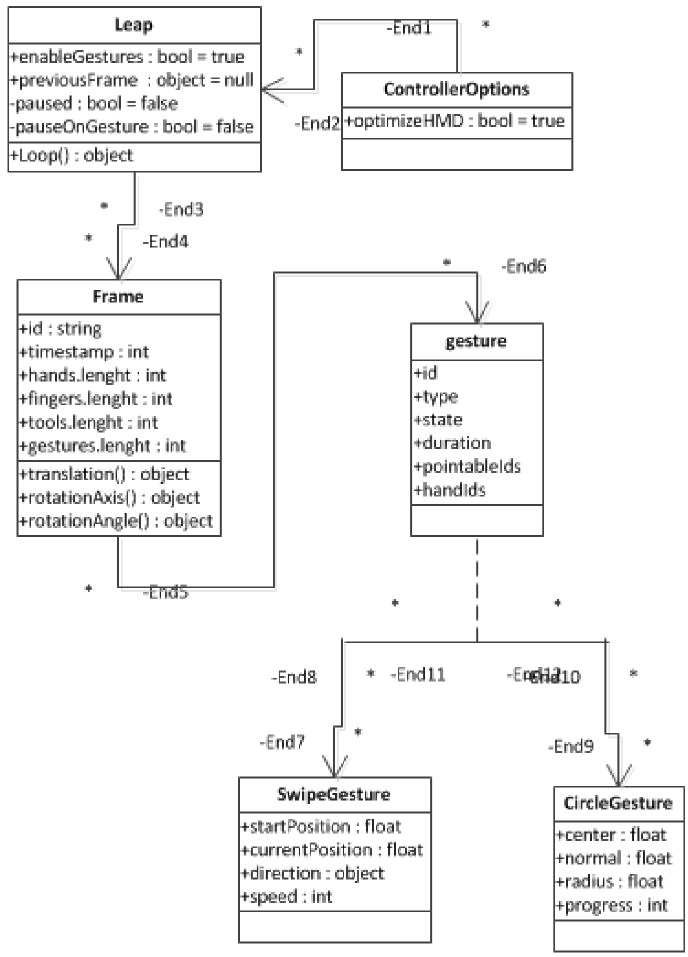

Figure B.1: UML diagram of the LMC module