

Otto-von-Guericke-Universität Magdeburg



Fakultät für Informatik

Bachelor-Arbeit

**RFID SENSORS-SMARTPHONE BASED TESTBED FOR
VIRTUAL STOCHASTIC SENSORS TO RECONSTRUCT
PARTIALLY OBSERVABLE DISCRETE STOCHASTIC
SYSTEMS' BEHAVIOUR**

Verfasser:

Ahmad Alwadi

Magdeburg, 2. April 2016

Dr.-Ing. Claudia Krull
Otto-von-Guericke-Universität
Magdeburg,
Institut für Simulation und Graphik
(ISG)

Prof. Dr.-Ing. habil. Graham Horton
Otto-von-Guericke-Universität
Magdeburg,
Institut für Simulation und Graphik
(ISG)

Declaration of Academic Honesty

I declare that the attached Bachelor Thesis is wholly my own work, and that no part of it has been copied from any work produced by others, provided by other students, taken from other persons programs or copied from any other source. I declare that all referenced work from other people has been properly cited and documented on the reference list.

Magdeburg, 2. April 2016

.....

Table of Contents

Abbreviations.....	I
List of Figures	II
1 Introduction.....	1
1.1 Objective	4
1.2 Outline.....	5
2 Related and Previous Work	6
2.1 Radio Frequency Identification.....	6
2.1.1 RFID Systems and Technology.....	7
2.1.2 RFID Tags	9
2.1.3 Near Field Communication Technology	11
2.1.4 Implementations of RFID and NFC Technologies.....	13
2.2 Virtual Stochastic Sensors for Reconstructing the Behavior of Partially Observable Systems	15
2.2.1 Virtual Sensors	15
2.2.2 Virtual Stochastic Sensors.....	17
2.2.3 The Utilization of HnMM by VSS	19
2.3 Hidden non-Markovian Models	20
2.3.1 Discrete Stochastic Models	21
2.3.2 Hidden Markovian Models.....	23
2.3.3 Hidden non-Markovian Models Formalization	26
2.3.4 Hidden non-Markovian Models Formula Definition	28
2.3.5 Solving the Tasks of HnMM	30
2.3.6 HnMM Implementations in Real-Life.....	31
2.4 Combination of HnMM and Proxel-based Method	32
2.4.1 The Proxel-based Method and Theory Background.....	32
2.4.2 Proxel-based Evaluation of HnMM	34
2.4.3 Proxel-based Decoding of HnMM	35
3 The Technical Approach Implementation.....	37
3.1 The Required Technologies for the Proposed Concept	38
3.2 Setting up the Technical Approach	43

4 Experiments to validate the Test bed	48
4.1 The Experiment Preparation	48
4.2 The Experiment Execution and the Results	51
5 Conclusion and Future Work	56
5.1 Evaluation and Future Work	57
References.....	58

Abbreviations

Auto-ID	A utomatic I Dentification
BPR	B usiness P rocess R eengineering
DES	D iscrete E vent-based S imulation
DSM	D iscrete S tochastic M odel
DTMCs	D iscrete- T ime M arkov C hains
EAS	E lectronic A rticle S urveillance
FDX	F ull D uplex
HDX	H alf D uplex
HF	H igh F requency
HMM	H idden M arkovian M odels
HnMM	H idden- n on M arkovian M odels
ICs	I ntegrated C ircuits
IDE	I ntegrated D evelopment E nvironment
IIS	I nternet I nformation S ystem
ISO	I nternational O rganization for S tandardization
IT	I nformation T echnology
LF	L ow F requency
MRP	M arkov R egenerative P rocesses
NFC	N ear F ield C ommunication
PODS	P artially O bservable D iscrete S tochastic
P2P	P eer- to - P eer
RF	R adio F requency
RFID	R adio F requency I Dentification
SE	S ecure E lement
SEQ	S equential
SPN	S tochastic P etri N ets
UHF	U ltra H igh F requency
VSS	V irtual S tochastic S ensors
VS	V irtual S ensors
WCF	W indows C ommunication F oundation

List of Figures

Figure 1: The Schema of the Technical Approach	38
Figure 2: Application User-Interface.....	40
Figure 3: Database Table.....	41
Figure 4: The Endpoint used by a Client to access the WCF Service, modified from [Chappell, 2010].....	42
Figure 5: Connecting WCF with SQL Database	43
Figure 6: Adding New Binding	44
Figure 7: Configuring the IIS	45
Figure 8: Opening the Connection Port.....	45
Figure 9: Connecting Desktop Application with SQL Database.....	46
Figure 10: Display the Experiments Results	46
Figure 11: Defining the IP-address and the Port Number in the Application	47
Figure 12: Example of Workshop Layout	48
Figure 13: Detecting the IP-address of the Server.....	50
Figure 14: Configuration of the Android Application.....	51
Figure 15: An Excerpt of the Acquired Sensor Data with the Corresponding Time Stamps	52
Figure 16: The Trace of Tag P with the Corresponding Time Stamps.....	53
Figure 17: Possible Generating Paths of the Tag P Workflow Protocol	54
Figure 18: The Probabilities of the Possible Paths in Downward Order for the Tag P Workflow Protocol	55

1 Introduction

The twenty first century has witnessed rapid developments in industrial science and informational technologies, which contributed heavily in introducing very advanced complex systems. Therefore, the competence in the marketplace has increased in such way that each step forward in a business should be carefully estimated and evaluated.

Nowadays, many enterprises face various difficult decisions and have to adapt to the new technological changes to keep up a positive sustainable position in the market place. Adopting a new technology is a strategic decision in many instances, since a particular value is added to the business model of an enterprise along with fundamental changes on the core business processes. As a matter of fact, the reason behind any modification or redesigning in the business processes is the recognition of the need of faster processes, less resources, efficient productivity or improvement of the competitive ability [Attaran, 2004].

For instance, business process reengineering (BPR) is regarded as a strategic action and decision to make [Attaran, 2004]. BPR is a “process design, process management, and process innovation. Reengineering involves revising organizational processes. It means designing the core business process instead of analyzing the current one. It involves reconfiguration of work to serve customers better” [Attaran, 2004]. It is used widely among companies and organizations around the world, where it is employed to achieve advanced performance and to reduce the organizational waste by implementing the proper modifications [Attaran, 2004]. Noteworthy is that BPR is correlated naturally with information technology. More precisely, information technology (IT) is not just a collection of tools to apply mechanization and automation of processes rather it can affect how the business is actually executed and engineer the business processes. Even more, IT is regarded as the key to enable the BPR implementations [Attaran, 2004].

Nevertheless, strategic decisions as well as operative actions are often associated with high risks due to the high costs and new investments factors. Roughly speaking, these fundamental changes require particular effort to be approved from business shareholders. This resistance is mainly due to lack of understanding of the new technology and the high associated costs, which are expressed as investment doubts [Uckelmann et al., 2011]. Therefore, shareholders and investors often require some kind of test environment or

experimental methods including real data. They are employed to verify the results, estimate the most likely outcomes, forecast the viability of an approach and show that a certain approach has a sufficient degree of validity and credibility to be applicable in a real life system.

As a matter of fact, resistance to new technology is considered as the force that forms the shape of the technology which demands a sufficient analysis [Bauer, 1997]. It is usually easier to analyze and examine the functionality of processes at the beginning and later on study the dysfunctionality as a dynamic deviation from the original processes. Therefore, the dysfunctionality was often taken into consideration while discarding the factor of resistance to new technology [Bauer, 1997]. As stated in [Bauer, 1997], resistance is "acute pain" to innovation progress. Resistance "affects socio-technical activity like acute pain affects individual processes, it is a signal that something is going wrong, it reallocates attention and enhances self-awareness, it evaluates ongoing activity, and it alters this activity in various ways to secure a sustainable future" [Bauer, 1997].

On the other hand, the rapid technical revolution in the contemporary century parallel with the continuously developing systems has not only changed the marketplace perspective but also reinforced significantly the research and innovation progress. Accordingly, research projects and emerging technology solutions are always in a continuous run. However, they demand sufficient mechanisms of testing to grant validation, verification and establish a certain degree of credibility [Sarma et al., 2015].

Different methodological testing approaches such as test beds, benchmarks and controlled experimentation are becoming well-established and more adopted to validate algorithms, theoretical concepts, application aspects and their practicability in real life [Hanks et al., 1993]. In this regard, so many researchers employ controlled experimentation to mimic the reality at best in their research projects. Therefore, they can feature expressively a system by modeling the relevant aspects of its environment and conclude valuable performance measurements [Hanks et al., 1993]. However, for researchers and experimenters, there are two common approaches to provide a practical experimental procedure. One approach is to emulate in a simplified way a system in experiments and later on find a way to convert the resulted outcomes into more complex real systems. The other approach is to target real systems environments and try to perform directly systematic experiments without any simplifications [Hanks et al., 1993].

Test beds and benchmarks are two well-known experimental methods in the research community with distinguished features. Benchmarks have a specific definition and are executed by standardized tasks. In contrast, test beds are used as simplified, exemplified versions of the complex large systems or environments [Hanks et al., 1993]. They involve more challenging unpredictable environments to allow the evaluation of the methods and algorithms which are being tested [Hanks et al., 1993]. The controlled experiment that is executed through test beds, can clarify the reason behind a certain behavior of a system. Additionally, test beds are able to shape the critical bridge between unique experimenter demonstrations and prevailing system, and they can serve for both hardware and application specific [Nelson et al., 2012].

In this regard, virtual stochastic sensor (VSS) is a recently developed paradigm, which is able to analyze the hidden processes in a partially observed discrete stochastic system. In a like manner to the well-known virtual sensors (VS), virtual stochastic sensor employs the readings captured by real system sensors to stochastically obtain the value of the other unmeasurable variables of interest [Krull et al., 2011]. It uses the recently introduced Hidden-non Markovian Models (HnMM) (see section 2.3) to characterize the stochastic relation between the real sensors readings (measured quantities) and the unmeasured variables of interest in a discrete system and it employs the Proxel-based method to compute the value of interest for VSS (see section 2.4) [Krull et al., 2011].

Accordingly, virtual stochastic sensors have an advantageous ability to reconstruct the behavior of partially observed systems based only on readable accessible data with time stamps [Krull, Horton, 2013]. The potential application areas of virtual stochastic sensors are very promising and can be abundant [Krull et al., 2011]. Therefore, many test simulations scenarios and controlled experiments have been conducted to show its capability in real life and to give it a sufficient validity. However, all the used dataset were whether completely artificial, generated using computer simulation; or tediously collected in real world, or downloaded from existing data [Krull, Horton, 2013; Krull et al., 2011; Buchholz, Krull, 2010; Krull, Horton, 2007].

For the purpose of adding an effective contribution, it is reasonable to build a technical approach by satisfying some fundamental requirements and employ it as a constructive technical key element in such test beds. This approach could participate not only as a feasible element of a specific experimental setup but also as a practical one for other test

environments in the research community. In order to meet a certain range of researchers' interests, the technical approach should be able to facilitate the implementation and evaluation of their algorithms, processes and methods. Additionally, it should serve to achieve the purpose of various experimental setups, so researchers will be able to execute different tasks, apply certain modifications and verify the impact of these modifications on the system performance. Since a test bed is a simplified simulation version of a larger complex system, the technical approach should be built at a low cost with maintaining the important aspects of: affectivity, flexibility, employing simple ways to collect the relevant data and efficient ways to analyze it [Nelson et al., 2012].

1.1 Objective

One of the main goals of this work is to design a technical approach that can participate as a key element in a wide range of VSS test bed scenarios. Radio Frequency Identification (RFID) technology can be employed in such test beds as a suitable equivalent of the real physical sensors and their resulting readings in real systems, where RFID readers can seamlessly identify tags attached to the objects in their reading range [Krull, Horton, 2013]. Furthermore, the possibility to store and process huge amount of information through RFID technology [Pop, Mailat, 2009] as well as the incredible drop in RFID tags costs make this technology very suitable to be employed for experimental environment purposes [Uckelmann et al., 2011].

Nowadays smart phone usage is extraordinary since smartphones are seamlessly purchased and almost carried by everyone. Therefore, the proposed concept is to develop a technical approach based on a smartphone device, in which an RFID application will be integrated. Moreover, a simple user interface will be designed to enable the researcher to choose the experimental scenario, which the approach is engaged in, and other relevant experiment features. Additionally, this integrated RFID application will be connected through a local wireless network with a central database that will be built in a host computer system to store the acquired experimental data. The experimental data obtained will be used later on by the VSS model to detect the value of parameters of interest, and therefore reconstruct the behavior of the targeted system.

To verify the functionality of the proposed technical approach, it will be employed and validated in one of the test environments of VSS. The chosen example application as it is

described in [Krull, Horton, 2013], was designed to simulate the implementation of VSS in a job shop production environment. As stated in [Krull, Horton, 2013], the example application was built in corporation with logistics experts to emulate a real existing job shop, it involves a realistic printed workshop layout and RFID system including RFID tags and RFID sensors. In order to obtain the experimental data the earlier proposed concept will be employed. Based on the manual execution of workflows over the printed workshop layout, the integrated sensor application in a smart phone will be used as a flexible sensor and the acquired sensor data will be collected in a central database hosted on a computer system.

1.2 Outline

This thesis consists of five chapters. In the first chapter, an introduction about the importance of testing, its mechanisms, test environments and different approaches are briefly demonstrated, later on the motivation and the objective of this thesis is presented. The second chapter contains a literature review on the RFID technology, VSS paradigm, the HnMM and the Proxel-based simulation method. The literature review will give an insight of the RFID technology including the RFID systems, RFID tags with their different types and the wide variety of RFID technology implementations will be presented. Since the recently developed virtual stochastic sensor paradigm happen to be the targeted theoretical concept for the proposed technical approach, the virtual stochastic sensor model and the relevant virtual sensor model will be illustrated within the second chapter. Furthermore, the recently introduced Hidden non-Markovian model is illustrated in details taking into consideration its origin and its essential role in virtual stochastic sensor paradigm. Later on, in the same chapter the Proxel-based algorithm will be discussed with its fundamental role in solving HnMM basic tasks. The third chapter will illustrate the proposed technical approach expressively with the significant details of the modeling and the implementation alongside with the technologies required to construct the proposed technical approach. The fourth chapter demonstrates the execution of a chosen VSS experiment application to validate the functionality of the proposed technical approach and its contribution as an essential key element in such test bed, which is described in [Krull, Horton, 2013]. Finally, in the fifth chapter, the conclusion of the work will be summarized and further work will be mentioned.

2 Related and Previous Work

2.1 Radio Frequency Identification

The term radio frequency identification (RFID) should be familiar to any student, researcher or engineer in the technology and informatics fields with some regular knowledge base. RFID is “a wireless technology that lets computers read the identity of inexpensive electronic tags from a distance, without requiring a battery in the tags” [Nath et al., 2006]. They are regarded as a specialized class of wireless communication systems employed for contactless data identification [Pop, Mailat, 2009; Juels, 2006]. In other words, any person with a good vision can easily identify and pick up a pen on an office desk full of office equipment. However, computer handle such processes in more arduous manner. Therefore, the automated identification of objects and human can be regarded as the attempt to give the inception of a computer vision. RFID technology has been reported in many instances as a technology, which can support the “perception” in computing devices through its explicit ability of labeling objects [Juels, 2006].

In the beginning of 1990 barcode technology has made an evolutionary change in the automatic identification systems and has dominated the market against all other identification systems over the next twenty years [Finkenzeller, 2003, p. 2]. Barcode is a binary code consists of a field of bars and gaps, which are prearranged pattern in a parallel configuration to symbolize data elements that indicate a certain symbol. The sequence of bars and gaps can be decoded numerically or alphanumerically [Finkenzeller, 2003, p. 3]. However, regardless of the cheap costs of barcode technology, their inability to be reprogrammed (read only technology), the limitation to a single item reading at a time and their low storage capacity have dropped severely their applicability in nowadays many implementations [Finkenzeller, 2003, p. 1]. In contrast, the wireless technology employed by RFID systems grants more flexibility and higher performance in many fields [Pop, Mailat, 2009; Juels, 2006].

In comparison to barcode technology the contactless identification systems i.e. RFID systems have various superior advantages such as unique identification, permanent information update, improved object security, minimal manual involvement though

applying automation process, which can speedily process a huge amount of data even if the object is moving [Pop, Mailat, 2009; Juels, 2006].

On the other hand, in the early days of RFID, there was a lack of knowledge about this advanced technology not only from the end user but also in the industry fields. Therefore, their implementations were more difficult than expected and limited to few applications such as ticketing [Finkenzeller, 2003, p. 1; Nath et al., 2006]. However, through the last years there was a huge tendency of employing automatic identification procedures (Auto-ID) in various real life applications to give information about people, animals, goods and products [Finkenzeller, 2003, p. 1; Uckelmann et al., 2011].

Since RFID systems compared to other identification systems possess conqueror features, they are becoming more well-established and employed in wide variety of different fields such as service industries, purchasing, logistics, industry and even in enhancing the quality of life such as ambient assisted living scenarios [Uckelmann et al., 2011; Nath et al., 2006].

2.1.1 RFID Systems and Technology

RFID systems are analogous to smart cards in the concept of storing data on an electronic data-carrying device which is called transponder or RFID tag. However, they contrast with smart cards by not using the galvanic contacts for managing the power supply to the RFID tags and transfer the data between RFID tags and RFID reader [Finkenzeller, 2003, p. 6]. The RFID systems employ the magnetic or electromagnetic fields, by utilizing concepts of radio and radar engineering fields as their underlying technical processes, which gives an interpretation to the term radio frequency identification as information carried by radio waves [Finkenzeller, 2003, p. 7].

There are countless versions of RFID systems and technologies depending on the targeted field of implementation. Nevertheless, there are basic features that distinguish one RFID system from another. These features are the amount of information that can be captured, read and exchanged; the power supply to the transponder (tags); the operating frequency and the resulting effective operating range (reading range) alongside with the size of the system components and the resulting costs [Finkenzeller, 2003, p. 11; Pop, Mailat, 2009].

For instance, there are two basic procedures that RFID systems operate with, either full duplex (FDX)/half duplex (HDX) systems or sequential systems (SEQ). In FDX and

HDX systems the response of the RFID tag is broadcast when the RFID reader's radio frequency field is on, in contrast, in the SEQ systems the reader's field is switched off shortly at regular periods [Finkenzeller, 2003, p. 11].

Furthermore, the data storage capacity of RFID transponders (tags) can take values from few bytes to many kilobytes. Not to mention the exception of 1-bit tags, which can be often deactivated (set to 0). They are used in certain applications especially Electronic Article Surveillance (EAS) to protect against thievery in shops and businesses [Finkenzeller, 2003, p. 11]. Another critical aspect is the power supply provided to the RFID tag in RFID systems, which determines whether a tag is active, semi-active or passive. This feature will be demonstrated in details in the next section.

One of the most important aspects of any RFID system is the operating frequency and the relevant effective operating range of the system. The operating frequency is the frequency at which an RFID reader executes the transmission. The transmission frequency of RFID tags is either neglected or usually identical to the transmission frequency of the RFID reader such in load modulation and backscatter [Finkenzeller, 2003, p. 13]. Accordingly, transmission frequencies are divided into three basic classes: Low Frequency LF (30-300 kHz), High Frequency HF /Radio Frequency RF (3-30 MHz) and Ultra High Frequency UHF (300MHz-3 GHz)/microwave (more than 3GHz).

The earlier classification leads to another sub classification of the RFID systems, which divides the RFID systems into three classes: close-coupling systems (0-1cm), remote-coupling systems (0-1m) and long-range systems (more than 1m) [Finkenzeller, 2003, p. 13]. Moreover, there is another classification based on the way of reading data from the RFID tags by the RFID reader, which can be also divided into three categories. These three categories are: the use of backscatter or reflection, where the frequency of the reflected waves matches the transmission frequency of the reader with a resulting frequency ratio (1:1); the use of load modulation where the reader's frequency is affected by the RFID tag with a corresponding frequency ratio (1:1); the utilization of subharmonics (1/n fold) and the creation of harmonic waves (n-fold) in the tags [Finkenzeller, 2003, p. 13].

Even though, there is a wide variety of RFID systems, in terms of the system structure all RFID systems are made up of two essential components. The first component is the RFID

tag, which usually includes a coupling element (coil, microwave antenna) and an electronic microchip. The RFID tag is attached to the object, which will be identified by the RFID reader [Finkenzeller, 2003, p. 7]. The second component is the interrogator or the reader, which contains a radio frequency module (transmitter and receiver), control unit and a coupling element [Finkenzeller, 2003, p. 7]. It can be used to read or to write/read based on its geared, typically it is connected to a PC, server or robot etc. to process the data received from the RFID tag [Finkenzeller, 2003, p. 7].

The communication link between the reader and the tags is regarded as bidirectional communication, which is done wirelessly to obtain the information stored in the tag [Langwieser et al., 2008]. This communication is guaranteed by electromagnetic waves that permit the exchange of information within the RFID system components [Finkenzeller, 2003, p. 6]. The typical communication is executed within a time window that consists of three sequence steps, in the first step the reader transmits a continuous wave to the tags. The radio field activates the tags and provide them with the required energy for receiving the reader orders. The second step is the transmission of the order to the tag. In the last step the reader deliver a continuous wave to the tags, which they modulate and backscatter back to the reader. Moreover, between two communication windows there is a transaction break, in which radio frequency transmission is switched off [Penttilä et al., 2006]. In this regard, the power transmission of the communication is governed by various intuitional regulations and standards. For instance, the European Telecommunication Standards Institute (ETSI) and Federal Communication Commission, in North America (FCC) standards and global International Organization for Standardization (ISO) regulations [Penttilä et al., 2006].

2.1.2 RFID Tags

A typical RFID system scenario includes a reader and tags alongside with an application host [Langwieser et al., 2008]. RFID tag is a tiny microchip designed for wireless utilization of data transmission. It is generally linked to an antenna in a package, which form an ordinary adherent sticker that can be attached on objects [Juels, 2006]. As mentioned earlier, the employed power supply mechanism is an essential aspect in any RFID system. In this regard, the RFID tags are classified into three types: active, semi-active and passive tags. Accordingly, the required reader will be determined based on the type of the implemented RFID tags [Finkenzeller, 2003, p. 13].

Active tags possess internal power supply as a battery, which provides the power to the Integrated circuits (ICs) and operations to transmit information to the reader. Therefore, their signal availability is always on, broadcasting their identity and can generate a signal without the help of RFID reader [Finkenzeller, 2003, p. 13; Langwieser et al., 2008]. Semi-active tags are similar to active tags with possessing their internal power supply. However, this power is just employed to provide supply to their integrated circuits and not for the radio transmission operations with the reader when they are interrogated. For this type of tags the earlier mentioned backscattering or reflecting methods is employed [Langwieser et al., 2008]. Furthermore, in the case of a fixed operating frequency of the reader, the associated effective operating distance (reading range) is correlated to the sensitivity of either the reader or the tag. However, they have a limited lifespan regarding their inner battery, which should be replaced within some years, which results as additional costs [Langwieser et al., 2008].

Passive tags possess no on-board power supply, which force them to obtain the required power supply from a fraction of the radio frequency (RF) energy generated by the interrogating reader [Finkenzeller, 2003, p. 13]. Therefore, in the case of a fixed operating frequency for passive tags, the correlated limitation of the reading range is governed by two characteristics: how much power the tag will use and how efficient is the power transmission to the tag [Langwieser et al., 2008]. The communication and exchange of information between the reader and passive RFID tags is done using the backscattering method.

As a matter of fact, passive tags are the most well-established tags among the other types due to their cheap costs and small sizes beside their unlimited lifetime [Penttilä et al., 2006; Langwieser et al., 2008]. In the recent years there were many development and enhancement added to the passive tags features, which increased their storage capacity incredibly and enable them to work in different environments [Nath et al., 2006].

The most important aspect of the passive tags is the ability to operate in any frequency band such as LF tags, HF tags, and UHF tags. Furthermore, in terms of RFID privacy in passive tags, the reading ranges of a tag can be classified in four different ranges: nominal reading range, rogue scanning range, tag-to-reader eavesdropping range and reader-to-tag eavesdropping range [Juels, 2006].

2.1.3 Near Field Communication Technology

Near Field Communication (NFC) is a recently developed technology. It is a very short-range wireless bidirectional technology, which allows contactless communication for mobile phones. In addition, it is regarded as specialized subset of RFID technology [Juntunen et al., 2010; Ozdenizci et al., 2011]. It is based on RFID technology where it is primarily designed for mobile phones as an intuitive method of setting up an ad-hoc connections with a reading range up to few centimeters [Francis et al., 2010]. It enables the connection between electronic devices up to 10 cm distance apart from each other and the exchange of data between them at up to 424 Kbits/second. NFC technology operates at the frequency (13.56MHz), which belongs to the High frequency category in RFID systems [Reveilhac, Pasquet, 2009; Ozdenizci et al., 2011].

NFC technology is primarily presented by NFCIP-1 (Near Field Communication Interface Protocol 1) and standardized on ISO18092, ECMA340 and ETSI TS102 190, and now NFCIP-2 (Near Field Communication Interface Protocol 2) is also established and outlined in ISO 21481, ECMA352 and ETSITS 102 312 [Reveilhac, Pasquet, 2009]. Therefore, NFC is compatible with proximity card standards, namely ISO 14443 and 15693 respectively as well as Felica contactless smartcard system [Reveilhac, Pasquet, 2009].

NFC devices can be classified into passive communication NFC devices and active ones. As in RFID system, passive devices have no power supply and are only feasible to be connected with active devices. In contrast, active devices have power supply, which enables them to send and receive data [Coskun et al., 2013]. Furthermore, peer-to-peer operation mode is an advance feature of the NFC technology, where it enables two active NFC devices to exchange information by switching between active and passive roles [Francis et al., 2010].

NFC standards have defined three main communication styles [Francis et al., 2010]. First operation mode is peer-to-peer (P2P) or “active” communication; this mode is outlined by ISO 18092 [Reveilhac, Pasquet, 2009] . It provides a communication between two NFC-enabled devices in a similar way to the communication in a “client-server” model [Francis et al., 2010]. The device that initiates the data transmission process is called the initiator and the other receiver one is called the target, the two devices employ their

emitted radio frequency fields to establish a communication between one another [Francis et al., 2010]. At the beginning the initiator sends a radio frequency carrier that serves to transmit data to the target. Once the transmitted data has been acknowledged from the target through modulating the existing RF field. The initiator turns the carrier waves off and the target switches to the initiator role by turning its carrier on and sends a response back to the original initiator. Additionally, when a NFC enabled device takes the initiator role it is regarded to be in “writing mode” and when it takes the target role it is considered to be in “reading mode” [Francis et al., 2010].

The second mode is reader/writer mode; in such mode the NFC device is capable of either “reading” or “writing” information from/on a tag or a smartcard for instance URLs, SMSs or phone numbers. The third mode is the card emulation mode where an active NFC device serves as a contactless payment, it resembles a contactless smartcard (ISO 14443). Since there is a secure element (SE) included in the device, important data can be saved in a secure storage which allows the utilization of vulnerable data that require high security level like payment application and ticketing [Reveilhac, Pasquet, 2009].

NFC technology presents the advantageous ability of centralization by the integration of many services in one place (e.g. smartphone), through applications such as payment, loyalty, ticketing and access keys for office and houses. Therefore, a smartphone can be turned into a practical real wallet including virtual cards, tickets and other feasible applications [Reveilhac, Pasquet, 2009]. Moreover, the NFC technology is an interoperable technology that can work with different devices such keyboards, camera and SD cards, etc. Since it has the ability to operate with different modes: card emulation, reader/writer and peer-to-peer operating modes, it can be easily employed to execute transactions and exchange information, where it can set a communication between a mobile phone from one side and a NFC reader, passive NFC tag or a mobile phone respectively on the other side [Reveilhac, Pasquet, 2009].

Additionally NFC devices can interact with HF RFID tags that are compatible with ISO 15693 [Francis et al., 2010]. Even though, NFC technology is recently emerged, it is witnessing an exploding growth with many promising implementations and potential corresponding services [Coskun et al., 2013].

2.1.4 Implementations of RFID and NFC Technologies

Due to the robust RFID standardization and the progressive miniaturization of RFID tags alongside with their incredible falling costs, RFID technology is becoming the main tool of automation identification procedures [Juels, 2006]. Furthermore, the concentrate of the industrial concept on standards that encourage the utilization of reusable tags and readers, has made RFID technology increasingly deployed in many applications in myriad fields and became more well-established [Nath et al., 2006].

For instance the proximity cards used for accessing buildings, the ignition keys built in millions of cars that include RFID tags for theft-deterrent [Juels, 2006]. Millions of households over the world have RFID tags implanted in them to expedite their return to their owners if they got lost [Juels, 2006]. By taking advantage of RFID technology the term smart appliances is becoming reality. Plenty of home appliances can operate cleverly in a way that eases the interaction with the consumer and presents more exciting features in everyday life utilizations for instance smart washing machines and smart TV controlled by mobile phones using NFC tags [Juels, 2006].

Thanks to the ability in RFID technology of reading the tags without the obligation of line-of-sight contact or the necessity of precise positioning, RFID reader can scan hundreds of tags per second with high accuracy [Juels, 2006]. For instance a consumer usually loses valuable time just to empty the shopping cart, put the products on the conveyor belts and wait for the cashier to scan each single item manually. Therefore, many retailers are using the RFID technology for inventory control and payment systems. Accordingly, a consumer can check-out just by passing the point of sale terminal and all the wanted product items in his shopping cart can be scanned and the total cost can be computed. Additionally, it is possible to take the costs from the consumers' RFID-enabled payment device and even send the bill to their mobile [Juels, 2006; Nath et al., 2006]. Moreover, in transportation field RFID technology can add major values to the business. For example in rental cars with RFID tags attached to them, the wagon identification number can be stored in the tag, which enables rental companies to execute an automatic inventories employing these RFID tags [Nath et al., 2006]. By using a network of statistic readers a system of the readers' locations can be constructed, which can help car companies to detect the locations of the relevant cars [Nath et al., 2006].

Furthermore, in airline industry every year billion of passengers check in and out for their boarding plans with more than millions checked bags are being transported. Although, the rate of the bags that have been directed to a wrong trajectory is usually very small, for example in 2004 it was less than 0.5 percent [Nath et al., 2006], still airplanes companies are suffering from momentous costs just to handle and correct this misrouting mistakes [Nath et al., 2006]. Automatic routing through using RFID tags and a network of RFID sensors can effectively diminish the misrouted luggage, severely drop the costs and as a result improve the customer service in the airline industry [Nath et al., 2006].

Even more, the RFID technology can contribute in feasible ways in the healthcare fields, through implementing RFID technology many regular health checkups obstacles and operational problems can be diminished. For instance, a nurse can easily scan the patient's tag to know the medical history and give the appropriate dose of treatment drug at the right time [Nath et al., 2006]. Additionally, the RFID technology can serve to support medication compliance and home navigation for elderly or handicap people [Juels, 2006; Jiménez et al.]. Therefore, by the utilization of RFID technology many different data entry, drug or treatment mistakes can be avoided, such mistakes might lead to endanger a patient health if not discarded [Nath et al., 2006]. In addition, in industrial areas, items identification and detection must be effective, fast and sincere. All industrial automations are converging towards rapid and real time-identification to reach an efficient level of accuracy that allows a sufficient controlling and contagious monitoring. Therefore, RFID technology appears to be one of the most feasible solutions, where it has the ability to provide fast autonomous tracking of item movements with real-time object visibility. This can lead to a significant improvement in the accuracy with increasing identification range. In addition, it can provide a simultaneous identification and location of the items associated with information regarding the items flow [Penttilä et al., 2006; Juels, 2006]

The most important thing is that with the outstanding improvement in microelectronics and low power conductor technologies, very small cheap RFID tags have become a reality [Nath et al., 2006, Uckelmann et al., 2011, 2011]. These features alongside with the RFID reader ability of reading tags in their surroundings without the necessity of particular positioning make the RFID technology perfect to take part as a practical technology in many test bed scenarios and test environments' setups, their utility in one of the VSS test bed will be demonstrated in the following chapter.

2.2 Virtual Stochastic Sensors for Reconstructing the Behavior of Partially Observable Systems

The technical revolution in the last decades has led to introduce a huge variety of modern complex systems. In order to optimize and enhance any existing system, it is essential to execute accurate measurements and continuous monitoring of the equipment and the processes within a system [Krull et al., 2011]. Therefore, considerable divergent approaches have attempted to gather the significance of the parameters in the system processes [Ibargüengoytia, Reyes, 2006]. However, in many cases important process parameters are unreachable either because of using incompatible traditional equipment or because the installation of some advanced ones is extensively expensive [Ibargüengoytia, Reyes, 2006]. Many of these systems have generally a certain recording protocol capability, where these recorded protocols are usually employed to expose a failure or an alteration from prescribed performance standards [Buchholz, Krull, 2010]. In order to send warnings, response fast and trigger the appropriate countermeasures, an immediate detection and a continues monitoring are required [Buchholz, Krull, 2010]. In this regard, many obstacles would arise, since in many cases a slightest delay may occur or some important process parameters are inaccessible directly or inaccessible at all [Krull et al., 2011]. As a matter of fact, the more accurate the obtained data is and more efficient the analysis of the available data is, the better enhancement and prediction of the system behavior will be. Therefore, many models and algorithms have been developed for a reliable and effective handling of the recorded protocols [Ibargüengoytia, Reyes, 2006]. One practical approach for efficient readings of ambiguously readable process parameters is done through the estimation of these parameters based on their relationship to other measured parameters in the exact process. This concept is employed by virtual sensors and the recently introduced virtual stochastic sensors [Ibargüengoytia, Reyes, 2006; Krull et al., 2011].

2.2.1 Virtual Sensors

Real physical sensors are employed for monitoring and controlling systems. However, in many cases they are not only expensive, risky and fallible, but also have a minimum delay. Not to mention that sometimes they are severe to install, operate and maintain [Krull et al., 2011; Ibargüengoytia, Reyes, 2006].

Therefore, virtual sensors were introduced as a powerful substitutional of real physical sensors, virtual sensors also known as soft sensors, smart sensors or estimators [Wilson 1997]. Virtual sensor is a paradigm employed to replace a real sensor, it is created using real data processes, where it collects readings from real existing sensors, controls variables and deduces the value of the variables of interest during runtime. Therefore, it permits the utilization of the calculated value as if it would be the result of a physical sensor itself, and thereby grants sensor data without using a real sensor [Krull et al., 2011; Wilson 1997; Ibargüengoytia, Reyes, 2006].

However, there is another approach employs similar concept regarded as analytical approach, it is usually implemented in traditional chemical processes. This approach attempts to associate the virtual value to other easier readable parameters through using advanced complex differential equations [Ibargüengoytia, Reyes, 2006]. Nevertheless, when multiple variables are of interest, it becomes more complex and ambiguous to obtain. Not to mention that any slightly change occurs in the process has a huge impact in the analytical model [Ibargüengoytia, Reyes, 2006]. Therefore, virtual sensors became more well established in many applications areas in the last decade [Krull et al., 2011]. For instance in online monitoring of parameters, where they could possibly be measured either sporadically or with a highly delay, the utilization of virtual sensors is recommended. Another application area is when the important system parameters are not directly measurable for example a friction of a tire in a driving vehicle [Krull et al., 2011].

Virtual sensors are feasible to take place instead of real sensors, when either their installation and maintenance is extensively expensive or the installation itself is impossible due to physical size limitations or surroundings limitations. One of the well-known example is the virtual sensor implementation to supervise the essential parameters in an internal combustion engine [Krull et al., 2011]. Moreover, one of the significant application field of virtual sensors is so called fault tolerance, where in case of a real sensor failure the virtual sensor will take over till the real sensor is repaired or back. This advance technique is employed in the Helicopter Adaptive Aircraft (HADA) where virtual sensors can be used for Fault Detection, Identification and Recovery (FDIR) of wing angle and actuator failure [Heredia, Ollero, 2010].

Virtual sensors are feasible for implementations related to physical quantities for instance voltage, energy, flow rate and temperature. As a matter of fact, there are common

characteristics among these quantities, where they are all continuous and obey deterministic laws such as algebraic or differential equations. Therefore, virtual sensors are prevalently used in processes of chemical engineering environments, wherein the relation between the cause and the consequence has a continuous and deterministic nature and follows mathematical equations [Krull et al., 2011, 2011]. However, these exact characteristics, which virtual sensor is solid to deal with, might be the reason for its disadvantages from another perspective. More precisely, many systems don't share any of the characteristics previously mentioned, where they are discrete, stochastic and non-continuous. Therefore, such system is regarded stochastic, characterized by discrete events and the recorded physical sensors results are random variables for instance traffic systems, assembly lines, logistics and communicational networks, where discrete stochastic models are built to analyze such systems (e.g. queuing models or stochastic Petri nets) [Krull et al., 2011].

However, the main obstacle of using virtual sensors hides in finding a suitable model that is able to transform the recorded results of physical sensors into the value of interest. In many cases it is really difficult to find the suitable model. On one hand there is an approach uses interim physical sensors to train the models and then substitutes them with virtual sensors in the following step [Krull et al., 2011]. On the other hand in many cases the system model is complex or even anonymous for instance nonlinear or hard to comprehend. Under these circumstances, neural networks are used to describe the model (e.g. neural networks with linear model) [Wilson 1997]. Accordingly, when dealing with discrete stochastic systems, obtaining the value of random variables becomes severely hard and even if they were concluded successfully, the results would be meaningless. Therefore, the typical virtual sensors are infeasible in these sectors [Krull et al., 2011]. Consequently, Virtual stochastic sensors were introduced as an equivalent of virtual sensors to take over in such particular scenarios [Krull et al., 2011].

2.2.2 Virtual Stochastic Sensors

Virtual stochastic sensors (VSS) are newly introduced paradigm, which share the same concept as virtual sensors. Virtual stochastic sensors take over in scenarios that virtual sensors are infeasible to deal with, wherein variables of interest are discrete and random instead of continuous and deterministic [Krull et al., 2011]. Virtual stochastic sensors as virtual sensors are able through using the protocols of entries (real sensor readings) to

compute the value of random variables of interest based on their relations with other measurable system variables. In this regard, the relations between the accessible variables and inaccessible variables of interest have a stochastic nature and cannot be expressed analytically [Krull, Horton, 2013]. Therefore, the results of VSS measurements are considered to be a statistical estimation of the true value [Krull, Horton, 2012].

Virtual stochastic sensors employ stochastic models to conclude the statistical output measures from the recorded random variables and to express the statistical relation between measured variables and unmeasured variables of interest. In contrast, virtual sensors as mentioned earlier use mathematical, continuous and deterministic models to describe the relation between measured quantities and unmeasured quantities of interest [Krull et al., 2011, 2011].

Typical virtual sensors deduce the scalar values based on the protocols of entries during runtime (real time) [Krull et al., 2011]. However, this is not the case in VSS, since it uses protocols of entries (samples of random variables) captured by real sensors over a duration of time from different locations in the system to conclude variables of interest. These statistical properties (quantities of interest) are not nearly accurate until an enough amount of sensor data has been acquired [Krull, Horton, 2012].

The supervised system must possess particular criteria, so virtual stochastic sensor can be applicable to it. For instance there is sufficient information about the system design and processes [Krull et al., 2011]. Moreover, the real sensors are already built into the system, since their data are used to create the model. Furthermore, there is a direct correlation between the accuracy of real sensors and the accuracy of VSS. More precisely, there is a dependency on how much sufficient information exists in the real sensors readings, where the more accurate the information gathered by real sensors, the more accurate the estimation of VSS will be. However, for VSS paradigm these criteria are unimportant as long as there is no correlation between the protocol entries and the quantities of interest [Krull et al., 2011].

As mentioned earlier it is a necessity to have adequate information to conclude accurately the value of inaccessible variables of interest. In order to acquire adequate information, the correlation between protocol entries and variables of interests must be valid. Therefore, there are certain characteristics that define the validity of this relationship

[Krull et al., 2011]. For instance there should be an impact of the value of variables of interest on the protocol entries of the system and this impact should not be easily affected by many stochastic actions. Additionally, the real sensor readings should be fully aware of alterations of the variables of interest. Namely, an event of an alteration in the variables of interest should be fully recognized by the real sensors so it could be exposed and analyzed [Krull et al., 2011].

These requirements and criteria must be represented in the system, so the virtual stochastic sensors are able to derive statistical estimation, which is the value of the desired inaccessible parameters in the system. Otherwise, the system cannot adopt the criteria of virtual stochastic sensors for an effective implementation, and thus the applicability of VSS will be futile and useless [Krull et al., 2011].

2.2.3 The Utilization of HnMM by VSS

It is essential in VSS to design a suitable discrete stochastic model that is able to characterize and analyze the system completely or partially. Therefore, Hidden non-Markovian Models come into sight as a solid candidate to model the system and express the stochastic relationship between protocol entries and the parameters of interest. Since HnMM are the combination of discrete stochastic models and hidden Markovian model (HMM), HnMM possess advantageous features from both models [Krull, Horton, 2009a]. Furthermore, HnMM are not only able to describe the system components of interest including the corresponding processes and parameters, but also can include the real sensor readings (protocol entries).

Therefore, HnMM can evaluate the measurements of sensors in the real system and setup the statistical estimation of the variables of interest [Krull et al., 2011]. By solving the HnMM, it is possible to deduce the system behavior that has most likely produced the given output. The Proxel-based simulation algorithm is employed to solve the HnMM and thereby can compute the VSS values of interest [Krull et al., 2011].

In the following section the reasons behind the utilization of HnMM in VSS as the computational model to represent the partially observable discrete system will be presented expressively. Furthermore, the selection of Proxel-based method among the other different analysis solution methods to solve the main common tasks of all hidden models Evaluation and Decoding tasks will be demonstrated.

2.3 Hidden non-Markovian Models

Nowadays it exists many diverse complicated real systems. They are deployed in wide variety of natural, technical and even everyday life fields. Yet to optimize and enhance any system, precise and clear observations need to be gathered, where these observations are the results of the contributions of extensive examination and accurate analysis of a system. Furthermore, these observations will be interpreted and analyzed to design the model, which will represent the correspondent real system with respect to a specified level of abstraction. Various simulation models have been introduced in the last decades to meet the ongoing generated requirements of real-world systems design [Krull, Horton, 2009a]. One of those models is the discrete stochastic model (DSM), which is regarded as a robust modeling paradigm to represent the real systems processes, yet the system has to be completely observable in order to use this model [Krull, Horton, 2008].

However, manifold types of real-world systems can be considered as partially-observable discrete stochastic (PODS) systems [Buchholz et al., 2011]. These systems can be observable not completely but only through their interactions with their environment, where these interactions can be translated into output signals and usually saved in the system recorded protocols [Krull, Horton, 2009a]. More precisely, the partially-observable discrete systems are systems that have an internal stochastic behavior that can be represented by discrete stochastic models [Van Der Aalst, Wil MP et al., 2000; Bobbio et al., 1998]. Moreover, in many instances the internal state of a process is not directly detectable, but rather concluded through the external noticeable output signals that are emitted from the internal system processes [Buchholz et al., 2011].

Therefore, the analysis of PODS systems became of interest in the last years, because it will enable a better insight of the inner working processes of the system. The revealing of such processes behavior, which are hidden by nature, allows the reconstruction of the unobservable behavior of real-world systems, and thus enhance the performance of those systems [Buchholz et al., 2011]. In many of these systems, particular output can be recorded readily, so by choosing the right model it is possible to abstract statistical useful information out of these recorded protocols. Furthermore, through applying the appropriate algorithm, it would be possible to benefit from these statistics to define

valuable parameters and obtain hidden information, which would contribute significantly in predicting and enhancing the system behavior in the future [Buchholz, Krull, 2010].

Hidden Markovian Models are capable of analyzing partially observable systems. However, they have some limitations because of containing discrete-time Markov chains as their hidden processes, and therefore their parameters are constant probabilities and the models are discrete in time [Buchholz et al., 2011; Krull, Horton, 2009a]. Furthermore, the restriction to discrete-time Markov chain (DTMCs) as hidden models permits only the representation of Markovian processes with fixed transition rates. Accordingly, the modelling power of HMM drops critically in regard to the applicability in the real life [Krull, Horton, 2008]. These facts provoked many attempts in the last years to overcome these limitations. However, they had the trend to focus on state durations flexibility and speech recognition capability [M. Russell, R. Moore, 1985; Krull, Horton, 2008].

Recently Hidden non-Markovian Models (HnMM) were introduced as the merge of DSM and HMM models and as a paradigm to model the impulsive PODS systems. HnMM enable a better analysis of realistic hidden models and dynamic processes [Krull, Horton, 2008] and empower the ability of constructing clear conclusions about the exact system behavior based on the output signals and protocols produced by it [Krull, Horton, 2009a]. This approach will give answers to many critical questions such as the most likely system configuration that produced a certain signal sequence and the absolute probability of a given signal sequence to be produced [Krull, Horton, 2009a].

2.3.1 Discrete Stochastic Models

Discrete stochastic models (DSM) are very effective simulation paradigm to describe real-system processes and reflect the system's course of actions. Therefore, they are frequently used to describe many processes in ecology, economic and industry areas [Krull et al., 2010]. The most efficient aspect of DSM is that they are discrete in state space and continuous in time, which enabling them to directly represent processes and location of real-systems in their model [Krull, Horton, 2008]. Through allowing the usage of time dependent transition rates, various types of distribution can be applicable in their processes such as Weibull and Normal [Krull, Horton, 2009a]. In contrast, one of the critical disadvantage of DSM is that their simulation algorithms need the system to be

completely measured and examined in order to build a discrete stochastic model. Since normally system simulations are executed with a fully parameterized models, one has to detect the exact model parameters by tracing and determining the appropriate processes of the real system [Krull et al., 2010a; Krull, Horton, 2008].

There are various types of DSM, for instance, stochastic Petri nets (SPN) and their extensions queuing models [Bobbio et al., 1998; Krull, Horton, 2008]. Queuing models are feasible to deal with data traffic in networks that exist in most of real-world systems with different packages and characteristics. These models break up the network into separate nodes (queuing models) and evaluate their properties before gathering them, then each node can be evaluated by applying traditional queuing theory [Krull et al., 2010b]. However, the usual problem that faces queuing models is to formulate a suitable formal representation, either by searching among existing known classes of queuing systems or by creating a new one. Later on analytical methods are employed to determine measures of the performance of a queuing system [Krull et al., 2010b]. Therefore, the solution formulas of a system should be mathematically solvable, which limits its modeling power to a variety of classes [Krull, Horton, 2008].

SPN are well-defined paradigm that usually used in a wide range to determine the reliability of the complicated relationships between system elements. For example, the reliability of interaction between the components of a modern car. Usually the performance measures of a SPN are derived by employing Monte Carlo simulation methods such as discrete event-based simulation (DES) [Krull, Horton, 2008]. In order to obtain the performance measures, the DES algorithm performs the model for multiple rounds meanwhile gathering the information from the observed behavior. These collected simulation outputs are statistically analyzed to derive the required measures [Bolch et al., 2006].

Even though these recorded outputs are used to specify the fundamental properties of the system or to expose a deviation from a predefined standard protocol. They are useless when it comes to determine exactly the source or the cause of an observed output (i.e. failure output) or an occurred deviation [Buchholz, Krull, 2010]. Not to mention that, there are still difficulties to adjudicate the probability of an observed output symbols sequence or to link it with a particular system behavior that could have produced it most likely [Krull, Horton, 2009a].

Accordingly, discrete stochastic models have vast modeling power and they are feasible in many applications domains. However, they have some limitations, therefore, the extension of DMS as hidden models constituent was reasonable stepwise in order to develop the modeling algorithms and to expand their potential areas of applicability in real-world systems [Krull, Horton, 2009a].

2.3.2 Hidden Markovian Models

Hidden Markovian Model by definition is “a doubly embedded stochastic process with a hidden stochastic process that is not observable, but can only be observed through another set of stochastic processes that produce the sequence of observations” [Rabiner, 1989]. More precisely, Hidden Markovian models are functional paradigm to analyze hidden systems. They are capable of representing and tracing processes, which are not straightway observable [Krull, Horton, 2008]. For this reason, they are frequently used in speech and pattern recognition and have been utilized as the standard simulation models for systems with non-observable characterizes since a long time [Buchholz, Krull, 2010; Rabiner, 1989]. They contain discrete-time Markov chain (DTMC) as their internal processes, which produce output signals in every discrete time step through another stochastic process [Krull, Horton, 2009a]. More precisely, in Markov models each state matches a noticeable (physical) event, yet these models are futile for many real-life systems application. Therefore, the concept of Markov models was expanded to cover other conditions, where the observation is a probabilistic function of the state [Rabiner, 1989]. A HMM is defined by the following five tuples as described in [Rabiner, 1989]:

- N , is the number of states in the model. In general the states are connected with each other, so every state is reachable from any other state. In the same time they are hidden but in many cases for implementation reasons the physical importance is linked to the states or the set of them, where $S = \{s_1, s_2, \dots, s_N\}$ and q_t denotes the state at time t .
- M , denotes the number of distinct observation symbols per state where the observation symbols correspond to the physical output of the system being simulated, where $V = \{v_1, v_2, \dots, v_M\}$.
- The state transition probability $A = \{a_{i,j}\}$ as defined in equation (1)

$$a_{i,j} = P[q_{t+1} = s_j | q_t = s_i], \quad 1 \leq i, j \leq N. \quad (1)$$

For the special case where any state can reach any other state in a single step then it will be $a_{i,j} > 0 \forall i, j$. For other types of HMMs it would be $a_{i,j} = 0$ for one or more (i, j) pairs.

- The observation symbol probability distribution in state j, $B = \{b_i(k)\}$, as shown in (2)

$$b_i(k) = P[v_k \text{ at } t | q_t = s_j], \quad \begin{cases} 1 \leq j \leq N \\ 1 \leq k \leq M \end{cases} \quad (2)$$

- The initial state distribution $\Pi = \{\pi_i\}$ as shown in equation (3)

$$\pi_i = P[q_1 = s_j], \quad 1 \leq i \leq \quad (3)$$

In addition a HMM is denoted by the 3 tuples $\lambda = \{A, B, \Pi\}$ which is called the model, where these components indicate the complete parameter set (actual dynamic behavior) of the HMM [Krull, Horton, 2008]. Given a HMM the form described earlier, it can generate the observation sequence $O = \{o_1, o_2, \dots, o_t\}$ which is called a trace and where $o_t \in V$ by executing the corresponding hidden DTMC states series $Q = \{q_1, q_2, \dots, q_t\}$ the so-called a state sequence or a path [Krull, Horton, 2008]. Thereafter, HMM should be able to perform the following main three tasks to be effectively used in real-world applications [Rabiner, 1989]:

- Evaluation: how to determine competently $P(O|\lambda)$ which is the probability of an observed sequence (trace) $O = \{o_1, o_2, \dots, o_t\}$ for a given model $\lambda = \{A, B, \Pi\}$ [Rabiner, 1989].
- Decoding: how to conclude (i.e. best explains in a significant way) the most likely system behavior (optimal state sequence $Q = \{q_1, q_2, \dots, q_t\}$) of a given model $\lambda = \{A, B, \Pi\}$ that produced the parallel generated sequence of output symbols $O = \{o_1, o_2, \dots, o_t\}$ [Rabiner, 1989].
- Training: given the observations sequence $O = \{o_1, o_2, \dots, o_t\}$, how to train the non-parameterized model $\lambda = \{A, B, \Pi\}$ to produce that wanted observations sequence O or to train it to maximize the probability of O ($P(O|\lambda)$) [Rabiner, 1989].

There have been different effective solution algorithms introduced to solve these basic problems (tasks) of HMM paradigm:

For the evaluation task the Forward algorithm is efficient to determine the overall probability $P(O|\lambda)$ of the observed sequence O produced by the model λ based on a greedy approach. It is capable to detect the finest equivalent model for a certain output, for instance a set of possible word meanings for an audio signal or a recorded speech [Rabiner, 1989; Krull, Horton, 2008].

The Viterbi algorithm is used for solving the decoding task. It attempts to uncover the hidden part of HMM by finding the most likely optimal state sequence Q for the model λ that had made the output sequence O , which is also based on a greedy approach. This algorithm is practical for speech and pattern recognition, therefore, they are the best well known applications of HMM [Krull, Horton, 2008].

The Forward-Backward algorithm (Baum-Welch algorithm) is used to solve the most difficult task among them all the training task, it tries to modify the parameters of the model λ to match at best the observed output symbols O by performing a sequential improvement steps through their local optimization methods starting with an initial estimation. Therefore it is considered computationally expensive [Krull, Horton, 2008], [Rabiner, 1989].

As mentioned earlier hidden Markovian models are effective models to detect the parameters of hidden models that have stochastic discrete processes based on the observed output sequence only [Buchholz et al., 2011]. Since they contain discrete-time Markov chains (DTMCs) as internal models, they are dependent on discrete time step size. Consequently, their state transitions rates are constant and time independent [Buchholz, Krull, 2010], which put an additional constraint to stick only with markovian memoryless processes. However, most of real systems are continues and they are not readily converted into DTMC. Although, it already exists the equivalent paradigm of DTMC for continuous time continuous-time Markov chain (CTMC) [Krull, Horton, 2008], they are still restricted to the memoryless state changes and can only represent systems with exponentially distributed triggering times [Buchholz, Krull, 2010; Krull, Horton, 2008]. Consequently, These restrictions limit the HMM ability to simulate a realistic representation of many real systems and reduce the strength of the modeling power significantly [Krull, Horton, 2008].

Since HMMs are futile for many real life applications, the recently introduced Hidden-non Markovian models were particularly developed to overcome the limitations of HMMs [Buchholz, Krull, 2010]. It was presented first as an extension of HMM for more general hidden discrete stochastic models, where it is continuous in time by enabling time-dependent processes and allowing any discrete stochastic system as its internal model. HnMMs have the ability through using the existing tools of HMM to analyze more realistic models in real life systems and empower the simulation algorithms applicability to solve many existing problems [Krull, Horton, 2008].

2.3.3 Hidden non-Markovian Models Formalization

As mentioned above HnMM is a recently presented paradigm as the integration between DSM and HMM, which is able to characterize more realistic models and can enable the association between produced output symbols and the possible system behavior that could have produced the given output. Therefore, the HnMM paradigm have the ability to solve problems were impossible to solve before using the two earlier mentioned models [Krull, Horton, 2009a] and thereby HnMM possess major advantages over both HMM and DSM [Krull, Horton, 2008].

The integration of HMM and DSM is done within three stages. The first stage is to link the stochastic signal output processes with the state transitions by allowing symbol emissions at state changes [Krull, Horton, 2007]. Since the HMM symbol emissions are correlated with the system states and in DSM the system state changes is regarded to be an essential element, it is a necessity to do the previous association between the signal output and the state transitions. The second stage is to convert the internal hidden models from a DTMC to a DSM [Krull, Horton, 2008]. The final stage is modifying the sequence of signal output (trace) and the sequence of internal system states (path) to be in tune with the definition of the HnMM model [Krull, Horton, 2008].

Before getting into the formalization of hidden-non Markovian models, it is essential to know the special cases of HnMM. Many special configurations exist for constructing HnMM where every single selection between two possible choices could affect the description of the model and thus the relevant adopted solution algorithm [Krull, Horton, 2009a].

The first selection to make is whether all transitions of the model (state changes) lead to symbol emissions or not. The simpler case is when all state changes in the model carry out signal outputs (Eall). On the other hand the more pragmatic case is when only some of the transitions of the model produce traceable symbol output (Esome). The reason behind the simplicity of (Eall) scenario is the ability to determine the time of state changes just by observing the exact time of symbol emissions (trace), since each state transition must carry out a signal output [Krull, Horton, 2009a].

The second choice should be made based on the possibility of recognizing the exact state change by two transitions or more, which might occur when changing the DSM into its state space. Therefore, there are two options, first one is that only one transition can be released from one state change (SConeT). The other more complex one is that many transitions can recognize the same state change (SCnT). Here (SConeT) is easier and clearer since the model is restricted with less possible routes to advance with the process [Krull, Horton, 2009a].

The last choice is particularly related to the non-Markovian processes. In this context, it is important to consider the option of Markov regenerative processes (MRP), where it exists reset points in time of the MRP model, thereby the whole series of past events before the particular point become neglected in the context of the model ongoing advancement. Therefore, it enables the reset of all non-markovian transitions and regenerate them newly.

In this regard, the selection between the two following options should be done. First option is when all non-Markovain transitions are reset whenever a state change occurs (Treset). The other one is to not reset some transitions (e.g. keep their age) while another state changes are happening (Tkeep) [Krull, Horton, 2009a]. As stated in [Krull, Horton, 2009a] the (Treset) is easier to handle in order to conclude system future, in contrast, the (Tkeep) is more pragmatic but difficult to deal with arithmetically.

Therefore, the selection between these different choices in the earlier scenarios will lead to different HnMM configurations. Consequently, this will demand different solution algorithm methods to solve each one of those possible HnMM configurations [Krull, Horton, 2009a].

2.3.4 Hidden non-Markovian Models Formula Definition

As stated in [Krull, Horton, 2009a] The current definition of HnMM is driven from HMM formulization in [Rabiner, 1989], as mentioned earlier HMM is defined with 5-tuples (S, V, A, B, π). However, the following modifications should be done in order to construct the HnMM formula. A set of state changes C will be appended, thus the HnMM is defined with 6-tuples (S, C, V, A, B, π). Moreover, the transition probability matrix A should be modified to represent the model transitions in DSM. Therefore, the state transition probability will be replaced with its non-Markovian equivalent that is called instantaneous rate function (IRF) or hazard rate function. It describes the movement of variables overtime mirrored by the triggering of the parallel transitions [Krull, Horton, 2009a]. It is shown in the following equation (4), where τ is the age of the activated non-Markovian transition.

$$IRF(\tau) = \mu(\tau) = \frac{f(\tau)}{1 - F(\tau)} \quad (4)$$

Accordingly the elements of A will be replaced by the Instantaneous rate functions of the transitions between the model states [Krull, Horton, 2009a]. Additionally, the symbol output emissions, which represented by B cannot be defined as a matrix anymore, because of the association between symbol outputs and state changes. After these modifications are done, the resulting HnMM formula is defined in [Krull, Horton, 2009a] as the following taking into consideration the second mentioned HnMM special case:

HnMM = (S, C, V, A, B, π)

Model: $\lambda = (A, B, \pi)$

States: $S = \{s_1, s_2, \dots, s_N\}$

State Changes: $C = \{c_1, c_2, \dots, c_L\} \ c_i \in (S \times S)$

Symbols: $V = \{v_1, v_2, \dots, v_M\}$

Transition Matrix:

$$A(t) = \{a_{ij}(t)\}_{N \times N}$$

$$SConeT \ a_{ij}(t) = \begin{cases} u_{ij}(t) & : \exists c_l = (s_i, s_j) \\ 0 & : else \end{cases}$$

$$\text{SCnT } a_{ij}(t) = \sum_{c_l=(s_i, s_j)} u_l(t)$$

Output Probabilities:

$$\text{SConeT } B = \{b_{ij}(m)\}_L$$

$$b_{ij}(m) = P(v_m \text{ at } t_k \mid q(t_k - \epsilon) = s_i \wedge q(t_k + \epsilon) = s_j)$$

$$\text{SCnT } B = \{b_i(m)\}_L$$

$$b_i(m) = P(v_m \text{ at } t_k \mid (c_l, t_k))$$

Initial Probability Vector: $\pi = \{\pi_i\}_N$

$$\pi_i = P(q(o) = s_i)$$

The last modification to be done is related to the discrepancy of the signal output sequence between HMM and HnMM. Wherein HMM the trace is a list of output symbols mirroring one by one the discrete steps of the DTMC [Krull, Horton, 2008]. Nonetheless, the capricious behavior of the DSM transition activation at any point in time implores a transformation in the configuration of the trace and the path. The transformation is done by the incorporation of the time dependence with the trace, through associating each output symbol with its production time stamp [Krull et al., 2010].

Therefore, a concatenation of pairs of (symbol, timestamp) described as (S, t) will form the trace. Furthermore, the corresponding transitions, which induced these output symbols emissions will be also attached with time stamps, forming the structure of the path as a sequence of (transition, timestamp) described as (T, t). This reflects the change occurred in the Path form from a sequence of states to a sequence of state changes [Krull, Horton, 2009a]. Taking into consideration some special HnMM cases, the trace and the path will be defined as the following:

Symbol Sequence: $O = \{(o_1, t_1), \dots, (o_T, t_T)\}$

State Change Sequence: $\text{Eall, SCnT } Q = \{(c_1, t_1), \dots, (c_T, t_T)\} (c_i \in C)$

$\text{Eall, SConeT } Q = \{((q_0, q_1), t_1), \dots, ((q_{T-1}, q_T), t_T)\} (q_i \in S)$

$\text{Esome, SCnT } Q = \{(c_1, p_1), \dots, (c_P, p_P)\} (c_i \in C, P \geq T)$

$\text{Esome, SConeT } Q = \{((q_0, q_1), p_1), \dots, ((q_{P-1}, q_P), p_P)\} (q_i \in S, P \geq T).$

2.3.5 Solving the Tasks of HnMM

In order to solve the three basic tasks for non-Markovian models in HnMM, the existing algorithms should be modified. Since many adjustments are applied to the structure of the model, its trace and path, the implementation of the exact old algorithm methods would be futile [Krull, Horton, 2009a]. Therefore, the Forward algorithm and the Backward algorithm are modified respectively to deal with the HnMM evaluation task. The task is concluding the probability of the trace for a given model λ that produced a given observable output sequence O as illustrated in equation (5) [Krull, Horton, 2009a].

$$\text{Evaluation: } O, \lambda \Rightarrow P(O|\lambda) \quad (5)$$

For the decoding task the modified Viterbi algorithm is used to determine most likely the sequence of visited internal states of the given model λ , which generated the given trace O as shown in equation (6) [Krull, Horton, 2009a].

$$\text{Decoding: } O, \lambda \Rightarrow Q = \operatorname{argmax}_Q(O|Q \wedge \lambda) \quad (6)$$

As for the training task, which is a task that attempts to parameterize a given model λ at best to give the observable sequence output O . Therefore, it is considered more as an optimization task rather than a direct computation one. In order to solve this task the Baum-Welch algorithm was modified [Krull, Horton, 2009a]. The task is defined as shown in (7).

$$\text{Training: } O \Rightarrow \lambda = \operatorname{argmax}_\lambda P(O|\lambda) \quad (7)$$

As stated in [Krull, Horton, 2009a] the adjustments of the Forward and Viterbi algorithms for the simplest HnMM case (Eall, SConeT, Treset) were feasible. Furthermore, their adaption could be also suitable for the option (SCnT) [Krull, Horton, 2009a]. However, the endeavors to adapt the other options (Esome, Tkeep) were respectively applicable only in theory. Additionally, it is still ambiguous how to apply the adjustment of the Baum-Welch algorithm to HnMM [Krull, Horton, 2009a]. Moreover, for now there is no general solver for the training task, nonetheless, it can be executed for special HnMM configurations [Krull, Horton, 2014]. Regarding all these adaption limitations of these algorithms, they are considered to be not completely applicable to all HnMM configurations. Therefore, alternative solution algorithms have been sought such as Proxel-based simulation method [Krull, Horton, 2009a].

2.3.6 HnMM Implementations in Real-Life

Hidden non-Markovian models (HnMM) have shown that they are functional models for analyzing partially observable systems by using the suitable solution algorithms to solve the HnMM basic tasks. One of the effective solutions algorithm approach is the Proxel-based method, which will be illustrated in details in the next section. It can execute the HnMM tasks, more precisely it can solve the evaluation and decoding tasks efficiently [Krull et al., 2010a; Krull, Horton, 2008]. This newly developed HnMM paradigm combined with the compatible analysis algorithm propose solutions for many unsolvable problems, which results many possible implementation scopes for the HnMM [Krull, Horton, 2008]. Some implementations fields of HnMM are:

The detection of machine fiasco in service industry fields, where it can detect most likely the system internal behavior that has produced a given fiasco or a deviation from the prescribed standard protocol by executing the decoding task. Therefore, it can be used to predict the source of the problem and evaluate the proper effort and cost for the needed reparation [Krull, Horton, 2008; Buchholz, Krull, 2010].

Furthermore, an advantageous implementation can be employed in the industrial production areas by using the HnMM training task, where it can construct a model of non-observable machine performance through utilizing recorded protocols to control the manufacturing specifications [Krull, Horton, 2008]. Additionally, it can serve in the medical diagnosis fields to conclude the most likely illness that caused the recorded symptoms of a patient based on the physical observations from a diagnosis backup or a prognosis of the reaction to the treatment, which could require matching one of the considerable illness to the stored symptoms of a patient [Krull et al., 2010a; Krull, Horton, 2008]. These implementations and many others are possible application fields for HnMM, where it can be feasible to analyze the bizarre course of actions or failures in a system, which usually include models with rare events [Krull, Horton, 2008].

One of the most important application of HnMM is its utilization by VSS paradigm to reconstruct the behavior of PODS systems. The combination of HnMM and Proxels can reveal the originally hidden information in the recorded protocols. These information can be used to conduct and retrace the behavior of the system which produced these outputs [Buchholz, Krull, 2010].

2.4 Combination of HnMM and Proxel-based Method

The major advantage of HnMM over other existing paradigms is the implication of the time behavior of the system. More precisely, it directs the spotlight on the state changes of the system rather than the states themselves through making the symbol emissions induced by state transitions and not by the states. Accordingly, it allows the time-dependent transitions to be represented by any continuous distribution functions [Krull et al., 2010]. In the previous section, some attempts to solve HnMM basic tasks through the adaption of the original algorithm methods associated with HMM were illustrated. However, these adaptations were accountable only for a number of restrictions correlated to the options selection of the model design [Krull, Horton, 2009a]. Regarding to the various HnMM configurations some algorithms were directly applicable, in contrast to others that required more specific model features (e.g. SConeT or Tkeep) [Krull, Horton, 2009a]. Nevertheless, HnMM was developed as a general purpose model, which rises an urgent need for a comprehensive solver to analyze its recorded symbol output trace [Krull et al., 2010]. For this reason a new approach was recently introduced, which employs the Proxel-based method as a solution algorithm to analyze HnMM [Buchholz, Krull, 2010] and to solve efficiently two of the three tasks of HnMM evaluation and decoding [Krull, Horton, 2008].

2.4.1 The Proxel-based Method and Theory Background

“The Proxel-based method is an intuitive approach to analyze discrete stochastic models (DSM), such as are described by stochastic Petri nets or queuing systems for example. The approach analyzes the models in deterministic manners, avoiding the typical problems of discrete event simulation (e.g. finding good-quality pseudo-random-number generator) and partial differential equations (difficult to set up and solve). The underlying stochastic process is a discrete-time Markov chain which is constructed while inspecting all possible behaviors of the model.” [Lazarova-Molnar, 2005]. The existing methods for simulation and analysis of stochastic systems are sorted into two classes: experimental and numerical approaches. The Proxel-based simulation method owns characteristics from both of the previous mentioned categories, thus has many advantages over many existing methods [Lazarova-Molnar, 2005]. For instance not only it does not apply random numbers in distinguish to the discrete event simulation (DES), but also it doesn’t

establish a system of differential equations in contrast to numerical methods. It rather explains effectively the flow of probability between the systems models in intuitional manners [Lazarova-Molnar, 2005]. More precisely, Proxels are considered more intuitive and unrestricted to specific models classes by its nature in comparison to partial or ordinary differential equation. Therefore, through using generic application, it is capable to simulate any discrete stochastic model, even models which considered stiff or contain rare events [Krull, Horton, 2009b].

The basic concept of Proxel-based method is turning all non-Markovian processes of a model memoryless [Krull, Horton, 2009b]. This concept is driven from the approach of employing the features of Markov chains to analyze non-Markovian models through supplementary variables [Krull, Horton, 2009b]. Supplementary variables can expand the system state by registering the age of this state. Therefore, the Proxel-based simulation utilizes the concept of supplementary variables and extends it through making any process memoryless by encoding the ages of all active and all race-age transitions at discrete points in time. Therefore, it is possible to calculate a transient solution of the discrete stochastic model algorithmically [Krull, Horton, 2009b]. A Proxel is a probability element, which is the basic computational unit of the state-space based analysis method [Krull, Horton, 2013]. A Proxel P , as shown in equation (8), is a point S in the expanded system state space. It includes information about the discrete system state dS , the age of the relevant transitions $\vec{\tau}$, which extends the discrete system state dS for a certain point in simulation time t and the probability of this combination p [Krull, Horton, 2009b]. Additionally, it is possible to store the route R of the system states which created a certain proxel [Krull, Horton, 2008]. Proxels are created only at discrete points in time. Thereby, the probability of any state change activation within one time step is given by the earlier mentioned instantaneous rate function (IRF) (4) [Krull, Horton, 2009b]

$$P = (S, p) = ((dS, \vec{\tau}, t), p) \quad (8)$$

For each Proxel generated, the algorithm works recursively to compute all possible successors (system states) for each discrete point in time and the firing probability of the relevant state transitions. This would build a tree of Proxels, wherein every proxel, located at the same remoteness from the tree root, is generated in the same time step. Therefore

each Proxel leaf would represent a possible state, which could be reached when the simulation process is finished [Buchholz, Krull, 2010].

The recently introduced Proxel-based simulation is a state space-based simulation approach, which is based on discrete-time Markov Chains (DTMC) [Krull, Horton, 2009b]. It is used to compute transient solutions for discrete stochastic systems, since it depends on a user-definable discrete time step and calculates the probability of all possible changes in a time step, even it takes into consideration the case of no change happening at all [Buchholz, Krull, 2010]. As mentioned previously these addressed states with their probabilities are gathered as Proxels. Accordingly, Proxel-based method deterministically explores and quantifies all the possible system development paths through a discretization of time and assigns them probabilities [Krull, Horton, 2008]. Therefore, it is well-feasible to analyze HnMMs, whereas each route between the Proxel tree root and a leaf describes a possible state sequence (path) of the underlying simulation model [Buchholz, Krull, 2010].

2.4.2 Proxel-based Evaluation of HnMM

The evaluation task is generally employed to compute the probability of a given trace generated by a given model. It is done through concluding the most likely model, which produced the observable sequence of symbols (trace) [Krull, Horton, 2012]. In case there are more than one considerable model, then the model with the highest trace probability will be presumed as the most likely model that generated the trace [Krull, Horton, 2012].

As stated previously a Proxel holds all the information required to estimate the future progress of a system. In the case of HnMM, the Proxel algorithm will take both a fully specified HnMM and a trace consists of output symbols with time stamps as the algorithm inputs [Krull, Horton, 2008]. The Proxel algorithm begins at the initial system state with probability 1. Then based on the present state and age of the relevant active transitions, it determines in discrete time steps the next possible successors and their state change possibilities [Krull, Horton, 2012]. In parallel, the validity regarding the corresponding trace is examined in order to add its sequence of output [Krull, Horton, 2008]. This is done by testing the generated successor Proxels for their capability of generating the given trace, where only valid ones are stored and pursued further [Krull, Horton, 2008]. A successor state is valid, if there is a symbol where the present path might produce it, or if

there is no symbol existed and the present path might not produce any [Krull, Horton, 2012]. However, the system development paths, which couldn't have emitted the given trace are neglected in order to save memory [Krull, Horton, 2008]. Therefore, all the states compassed at the end of the output sequence are the end states of the possible development paths [Krull, Horton, 2012]. The probability of these paths should be summed up, which gives the overall probability to produce the given trace by the corresponding model [Krull, Horton, 2008]

2.4.3 Proxel-based Decoding of HnMM

The Decoding task is to conclude the most probable path correlated to a given output sequence. Namely, it computes most likely the system internal behavior that produce the given system trace [Krull, Horton, 2012]. So in the application of Proxels to HnMM, the most important is to pursue the future development of the system that could have generated the desired trace [Krull, Horton, 2012]. Therefore, any invalid Proxel, which could not have produced the desired output sequence or could give a distinguish result, would be neglected and there is no need to pursue further more [Buchholz, Krull, 2010]. As a consequence, this will save the memory, decrease the number of child Proxels generated per each step and reduce the comprehensive computational effort [Buchholz, Krull, 2010, 2010; Krull, Horton, 2008].

As a matter of fact, since the output sequence and the timestamps at which they have been produced are already known, the times of the state changes happening is also known ahead. If a symbol output emission occurred, the probability to stay in the certain state is always zero, thus a state change have happened [Buchholz, Krull, 2010]. Not to mention, in order to execute the decoding task, it is essential to store the route information, which is the path including all state changes that led to a given Proxel [Krull, Horton, 2008]. Yet this is not the case in most Proxels implementations, where only the current path is stored [Buchholz, Krull, 2010]. However, storing the route information will result a memory overflow by increasing the storage space required per Proxel significantly. Solving this problem could be possible in the original Proxel algorithm, where merging Proxels with the same state and age per time step is allowed by adding their probabilities. This approach will not only save memory but also the computational power of generating Proxels children and grandchildren and so on. Unfortunately, this is not combatable with the concept of saving the route of information [Krull, Horton, 2008]. Since it is almost

impossible to join Proxels with the same state and age but with different historical paths, a new method were developed to combine the routes of two Proxels sharing the same discrete system state and age. This would reduce the number of generated Proxels but not the state space, which is still considered quite large [Krull, Horton, 2008]. Additionally, in the case of HnMM the probabilities of the successor Proxels should be calculated as conditional probabilities, since the probability of a state change should be computed under the circumstances that the relevant trace symbol has been produced at a certain time. Accordingly, the state change probability should be multiplied by the probability of producing the corresponding trace symbol [Buchholz, Krull, 2010].

At the end of the Proxel HnMM algorithm, a Proxel tree is built. This tree represents all the development possible paths that the system could follow to create the given trace. In essence, each path between a Proxel leaf and the root describes a sequence of state changes that would have generated the certain trace, where the probability of the path is stored as the probability of its Proxel leaf [Buchholz, Krull, 2010]. Therefore, by using the Proxel tree, which includes all the essential information to solve the HnMM, It is possible by backtracking step to conduct the most probable internal behavior of the system which generated the trace [Krull, Horton, 2008].

It is very promising what the recently introduced combination of HnMM and Proxel-based method is capable of. The potential application fields of this approach are manifold [Buchholz, Krull, 2010]. For instance, this combination can be used to retrace the unobservable behavior of discrete stochastic systems based only on recorded system output [Buchholz, Krull, 2010]. More precisely, it can extract originally hidden information from noisy or even ambiguous output system protocols [Buchholz, Krull, 2010], which will exploit the undiscovered richness of already recorded data and add more significance to the acquired information. All these advanced abilities form the main concept of the virtual stochastic sensor paradigm to reconstruct the behavior of PODS systems [Krull et al., 2011; Buchholz, Krull, 2010]. Test simulations scenarios and controlled experiments were executed to show its capability in real life and to give it a sufficient validity. However, the generated data set were whether artificial or tediously collected. Therefore, constructing the proposed technical approach is very reasonable. In the following chapter the technical approach and its implementation are demonstrated.

3 The Technical Approach Implementation

As mentioned earlier, the basic goal of this work is to build a technical approach that can participate as a constructive element in many VSS test bed scenarios. The RFID technology appears to be a robust candidate to take a part in such test beds due to its ability to store reasonable amount of information, unique identification and the ability to be reprogrammed [Pop, Mailat, 2009]. Moreover, the advanced miniaturization of RFID tags alongside with their incredible drop in costs [Uckelmann et al., 2011], make the utilization of RFID technology and its procedure in VSS test beds feasible to emulate physical sensors and their operations in real system.

The proposed technical approach should be built on a concept of reaching a sufficient availability in the research community. Therefore, it is designed to function using easily reachable devices and modest technology, so researchers and experimenters can employ it seamlessly in their experiments. Smartphones nowadays are a ubiquitous technology since they are easily purchased and carried by almost everyone. Accordingly, the proposed concept is to design a multi-terminal technical approach based on a smartphone device that supports the NFC technology, in which an RFID sensor application will be integrated and connected to a central data base hosted on a server or a computer system. The acquired sensor data associated with their recorded time stamps will be stored in a central database hosted on the computer system and the stored information will be retrieved and displayed for the researcher.

Furthermore, a concise clear user interface is built to enable the researcher to use the RFID sensor application, which allows him\ her to select the experimental scenario and other important features related to the experiments. Thereafter, the acquired experimental data is stored in an external central database built in a host computer system. Therefore, a local wireless connection is utilized to connect the integrated RFID sensor application in the smartphone with the central database.

Due to the availability of smartphones and prevalence of wireless connections, this approach will be able to participate as an efficient element in many VSS test bed scenarios, which require the implementation of the RFID technology to execute their experiments.

3.1 The Required Technologies for the Proposed Concept

To reach the proposed multi-terminal concept, this technical approach is constructed using a combination of a desktop application, an SQL server database, a windows communication foundation (WCF) service and the particular developed Android application for labeling and reading the RFID tag as it is shown in Figure 1.

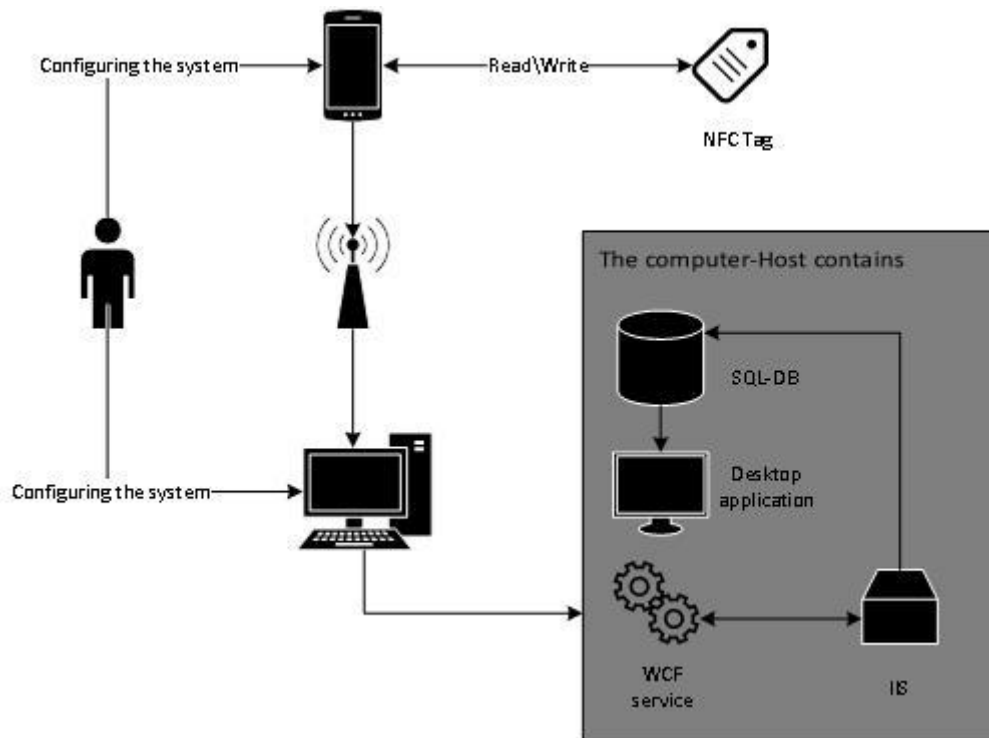


Figure 1: The Schema of the Technical Approach

First the particular Android application for reading RFID tags is designed based on the Xamarin technology tool using Visual Studio and C# programming language. The Xamarin development platform technology enables the developer to code and design an application using one single programming language for targeting all three supported mobile platforms: iOS, Android and Windows Phone with the ability of publishing it to Google Play or Apple Store [Petzold, 2014, p. 8].

The Xamarin platform is by definition “a platform built to provide a single language, C#, for the development of apps. Xamarin uses the Mono Framework to execute compiled C# source code on the different platforms. Xamarin integrates seamlessly with Visual Studio, but Xamarin does also provide its own integrated development environment (IDE) – the Xamarin Studio. Xamarin 2.0 was released in early 2013 and was the first unified

Xamarin platform, which embraced before separate iOS, Android and OSX development tools. The Xamarin platform could then support C# code-sharing across device platforms” [Nielsen, 2015]. Furthermore, Mono is “an open source project that provides a C# compiler and CLR on non-Windows operating systems. Mono runs on Mac, Linux, BSD, and other operating systems. Along with the C# compiler, additional languages run on Mono, including F#, Java, Scala, Basic, and others” [McClure et al., 2012, p. 3].

By using Xamarin.Forms a developer can target at the same time all the three supported mobile platforms. However, the targeted platform alongside with the corresponding Xamarin platform package should be compatible with the developer’s hardware and software requirements. For instance, in case the intended device is an iOS device, a Mac with an installed Apple XCode is required as well as the Xamarin platform. However, targeting Android devices require Visual Studio on a PC or Xamarin Studio on a PC or a Mac [Petzold, 2014, p. 8]. Noteworthy is that a developer must be aware of the different versions of Android operating system for instance some Android devices are running on Android 4.0.3 version and others may run on 4.4.2 version [McClure et al., 2012, p. 10]. For test reasons this application will be built to run on Android 4.0.3 operating system and the later coming versions.

Since some NFC devices can interact with HF RFID tags that are compatible with ISO 15693 [Francis et al., 2010], in this Android application Xamarin.NFC library is used to enable the application to write\ read the RFID tag by employing the NFC technology embedded in the smartphone. However, after testing various Android smartphones devices in order to read the RFID tags, some could not identify the tags or read them as empty tags. Therefore, RFID tags were replaced by NFC tags, where NFC technology is regarded as special subset of RFID technology and operates at the frequency (13.56MHz) which belongs to the High frequency category in RFID systems [Juntunen et al., 2010; Ozdenizci et al., 2011]. This replacement will not affect the main goal of the proposed technical approach or the possible test bed scenarios.

Furthermore, a clear user interface is designed to allow the researcher to configure the experimental system as illustrated in Figure 2. The researcher is able to identify the IP-address of the server that hosts the WCF service, select the test bed scenario, write the Tag-ID as a pre-configuration step, and define the Sensor-ID and insert the relevant symbol. In order to reach a sufficient user controlled interface, configuring the experiment

system is done manually to give the researcher enough flexibility and the ability to use the same smartphone as a different sensor, redefine the Tag-ID and insert the right symbol that will be generated as the combination of reading a specific Tag-ID by a certain Sensor-ID.

The most important step is to create in the Android application a connection using the http protocol to the windows communication foundation (WCF) web service hosted through an internet information system (IIS) process to enable reading from and writing data to the SQL database.

Secondly, an SQL server is employed to build the central database in the host computer system. Microsoft SQL Server is a relational database management system, which is able to utilize the computer device as a database server and permits applications to interact with the database using connection strings in order to insert update into the database and retrieve information from it. Therefore, SQL server database is used to store all the sensor data that will be acquire during the test bed execution using the Android NFC sensor application in a table as shown in Figure 3. Moreover, the desktop application will retrieve the collected data from this database table and display it as experiments results.

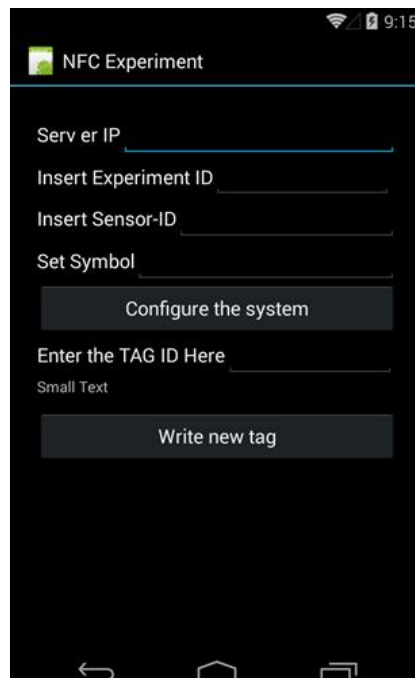


Figure 2: Application User-Interface

Table-Semantic			
	Column Name	Data Type	Allow Nulls
🔑	Entry_ID	int	<input type="checkbox"/>
	Experiment_ID	nvarchar(MAX)	<input checked="" type="checkbox"/>
	Sensor_ID	nvarchar(MAX)	<input checked="" type="checkbox"/>
	Tag_ID	nvarchar(MAX)	<input checked="" type="checkbox"/>
	Symbol	nvarchar(50)	<input checked="" type="checkbox"/>
	TimeStamp	datetime	<input checked="" type="checkbox"/>
			<input type="checkbox"/>

Figure 3: Database Table

It is not possible to build a connection between an Android application and a database hosted on another physical place, for instance on a server or another computer system due to security issues. There is no secure connection between the Android RFID sensor application and the SQL Server, which makes the transferred information between both sides vulnerable against hacking. Therefore, constructing the proposed technical approach demands the utilization of WCF web service.

WCF is “a software development kit for developing and deploying services on Windows. It is literally a better .NET. WCF provides a runtime environment for your services, enabling you to expose Common Language Runtime (CLR) types as services and to consume other services as CLR types. Although in theory you could build services without WCF, in practice, building services is significantly easier with WCF. WCF is Microsoft’s implementation of a set of industry standards defining service interactions, type conversions, marshaling, and the management of various protocols. Consequently, WCF provides developers with the essential off-the-shelf plumbing required by almost all applications and, as such, it greatly increases productivity” [Lowy, 2010, p. 1].

Every WCF service is governed by a combination of three elements Address, Binding and Contract that are regarded as the ABC of the service. These triumvirate elements are fused together to construct the endpoint of the service. Therefore, the endpoint is regarded as the service’s interface, where the client uses the endpoint to connect to the service. The address determines where the service can be found, the address is the URL that labels the device and the endpoint on that device. The binding describes how the connection with the service will be, it describes the protocol combination that can be employed to connect the endpoint. The contract determines what the service does, namely it determines which service contracts the WCF service class [Lowy, 2010, p. 29; Chappell, 2010].

However, as it is stated in [Lowy, 2010, pp. 11–12], “the WCF service class cannot exist in a void. Every WCF service must be hosted in a Windows process called the host process. A single host process can host multiple services, and the same service type can be hosted in multiple host processes. The host can be provided by Internet Information Services (IIS), by the Windows Activation Service (WAS) on Windows Vista or Windows Server 2008, Windows 7 or later, on the Windows Server AppFabric, or by the developer as part of the application”.

Therefore, a connection between the database and the Android application should be created by employing WCF web service. This web service will be hosted through an IIS, on this service the connection between database and WCF web service will be created with all the required functions (read and write to database tables).

Furthermore, an endpoint will be established in order to be utilized by any other application using http or https protocol as shown in Figure 4 [Chappell, 2010]. By implementing this web service an indirect connection between the Android application and the database will be created.

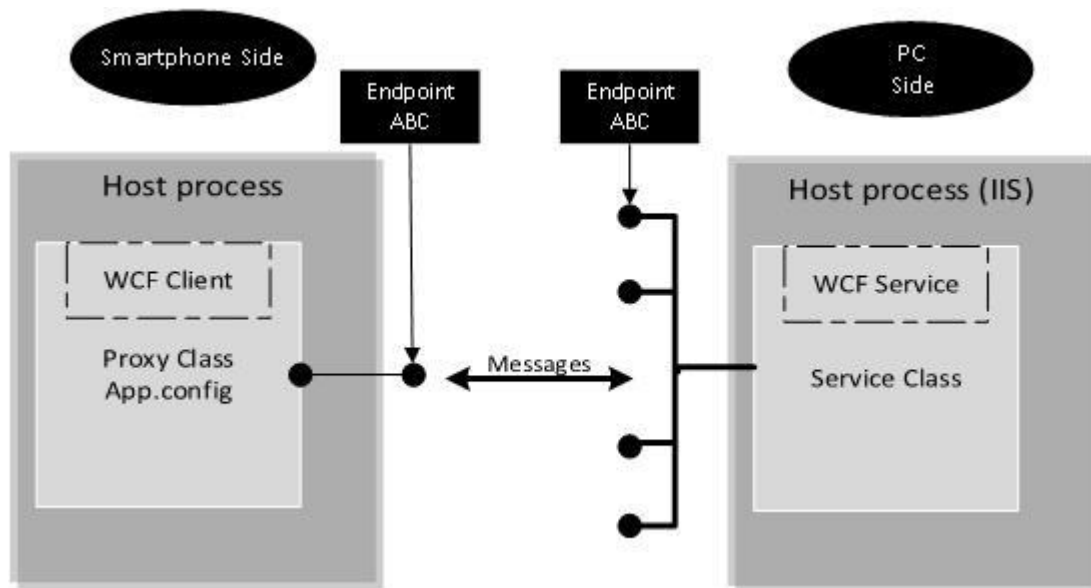


Figure 4: The Endpoint used by a Client to access the WCF Service, modified from [Chappell, 2010]

Eventually the proposed approach will require a desktop application. The employed desktop application is built using C# programming language to display all the results of the test bed, which has been collected by the utilization of the Android application and stored in the SQL database.

3.2 Setting up the Technical Approach

As mentioned earlier, for security and performance reasons it was not possible to connect directly the Android application in the smart phone with the SQL database hosted on the computer system. Therefore, a WCF web service was employed as a bridge between the Android application and the database. To structure the technical approach the four components mentioned earlier were built.

However, to accomplish a working technical approach, these components must be connected to each other. More precisely, the WCF service hosted in the IIS process should be connected to both the SQL database and the Android application to insert the acquired sensor data to the database. Furthermore, the connection between the SQL database and the desktop application should be configured to be compatible with the host computer system. Additionally, the IIS host process requires certain commands to adopt the incoming connections.

Therefore, all the needed commands and the required configurations to setup the technical approach will be demonstrated in the following steps:

1. Connecting the WCF with the SQL database: The connection was defined by a connection string as illustrated in Figure 5. Nevertheless, to configure the system in another host server, the researcher has to change the connection string inside the code to match the right server name and database name.

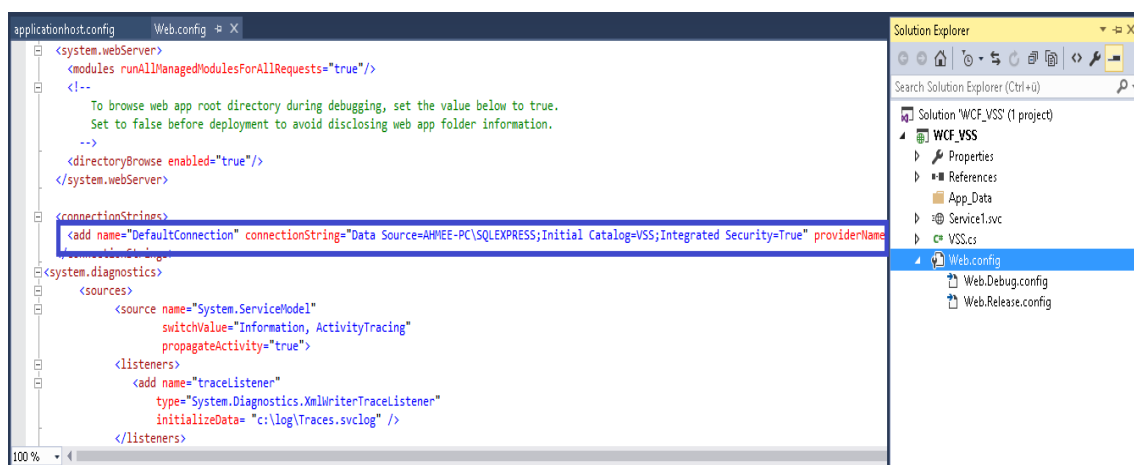


Figure 5: Connecting WCF with SQL Database

2. Adding a new binding: The WCF service accessible through the network. Therefore, a configuration of a remote access to IIS Express that hosts the WCF service is done by making IIS Express accept remote access by changing the configuration in “application.host.config”. Later on a new binding should be included to the bindings’ part through adding a new code line as demonstrated in Line 1. This code line specifies the IP-address of the server and a certain port number where the chosen port number can take values between (1, 60000), as shown in Figure 6.

<binding protocol="http" bindingInformation="*:Port Number:IP-address"/> Line 1

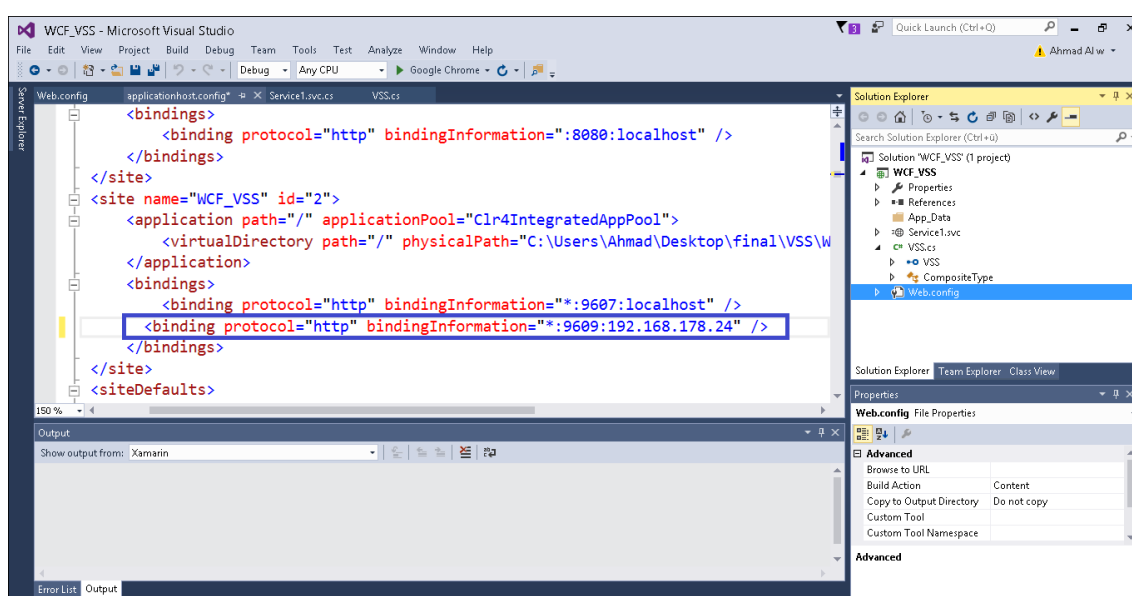


Figure 6: Adding New Binding

3. Configuring the IIS: The IIS should accept the incoming connection through the port defined earlier. Therefore, the command prompt (cmd) as administrator should be used to run the following specific command described in cmd 1.

netsh http add urlacl url=http://IP-address:Port/ user=everyone cmd 1

Noteworthy is that defining the “user” as “everyone” might differ from one device to another depending on the language of the computer system that is used as the server. Since the employed server is a German server, the word “everyone” was replaced by the word “jeder”, as shown in Figure 7.

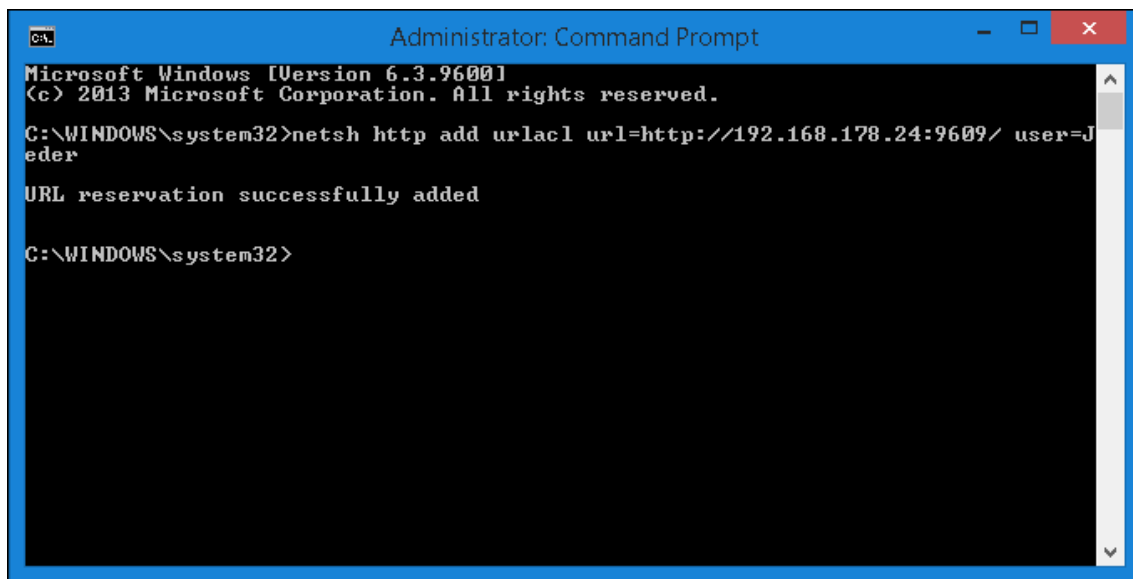


Figure 7: Configuring the IIS

4. Opening the connection port: The targeted port is the one that was used earlier to configure the IIS, where this port should allow the connection to pass through it. Therefore, the port needs the permission to open by running another specific command described in cmd 2. The command prompt (cmd) as administrator should be used again to run this command as it is shown in Figure 8.

```
netsh advfirewall firewall add rule name="IISExpressXamarin" dir=in  
protocol=tcp localport=Port profile=private remoteip=localsubnet action=allow
```

cmd 2

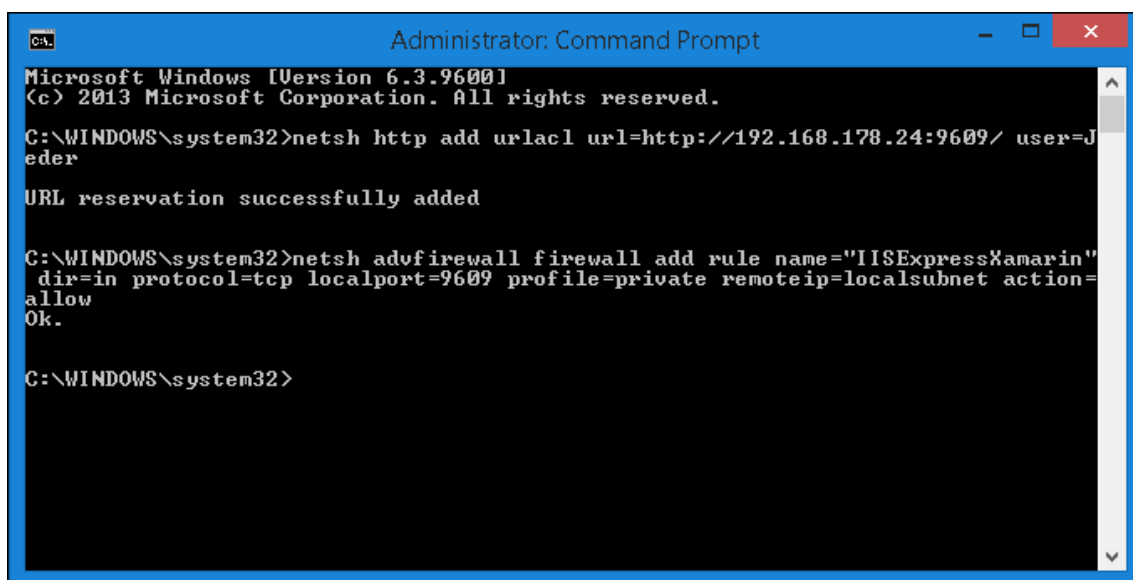


Figure 8: Opening the Connection Port

5. Connecting the desktop application with the SQL database: In the desktop application a form was created, which includes the Grid View tool, this tool will display the sensor data which has been stored in the database as the experiment results. Therefore, it is necessary to connect the desktop application with the SQL database to retrieve the stored data in the database by defining the connection string inside the code with the relevant server name and database name as shown in Figure 9. Additionally, two buttons were added to the form for refresh and exit, by clicking on the Refresh button the last update from the database will be displayed and by clicking on the Exit button the desktop application will be closed, which is illustrated in Figure 10.

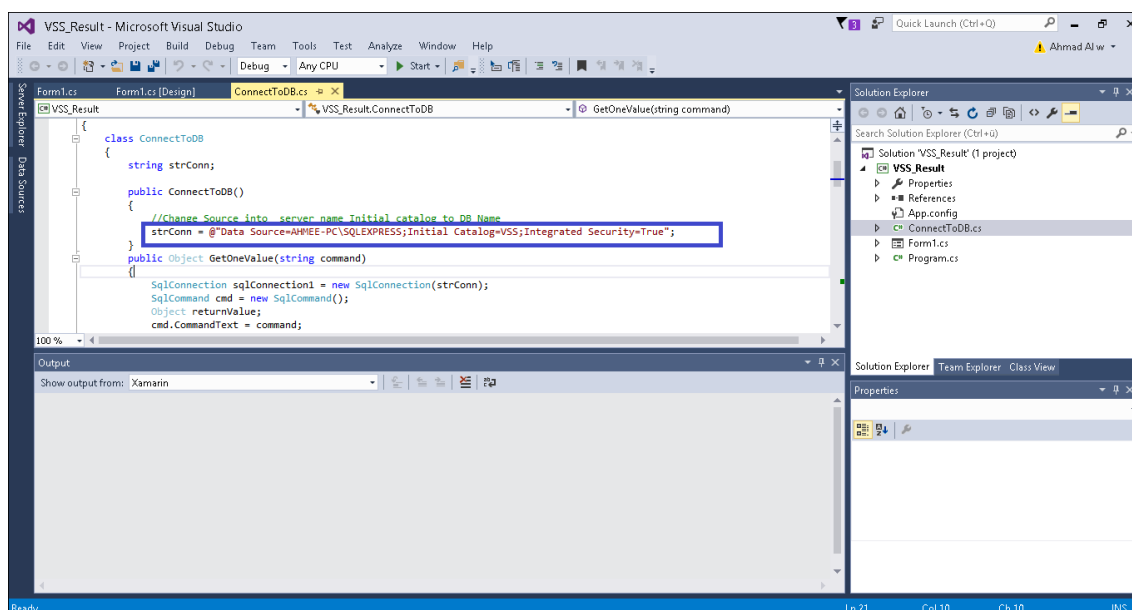


Figure 9: Connecting Desktop Application with SQL Database

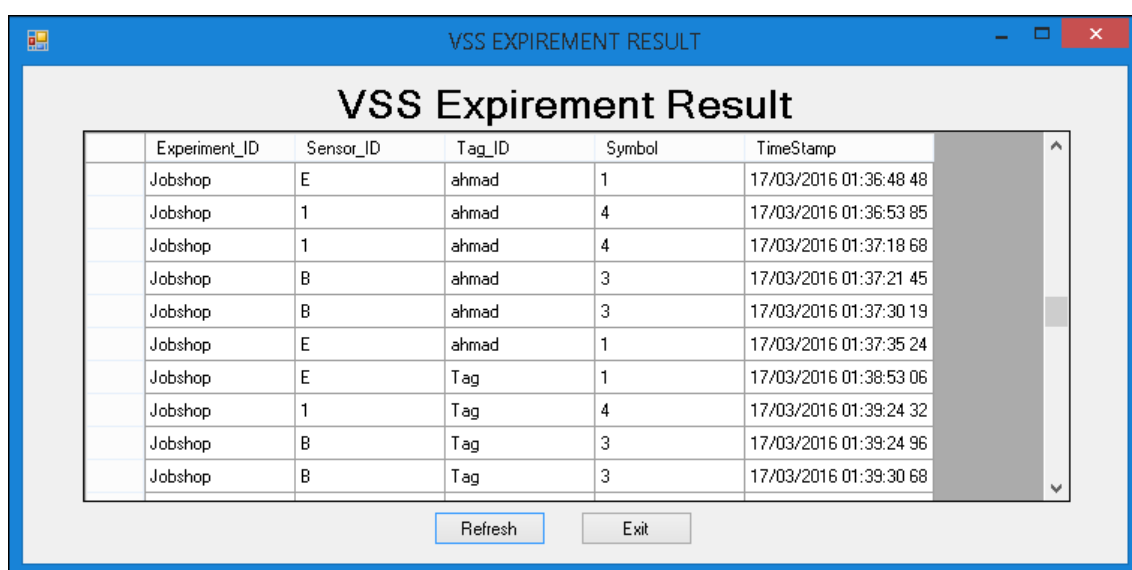


Figure 10: Display the Experiments Results

6. Connecting the Android application with the created WCF: The IP-address and the chosen port number of the server that hosts the WCF service must be inserted by the researcher using the application user interface as shown in Figure 11.

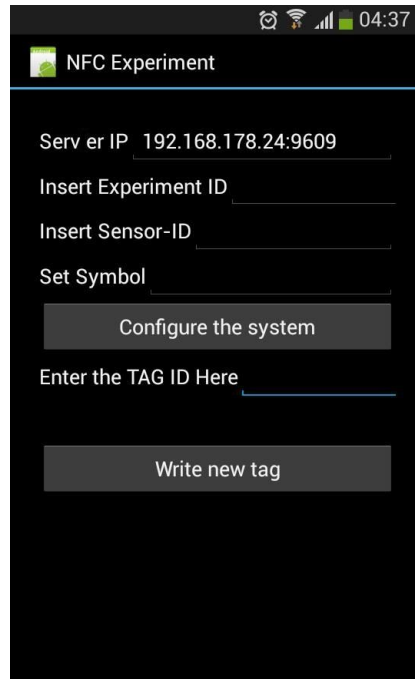


Figure 11: Defining the IP-address and the Port Number in the Application

By running the needed commands and applying the required configurations through the sequence of steps demonstrated earlier the technical approach has functioned properly as planned. Moreover, the developed Android application is tested to be compatible to run on different Android smartphones with the operating system version 4.0.3 or the later coming versions. Furthermore, this technical approach has accomplished the sought concept of achieving a sufficient level of simplicity and availability. The required equipment are just a smartphone device that supports the NFC technology, a computer system, local wireless network and a number of NFC tags that are attached to movable objects to generate and collect experimental data in various experiment applications. Therefore, this technical approach possesses the qualifications to contribute as a key element in many VSS test bed scenarios. In the following chapter a validation of the capability of this technical approach and a test of its functionality will be presented. Therefore, the technical approach will participate in one of the VSS test bed scenarios, where it will be employed to generate the experimental data set and store the acquired sensor data to be later on used in the HnMM and Proxel-based method implementation.

4 Experiments to validate the Test bed

To verify the functionality of the earlier demonstrated technical approach and to give it a sufficient degree of credibility, it has been employed in one of the test beds of VSS. The chosen example application is described in [Krull, Horton, 2013]. It was designed to simulate the implementation of VSS in a job shop production environment. As stated in [Krull, Horton, 2013], the targeted example application was built in cooperation with logistics experts to emulate a real existing job shop, this was illustrated by a realistic workshop layout. The printed workshop layout consists of various workplaces with different machines and storage areas. The highlighted locations refer to the different workplaces (1, 2, 3) and storage areas (A, B, C) alongside with the entrance\ exit area (E) as illustrated in Figure 12 [Krull, Horton, 2013].

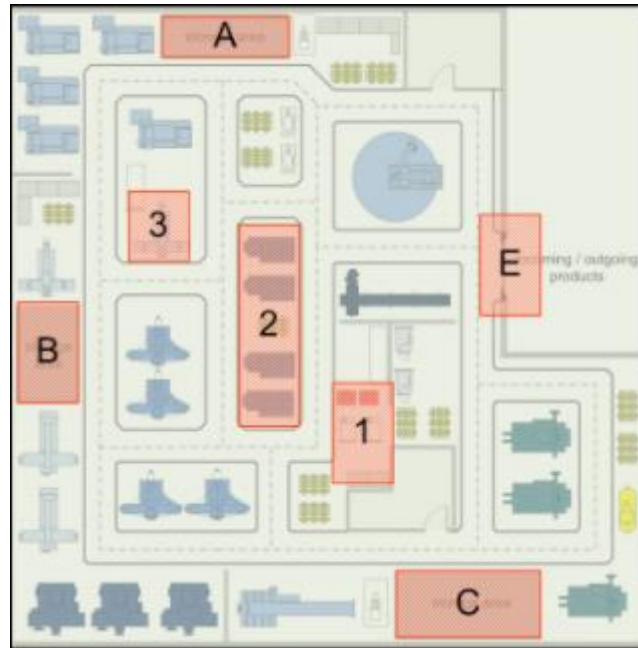


Figure 12: Example of Workshop Layout

4.1 The Experiment Preparation

The technical approach described earlier was used in this experiment setup to collect the experimental data and store it in the central database, which is hosted on a computer system. Therefore, four smartphones, on which the developed Android application was installed, were located at the neuralgic points of the printed workshop layout. The selected locations for these smartphone sensors were the entrance\ exit E area, the storage areas A

and B alongside with the workplace 1 as defined in [Krull, Horton, 2013]. Noteworthy is that the smartphones should not be placed faced down, since such position could turn off the smartphone, and therefore they were placed in a horizontal or vertical upstanding positions. Additionally, the screen lock needs to be set to minimum ten minutes so the smartphone will not turn off during the execution of the experiment. As mentioned earlier, since some smartphones could not read RFID tags or even identify them, NFC tags were used as an equivalent replacement of the RFID tags. This alteration did not affect the purpose of the experiment or the main goal of the proposed technical approach. Therefore, NFC tags were labeled to be handled as a single order over the printed workshop layout.

By using the write ability in the developed Android application, distinct IDs were written on the NFC tags, where each Tag-ID was associated to a certain known job in the workshop as a pre-configuration step before starting the experiment. Initially, the Tag-ID should be written using the user interface as shown in Figure 2. Secondly, the “Write new tag” button should be clicked for the first time to prepare the NFC technology embedded inside the smartphone for the write mode. Subsequently, the same button should be pressed again and held while passing the smartphone over the tag to transfer the desired information to the tag. As described in [Krull, Horton, 2013], every sensor generates a certain symbol when a tag is identified in its reading range as shown in Table 1. Similarly, in the Android application each smartphone sensor was defined by a distinct Sensor-ID. Furthermore, the Android application is able to link the Sensor-ID with the right symbol and associate it with a time stamp, which is the time of identifying the tag by the smartphone with 1-second accuracy. In order to add the flexibility factor the configuration of the Sensor-ID with the corresponding emitted symbol was done manually by using the simple user interface in the developed application as illustrated in Figure 14.

Table 1: Sensor-ID with the corresponding generated Symbol

Sensor-ID	The Emitted Symbol
E	1
A	2
B	3
1	4

The example application was conducted in the Otto-von-Guericke University (OVGU). Since this technical approach works over a wireless local area network, its four

components: the IIS server, the SQL server, the desktop application as well as the smartphone sensor application must be connected through the same network. However, there was a problem in connecting to the system server due to the OVGU network infrastructure, where a firewall is applied over the network that prevents the package from passing through the network into the server. Therefore, a local router device was used and configured to work as DHCP, and thereby the server was given a static IP-address.

As recapitulation, the following steps should be done so the application is ready to be used in the experiment setup:

1. Connecting the four components with the same network using a router device.
2. Defining each NFC tag with a unique Tag-ID using the “Write new tag” button.
3. Configuring each smartphone by specifying the targeted experiment, inserting the distinct Sensor-ID and setting the corresponding emitted symbol.
4. Detecting the given IP-address of the server that hosts the WCF service as shown in Figure 13, thereafter, inserting it with the earlier specified port number.
5. The “configure the system” button should be pressed to regulate the smartphone for reading the tags and send the acquired sensor data with the corresponding time stamps to the SQL database as shown in Figure 14.

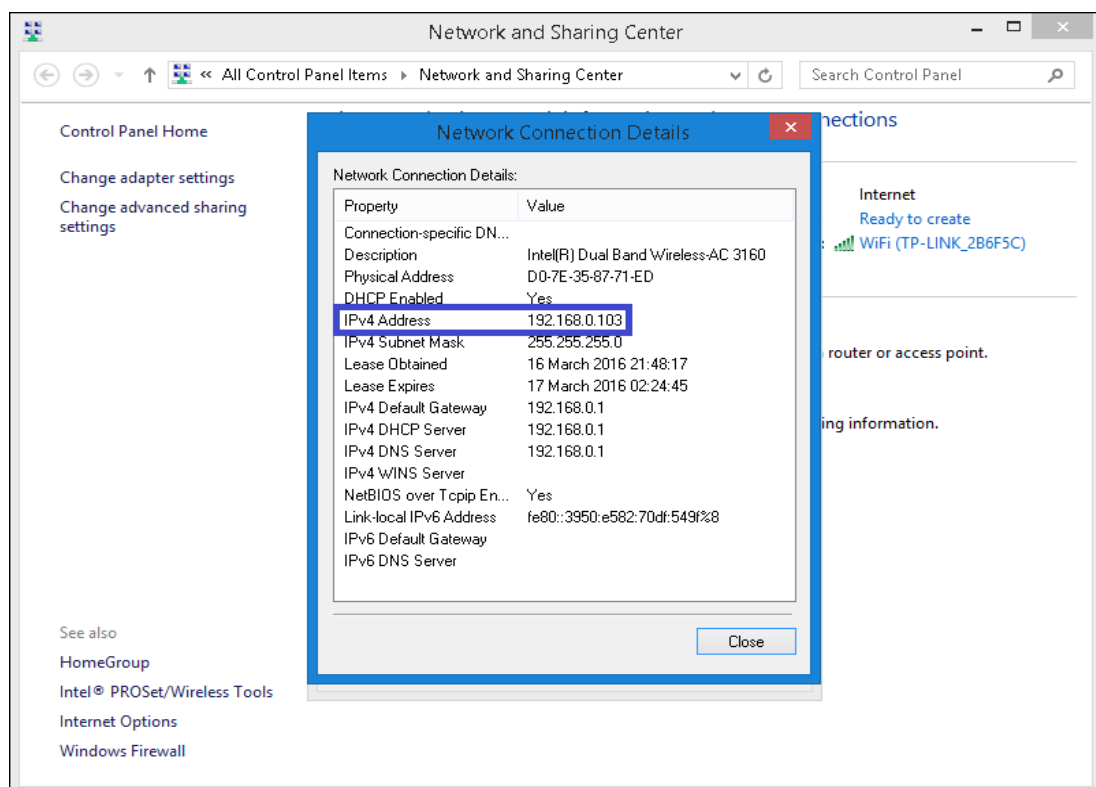


Figure 13: Detecting the IP-address of the Server

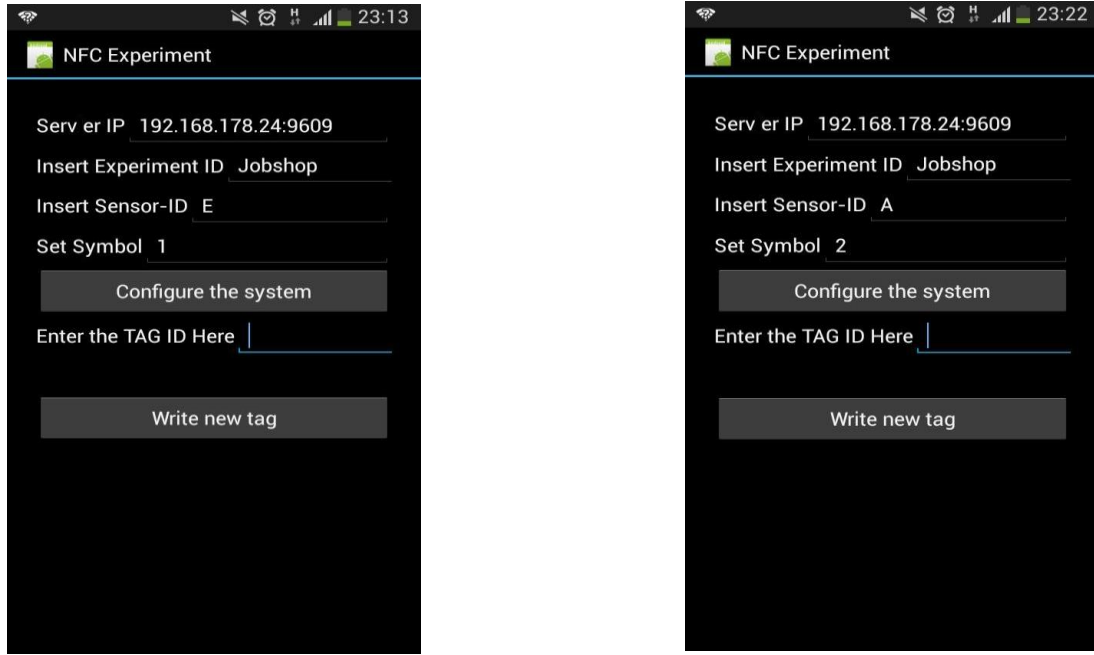


Figure 14: Configuration of the Android Application

4.2 The Experiment Execution and the Results

The acquisition of the sensor data was done through manual handling of the NFC tags over the previous described experiment setup including the four smartphone sensors located on the four neuralgic points. Therefore, a stopwatch was required to control the processing times, where the real system times were scaled down to seconds as the experiment time unit. As stated in [Krull, Horton, 2013], the time periods of the processing steps in the workplaces (1, 2, 3) have Uniform distributions. The duration of moving NFC tags over the workshop layout alongside with the leaving and entering times were considered to be normally distributed with a mean value of three seconds and a standard deviation of two seconds. The period of times spent in the storage areas were assumed to be arbitrary, and therefore associated with exponential distributions.

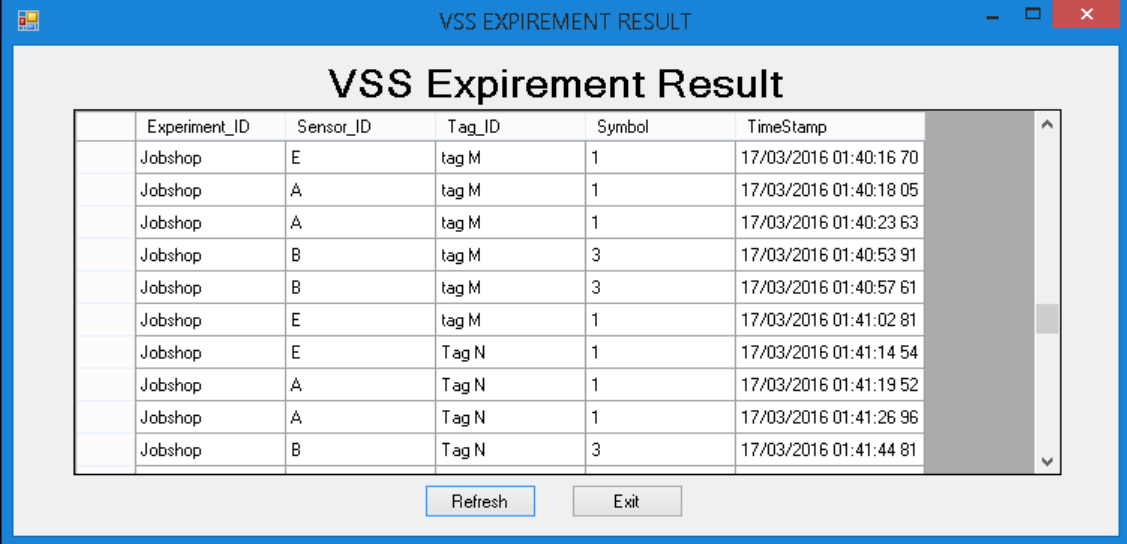
Since the NFC technology operates in a very short wireless range at frequency of (13.56MHz) [Reveilhac, Pasquet, 2009], the NFC tags must pass in a very close distance to the smartphone to be identified. Every single tag must be scanned twice by each smartphone sensor to emulate the process of entering and leaving the sensor reading range and to record the corresponding identification times. Each tag was manually advanced through a predefined path between different workplaces and storage areas over the printed

workshop layout. The tag was progressed and placed on the workshop locations along its predefined path according to the corresponding earlier mentioned times until the workflow is completed. Every predefined workflow path includes one or two processing steps, at least one storage step and starts\ends with the entrance\exit location to resemble their equivalent workflows inside the existing prototypal workshop [Krull, Horton, 2013]. The Tag-IDs with the corresponding predefined workflow paths and the Uniform distributions of the processing times in the workplace areas are shown in Table 2.

Table 2: Tag-IDs with their Workflows path and the relevant Processing times

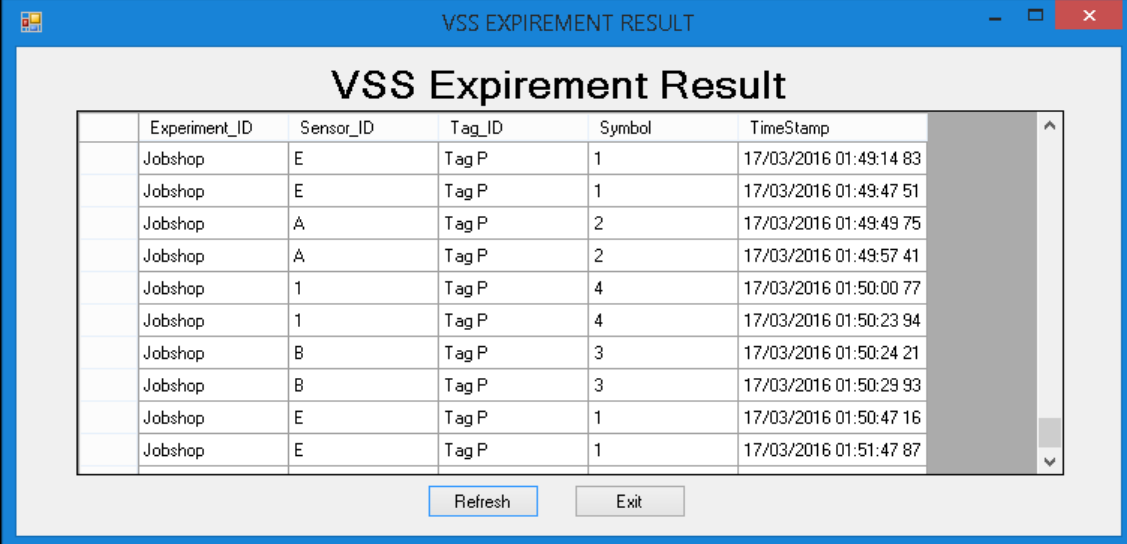
Tag K	E-C-1-E	Step 1~ Uniform (20s, 30s) Step 2~ Uniform (10s, 20s) Step 3~ Uniform (15s, 25s)
Tag L	E-C-1-B-E	
Tag M	E-A-2-3-B-E	
Tag N	E-A-2-B-3-E	
Tag O	E-A-1-2-B-E	
Tag P	E-A-1-B-2-E	

The acquired sensor data with their recorded timestamps were stored in the SQL server database, where the sequence of pairs of (Symbols, Timestamps) represent the trace of each workflow. The stored information was retrieved and displayed by the desktop application as shown in Figure 15. Later on a single trace was chosen in order to reconstruct the corresponding path that produced it. The chosen trace was the trace that was generated by executing the workflow path of tag P as shown in Figure 16.



Experiment_ID	Sensor_ID	Tag_ID	Symbol	TimeStamp
Jobshop	E	tag M	1	17/03/2016 01:40:16 70
Jobshop	A	tag M	1	17/03/2016 01:40:18 05
Jobshop	A	tag M	1	17/03/2016 01:40:23 63
Jobshop	B	tag M	3	17/03/2016 01:40:53 91
Jobshop	B	tag M	3	17/03/2016 01:40:57 61
Jobshop	E	tag M	1	17/03/2016 01:41:02 81
Jobshop	E	Tag N	1	17/03/2016 01:41:14 54
Jobshop	A	Tag N	1	17/03/2016 01:41:19 52
Jobshop	A	Tag N	1	17/03/2016 01:41:26 96
Jobshop	B	Tag N	3	17/03/2016 01:41:44 81

Figure 15: An Excerpt of the Acquired Sensor Data with the Corresponding Time Stamps



VSS Expirement Result

Experiment_ID	Sensor_ID	Tag_ID	Symbol	TimeStamp
Jobshop	E	Tag P	1	17/03/2016 01:49:14 83
Jobshop	E	Tag P	1	17/03/2016 01:49:47 51
Jobshop	A	Tag P	2	17/03/2016 01:49:49 75
Jobshop	A	Tag P	2	17/03/2016 01:49:57 41
Jobshop	1	Tag P	4	17/03/2016 01:50:00 77
Jobshop	1	Tag P	4	17/03/2016 01:50:23 94
Jobshop	B	Tag P	3	17/03/2016 01:50:24 21
Jobshop	B	Tag P	3	17/03/2016 01:50:29 93
Jobshop	E	Tag P	1	17/03/2016 01:50:47 16
Jobshop	E	Tag P	1	17/03/2016 01:51:47 87

Figure 16: The Trace of Tag P with the Corresponding Time Stamps

However, these collected sensor data has to be modified to be sufficient for reconstructing the paths of single jobs in the system. Therefore, the real time stamps were changed to a proper double format through converting the clock time to seconds. To decrease the computational effort, the original values of the time stamps in every trace were reduced where possible [Krull, Horton, 2013], in the chosen trace the time stamps were reduced by -1100. These alterations affected only the total probability of the trace which can be neglected in this regard as shown in Table 3.

Table 3: The absolute\ reduced time stamps values in tag P trace with corresponding probability.

Original values	Symbols	Reduced values	Symbols	Probability
	1	85.5129997	1	1.02E-14
1187.513	1	87.5129997	1	
1189.753	2	89.7530003	2	
1197.41	2	97.4100002	2	
1200.77	4	100.77	4	
1223.943	4	123.943	4	
1224.217	3	124.217	3	
1229.937	3	129.937	3	
1247.163	1	147.163	1	
1307.87	1	149.163	1	

The path reconstruction was done using the HnMM for each single workflow and the Decoding method. Therefore, every single trace was used as the model input, and the method results are the possible paths with their relevant probabilities. The most likely path that generated the corresponding trace is the one with highest probability, which is compared later to the original workflow that produced the trace [Krull, Horton, 2013].

The behavior reconstruction of the targeted path generated 28 possible paths as shown in Figure 17. The first two columns represent the logarithmic and the normal probability of the path, the other columns are pairs of state change timestamps and system states, where the first row in the table is the path with the highest probability.

[illegible]

Figure 17: Possible Generating Paths of the Tag P Workflow Protocol

Based on the protocol, the number of possible paths of the six generated traces took values from less than ten to thousands. Since each Tag-ID in this experiment is related to a certain workflow path (see Table 2) and thereby a corresponding trace, the Tag-ID with the number of the possible paths that could generate its trace are illustrated in Table 4.

Table 4: The Tag-ID with the Corresponding Number of Possible Paths that could generate its Trace

Tag-ID	Number of Possible Paths
Tag K	6
Tag L	6
Tag M	15
Tag N	1204
Tag O	3
Tag P	28

The probabilities of the 28 different paths of the workflow protocol, which generated the trace of tag P is illustrated in Figure 18. Most important is that all the reconstructed possible paths match the workflow E-A-1-B-2-E, which is the workflow path used to produce the trace of tag P.

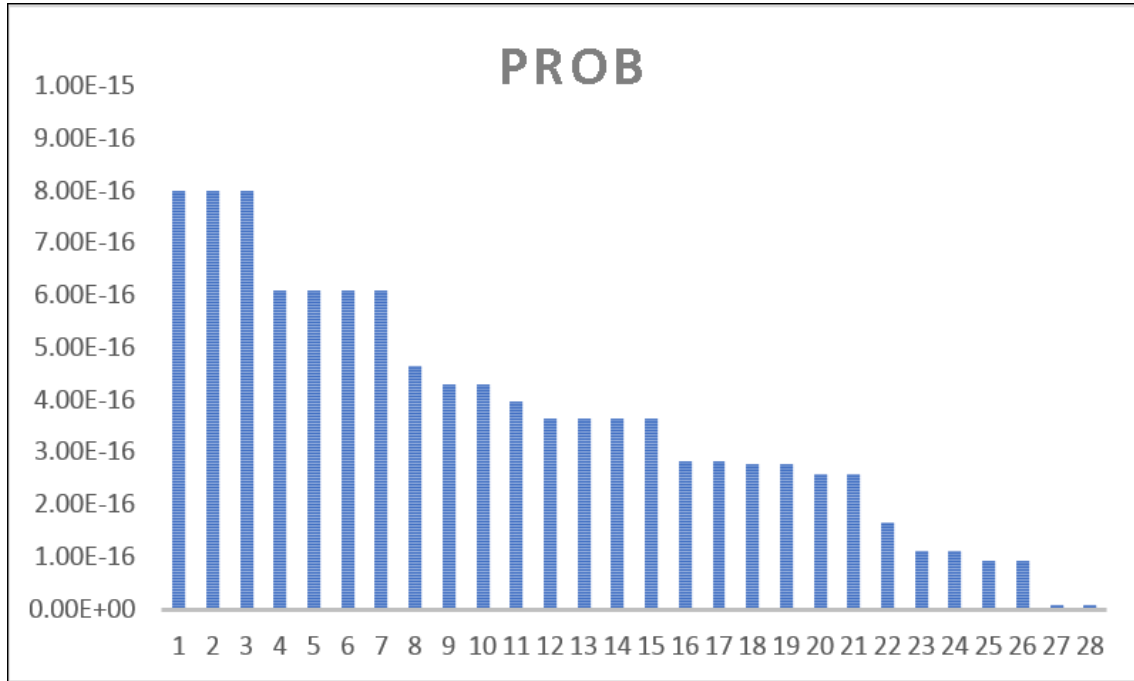


Figure 18: The Probabilities of the Possible Paths in Downward Order for the Tag P Workflow Protocol

The execution of the earlier illustrated experiment verified the functionality of this technical approach and approved its practicability as essential element in one of the VSS test bed scenarios. As mentioned earlier the experiment was conducted in the Otto-von-Guericke University using available modest equipment. The experimental data set were gathered using the technical approach, a realistic workshop layout and manual execution of workflows. By implementing the technical approach the experiment was accomplished seamlessly with high accuracy and within relatively short time.

In contrast to the former methods employed to generate data set in the VSS experiments, which were whether entirely artificial, hardly collected in the real world or downloaded from existing data. The technical approach was capable of generating and gathering realistic experimental data, which was later on used by the VSS to reconstruct the behavior of the partially observable system, and thus the experiment results were more genuine. Therefore, the goal of constructing this technical approach is achieved.

5 Conclusion and Future Work

The fifth chapter recaps all demonstrated concepts, the observed obstacles, the proposed technical approach and the computational results of the conducted experiment. This chapter includes an evaluation of the work, and an outlook on future possible enhancements and the potential implementations.

The proposed technical approach aims to participate as an essential element in a wide variety of VSS test bed scenarios, in which RFID or NFC technology is utilized, to generate and acquire real experimental data. This thesis contains five chapters, which comprise a brief introduction, the formation of the compatible concept, a literature review on the RFID technology, VSS paradigm, the HnMM and the proxel-based simulation method. Finally the construction of the technical approach alongside with its practical implementations are demonstrated.

In the third chapter the significant details of the modeling and the implementation of the technical approach is presented. More precisely, the technical approach is based on a developed sensor application installed on a smartphone that supports the NFC technology and connected to a central database hosted on a server or a computer system.

The fourth chapter demonstrates the execution of a chosen VSS experiment application to validate the functionality of the technical approach. The data generation and gathering process was done through a manual execution of workflows using a realistic printed workshop layout, predefined NFC tags, a central database hosted on a PC and four smartphones, on which the developed sensor application was installed, located in four selected workplace locations. The installed sensor application allows the researcher to define the NFC tags by using the ability of writing on the tag as a pre-configuration step. Furthermore, the four smartphones were able by using the sensor application to identify the NFC tags in their reading range and send the sensor data alongside with the time stamps of the tag identification to the SQL server. In addition, the acquired sensor data associated with their recorded time stamps were stored in the SQL server database hosted on the computer system and displayed as experiment results by the desktop application. Later on these sensor data were used by the HnMM and Proxel-based method to reconstruct the behavior of the partially observable system.

5.1 Evaluation and Future Work

Generally speaking, generating experimental data to evaluate the credibility of a new concept is a very tedious task. Normally, random number generators are employed to generate problem instances, which share a specific form to conduct experimental analysis. However, those generated data often lack real system conditions in essence of being artificial. The potential bias of the random number generator is often unavoidable and the generated data instances contains a certain form of correlation. In addition, other obstacles might come along such as reading errors or unexpected behavior, which are disregarded if not explicitly included in the simulation model. Therefore, the proposed technical approach diminishes those kind of problems and provides a better genuine experimental data generation and gathering, which involves realistic experimental environments. In addition, performing a certain modification on the targeted experiment environment scenario is more flexible, whereby an extra smartphone for instance can be added to emulate a sensor. In contrast, modifying a random number generator to produce another form of the experimental data requires performing in some cases a profound changes in the source code. Furthermore, this technical approach is fully functional to engage in many other test beds which require generating and collecting experimental sensor data. All that a researcher needs is smartphone devices, a computer system and NFC tags that are attached to moveable objects.

Moreover, the technical approach can be extended to include all the different RFID system operating frequencies, so it will be able to identify different types of RFID tags in different reading ranges. Many other possible enhancements on the technical approach can be done for instance overcoming the restriction of connecting all its components over a local wireless network by giving a real IP for the host server and the smartphone, whereby the smartphones and the server can be in different cities or towns and the technical approach can still perform its functions. In addition, it is reasonable to seek further developments on some features that can add more flexibility and availability to this technical approach. For instance modifying the user interface by adding more enhancements to make it more aesthetic, clear and attractive, so the technical approach will be more desirable to be employed in a wider variety of test beds and satisfy a bigger range of researchers' interests in the research community.

References

- Attaran, Mohsen (2004): Exploring the relationship between information technology and business process reengineering. In *Information & Management*, vol. 41 (iss. 5), pp. 585–596.
- Bauer, Martin (Ed.) (1997): *Resistance to new technology: nuclear power, information technology and biotechnology*: Cambridge University Press.
- Bobbio, Andrea; Puliafito, Antonio; Telek, Miklós; Trivedi, Kishor S. (1998): Recent developments in non-Markovian stochastic Petri nets. In *Journal of Circuits, Systems, and Computers*, vol. 8 (iss. 01), pp. 119–158.
- Bolch, Gunter; Greiner, Stefan; Meer, Hermann de; Trivedi, Kishor S. (2006): *Queueing networks and Markov chains: modeling and performance evaluation with computer science applications*. 2nd ed.: John Wiley & Sons.
- Buchholz, Robert; Krull, Claudia (2010): Using hidden non-markovian models to reconstruct system behavior in partially-observable systems. In: *Proceedings of the 3rd International ICST Conference on Simulation Tools and Techniques*. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), p. 86.
- Buchholz, Robert; Krull, Claudia; Horton, Graham (2011): Reconstructing model parameters in partially-observable discrete stochastic systems. In K. Al-Begain, S. Balsamo, D. Fiems, A. Marin (Eds.): *Analytical and Stochastic Modeling Techniques and Applications: 18th International Conference, ASMTA*. Venice: Springer (LNCS sublibrary. SL 2, Programming and software engineering), pp. 159–174.
- Chappell, David (2010): Chappell & Associates (2010). In *Microsoft-Introducing Windows Communication Foundation*, © Copyright Microsoft Corporation, pp. 1–144.
- Coskun, Vedat; Ozdenizci, Busra; Ok, Kerem (2013): A survey on near field communication (NFC) technology. In *Wireless personal communications*, vol. 71 (iss. 3), pp. 2259–2294.
- Finkenzeller, Klaus (2003): *RFID Handbook: Fundamentals and Applications in Contactless Smart Cards and Identification*: John Wiley & Sons.

Francis, Lishoy; Hancke, Gerhard; Mayes, Keith; Markantonakis, Konstantinos (2010): Practical NFC peer-to-peer relay attack using mobile phones. In Siddika Berna Ors Yalcin (Ed.): *Radio Frequency Identification: Security and Privacy Issues: 6th International Workshop, RFIDSec 2010, Istanbul, Turkey, June 8-9, 2010, Revised Selected Papers*: Springer Science & Business Media (6370), pp. 35–49.

Hanks, Steve; Pollack, Martha E.; Cohen, Paul R. (1993): Benchmarks, test beds, controlled experimentation, and the design of agent architectures. In *AI magazine*, vol. 14 (iss. 4), pp. 17–42.

Heredia, Guillermo; Ollero, Aníbal (2010): Virtual Sensor for Failure Detection, Identification and Recovery in the Transition Phase of a Morphing Aircraft. In *Sensors*, vol. 10 (iss. 3), pp. 2188–2201.

Ibargüengoytia, Pablo H.; Reyes, Alberto (2006): Constructing virtual sensors using probabilistic reasoning. In: *MICAI 2006: Advances in Artificial Intelligence*: Springer, pp. 218–226.

Jiménez, Antonio R.; Seco, Fernando; Zampella, Francisco; Prieto, Jose C.; Guevara, Jorge: Indoor Localization of Persons in AAL Scenarios Using an Inertial Measurement Unit (IMU) and the Signal Strength (SS) from RFID Tags. In: Botía, Fujinami et al. (Ed.) *2013 – Evaluating AAL Systems Through Competitive*, pp. 32–51.

Juels, Ari (2006): RFID security and privacy: A research survey. In *Selected Areas in Communications, IEEE Journal on*, vol. 24 (iss. 2), pp. 381–394.

Juntunen, Antero; Luukkainen, Sakari; Tuunainen, Virpi Kristiina (2010): Deploying NFC technology for mobile ticketing services-identification of critical business model issues. In: *Mobile Business and 2010 Ninth Global Mobility Roundtable (ICMB-GMR), 2010 Ninth International Conference on*. IEEE, pp. 82–90.

Krull, Claudia; Buchholz, Robert; Horton, Graham (2010a): Matching hidden non-markovian models: Diagnosing illnesses based on recorded symptoms. In *The 24th annual European Simulation and Modelling Conference*, pp. 133–138.

Krull, Claudia; Buchholz, Robert; Horton, Graham (2011): Virtual stochastic sensors: how to gain insight into partially observable discrete stochastic systems. In *The 30th IASTED International Conference on Modelling, Identification and Control*.

Krull, Claudia; Horton, Graham (2007): Expanded hidden Markov models: allowing symbol emissions at state changes. In: Proceedings of 14th International Conference on ANALYTICAL and STOCHASTIC MODELLING TECHNIQUES and APPLICATIONS. Prague, pp. 185–190.

Krull, Claudia; Horton, Graham (2008): The effect of rare events on the evaluation and decoding of hidden non-markovian models. In 7th International Workshop on Rare Event Simulation, pp. 153–164.

Krull, Claudia; Horton, Graham (2009a): Hidden non-markovian models: Formalization and solution approaches. In Inge Troch (Ed.): Proceedings / MATHMOD 09 Vienna, 6th Vienna Conference on Mathematical Modelling. February 11 - 13, 2009, Vienna University of Technology, Austria, vol. 35. Vienna: ARGESIM (ARGESIM Report, 35), pp. 682–693.

Krull, Claudia; Horton, Graham (2009b): Proxel Based Simulation: Theory and Applications. In S.M. Ermakov, V.B. Melas, A.N. Pepelyshev (Eds.): 6th ST. Petersburg Workshop on Simulation. ST. Petersburg. 2 volumes. ST. Petersburg, pp. 709–713.

Krull, Claudia; Horton, Graham (2012): Hidden non-Markovian reward models: virtual stochastic sensors for hybrid systems. In C. Laroque, J. Himmelspach, R. Pasupathy, O. Rose, A. M. Uhrmacher (Eds.): In Proceeding of the Winter Simulation Conference. IEEE: Winter Simulation Conference, p. 224.

Krull, Claudia; Horton, Graham (2013): Virtual stochastic sensors for reconstructing job shop production workflows. In: EUROSIM '13: Proceedings of the 2013 8th EUROSIM Congress on Modelling and Simulation. Washington, DC, USA: IEEE Computer Society, pp. 276–281.

Krull, Claudia; Horton, Graham (2014): Virtual stochastic sensors for hybrid systems—mutual influence between continuous and discrete system parts. In ASIM - 22. Symposium Simulationstechnik, pp. 211–218.

Krull, Claudia; Xu, Wenjing; Horton, Graham (2010b): Proxel-based simulation of queuing systems with attributed customers. In International Journal of Simulation and Process Modelling, vol. 6 (iss. 1), pp. 50–57.

- Langwieser, Robert; Lasser, Gregor; Angerer, Christoph; Rupp, Markus; Scholtz, Arpad L. (2008): A modular UHF reader frontend for a flexible RFID testbed. In: Proceedings of the 2nd international EURASIP workshop on RFID technology. Budapest: Citeseer.
- Lazarova-Molnar, Sanja (2005): The proxel-based method: Formalisation, analysis and applications. Otto-von-Guericke-Universität Magdeburg, Universitätsbibliothek.
- Lowy, Juval (2010): Programming WCF Services: Mastering WCF and the Azure AppFabric Service Bus: O'Reilly Media, Inc.
- M. Russell; R. Moore (1985): Explicit modelling of state occupancy in hidden Markov models for automatic speech recognition. In: Acoustics, Speech, and Signal Processing, vol. 10. IEEE International Conference on ICASSP, pp. 5–8.
- McClure, Wallace B.; Blevins, Nathan; Croft IV, John J.; Dick, Jonathan; Hardy, Chris (2012): Professional Android Programming with Mono for Android and .NET/C#: John Wiley & Sons.
- Nath, Badri; Reynolds, Franklin; Want, Roy (2006): RFID technology and applications. In IEEE Pervasive Computing (iss. 1), pp. 22–24.
- Nelson, Phyllis R.; Nguyen, Minhdao H.; Yang, Chien-Cheng J. (2012): Cautionary Tales: Lessons Learned About Unanticipated Behaviors in OC Systems. In Informatik-Spektrum, vol. 35 (iss. 2), pp. 87–92.
- Nielsen, Bobby (2015): Cross Platform Mobile Development. Master's Thesis. Department of Computer Science, Denmark. University of Aarhus.
- Ozdenizci, Busra; Ok, Kerem; Coskun, Vedat; Aydin, Mehmet N. (2011): Development of an indoor navigation system using NFC technology. In: Information and Computing (ICIC), 2011 Fourth International Conference on. IEEE, pp. 11–14.
- Penttilä, Katariina; Keskilampi, Mikko; Sydänheimo, Lauri; Kivikoski, Markku (2006): Radio frequency technology for automated manufacturing and logistics control. Part 2: RFID antenna utilisation in industrial applications. In The International Journal of Advanced Manufacturing Technology, vol. 31 (iss. 1-2), pp. 116–124.
- Petzold, Charles (2014): Creating Mobile Apps with Xamarin. Forms: Microsoft Press.
- Pop, Corina; Mailat, Gabriela (2009): RADIO FREQUENCY TECHNOLOGY IN LIBRARIES. In: International Conference on Economic Engineering and Manufacturing

Systems, vol. 10. International Conference on Economic Engineering and Manufacturing Systems. Braşov. RECENT. 10 volumes. Romania: RECENT (27), pp. 391–396.

Rabiner, Lawrence R. (1989): A tutorial on hidden Markov models and selected applications in speech recognition. In *Proceedings of the IEEE*, vol. 77 (iss. 2), pp. 257–286.

Reveilhac, Marie; Pasquet, Marc (2009): Promising secure element alternatives for NFC technology. In: *Near Field Communication, 2009. NFC'09. First International Workshop on. IEEE*, pp. 75–80.

Sarma, Kandarpa Kumar; Bhuyan, Manasjyoti; Sarma, Manash P.; Mastorakis, Nikos (2015): High Data Rate Wireless Communication Test bed Frameworks-Insights into Design Aspects. In Nikos E. Mastorakis, Imre J. Rudas (Eds.): *Advances in Electrical and Computer Engineering*. Spain: Wseas, pp. 223–227.

Uckelmann, Dieter; Harrison, Mark; Michahelles, Florian (Eds.) (2011): *An architectural approach towards the future internet of things*. Berlin, Heidelberg: Springer.

Van Der Aalst, Wil MP; van Hee, Kees M.; Reijers, Hajo A. (2000): Analysis of discrete-time stochastic petri nets. In *Statistica Neerlandica*, vol. 54 (iss. 2), pp. 237–255.

Wilson, Edward (1997): *Virtual sensor technology for process optimization*, 1997.