A COMPLEX EVENT PROCESSING FRAMEWORK IMPLEMENTATION USING HETEROGENEOUS DEVICES IN SMART ENVIRONMENTS

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ABSTRACT

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Significant developments in microprocessor and sensor technology make wirelessly connected small computing devices widely available; hence they are being used frequently to collect data from the environment. In this study, we construct a framework in order to extract high level information in an environment containing such pervasive computing devices. In the framework, raw data originating from wireless sensors are collected using an event driven system and converted to simple events for transmission over a network to a central processing unit. We also utilize complex event processing approach incorporating temporal constraints, aggregation and sequencing of events in order to define complex events for extracting high level information from the collected simple events. We develop a prototype using easily accessible hardware and set it up in a classroom within our university. The results demonstrate the feasibility of our approach, ease of deployment and successful application of the complex event processing framework.

Keywords : Complex Event Processing, Rule Engine, Wireless Sensor Networks, Pervasive Computing, Event Driven Architecture

ÖZ

AKILLI ORTAMLARDA HETEROJEN CİHAZLAR KULLANARAK KARMAŞIK OLAY İŞLEME UYGULAMA ÇATISI GERÇEKLEŞTİRİLMESİ

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Yüksek Lisans, Bilişim Sistemleri Bölümü

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Mikroişlemci ve algılayıcı teknolojisindeki önemli gelişmeler kablosuz bağlantılı küçük bilişim cihazlarının kolayca bulunabilmesine imkan sağladı; bu yüzden bir ortamdan veri toplanması için bu cihazlar sıklıkla kullanılmaya başlandı. Bu çalışmada, bu tip yaygın bilişim cihazlarının bulunduğu bir ortamdan yüksek seviye bilgi çıkarımı yapmak için bir uygulama çatısı geliştiriyoruz. Bu uygulama çatısında, kablosuz algılayıcıların elde ettiği ham veri olay tetikli bir sistem ile toplanıyor ve bir ağ üzerinden merkezi işleme birimine gönderilmek üzere basit olaylara çevriliyor. Ayrıca bu basit olaylardan yüksek seviyede bilgi çıkartmak için zamansal kısıtlamalar, kümeleme ve olayların sıralanması gibi özellikleri içeren karmaşık olay işleme yaklaşımını kullanıyoruz. Kolayca erişilebilen donanımı kullanarak bir prototip geliştiriyoruz ve onu üniversitemiz içerisinde bir sınıfa yerleştiriyoruz. Sonuçlar yaklaşımımızın yapılabilirliğini, kolay konumlandırılmasını ve karmaşık olay işleme uygulama çatısının başarıyla uygulandığını göstermektedir.

Anahtar Kelimeler : Karmaşık Olay İşleme, Kural Motoru, Kablosuz Algılayıcı Ağları, Yaygın Bilişim, Olay Tetikli Mimari

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To my grandma

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ADC	Analog to Digital Converter
AJAX	Asynchronous JavaScript and XML
API	Application Programming Interface
BRMS	Business Rule Management System
CE	Complex Event
CEP	Complex Event Processing
DRL	Drools Rule Language
ECA	Event-Condition-Action
EDA	Event Driven Architecture
EPTS	Event Processing Technical Society
I^2C	Inter-Integrated Circuit
IDE	Integrated Development Environment
IR	Infrared
JMS	Java Message Service
LAN	Local Area Network
MOM	Message-Oriented Middleware
PIR	Passive Infrared
RFID	Radio Frequency Identification
SQL	Structured Query Language

USB	Universal Serial Interface
WSN	Wireless Sensor Networks
WSAN	Wireless Sensor and Actor Networks

CHAPTER 1

INTRODUCTION

Pervasive computing, also referred to as ubiquitous computing, has become popular with many mobile devices and computing units being used widely in our daily lives. With the help of new wireless communication technologies most of these devices have the capability to communicate with each other. Such networked computing devices let the users access data anywhere, anytime.

1.1 Background

Mark Weiser defines [1] three different era for computing technology; main frame computing era where one computer is used by many users, personal computing era where one computer is used by one person and pervasive computing era where one user uses many computers. A person can use the computers knowingly or can interact with embedded devices unknowingly. Weiser also states that these computing units shall become hidden until they become totally invisible to users [2]. Hidden devices monitoring their environments and other computing units together can provide significant information to users. The ease of access to data and using microcontrollers on everyday objects initiate the pervasive computing application development. With pervasive computing we can construct intelligent objects, context-aware spaces and smart environments.

When current technology was not available, pervasive computing was Weiser's vision, but today developments in computing technology have made it a much more viable research area. There are still missing pieces to obtain a complete pervasive environment but new computing approaches help us to progress towards it. In this study, we construct a pervasive computing framework and for this we use currently available technology to test its feasibility. We want to provide a complete framework that collects data and processes them to obtain higher level information. We use Complex Event Processing paradigm to obtain a smart environment with help of a Wireless Sensor Network (WSN).

Wireless Sensor Network (WSN) technology is beneficial to provide an infrastructure that supports heterogeneous devices and wireless connection between them. Wireless Sensor Networks are basic networks where more than one sensor is gathering data and transmitting it through a wireless medium. Gathering environmental data and monitoring a physical location are mostly done by WSN's in recent research studies. Usually sensor nodes in a WSN consist of a sensor, processor, transmitter and a power unit. The data from these sensor nodes are transferred wirelessly to a sink node. This sink node acts as a gateway for the other components of the system where further processing is done on the collected data. WSN's are densely deployed and do not have a fixed topology; the nodes transmit data with multi-hop so that even if one of the nodes fails, the network still continues to work correctly. There are ongoing researches for deployment, routing and other networking problems related to WSN's; on the other hand the researches about pervasive applications use sensor nodes that are communicating wirelessly. Most of the current pervasive computing applications use sensor networks but not all of them utilize these characteristics of WSN's. We also use a network of sensors but the topology of the network is predefined and sensor nodes are communicating only with the sink node.

In pervasive computing, data gathered in an environment must be processed and converted to meaningful information in order to obtain a smart environment. Event processing is an approach generally used in event driven systems where computing is done over the simple events gathered from various sources. In real life there are events that can be represented as a set of other simple events which are called Complex Events. While event processing is simply gathering, filtering and analyzing simple events, Complex Events need more processing to be extracted. The events forming a complex event mainly have conjunctions, disjunctions, sequences or temporal relationships with each other. The technology to deduce them is called Complex Event Processing (CEP). Traditional event processing only deals with simple events and gets basic information on those events. With CEP it's possible to gather more meaningful events happening in an environment, and high level information is essential in order to develop pervasive computing applications.

1.2 Outline

The aim of this study is to implement an event driven system in a classroom environment and to extract meaningful information from the raw data collected by the deployed sensors, by using Complex Event Processing. The availability of current technology for the purpose of making our environments smarter will be discussed.

This chapter provides background information regarding Wireless Sensor Networks and Complex Event Processing which are used for pervasive computing scenarios for smart environments. Chapter 2 gives more information about these technologies and applications that use them by providing a review of previous work and related literature. Chapter 3 presents the design of our event driven framework that uses Complex Event Processing technology. We also express the details about software-hardware components of the system and software tools used in this chapter. After designing our system, we develop a prototype to test it. Afterwards, we test our design in a real-life environment and discuss the results. Chapter 4 provides the details of our prototype and real life implementation. It also details limitations, shortcomings of our system and discussion about this case study. Suggestions to improve our design are also discussed in this chapter. Finally, Chapter 5 presents the conclusions and further research venues.

CHAPTER 2

LITERATURE REVIEW

This chapter discusses previous studies and research carried out in Wireless Sensor Networks and Complex Event Processing fields. In 2.1 literature about Wireless Sensor Network (WSN) is mentioned in detail; the general ideas about WSN's and their characteristics, difficulties in development and different data acquiring techniques are discussed. Section 2.2 clarifies some basics about complex event processing (CEP) and event detection while section 2.3 mainly focuses on CEP in the area of WSN's. Finally in section 2.4, literature about applications in WSN and event processing area is discussed to form a base for the implementation part of this thesis.

2.1 Wireless Sensor Networks

Wireless Sensor Networks are composed of sensor nodes which have sensing, processing, transmitting and also power components. WSN's are densely deployed, in most of the applications their topologies are not predefined and can change by time, number of nodes in a network is usually high and the sensor nodes are low cost, error prone and limited in terms of processing capacity [3]. Because of the topology changes, the sensor nodes should broadcast their existence to the neighboring nodes, a multi-hop network is needed for energy efficiency and also to prevent network errors. Most of the time WNS's are only used to get information about phenomena but in some cases there can also be actuators alongside sensors in the network. Wireless Sensor and Actor Networks (WSAN) also react to the information they gather but this structure brings more requirements with it. First of all the actors and sensors should be coordinated and also there should be low latency [4] between sensing and actuating components.

WSN’s have a layered architecture just like traditional networks. There are studies carried out in different layers of WSN’s. In [5] different MAC protocols for WSN’s that are aimed to be power efficient are surveyed. In the network layer, different approaches are researched, while broadcasting approach is the most used one, flooding and gossiping are other approaches to save battery on the nodes [3]. The research [6] takes a different approach called “Directed Diffusion” and sends an interest to nodes and nodes send back information by the same path back to the sink. With that, the routing back to the sink becomes data centric.

The requirement of automatic generation of a network in WSN’s brings forth lots of research in that area. In [7] a specific framework for assigning roles to WSN nodes is described in order to give nodes specific roles automatically to form the WSN. Three different algorithms are defined to form different types of networks: coverage to turn on/off nodes for best coverage, clustering for better data delivery, in-network aggregation to reduce communication for power saving. In the upper layers there are mostly middleware examples. The research [8] suggests a rule-based middleware called FACTS. Unlike mentioned in [3] all nodes have a unique ID and they produce facts which trigger rules in the system. This approach allows application development with event based rule language. While [7] separates WSN infrastructure and application layer, this research says that network state changes should be covered by application developers. FACTS is an event driven rule based system where there are facts created by the sensor nodes and rules that are written by the application developer. Different than this study at hand, the system described here is implemented inside the sensor network. Another study [9] relies on query processing to get desired information from WSN’s. The proposed system called TinyDB is implemented on the WSN as a distributed system and with statements similar to SQL the data is queried to join, aggregate it. This study also focuses on different issues of querying on WNS such as “What sensor nodes have data relevant to a particular query?”, “In what order should samples for this query be taken, and how should sampling be interleaved with other operations?” and “Is it worth expending computational power or bandwidth to process and relay a particular sample?”. The study claims that with the features of their system they are able to reduce power consumption by their acquisition techniques.

2.2 Event Detection and Complex Event Processing

In real life environments lots of atomic events happen which are the sources for bigger events that are more meaningful and the users are more interested in those events. While sensors are physically used to detect atomic events in an environment, event detection paradigm becomes important to be able to develop event driven systems. To give users more meaningful business level events the atomic events are aggregated, composed or filtered in order to get these so called Complex Events. The research [10] defines a reference architecture for Event Processing. They suggest that there should be 4 layers as Event Originator, Event Modeler, Event Processing Medium and Event Consumer. Event Originator is the source of events which can be both atomic and complex events while Event Modeler is where the triggers of complex events are defined.

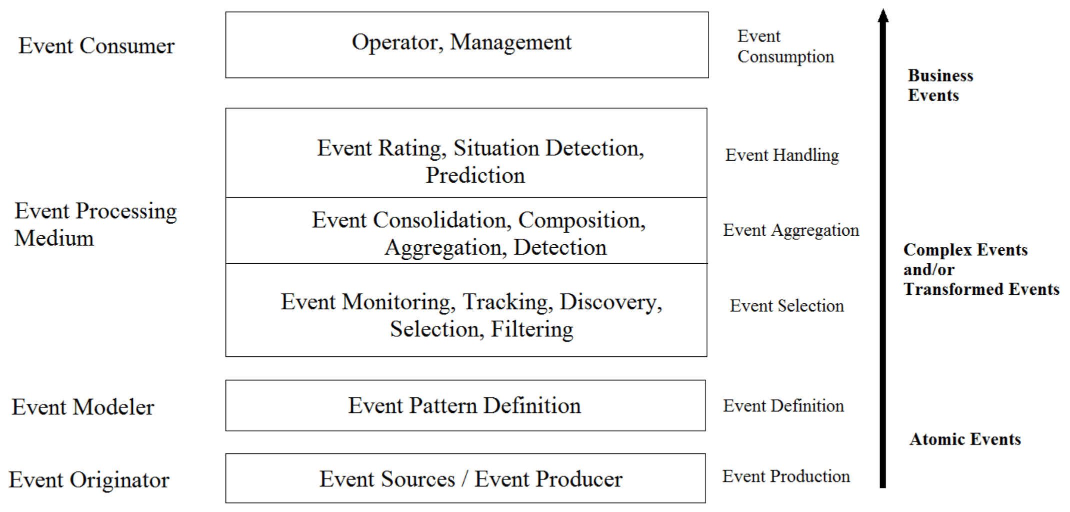


Figure 2.1- EP Reference Architecture (Paschke, A. & Vincent, P. 2009).

Event Processing Medium is the main platform to process events. This platform has the infrastructure for event selection, aggregation, classification within hierarchies and event abstraction to be able to generate higher level events. This platform can be a single agent or a distributed event processing network. Finally the Event Consumer is defined as the receiver of the high level events and it’s also stressed that the consumer might create further events thus act as event originator. Current technologies and event-based applications are examined in detail in [11]. Technologies such as active databases, materialized views, stream processing, message oriented middleware and WSN are explained within the context of event processing. A variety of applications like environment monitoring, information dissemination, fraud detection, financial applications, smart homes, ambient intelligence are analyzed and their event processing features are listed. In conclusion they have stated the areas which require further research. They have explained that most of the applications have their own event semantics which are not explicitly defined. The event enrichment area is told as an open and difficult research area with the combination of information from heterogeneous sources to produce events of higher level of abstraction. They have examined that little experience exists in integrating low end sensors with high end stream processing engines. They have also expressed that performance modeling and benchmarking is another research area.

In research [12] an event-oriented approach is taken to process RFID data, by devising RFID application logic into complex events. Two scenarios, historical tracking and real time tracking by RFID tags, are examined and the raw data collected by RFIDs are transferred to semantic data. To achieve this goal an RFID complex event detection engine that supports temporal constraints is used. In another similar research [13] a complex event processing engine is used to process RFID data. The details of event types, event operators and event rule definitions are explained and after simulation and performance evaluations it's stated that with this method, time to process events can be reduced by 57%. In [14] CEP technology is used in a mix middleware where not only RFIDs but also WSN's are used. They have adopted CEP that has the functions of filtering, grouping and aggregating event data in real-time. By using temporal constraints and also membership relations more meaningful reports are provided. Different than other studies a prototype of the designed system is implemented.

Some researches are based on middleware solutions. In study [15] an adaptive middleware which extends publish-subscribe paradigm to provide a complex event detection service is designed. Events are defined by message filters to select relative events, composition operators for combination of events and parameters to be able to satisfy mutual relations. With the help of windows only messages published in the limited amount of time can also be defined. In this middleware extension distributed detection of complex events inside a network of brokers is presented. Another research [16] done on a middleware also use distributed complex event detection. It's stated that event receivers may be overwhelmed by the number of primitive events and would benefit from higher level of events. CE detectors used in this study are "simple automata with a regular structure which have the ability to detect concurrent event patterns". Study [17] also uses a middleware approach that is based on CEP. They have extended a previous RFID middleware with CEP abilities because they stated that the real advantage of RFID technology lays on real time knowledge. They have used a cache strategy to improve the performance of data stream and used active databases to query over historical, current and future data. The study is based on an SQL like processing language and pub/sub system to deliver reports to users.

2.3 Event Processing on Wireless Sensor Networks

Wireless Sensor Networks or even only sensors are accepted to be the best technologies to gather real life data, however the raw data are not meaningful for high level applications or for end users. Event Processing is a decision system that takes the raw data from WSN's and turns it to information. Study [18] discusses the parameters influencing architecture of an event processing system within wireless environments. Three different parameters are examined: network load, delay of event recognition and the storage needed to reliably detect and process events. They have stated that the cost of event processing in a centralized manner depends neither on the event class, nor on the frequency of the occurrence of events. Meanwhile for the distributed processing higher processing burden and storage is needed for sensor nodes while the network load is depending on the number of events. They have also discussed that higher temporal event complexities lead to a greater energy consumption which directly affects networks and thus applications lifetime. In [19] a different approach to detect events in WSN's is presented. How complex filters can be expressed as tables of conditions is shown. This approach adopts the same data model and query semantics of TinyDB but extends the query language by allowing tables of filter predicates. They have stated that their algorithms are capable of running with limited memory and can distribute the storage burden of nodes while they are tolerant to message loss and node failure. Another research [20] is pointing out the challenges of data processing in Wireless Sensor Networks. Three major categories; data gathering, data processing, data forwarding, are inspected. It's stated that algorithms must consider lost samples for data analysis and processing, also high storage requirements is another problem because of hardware limitations of sensor nodes. The paper also suggests solutions for a real life problem using WSN's. The study [21] presents the ongoing work of distributed event detection on WSN's their algorithm is divided to 4 different phases. In 'hello' phase, sensor nodes detect neighboring nodes and in 'calibration' phase the nodes are established by checking their position and the background noise. Different from other research, this study uses a 'training' phase where new reference patterns are used for future runs of 'recognition' phase that is the event detection phase of the algorithm. They study current studies and express the points that should be taken into account to develop suitable systems. State specifications, state detection algorithms, event ordering and event delivery are some areas that are presented by that research. Research [22] is describing a system that is observing the data obtained from WSN, comparing data to admissible conditions and taking action if needed.

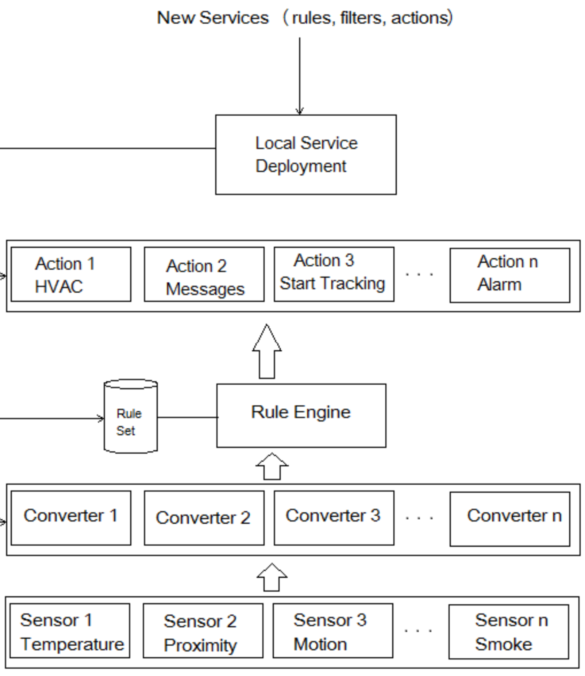


Figure 2.2- High Level Architecture of Study [22] (M. Marin-Perianu, N. Meratnia, M. Lijding, and P. Havinga, 2006).

They state that requirements for such a system are: first heterogeneity which uses smart tags, sensor nodes, mobile devices and gateways; second massive deployment and lastly context-awareness. Their system uses rules both on a central system and also on sensor nodes. The rules on sensor nodes are shown as converters in Figure 2.2 and business rules are deployed in Rule Engine. Local Service Deployment is the administrative part of the system that creates rules, actions or filters. An event-based architecture is given in [23] that is used on RFID networks in hospitals. The system is used for data collection, filtering, management and interpretation tasks between RFID sensors and hospital enterprise applications. Different from other studies, a semantic representation is used to match event patterns. It's stated that the results indicate better management of available equipment.

Complex Event processing takes event processing to a further level by deducing more meaningful information from the gathered data. Some groups go on studying this paradigm as an approach to get high level information. Study [24] is basically a middleware solution with CEP support that is implemented in a WSN application. The main outcome that is pointed out is that the system is programmable in the runtime. They have stated new rules can be defined in the runtime and the distributed system will match for them. In another research [25] a medical sensor network is inspected with usage of a rule based system to detect events. A simple rule engine is used to define rules and infer data coming from the sensor network. It is stated that a rule based engine can provide "a flexible and easily extensible framework for processing, managing and contextualizing sign information from a sensor network". This rule based processing engine is not supported with CEP. A similar research [26] also uses a sensor network but it extends the network capability by using a CEP engine. It uses a simple scenario where a patient is using medical sensors that are communicating with a centralized system. Medical information area is presented as a critical area and it's pointed out that CEP is ideal for this dynamic environment in contrast to traditional database approach. Study [27] also presents a CEP system working on WSN's but this study differs by their definition of complex events. They define complex events as "set of data points hiding interesting patterns that are difficult or even impossible to capture using traditional techniques such as thresholds". Their algorithm has 3 phases: Learning, Initial Detection and Escalation phases. Learning phase acts as calibration by listening to the surroundings for a given time and getting minimum, maximum and average measurements. Initial Detection is the main part responsible to get measurements which are different than the measurements sensed in the learning phase. Finally escalation phase is responsible to distinguish true and false positives and is not necessary for most of the detections. They have presented that their approach allows non-parametric event detection and also approximate event detection by giving users the possibility to search for different events by defining similar event patterns. Study [28] is proposing a CEP framework to model surgical events and critical situations in an RFID automated hospital. They have stated that for a surgery there are many actors and places and RFID plays an important role to identify and track persons, objects that are needed for the surgery. The components of the system are shown in Figure 2.3. Apart from the RFID's some embedded sensors that are monitoring patients' health are used to derive complex events during the operation which are very critical in that scenario.

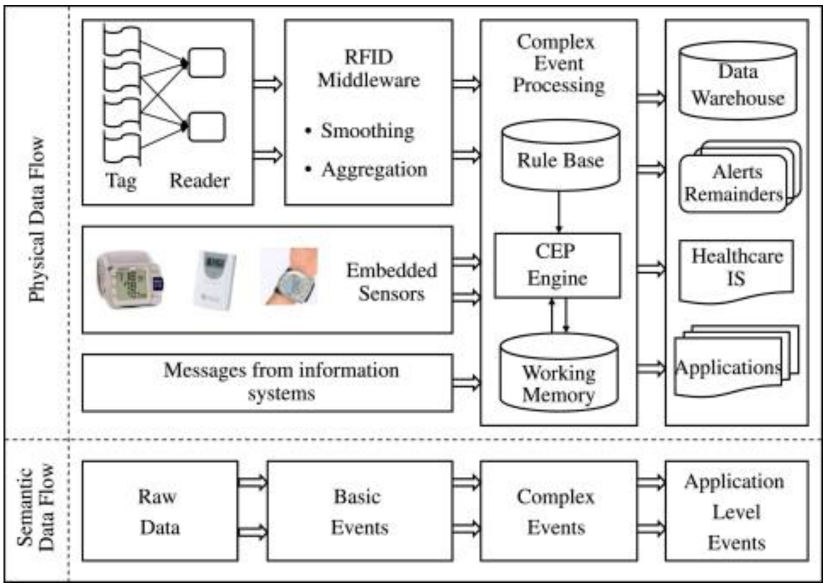


Figure 2.3- Physical and semantic data flow in RFID-enabled hospital (Yao, W., Chu, C.-H. & Li, Z. ,2011).

A prototype is implemented and rules with temporal parameters are used in CEP engine to track patients' health during the operation which will help doctors react immediately when needed. Another study [29] examines if an event based system with complex event detection is a potential tool for supporting the detection of real world states in WSN. Different from other research in this area, they have stated that CEP is still ill-suited to support efficient specification and detection of complex events in real-world states.

2.4 Applications Areas

While the micro sensor technology led to implementation of small computers to everyday objects and environments, the research interest in applications of pervasive computing has increased. Most of them are event based but not all of them use CEP technology. Those researches show different applications areas where pervasive computing can be used. Research [30] details some areas for pervasive computing and presents some issues to implement them. While healthcare, domiciliary care, environmental monitoring and intelligent transport system are mentioned as main areas of application it's stated that current lack of low cost technology and power sources is the main issue. Also it's told that such systems gathering sensitive data may have implications for privacy, security and safety. Likewise study [31] also gives a brief outline for WSN applications. The study claims that "most researches do not have the resources to design, build, deploy and maintain a WSN application". On the other hand they encourage building new WSN applications by stating that creating and deploying applications is a direct way to examine what users want. They have also stated every developed application will help get better usage of WSN applications. The main problems stated by that research are limitation of hardware, lack of research different than energy consumption and network protocols for WNS's. In research [32] current applications that are targeting to make our environments smarter are discussed and components for a smart environment are described (Figure 2.4).

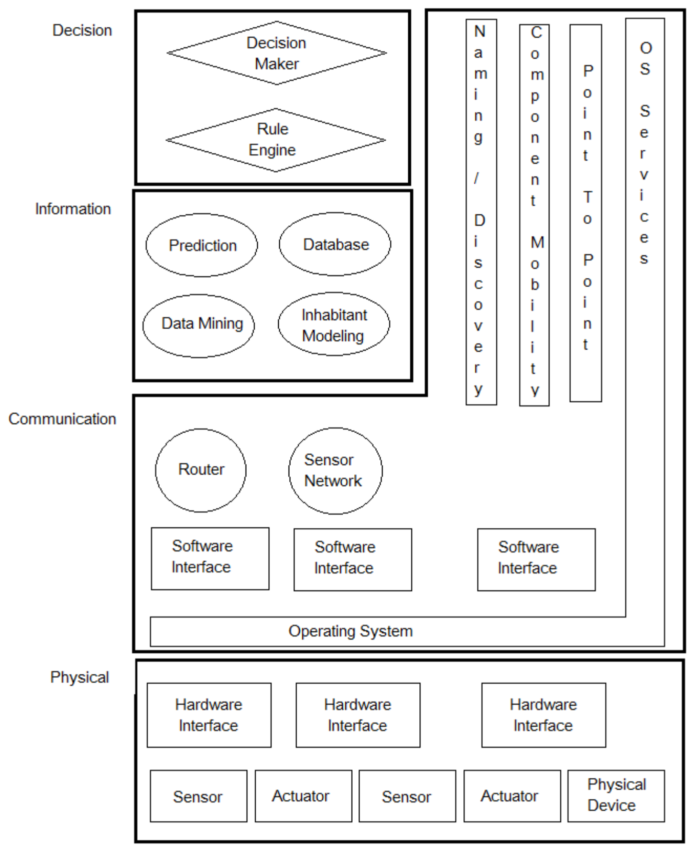


Figure 2.4- The Components of a Smart Environment (Cook, D. J. & Das, S. K., 2007).

Sensors and other hardware are responsible for monitoring the environments and communication components (Routers, WSN, etc.) are used to make this data available to higher components which then transform data to information and make decisions by using this information. A smart environment is described as "one that is able to acquire and apply knowledge about the environment and its inhabitants in order to improve their experience in that environment". While sensors and other hardware are stated to be vital to monitor the environment to build a fully automated system, a decision-making component is suggested to be built upon these layers as shown in Figure 2.4.

While the previous research suggests components and architectures for such applications there is also some research which implements WSN or event-based systems in a specific area. Research [33] presents a smart home application specifically designed for elderly care. They state that they use both WSN and RFID's to be able to track and identify caregivers inside the house. The experiments are done in a controlled lab environment and apart form caregiver identification, automated lighting and playing personalized music is also implemented in the application. They state that their approach is light-weight and stay invisible while supplying necessary information. In the study [34] a remote surveillance and monitoring application is detailed. WSN technology is used to enhance the detection capabilities and improve alarm functionalities. The research attempts to track changes and also give automated real-time alarms to the end users. A four tiered architecture is used where the first tier is the sensor nodes which are responsible to track environment. The second tier is the gateway tier and it forwards the information to upper layers. Another responsibility of this tier is to use Video Surveillance System to get the visuals where something is detected by the sensors. The third tier is the management tier where users can define alarms and controls the system. The last tier is the alarming and display subsystem. Simulation and real life implementation are both evaluated in that research. Study [35] also uses a WSN for surveillance but mainly focuses on energy efficiency. They state that this application requires some important points to be taken into account. First one is Longevity, the system shall last for at least a few days. Stealth is the second requirement because it's crucial for military surveillance. They also declare that the system shall have an adjustable sensitivity and effectiveness in terms of latency and precision. With their WSN routing and event dissemination algorithms they claim that their system is adaptable and achieves an improvement in network lifetime. A WSN system that is monitoring the seabirds is described in [36]. Temperature, humidity and PIR sensors are used in burrows of the birds and the gathered data are transferred to a central system with the help of sensor nodes and gateways. To improve the quality of data and reliability, the centralized software is improved; also RFID nodes are integrated into a WSN system. A healthcare system using WSN's is described in study [37]. Medical sensor nodes are collecting data such as blood pressure, body temperature, blood sugar levels of patients. The gathered data are then sent to a sink node which is a web server. The doctors are able to track patients remotely with the proposed system. Different than the previously discussed studies, research [38] is used in a bigger area aiming to prepare a city wide WSN testbed. Their research describes the ongoing implementation that monitors wind-speed, direction, relative humidity, temperature and pressure. The sensor nodes are fixed to street lights which supply power to the nodes, the nodes communicate with Wi-Fi protocols and use current security solutions developed for Wi-Fi. They have stated that with this testbed they support innovation for WSN applications. On the other hand, research [39] states the difficulties to establish an infrastructure for smart cities. Large number of sensor and mobile devices and their heterogeneity are stated as two important factors that should be taken into account during the design. The city is said to have simple, complex, temporal and other types of context sensitive events together which it brings the need for event composition and management services. They have pointed out that event-based computing plays a centralized role in the realization of these applications.

CHAPTER 3

COMPLEX EVENT PROCESSING FRAMEWORK

In this study, we construct a framework to extract high level information in order to get smart environments. This framework works with wireless sensors and other data sources; it also utilizes complex event processing for information extraction. The software components of our proposed framework support event driven architecture and we choose to use a messaging system which lets the fusion of events in a structural but simple way. The most important part of our system, the reasoning component is selected as a rule based system that also allows Complex Event Processing of the events. This module is capable of processing events with time dimension that lets us define more complex event rules for our system.

The event driven system we aim to develop is meant to work in a wireless sensor environment. The hardware components of our system are selected from a wide range of electronics prototyping platforms. We want our nodes to be programmable and support different kinds of communication interfaces. To make our system more generic we choose our boards to be compatible with different types of sensors and be assembled as desired.

This chapter discusses the hardware and software design of the system we develop. In 3.1 an overview of the framework we construct is given while in 3.2 details about the software components of the event driven system are explained. Section 3.3 clarifies the design of selected hardware; sensor boards, sensors and communication interfaces.

3.1 Framework Overview

We aim to construct a complete framework to be able to extract high level information in a pervasive computing environment. In such an environment there are numerous data sources providing raw data; event processing paradigm deals with this data and tries to make meaningful extractions. Complex Event Processing technology takes this approach one step further and helps with extracting high level information. Our goal is to construct a framework that will help gather data from sensors and other data sources and process this data to be able to provide meaningful information for higher level applications. We want our framework to be able to get data from both existing and also newly deployed data sources. We believe currently easily accessible hardware and software can be used to construct such a framework. This helps the deployment of the framework to be easy and at the same time inexpensive. Also, with the help of available Complex Event Processing software we aim to extract higher level information by using the available environmental data.

The framework we present is used in a classroom environment where we have setup a set of wireless sensors and an RFID reader. We first implement a prototype and we use a classroom in our institute in order to test it in a real life environment; we carry out our experiments when there is an ongoing class inside the classroom. Our goal is to present the feasibility of our approach and for this we use sensor nodes that are available within our institute. The prototyping and the real life application details will be discussed in Chapter 4.

3.1.1 Conceptual Design

Figure 3.1 gives a summary of our conceptual design. In this study we aim to gather simple events from heterogeneous sources and by using a rule engine we extract high level information. We use Wireless Sensors, RFID data and also supplementary data from a database. In our framework, incorporating additional data sources as event producers is always possible. The raw data provided by sensors are converted to simple events, these and events from other data sources are transferred to a centralized processing unit. We decide to use a publish/subscribe messaging system to get those simple events to the unit where our Rule Engine resides. In order to add a new data source to our framework, we define them as new publishers and change our processing engine to subscribe to their data. The centralized processing unit is a rule engine that supports complex event processing. With predefined rules that utilize temporal constraints, aggregation, sequencing and filtering, we try to extract higher level information from the cloud of events produced. We do not run queries over the events that happen; instead we define our queries beforehand and let our system make detections whenever new events match the patterns. The main component containing Event Producers, Messaging Service and Processing Engine in Figure 3.1 refers to our framework that converts raw data to simple events, simple events to information and finally by Complex Event Processing into high level information.

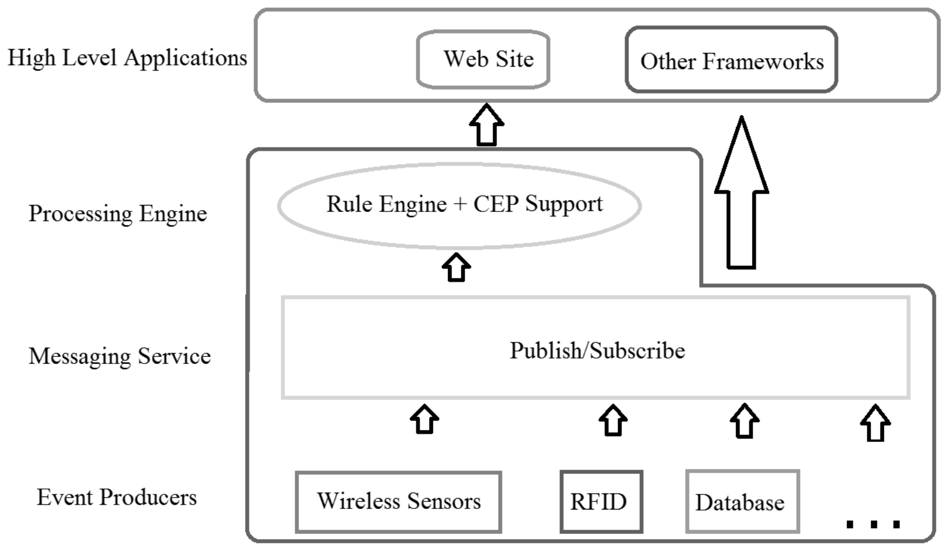


Figure3. 1 – Conceptual Design

For this study we create a web page to demonstrate our high level information to end users, for other scenarios it’s possible for other frameworks to subscribe to both high level information and simple sensor events. Various other applications can use our framework to get meaningful information from a pervasive environment without dealing with the low level information present.

3.1.2 Complex Event Processing

Event processing is the most important part of our system because in this research we aim to make our environments smarter by using a network of sensors and making meaningful deductions with the use of complex event processing. This module subscribes to the topics created by event generators and thus retrieves the messages as soon as they are produced. The retrieved events are used by the reasoning engine to create knowledge from information. This engine supports complex event processing with the help of temporal reasoning and also sliding windows.

The Event Processing Technical Society (EPTS) has published a glossary to provide a common language for event processing community [40]. The definitions given in this glossary are presented below to clarify the difference between normal and complex events:

Event
‘Anything that happens, or is contemplated as happening.’

Complex event
‘An event that is an abstraction of other events called its members.’

Complex event processing (CEP)
‘Computing that performs operations on complex events, including reading, creating, transforming, or abstracting them.’

This means that complex events are produced from the events that have already occurred. A sensor reading is also a simple event and when all sensor events are gathered, a cloud of events will be formed with each one having different timestamps. Complex Event Processing is inspecting the cloud of events and deducing a new event composed of the other events. With temporal reasoning, absence of events and other parameters, the events that cannot be formed with simple sensing capabilities are derived by complex event processing.

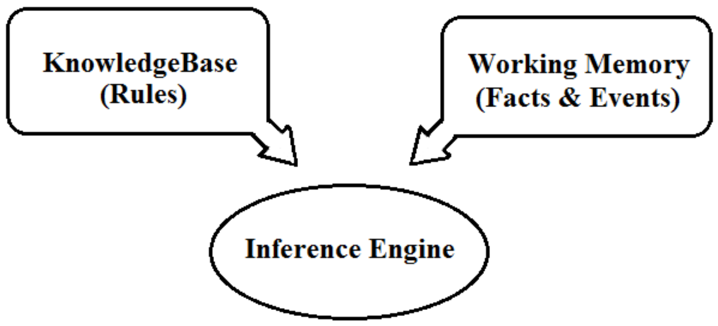


Figure 3.2 – CEP Engine Modules

Since CEP needs an inference engine to drive answers from the knowledge base, in this study we use a rule-based engine for reasoning over events. This component is formed by a rule base where all extraction rules are stored, an inference engine to run these rules and a working memory to reason over the event cloud (Figure 3.2). CEP system uses event matching, event abstraction, temporal-spatial reasoning and detecting relationships for deriving complex events from simple events.

3.2. Software Components

We aim to implement a complex event processing framework to be able to gather meaningful results from different sensor events and we utilize Event Driven Architecture (EDA) to achieve this goal. Sensor readings are our events that will drive our system and CEP component will make reasoning over these measurements. A conceptual model is proposed in [41] and it offers three different components of EDA; event producers-consumers, event channel and event processing agent. In this study an event producer component, an event processing engine and the messaging channel between these components are designed to work seamlessly with each other. Event generator layer is formed by microcontrollers that convert raw sensor data into simple events and the component that transmits the events. To make our messaging more flexible we implement a publish-subscribe system as our Event Channel. The messaging system is used to make communication between two components of the system loosely coupled. Finally we implement a CEP system to reason over the sensor readings. We have chosen a rule engine with temporal reasoning to form CEP rules. While data from the servers can be converted to information by simple logical converters, CEP helps to convert information into knowledge. This module gets sensor messages by the event channel and also publishes results back again to the event channel. The published Complex Events are presented by a simple webpage at the application layer.

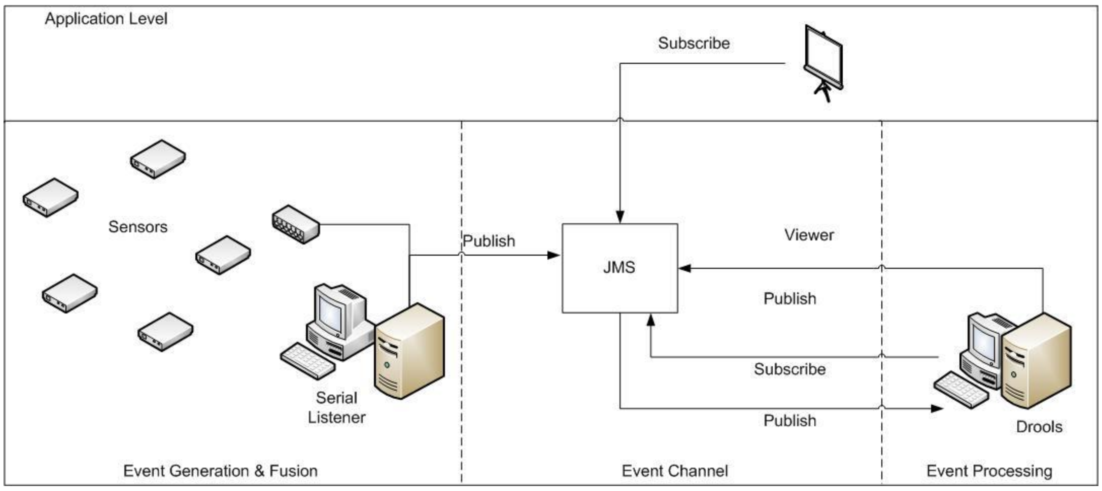


Figure3. 3 – EDA System Diagram

The details of the components shown in Figure 3.3 are briefly explained in the next subsections.

3.2.1. Event Sources

The sensor nodes used in this study are described in 3.3.1 and they are the main event generators for our system. Since the microcontrollers let us format and send the output messages according to our needs, we have sensor type, sensor ID and measurement combined and sent as one string. This lets us to be able to identify which sensor sends the data to our sink and what the last reading of that sensor is. The string message starts with the type of the sensor denoted as a character, continues with the ID of the sensor and finally following a colon it provides the measurement. There is a special character at the end to specify the end of the message. Table 3.1 shows the characters used as sensor types.

Example messages then become:

L0:762/r meaning, light sensor whose ID is 0 lastly measured 762.

S1:24,6/r meaning , temperature sensor whose ID is 1 lastly measured 24,6.

Table 3.1- Sensor Type Characters Used In Messages

Character	Sensor Type
H	Hall Effect
I	Infrared Proximity
L	Light
S	Temperature
T	RFID
H	Optical Detector
E	Electret Microphone
M	PIR Motion

These messages are the outputs of our event generators and we gather them in one place with the help of a sink node. The sink node gets the messages through a wireless medium and sends them to a virtual serial port via USB. In order not to throttle our one sink node we have coded our microcontrollers to only send state changes for hall effect, infrared proximity, optical detector and motion sensors while temperature, electret microphone and light sensors are sending the measurements at fixed time periods.

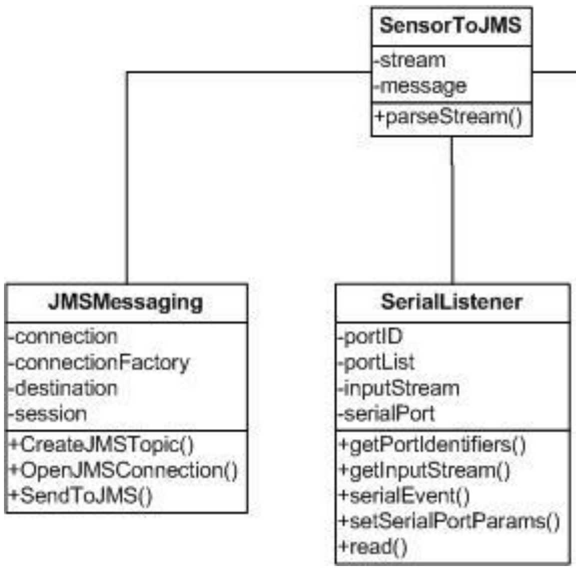


Figure 3.4 Class Diagram for SensorToJMS component

The sink node sends all messages to our local server where we have implemented a simple serial port reader to gather all messages sent by our WSN nodes. This module gathers the messages and parses them according to their types and passes this information to our Event Channel where the messages are disseminated to other components of our system. Our component called **SensorToJMS** has four classes, the first one being the *SerialListener* class which is responsible for gathering data, second is the main class which acts as a controller and it also parses incoming messages and third one, *JMSMessaging,* is for messaging between components which is described in the next subsection. The final class *DB* serves the purpose of recording all messages in a persistent environment.

Apart from the sensor producers we have decided to use a static event generator to be able to understand the timed events planned to occur in the environment where our sensors are placed. In this study we want to get lecture hours and other simple facts from a given schedule and send them over the event channel to the event processor. Our **StaticEventGenerator** is a simple java program that runs on timed triggers with the help of Windows Task Manager. The purpose of the program is to check the schedule database if there is a lecture starting or ending at that time and if it’s the last lecture. The corresponding information is sent to the Event Channel waiting to be consumed by the subscribers and also it's registered to a database.

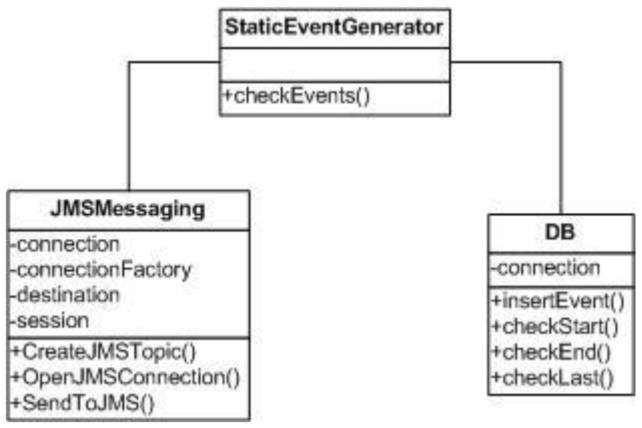


Figure 3.5 Class Diagram for StaticEventGenerator component

3.2.2. Event Channel

Event channel in an EDA system makes different components of the system loosely coupled which is a good practice for software engineering [42]. To provide this messaging system more flexibility we use a publish-subscribe system for event channeling so that other systems also can use our event generation system. Since we have developed our components with Java coding language, Java Message Service (JMS) is a suitable tool to be used as our Event Channel.

Java Message Service [43] is a middleware messaging system, also referred to as Message Oriented Middleware (MOM), which enables loosely coupled connection between different java applications. JMS supports two different message delivery models: point to point and publish-subscribe. While the first model allows messaging between 2 clients, publish-subscribe model allows 2 or more clients to communicate with each other. JMS API is composed of a JMS Provider which implements all JMS specifications, JMS Clients that will send/receive messages and JMS Messages that are used to communicate between clients.

Event channel used in our research is Apache ActiveMQ [44], which is an open source JMS implementation. The two components Event Generator and Event Processing are JMS Clients that are developed using Java language. The event generator publishes JMS messages with every source being a different JMS Topic and the event processor subscribes to all these topics to get sensor readings. Finally the outputs of the event processor are also published to JMS for other components to get meaningful results without subscribing to sensor topics.

We have arranged our JMS to have different topics for every sensor, this way a system that wants to get only specific types of sensor readings will only need to subscribe to the topics of these sensors. When a new reading is published to JMS by event generators, JMS automatically forwards it to all the subscribers.

For this study we use a remote server for our JMS provider apart from the implementation where our event generator is running. Both our event generator and event processor has one class called JMSMessaging to utilize publish-subscribe model in both clients. Also we have implemented a database to store all the messages published by topics in order to be able to inspect the messaging history.

3.2.3. Event Processing

This study uses Drools Business Logic Integration Platform [45] which has started as a business rule management system (BRMS) with a forward chaining inference based rules engine and then renamed with the addition of more components. In 2009 with version 5, developers added event processing and workflow capability to their system and after a few years they renamed their product to turn it to a complete Logic Integration Platform. The new component implemented for event processing is called Drools Fusion and as described in their web page it adds some features for event processing while keeping the rule engine fully active. The new features of Drools Fusion are:

- *Understand and handle events as first class citizens of the platform*
- *Select a set of interesting events in a cloud or stream of events*
- *Detect the relevant relationships (patterns) among these events*
- *Take appropriate actions based on the patterns detected*

The previous versions of the rule engine were only working with facts that are onetime events that have no time parameters. With Drools Fusion, it's now possible to define events with time parameters and the engine will handle them knowing they are events not facts. Another new feature of Drools Fusion lets the users define events with a timestamp and duration so that temporal reasoning over events can be made. With all events having a timestamp and duration, Drools makes it possible to find relationships between events by using time constraints. Figure 3.6 shows different temporal relationships between events. Drools fusion also supports making reasoning for absence of events while the presence of events can be reasoned on a sliding window concept where the window size could be the last number of happenings of the event or a defined time interval. While all the events are stored in working memory, Drools Fusion implements a special garbage collector where the unnecessary events that are not used in the rules are disposed.

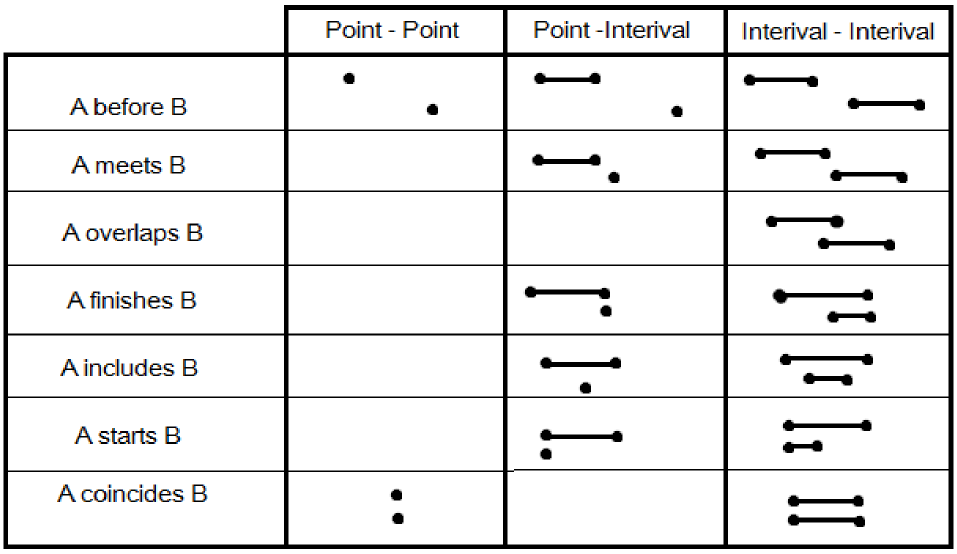


Figure 3.6 – Temporal Relations between Events (Courtesy of JBoss Drools, http://www.jboss.org/drools/drools-fusion.html)

Drools has its own rule language called Drools Rule Language (DRL). Like most of the rule languages, it's structured as Event Condition Action (ECA) rules. Events are the triggers for the rules, conditions are checked if the rule is going to evaluate as true and actions are the consequences of the rule if it returns true. For Drools Rule Language there are the *when* and *then* operators, where the condition and action of the rules are coded consecutively. The rule engine checks the 'when' condition and if it's evaluated true, continues with the 'then' part of the rule. The code-block shows the simple structure of a rule but the power of CEP remains in the conditions where many different operators can be used. All the rules are stored in a text file with the extension ".drl " and then inserted into the knowledge base of the rule engine.

```
rule "ruleName"
when
      //Conditions

then
      //Actions

end
```

Simple code-block for Drools Rule Language

For this study, we have implemented the Drools rule engine in a remote computer where the sensor readings are accessible by subscribing to their topics on JMS. The rules are written in Drools Rule Language (DRL) and stored in a ".drl" file which is then imported into the knowledge base for the events to fire them. Whenever an event is inserted, fireAllRules() function is called for our rule engine to process new events. This function lets the rules to be checked whenever a new event is inserted into the working memory.

Our third component called **JMStoDrools** is responsible for subscribing to the topics of the sensors, creating objects from the messages received and inserting them into the knowledge base. With the Drools API, the events are reasoned over the rules we have created and after that the results are published back again to JMS. We have *Drools* class for reasoning, *JMSMessaging* class for publishing and subscribing, and the *event classes* for forming the objects that are going to be inserted into the working memory. The rules are created to be able to derive complex events from simple sensor readings. The next chapter will briefly describe the system working in a sample environment and how the rules are structured for such an application.

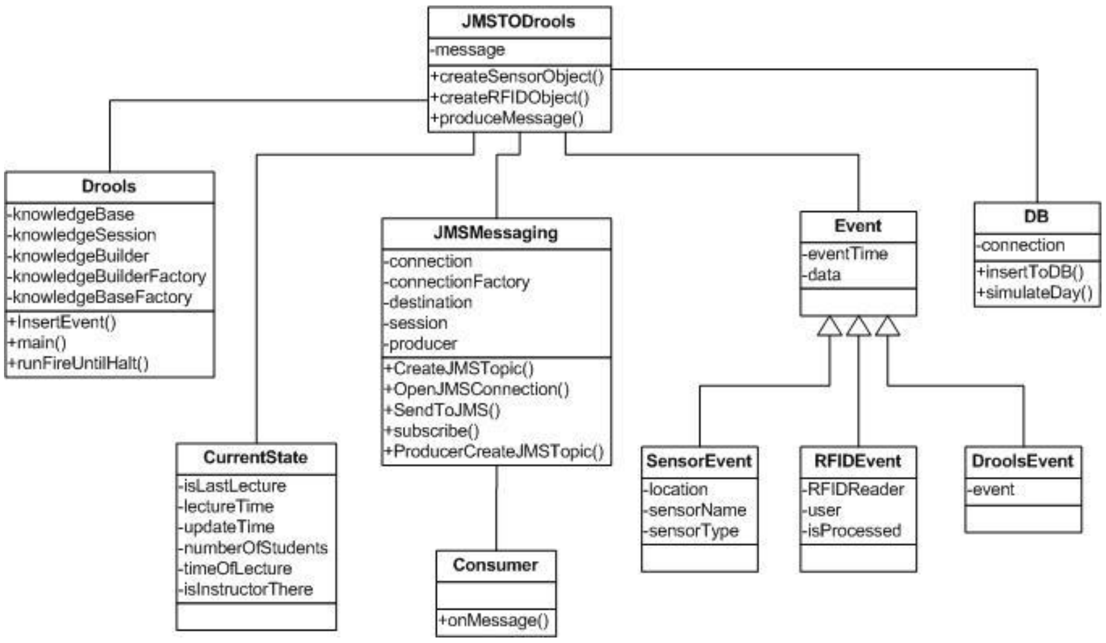


Figure 3.7 – Class diagram for JMSToSensor Component

The *SensorEvent* class is the class that represents the events detected by various sensors in the classroom while *RFIDEvent* class is used only for RFID readings. *DroolsEvent* class is used to insert the events extracted by the rule engine into the working memory. Finally we have also created a class called *CurrentState* to be able to store current static condition of the classroom in the working memory. Information about instructor, number of students and lecture times are stored in this class in the working memory. When a state change occurs we are updating this class inside the working memory and our rule engine is firing the rules, checking them again according to the changes of the state. *Drools* class is our event processing engine where we create our working memory using our rules. This class is heavily dependent on the Drools API. *JMSMessaging* class is used to subscribe to the Sensor and RFID Events and also to publish the deduced events to the JMS. Finally *DB* class is used to record Drools Events to a database and also to simulate past values which are recorded to the database.

3.3. Hardware Components

Recent progress in the technology of WSN has led to different types of WSN hardware to be produced for both commercial use and research purposes. For our research we want to use a flexible platform to be able to use different kind of sensors. Furthermore we need a platform that is easily programmable to have control over the data that should be sent over selected communication interfaces. We decided that the Arduino [46] platform satisfies all the requirements we needed, thus the sensor boards and sensors are selected to be used with this platform and coding of sensor boards are carried out using the Arduino language which is a set of C/C++ functions that can be called within the code.

3.3.1. Design of Sensor Boards

The Arduino platform has different kinds of development boards that work with different types of applications. For our study we decided that "Arduino Uno" will suit the best because of its processing ability, output power variety and number of analog and digital inputs. In our setup, we use two or more sensors on one board thus the need for more power and more number of inputs was inevitable. Appendix A: Sensor Board Schematic For Arduino Uno, shows the detailed design of the boards used in this research.

Table 3.2-Summary Information about Arduino Uno

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage	7-12V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (Atmega328) of which 0.5 KB used by bootloader
SRAM	2 KB (Atmega328)
EEPROM	1 KB (Atmega328)
Clock Speed	16 MHz

This development board basically reads the voltage values from the input pins and converts them to readable values. These pins are 10 bit analog to digital converters (ADC). For analog input pins the output of this transfer is a value between 0 and 1023 while the output values for digital input pins are 0 or 1. These input pins can also be used as output pins that can provide a maximum of 40 mA, operating at 5V.

32 KB flash memory is sufficient enough to implement a simple measurement reading and data transferring code block. A simple code block for this type of application can only be a few KB's in size. Furthermore Arduino Uno also has support for different libraries that can

be used for coding more complex applications on nodes, thus 32KB flash memory can be used freely without any memory problems.

Arduino Uno boards can work with input voltages from 7 to 12V. We use 7.4V and 9V batteries for our setup since we want to make our setup completely wireless. The power for these boards can also be supplied by USB ports or power adapters. For communication between a computer RX and TX pins on the board are used. The serial communication is completed by using the USB port as a virtual serial port on the computer.

The following subsections describe the sensors used in this research and define how they are designed to work with the development boards.

3.3.1.1. Hall Effect Sensor

Hall Effect sensors are used to detect magnetic fields; the output voltage of these sensors will vary according to the magnetic field around them. The sensor used in this study, Melexis US1881 [47], is a latching Hall Effect sensor. This makes the sensor to give the same output until it senses a magnetic field of reverse polarity. The operating voltage of this sensor is 3.5V to 24V. If the sensor is triggered by a magnetic field it will give same output voltage as the input voltage while it will only output ground while resting still.

The 3 pins are used for input, ground and output connections. A 10KΩ resistor is used between input and output pins.

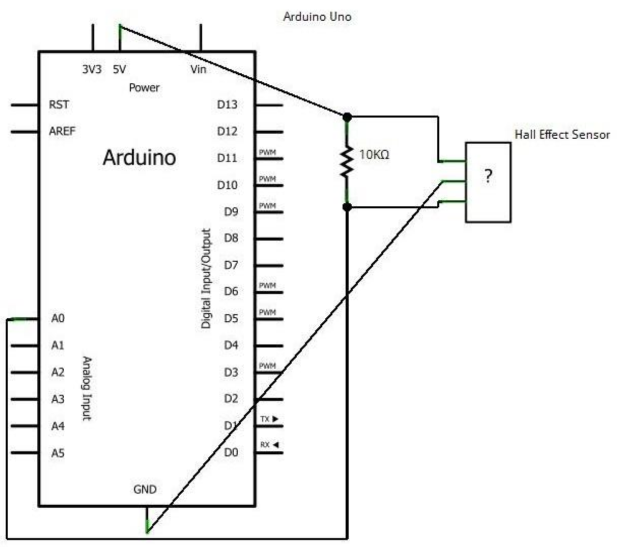


Figure 3.8- Hall Effect Sensor (US1881) Connection on Development Board

3.3.1.2. Infrared Proximity Sensor

Proximity sensors are used to sense presence of an object. Infrared (IR) proximity sensor has one IR receiver and an IR light. It senses the intensity of reflected IR that is sent by its own IR light. The sensor output changes according to distance of the object reflecting the IR. Our study uses two different IR proximity Sensors; Sharp GP2Y0A02YK0F [48] for sensing long range (15cm to 150cm) and Optical Detector QRD1114 [49] to sense nearby objects (0.5cm to 1 cm). Both sensors work with operating voltage of 5 V. Sharp sensor is connected with 3 wires as input, ground and output while optical detector is connected with 4 pin. Two wires used for ground connection and others are input and output pins. As a pull up resistor a 5.6kΩ resistor is used between input and output connections and a 200kΩ resistance is used for input connection.

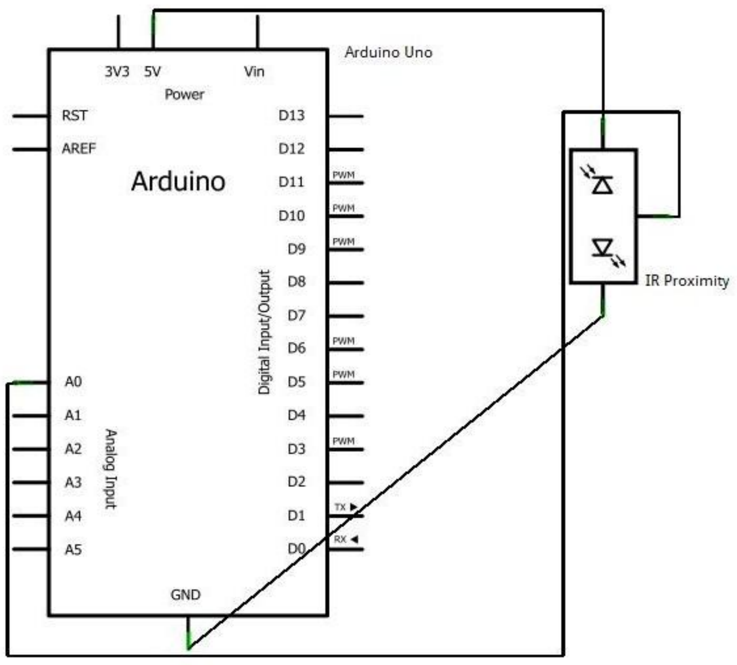


Figure 3.9- Infrared Proximity Sensor (Sharp) Connection on Development Board

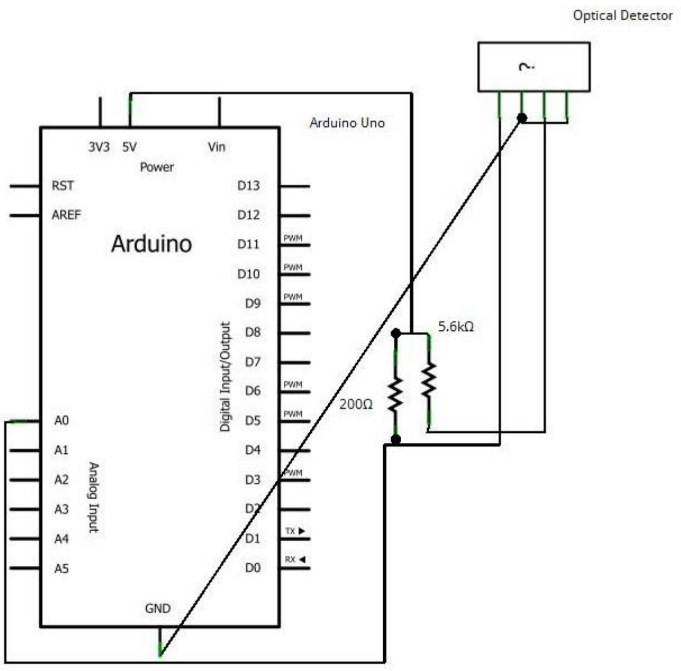


Figure 3.10- Optical Detector (QRD1114) Connection on Development Board

3.3.1.3. Passive Infrared (PIR) Motion Sensor

PIR sensors are used to detect radiated IR measurements from the objects. The sensor detects the changes around the sensor so it's commonly used as motion detectors. When an infrared source with one temperature passes in front of the previously sensed infrared source with a different temperature the sensor sends a low signal from its output pins. The sensor used in our study [50] is an open collector, works from 3.3 to 12 volts and needs a resistor (10kΩ) between its input and output pins. The other pin is connected to ground.

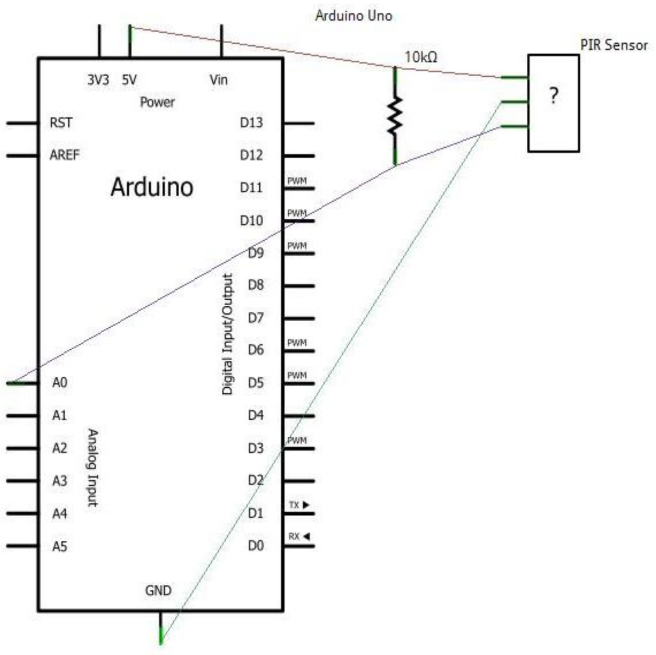


Figure 3.11- PIR Motion Sensor (SE-10) Connection on Development Board

3.3.1.4. Photoresistor

Different from the previously discussed sensors, GL5528 [51] is only a resistor whose resistance changes depending on the amount of light the sensor is exposed to. When the resistance changes, the amount of voltage passing through changes, as a result ambient light measurement can be detected. To measure the ambient light, one end is connected to power and the other to a pull-down resistor to ground. By connecting point between the fixed pulldown resistor (10kΩ) and the photocell resistor to the analog input the measurements can be read.

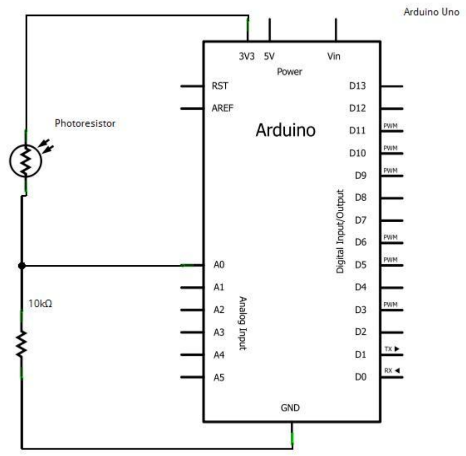


Figure 3.12-Photoresistor Connection on Development Board

3.3.1.5. Electret Microphone

An electret microphone is a type of microphone which has an electret material to hold electrical charge constantly thus removing the need a charge placed on it unlike the condenser microphone. This sensor [52] has an amplifier to make the sounds convertible by microcontrollers ADC. It works from 2.7V to 5.5V and 3 pins are connected as input, ground and output.

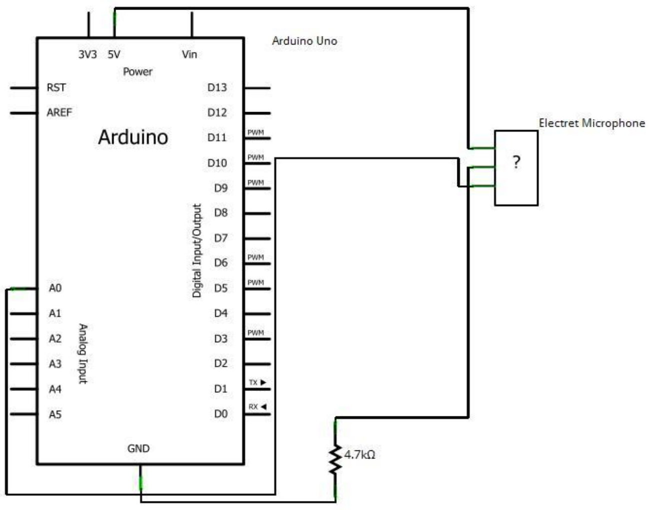


Figure 3.13 - Electret Microphone Connection on Development Board

3.3.1.6. Temperature Sensor

Temperature sensors or thermometers are devices that are used to measure the temperature through different principles of physics. The digital temperature sensor we use in our study is an I²C (Inter-Integrated Circuit) device which makes it easier to use with our development boards. TMP 102 [53] sensor is capable of measuring ambient temperature from -25°C to +85°C and can be powered by voltages between 1.4V to 3.6V.

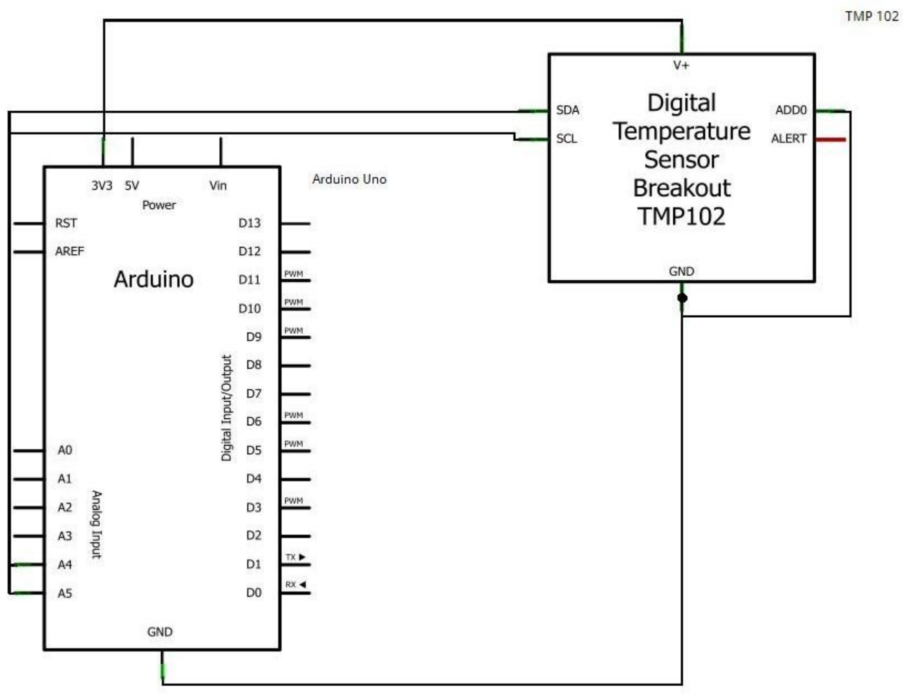


Figure 3.14 - Temperature Sensor Connection on Development Board

3.3.1.7. RFID Reader and Tags

RFID (Radio Frequency Identification) is an identification system which uses radio waves to identify electronic tags. Redbee RFID Reader [54] is selected for our study because of its communication interface variety, it can be used via USB or Xbee interfaces. The reader is compatible with all 125kHz RFID tags and can store up to 48 tags in its memory. With its 10 cm range and simple serial communication this reader is found to be suitable for our WSN application. The reader can be powered by USB or external power supply of 6V to 12V. Redbee RFID reader sends an acknowledgment or negative acknowledgment message over the serial interface with the ID of the tag that is read.

3.3.2. Coding with Sensor Boards

Arduino development environment Arduino 1.0 [55] gives users the opportunity to use their own code to have control over analog and digital input/outputs. With its C/C++ like coding language it's easy to get the measurements from the sensors and send them over a serial connection. Arduino also has different libraries for more complex programming scenarios; Ethernet library for web server applications, wire library to communicate with I^{2}C devices, servo for controlling servo motors, SD library to use SD card on applications and many other libraries are also available.

Every Arduino code must have 2 main functions to be able to work. First one is the *setup()* function where variables are initialized and libraries are included. This function will work only once after a reset of power of the board. The second one is called the *loop()* and as the name suggest this function runs as long as there is power on the board. All sensing and communication functions must run in this function.

```
void setup() {

//Initialize Variables
//Include Libraries
}

void loop() {

// Read Measurements
// Send Measurements
}
```

Main code-block for development boards

There are two functions to get readings from the digital and analog pins, *DigitalRead()* and *AnalogRead().* When the pin number is used as parameters with these functions, the result of the corresponding pin is returned. With the same principle *DigitalWrite()* and *AnalogWrite()* are used to give outputs. For our study, we only use input functions and want to increase the reading periods as long as we can in order to obtain a longer battery life. To give a break on this looping code, a function called *delay()* is used with desired milliseconds passed as parameters.

Finally to send these readings to a remote machine, *Serial* class is used. This class is created mainly to communicate through serial ports by using RX and TX pins. While *begin()* function starts serial communication with the desired baud rate, *print()* and *println()* functions sends the output through serial ports. While the most common communication is done by USB, we will discuss other communication interfaces in the next subsection.

In our research, we want our nodes to only read measurements and send them via wireless communication to a remote machine. Thus we abstain from putting logic in these development microcontrollers. Arduino lets us use all known control structures, but for this study we only use them for simple operations. We plan that our codes only get the measurements from the sensors and form a structured message, then send it over a communication interface. While some of the sensors send readings constantly (temperature, ambient light) we want others to send messages when a difference in the measured phenomenon is detected (PIR Motion, Hall Effect). The code-block below is a very simple example of our codes. The next chapter will explain more about the actual codes in a real test environment. This code reads an analog input from pin 0 of the board and sends a message over serial connection by using 9600 baud rate, then waits 2 seconds before getting the reading again.

```
void setup() {

  int reading = 0;
  Serial.begin(9600);
}

void loop() {

  reading = AnalogRead(0);
  Serial.print("Sensed Measurement:");
  Serial.println(reading);

  delay(2000);
}
```

Simple code-block example for development boards

Using a software application provided by the Arduino platform, the code can be uploaded to the microcontroller by selecting the serial port that the board is connected to. This application also acts as a simple IDE to write and compile the Arduino code.

3.3.3. Communication Interface

The Arduino Uno has the ability to communicate with a computer or other microcontrollers. As stated in 3.1.1, the communication is done over a serial interface, ATmega328 provides serial communication, which is available on RX and TX pins. To convert this serial communication to a USB interface an ATmega8U2 converter is used on the board and USB connection on the computer appears as a virtual com port. This allows access to the microcontroller using a USB cable.

To form a WSN, the microcontrollers need to communicate with each other over a wireless medium. Arduino development boards support extendable modules such as Bluetooth, Ethernet and ZigBee [56] (IEEE 802.15.4) modules. Since our applications do not need long range communication and also battery usage is important, we have decided IEEE 802.15.4 to be our wireless communication interface. Special modules called Xbee Modules [57] are available for use with Arduino microcontrollers. This module simply communicates with the microcontroller via RX and TX pins, packages the messages and then sends them over the wireless medium.

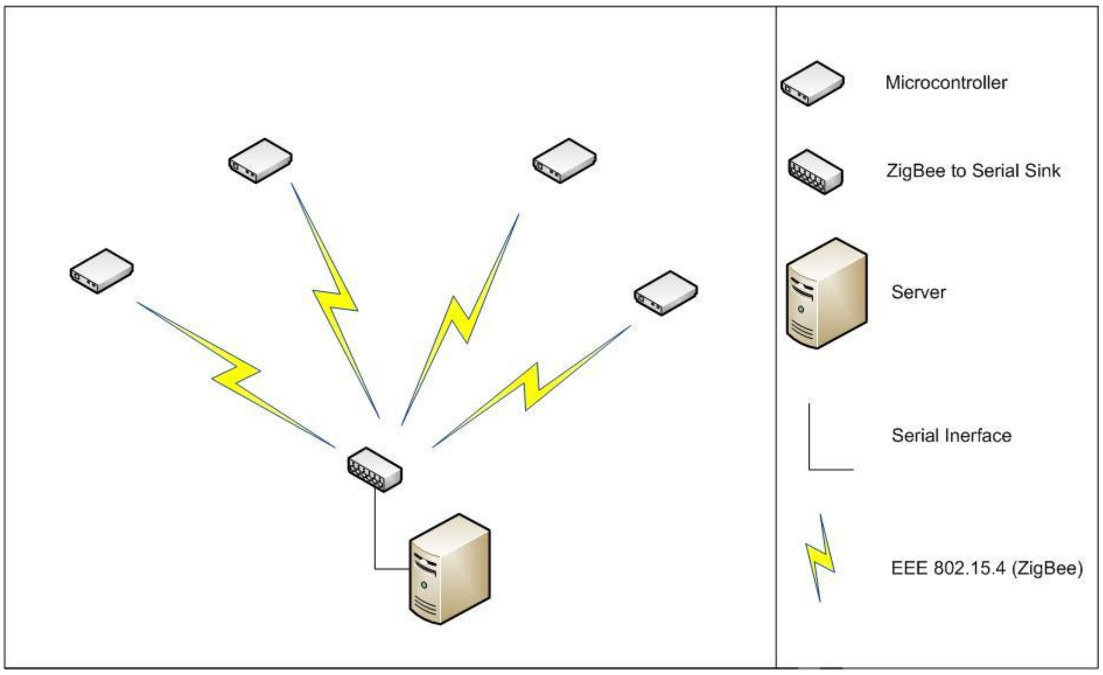


Figure 3.15 – Microcontroller Network Schema

For our study we use Xbee modules on every microcontroller as well as the RedBee RFID reader, thus obtain a complete network of sensors communicating on ZigBee. We also use a sink module that gathers the data over ZigBee and streams it through serial communication by means of a virtual com port over USB. Our nodes are adjusted to work on 57600 baud rate and they are communicating with the sink node while sink node is broadcasting to the network. X-CTU [58] software by Digi is used to modify the properties of Xbee modules.

CHAPTER 4

PROTOTYPING AND REAL LIFE APPLICATION

This chapter briefly explains the details of our case study where we have implemented our sensors and CEP system. The design of the system that is explained in Chapter 3 is used in this implementation. A classroom environment is selected for this study where daily class activities take place. With the help of the sensors that are placed in a simple classroom, we aim to detect complex events occurring throughout the day and help that classroom become smarter. In addition, we want to automate daily routines; we detect the automation cases where actions can be taken, although actuation part of the system is not a part of this study.

In subsection 4.1, the setup for the smart environment is described starting with coding and implementation and it continues with placement of sensors and microcontrollers. Subsection 4.2 gives information about the complex events to be deduced and details the rules used in this context. Finally in subsection 4.3, conclusion of the real life application is discussed.

4.1. Classroom Environment Setup

The aim of the study requires a simple classroom to be monitored with sensors and simple events occurring in this classroom should be collected and processed to get complex events. The microcontrollers that are detailed in Chapter 3 are used to construct this setup and the sensors are connected to the microcontrollers as detailed in that chapter. The microcontrollers are coded to send the desired messages to the sink node and these messages are processed to get complex events. We use three remote computers for this setup. The first one is in the classroom where the sensors are placed and the sink node is connected to that computer to get the readings from the sensors. The second one is responsible for reasoning on all the events and facts and publishes the extractions back to the JMS. For the Event Channel we use ActiveMQ JMS broker which is residing on the third unit where we are also using mySQL [59] database to track all the JMS messages. We also develop a webpage with AJAX technology that is also subscribing to the rule engine outputs in order to represent the current extracted high level information. This web page is served in the same computer where the event channel is implemented on Apache ActiveMQ. Jetty [60] web server is used to publish the webpage and to interact with JMS server Active MQ libraries are used. Table 4.1 shows the system information of all three computers used in this study. We use Java programming language to code all of our components and microcontrollers are programmed with their own coding language called Arduino.

Table 4.1- System Information of Computers Used in Implementation

	Computer 1 (Event Producer)	**Computer 2 (Event Messaging)**	**Computer 3 (Rule Engine)**
Processor	Intel Pentium 4	Intel Core I7	Intel Core 2 Duo P8600
Clock Speed	2.0 Ghz	1.73 Ghz	2.4 Ghz
RAM	736 Mb	4 Gb	4 Gb
Operating System	Microsoft Windows XP	Microsoft Windows 7 64 bit.	Microsoft Windows 7 32 bit.
Java jre version	1.6.0_26	1.6.0_25	1.6.0_26
Used Software Libraries	RXTXComm.jar	mysql-connector-java-5.1.18-bin.jar	mysql-connector-java-5.1.18-bin.jar
Database	-	mySQL 4.1	mySQL 4.1
Apache ActiveMQ	-	Version 5.5.0	-
JBoss Drools	-	-	Version 5.3.0

4.1.1 Software Setup

To be able to use the framework generically in all environments, it's intended that no special setup is required for the components of the system. The main differences between different scenarios are the rules and the complex events which are described in the next subsection for the classroom environment.

As explained in Chapter 3, our system has two main software components; SensorToJMS and JMStoDrools. The sensors are sending messages over Zigbee and the sink node is gathering them to transmit over serial interface to our first component. SensorToJMS is responsible to parse the messages and publish them to JMS which is running on a remote computer. The second component, JMStoDrools, is subscribing to these topics from a remote computer and inserts the incoming messages to the Event Processing Engine which is running on another computer.

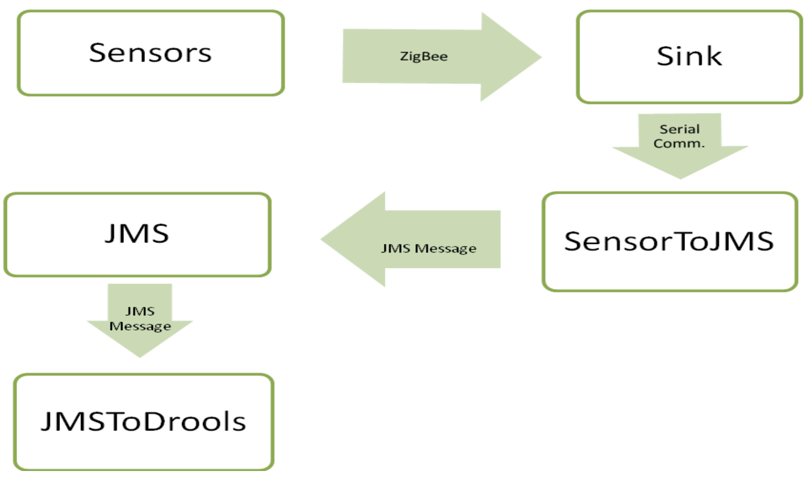


Figure 4.1 – Messaging between components

Microcontrollers are coded to be able to send messages over the wireless medium. While the temperature, noise level, ambient light intensity sensors are sending messages over a time period, the other sensors are only sending the state changes to preserve battery. To make this available, simple logic is used on microcontrollers. The codes running on microcontrollers are presented in Appendix B.

4.1.2 Hardware Setup

This case study is completed with 8 different types of sensors, one of them being an RFID reader. We propose to get measurements from the classroom and from the outside of the building to help us do the predictions. Our aim is to detect:

- State of the door (locked-unlocked, open-closed),
- People passing through the door,
- People's ID's who enter the classroom,
- Ambient temperatures both inside and outside,
- Ambient light intensity both inside and outside,
- Noise level in the classroom,
- Motion in the classroom.

With the help of these simple events and schedule information (facts about lectures) we aim to deduce complex events by using the framework. The sensors that are described in Chapter 3 are used to detect these simple events and these sensors are placed on the microcontrollers in 4 different locations of the classroom (Figure 4.2). Table 3 shows details about the usage of sensors for event detection. The following subsections tell about the placement of sensors and microcontrollers. We have selected door, one wall and outside as our microcontroller placeholders and those microcontrollers have multiple sensors on them. To detect the ambient light inside the classroom at two different locations we use two photoresistors. Likewise we need two different PIR Motion sensors to be used in our setup to be able to cover a larger area.

Table 4.2- Sensor Usage Details

Event Detected	Sensor Used
Door state- Open/Closed	Hall Effect Sensor and Magnets on door.
Door state- Locked/Unlocked	Optical Detector inside the lock to sense door lock.
People passing through the door	Infrared proximity sensor in door threshold
People ID's	RFID Reader
Ambient Temperature	Temperature Sensor inside and outside of the room
Ambient Light Intensity	Photoresistor inside and outside of the room
Noise level in the classroom	Electret Microphone inside the classroom
Motion in the classroom	PIR Motion sensor in the classroom

Each of the microcontrollers is using an Xbee ZigBee radio to communicate wirelessly with the sink node. Sink node is a convertor which gets the messages from ZigBee and sends them over a serial interface to the event collector unit. Our first component called SensortoJMS is residing on this computer.

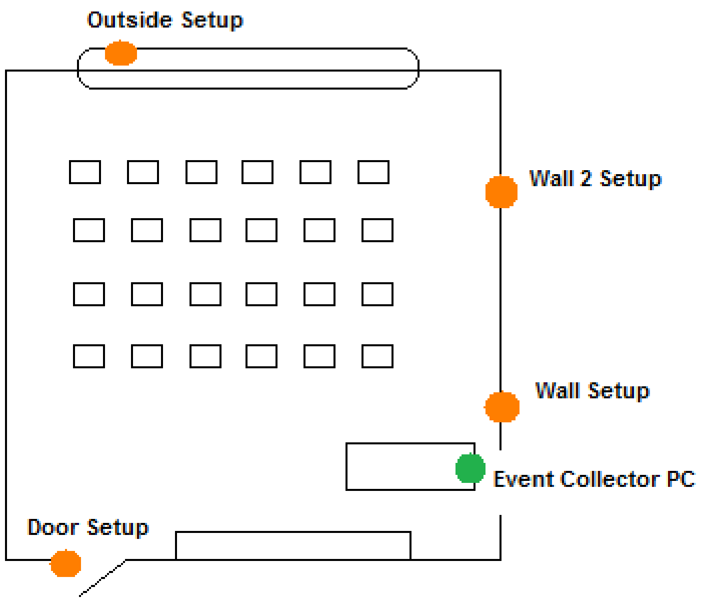


Figure 4.2 – Microcontrollers Schematic

4.1.2.1. Door - Microcontroller Setup

Since three different sensors are directly related with the door of the classroom, we place these sensors onto a microcontroller with a radio to communicate with the sink. We also place a PIR Motion sensor near the door to be able to detect movements when an object comes through the door. The door setup has:

- One Optical Detector
- One Infrared Proximity Sensor
- One Hall Effect Sensor with magnets on door
- One PIR Motion Sensor
- Two 7.4 V batteries to power microcontroller and sensors
- One ZigBee radio

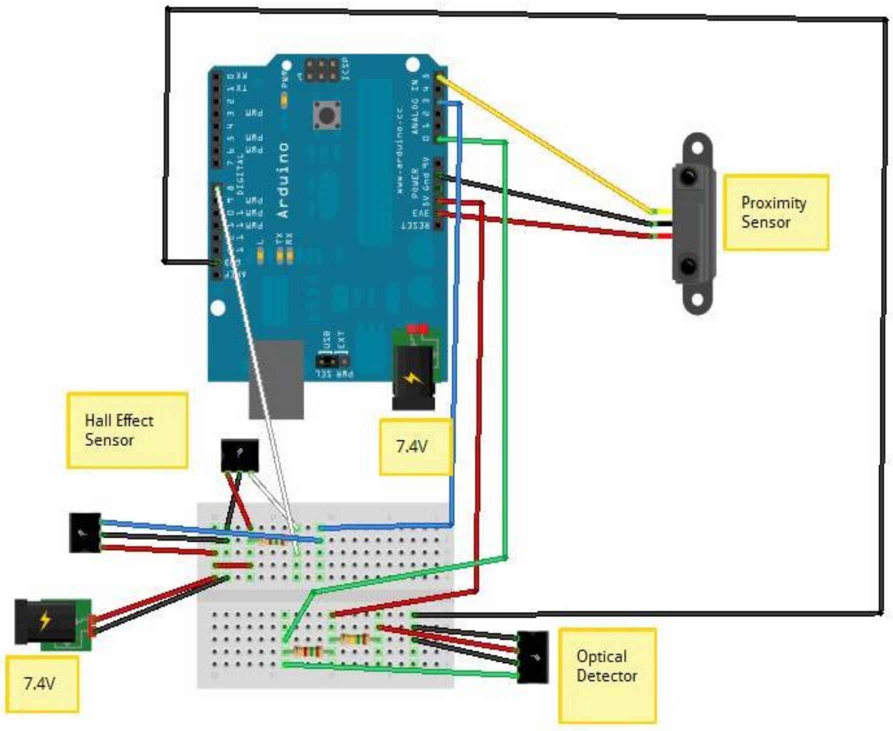


Figure 4.3 – Microcontroller Setup - Door

4.1.2.2. Outside - Microcontroller Setup

We are interested in the values of temperature and ambient light intensity outside the classroom so we can deduce events according to these values. The microcontroller is placed outside and has:

- One temperature sensor
- One photoresistor
- One 4.7V battery to power microcontroller and sensors
- One ZigBee radio

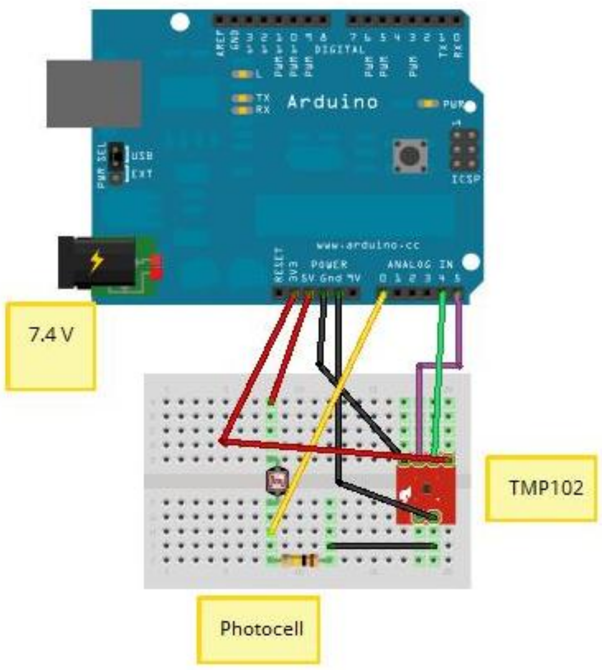


Figure 4.4 – Microcontroller Setup –Outside

4.1.2.3. Inside, Wall - Microcontroller Setup

Inside the classroom we are interested in temperature, ambient light intensity and noise level values. This setup has:

- One temperature sensor

- One photoresistor
- One Electret Microphone
- One 4.7V battery to power microcontroller and sensors
- One ZigBee radio

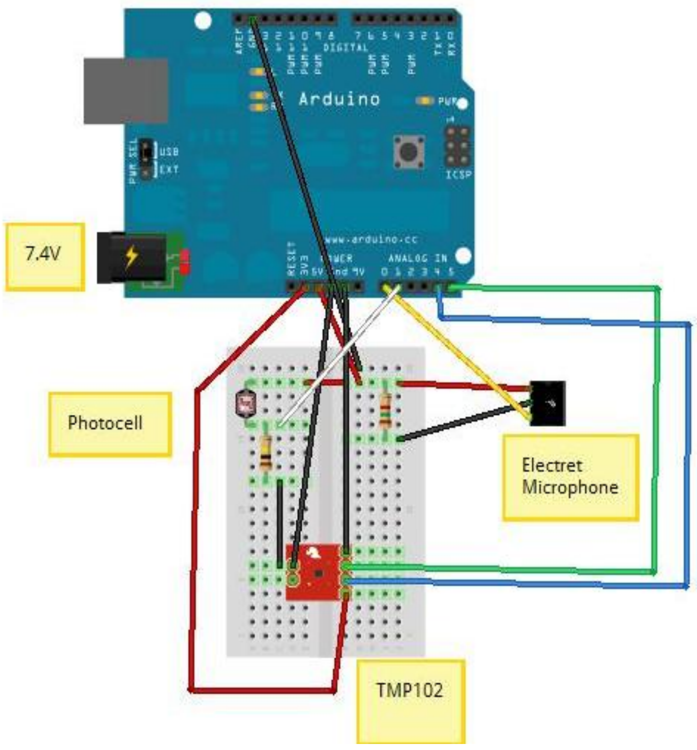


Figure 4.5 – Microcontroller Setup –Inside, Wall

4.1.2.4. Inside, Wall 2- Microcontroller Setup

Since we want to measure two different light values inside the classroom and also want to increase the coverage area of motion detection, we place two sensors on the same wall of the classroom. The setup has:

- One photoresistor
- One PIR Motion Sensor
- One 4.7V battery to power microcontroller and sensors
- One ZigBee radio

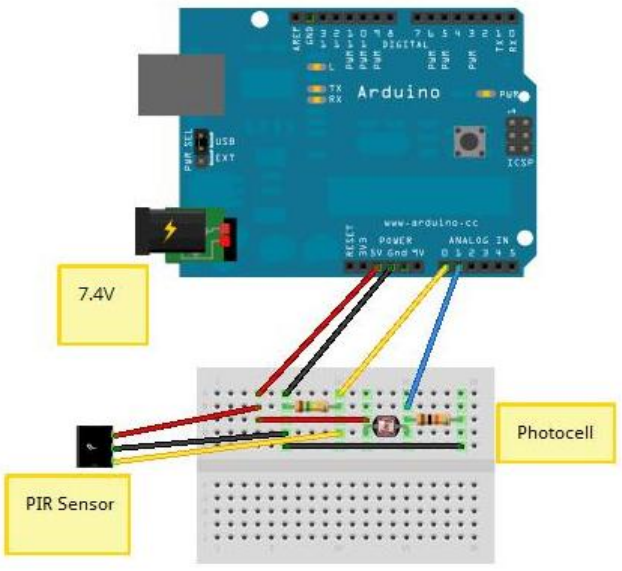


Figure 4.6 – Microcontroller Setup –Inside, Ceiling

4.1.2.5 RFID Reader

RedBee RFID reader is placed next to the entrance to get the ID's of the students and instructor in the classroom. 10 RFID tags are given to the students to be read when they are entering or exiting the classroom. This module also communicates over Zigbee. With the reader module an extra radio modem and 7.4V battery are also placed next to the door.

Figure 4.7 - Redbee RFID Reader

4.2. Complex Events and Rules

A classroom is a place where students attend lectures; the main actors for a classroom are students and instructor. For this study we select a classroom as our application area because lots of activities are taking place during the day around different actors. At first glance, attending a class seems as the only activity for a classroom, but in realty there are hidden actors for the classroom like institute personnel responsible for the security of the classroom equipment. Students and instructor may be the main actors, but during a day the classroom is used for different courses, thus making different people the main actors for the activities.

For this study we want to deduce complex events in the classroom with the help of the sensors that are placed in the classroom. A daily routine for a classroom is:

1. Institute personnel unlock the door for the classroom in the morning
2. Students enter the classroom for the lecture
3. Instructor enters the classroom and starts the lecture
4. A break may be given during the lecture
5. Lecture ends, instructor and students leave the classroom
6. If there are more lectures the routine repeats steps 2 to 5
7. If there are no more lectures, personnel check the classroom and lock the doors

This routine is the main scenario but there may be different actions in a lecture day. The lecture may start later than normal, the lecture may be extended or cancelled. The personnel may forget opening the door or locking them when the day ends. With our complex event detection, we want to make smart decisions and extract high level information with the help of our rule engine.

As a second objective to practice pervasive computing, we want to make automated decisions for simple activities in a classroom. Automated light and curtain control to provide necessary lighting is an example for this. For this study we have decided that our rules shall be grouped for 3 different time periods: start of the lecture, during the lecture and end of the lecture. Table 4.3 shows the decisions the rule engine shall make.

Table 4.3- Decisions for the Classroom

Start Of the Lecture	During The Lecture	End of the Lecture
Will the lecture start on time?	The lights and curtains should be prepared automatically	Did the lecture end? Is it the last lecture?
Are the doors open for students to enter? Do personnel know this?	Is the temperature of the classroom appropriate? Should we open the windows?	For the end of the day is the classroom locked securely?
Did the lecture start?	Is there a break during the lecture? Did the break end?	

These decisions are a cluster of both simple and complex events. We have separated the complex events from this cluster and decided which simple events are forming these complex events with the help of which temporal parameters. The corresponding rules in the Drools Rule Language format are given in Appendix 3.

- CE 1: Lecture will be delayed
    - Are most of the (30%) students in the classroom?
    - Is the temperature inside over 17^{o}C
    - Is the door still locked when there is 1 minute left for lecture start time?
- CE 2: Lesson Started
    - Lecture start time has passed
    - Instructor is in the classroom
    - Most of the students are in the classroom (60%)
    - The door is closed
- CE 3 :Break given
    - 30 to 90 minutes passed since the lecture started
    - OR 30-90 minutes passed since the last break
    - Door is open

    - People passing through the door
- CE 4: Break ended
    - 5 to 30 minutes passed since the break
    - Door is closed
- CE5: Lecture Ended
    - Less than 15 minutes remain for the lecture end or end time is passed
    - Door is open
    - People passing through the door
    - Instructor leaves the classroom
    - Most of the students leave the classroom (less than 30% remain)
- CE6: Lecture finished early
    - Door is open
    - People passing through the door
    - More than 15 minutes remain before lecture finish time
    - Instructor leaves the classroom
    - Most of the students leave the classroom (less than 30% remain)
- CE7: Day ended
    - CE 5 OR CE6 is deduced
    - Current lecture was the last one in the schedule
    - There is no movement inside the room
    - Noise level is low
- CE8: Classroom Check
    - CE7 is deduced
    - The door is locked
    - The noise level is low after the door is locked.
    - There is no motion in classroom after the door is locked.
    - The light intensity is low in classroom.
- CE9: Day started
    - CE7 is deduced
    - CE2 is deduced

There are also automation rules we also define as complex events

- AR1: Open the curtains
  - Photoresistor values are low in the classroom
  - Photoresistor values are high outside
- AR2 :Open the lights
  - Photoresistor values are low in the classroom
  - Photoresistor values are low outside
- AR3 : Open the window
  - Temperature values are high in the classroom
  - Temperature values are low outside
  - Temperature values are above 19^{o}C outside
- AR4 : Run air conditioner
  - Temperature values are high in the classroom
  - Temperature values are high outside
- AR5 : Run heater
  - Temperature values are low in the classroom
  - Temperature values are low outside

These complex events and automation rules are derived and fired by the system we have implemented in this study. The results of our research are given in the next subsection.

4.3 Results and Discussion

A prototype of the designed system is completed to observe the shortcomings of the system in a controlled environment. After making the necessary changes, a real life application is developed in a classroom environment and the outcomes are observed. The next subsections detail the experience we gained during prototyping and real life application.

4.3.1. Prototyping

A test setup is first implemented in the "Wireless Lab" of Informatics Institute to see the results of the implemented system on a prototype. Hardware components of the system are prepared as sensor nodes and they are placed on the door, ceiling and wall of the laboratory. The final set is placed outside the window to get the measurements of outside temperature and ambient light intensity. (Figure 4.8 and Figure 4.9)

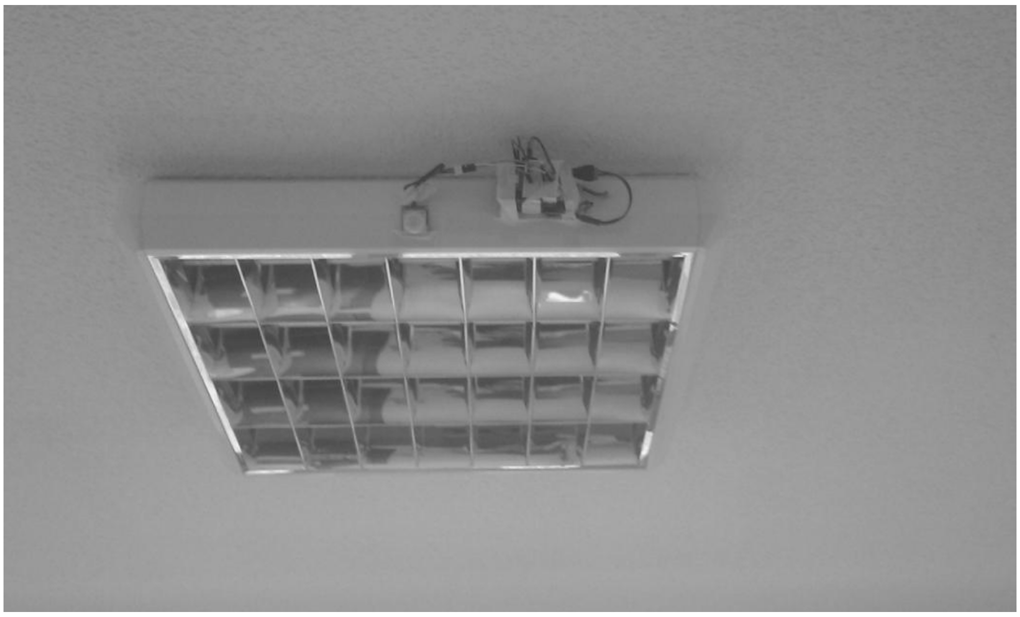


Figure 4.8- Prototype Implementation In Wireless Lab-Ceiling

During the hardware implementation, we have seen that power requirements for the sensors may be overwhelming for the microcontrollers. The door setup has 4 different sensors and two of them (PIR and Hall Effect) need to be powered externally to operate robustly. We have also examined that low capacity batteries run out quickly when the quantity of messages sent by one microcontroller is large in amount. This led us to use some precautions; we have used 7.4V 1000mA batteries on microcontrollers and added extra batteries to power the sensors when needed. As the processing power consumption is lower than transmitting power consumption we have decided to use some control structures to reduce the message sending frequency of the microcontrollers. The basic design for this was to send the messages when a state change is detected. Opening a door, motion detection, door unlocked are examples of this messages and the messages are only sent once by the microcontroller. The photoresistor and temperature sensors are measuring constantly changing phenomena but these measurements are not time critical measurements so we have decided to use a time period to delay the message sending. For this prototype sixty seconds was the delay time before another measurement is sent over the wireless medium.

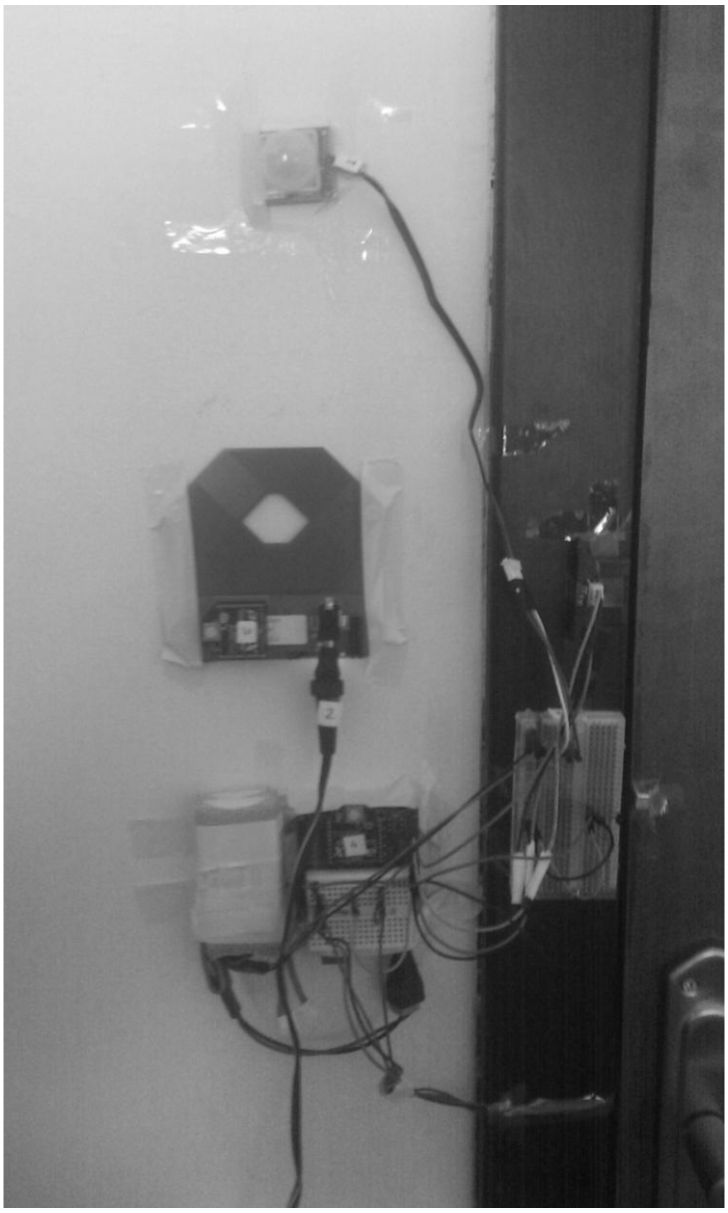


Figure 4.9- Prototype Implementation on the Wireless Lab-Door

This decision was important because we didn't want to use any processing on the sensor nodes. For this study our aim is to keep whole logic of the system at one point. When we look at the system components, we can see that apart from Event Processing Engine other components do not contain any logic. We use this design to be able to easily maintain the processing module when needed. Thus the coding of the microcontrollers is carefully adjusted that no logical reasoning is done over the measurements. The codes only detect the measurements and send them when there is a state change. As described in Chapter 3 the microcontrollers' output is either 1-0 or a value changing between 0-1023. Sensor nodes are not aware of the meaning of the value they measure. The only exception for this structure was the special I^2C temperature sensor which changes the value to a decimal showing the ambient temperature as Celsius degree. Even for this exception, microcontroller is not aware that this value represents a meaningful measurement.

Another reason to decrease the volume of messages sent by the microcontrollers was the reading capacity of our sink node. Buffer size for a serial connection is limited, thus high volume of events should be taken into account. Since we are using a special character for the end of the messages, getting wrong measurements is not possible for our system but missing data may end up with defective reasoning in the real environment. There are two possible solutions for this problem. First one is omitting missing data and reasoning over the arrived data coming from the same sensor. Event processing engine may decide state changes by inspecting all the messages coming from the sensors. Second solution is reducing messages to send messages without any conflict by sending state changes only. We apply the second solution which is more suitable because it is also a better practice for power preservation.

The event processing component of our system is designed to work with the inputs of events without any user interaction. Drools rule engine lets the users control when to fire the rules and also makes it possible to run the processing engine in a loop until user decides to stop it. For this research we have decided that rule engine should fire the rules whenever a new event is added to the system. Since we are already using a messaging system, we are aware of the incoming sensor events, thus running the rules at receiving time is a proper solution. The complex events can be detected by any of the input coming from the sensors so this way we are sure that none of the events are missed by the rule engine. This is the right way to implement an event driven system because the system is reasoning over the incoming events without any user input or by predefined actions.

4.3.2. Real Life Application

After we have successfully completed our prototyping in the laboratory, a real set-up is established in a classroom in the Informatics Institute. (Figure 4.10 and Figure 4.11) The four microcontroller setup and the RFID reader described in Chapter 3 are implemented in the classroom where real lectures are given. The SensorToJMS component is resting on a computer in the classroom which has the sink node attached. The gathered measurements are then distributed to the ActiveMQ JMS server over the Local Area Network (LAN). The remote computer running the JMS server lets our JMStoDrools component to subscribe to the events and the reasoning is completed in the computer where this component is residing. The outcome of our CEP engine is then shown on a webpage as an example of the application layer (Figure 4.12).

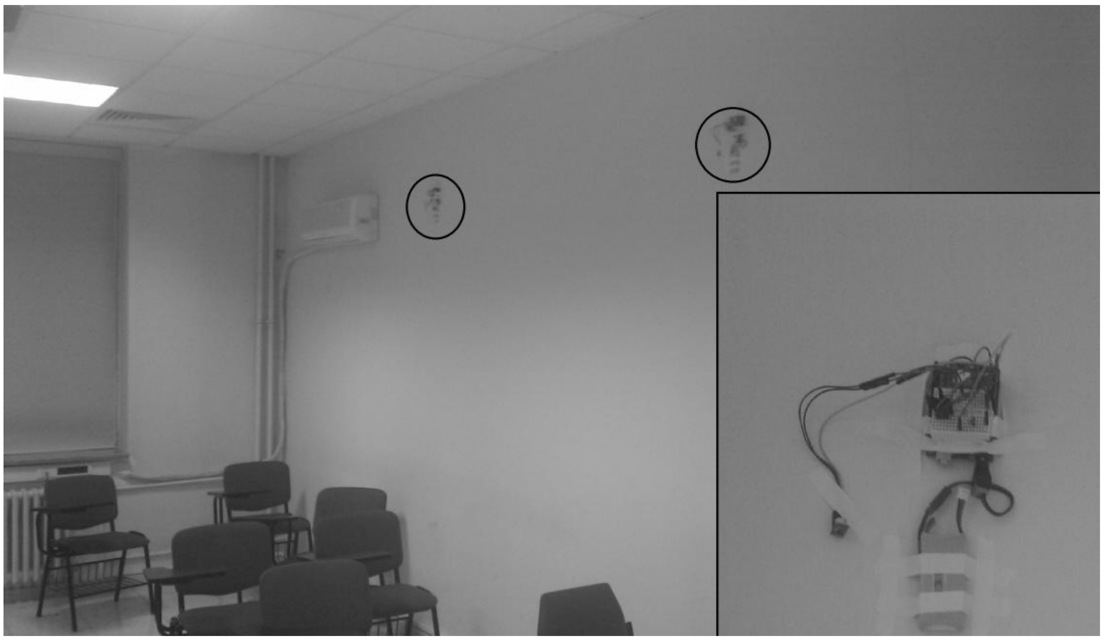


Figure 4.10- Prototype Implementation In Classroom-Wall

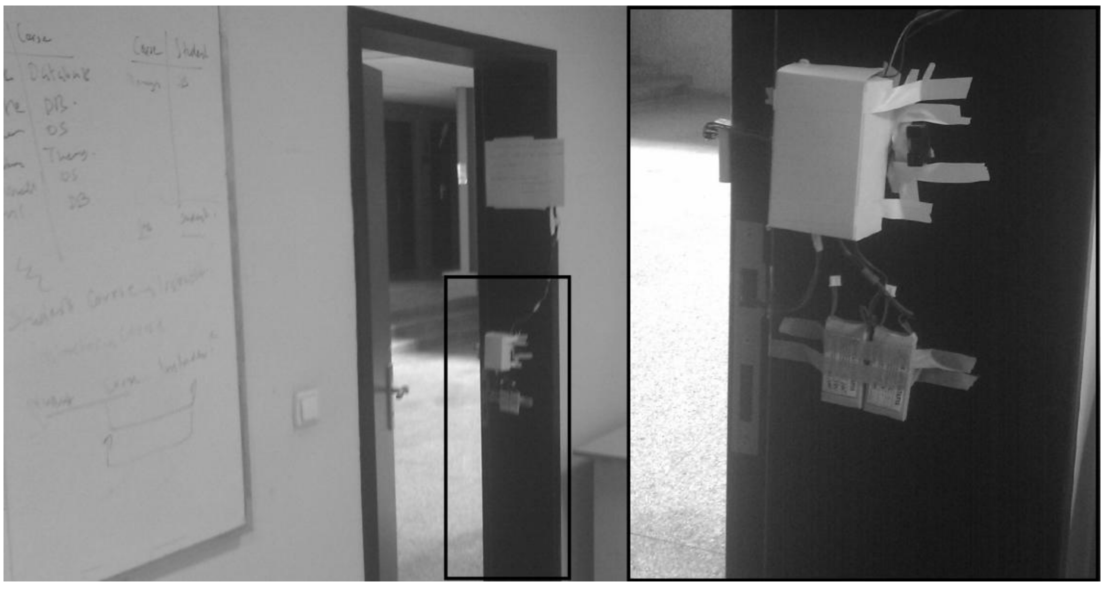


Figure 4.11- Prototype Implementation in the Classroom-Door

We have run our system during a day where one lesson is taking place in the classroom we have implemented our framework. The start and end of the day are thus only connected to that one lesson. Some assumptions are needed to be able to detect complex events happening in the classroom. These assumptions are implemented in the rules mainly as temporal and also as other conditions. For a simple lesson we assume:

- It will last for 3 hours

- The first break could be given after 30-90 minutes of lecture start

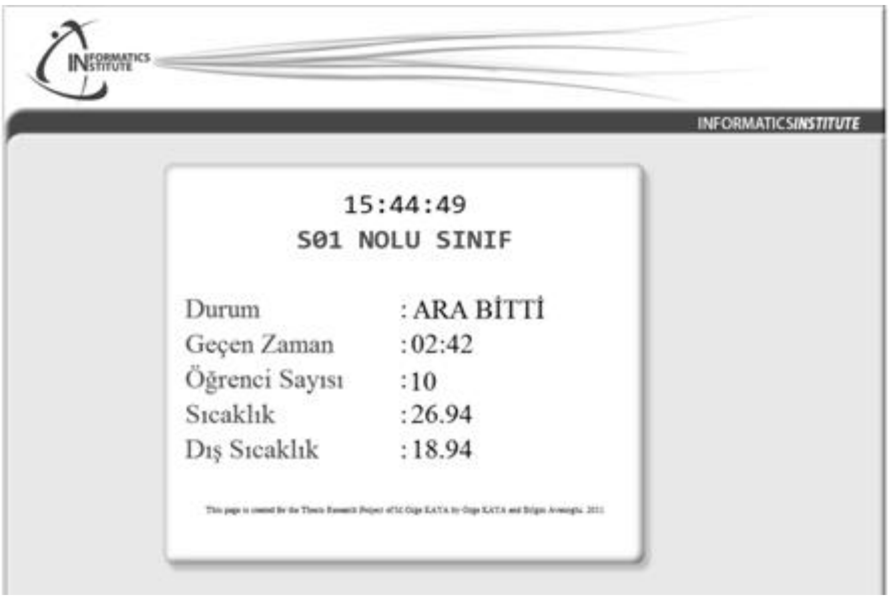
- 30% of the students are needed for lecture start

- Lectures could start at 40th minute of the hour and end at 30th minute of the hour.

- A break should as long as 5 to 30 minutes

- A normal lecture ending should happen if there is less than 15 minutes remaining to the end time of the lecture.

The engine is running constantly and we can't have any restriction over the frequency of the events incoming in a real environment. We have observed that during the reasoning there is not high amount of processer usage. Still we use a dedicated computer to operate as the Event Processing part of our system. Also as we can't be sure about the amount of events in the cloud at a given moment, we need a high memory in our system. All the events are inserted into the working memory and this causes memory problems when the amount of events gets higher. Drools helps to solve this issue by removing the old, non relative events from the working memory; by checking the rules in the rule base the engine decides which events are not related with the rules. Also Drools API gives the possibility to change events in the working memory. Programmer can design the system so that new events with the same types are not inserted into the knowledgebase again, instead they can update the parameters of an old event. With changing timestamp, the rules should be fired again which is done automatically every time when any of the events in the working memory are changed. This method is not used in our study because the volume of events is not too much to cope with in our use case.



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This page is created for the Thesis Research Project of M. Özge KATA by Özge KATA and Bilgin Avenoglu 2011

Figure 4.12- Webpage showing the results of event processing

In this real life application we develop a simple web page to show high level information to end users (Figure 4.12). This web page is subscribed to both high level information and also to low level data coming from the sensor nodes. This is a simple application that uses our framework but it shows the availability of our framework for other applications.

Table 4.4- Complex Event Detection Times

	14.12.2012		20.12.2012		21.12.2012		28.12.2012		04.01.2012	
	Real Time	**CEP**	**Real Time**	**CEP**	**Real Time**	**CEP**	**Real Time**	**CEP**	**Real Time**	**CEP**
Lecture Started	13:52	13:52	13:53	13:53	13:48	13:48	13:48	13:48	13:46	13:46
Break Given	14:47	14:47	14:38	14:38	14:31	14:31	14:39	14:39	15:08	15:08
Break Ended	15:01	15:01	14:51	14:45	14:39	14:39	14:59	14:59	15:20	15:20
Break Given	15:36	15:36	15:45	**N/A**	15:42	**N/A**	15:44	15:44	16:10	16:10
Break Ended	15:55	15:55	15:57	**N/A**	16:03	**N/A**	16:05	16:05	16:15	**N/A**
Lecture Ended	16:34	16:35	16:41	16:45	16:38	16:43	16:40	16:40	16:45	16:45

We have completed our study by running our system on five different days and successfully extracting high level information. Four hours of data collection for each day give us the results presented in Table 4.4. Only six important complex events are listed in that table while there are also other CE rules and automation rules. The real occurrence time of the complex events and the deduction made by our framework is compared. Apart from three CE all the others are deduced in the same minute; we can say that our framework is able to extract high level information in the same minute whenever a complex event happens. As seen in the Table 4.4, five of the complex events are not detected due to the reasons discussed in the next subsection. As there are a total of 30 complex events presented in the table we have observed that our framework is capable of detecting complex events with **83.3%** of success ratio. We have reached our aim of deducing predefined complex events, thus proved that a simple environment can be turned into a smarter one with the help of WSN's and CEP using the currently available software and hardware products. The limitations and the observations experienced in this implementation are discussed in the next subchapter.

4.3.3. Discussion

With this study we believe that we are able to use CEP technology on WSN's to convert information into knowledge. With current commercial WSN products and Business Rule Engines, which are mostly used for banking applications or organizational decision making, we are able to implement a sample system in our institute. This study shows that current technology can be used to make smart environments which are the main actors for the future pervasive computing scenarios.

During the study we have encountered some difficulties while extracting our complex events. The first issue we had to deal with was the volume of the events happening in the classroom environment. Although we have decided to transmit only the state changes, some sensors must be active and transmit the events whenever they occur (PIR Motion, Electret Microphone). This may cause a large amount of transmission according to the sensed area. Figure 4.13 shows the number of events in the classroom and it's clearly seen that when only state changes are sent, volume of events greatly decrease. For our study we have seen that electret microphone senses a large number of events during a lecture which causes a lot of transmission and brings forth the problem of missing events. Also these electret data are not included in the figure because the number of electret microphone data is 1000 times more than the next highest value. The volume problem will be seen more frequently when the number of sensors in the environment is increased. The solution for this shortcoming might be using another sink node to decrease the volume of events on one sink node or implementing some more logic on the sensors to decrease the volume of events. We think that adjusting sensors to send state changes and also some reminders within a fixed interval will be a practical solution for the missing events.

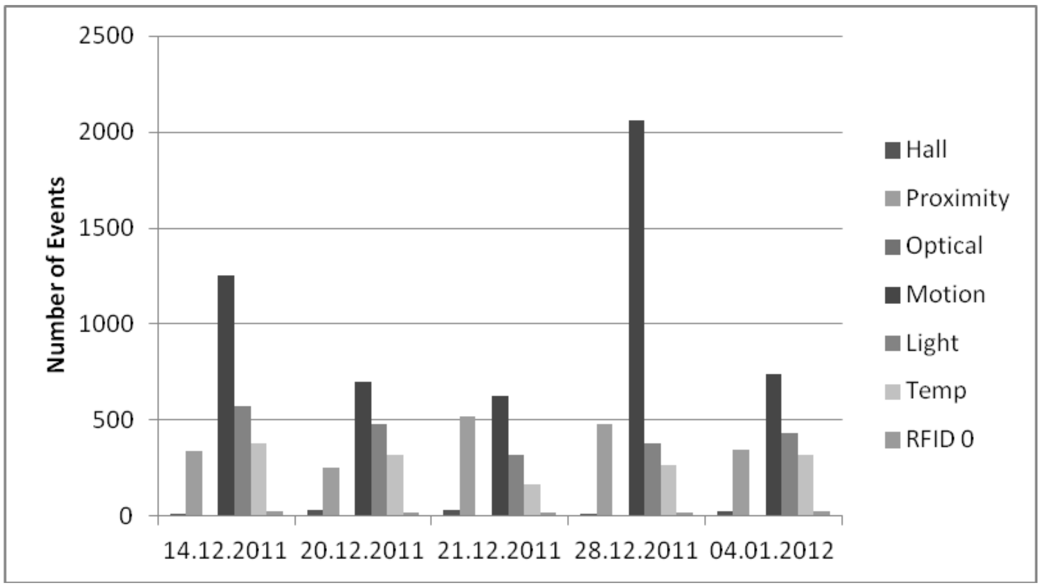

Figure 4.13- Number of Events for Five Days of Measurement

Another issue examined was specific to our case because our scenario was heavily dependent on deduced events. Some complex events were pre-conditions of other complex events like the "CE 3: Break given". In order to decide the break given, the lecture must have been already started. When everything works without any problem this issue was not seen, but in an uncontrolled environment there may be some difficulties apart from the shortcomings of the system. In our case, our sensors were removed from their places, sensor cables were unplugged by accident in the classroom. These issues cause events not to be extracted if they are dependent on these sensors. And furthermore the other complex events cannot be deduced either, if the lost complex event is in their pre-conditions. This study was dependent on the number of sensors and sensor types thus these problems were to be faced during the implementation. To be more precise and overcome this issue, we suggest increasing the sensor types and number in the environment in order to gather more events. By using different types of sensors we can sense more things within the environment which may help writing alternative rules to detect the same complex event. For this implementation we think using pressure sensors under chairs, using a color light sensor for projector, using accelerometers carried by students are some examples of improving the sensing capability of the system used. Using more sensors will apparently lead us to the first issue that is discussed so it is essential that both issues must be solved together.

Apart from the shortcomings, we believe that it’s possible to extract high level information in a classroom by using the methodology of this research. The sensor numbers and types are limited for this study, but with the events we have gathered from the classroom we have successfully deduced our Complex Events. We have discussed that with more types and number of sensors we can improve the precision of our system. However this does not mean we are not able to extract Complex Events with our system. By definition of the complex events [40] there must be other events as the member of the Complex Event. More members in the defined event do not always mean a better extraction of the Complex Event. In this study we have seen that measuring the noise level in the classroom was not beneficial for our Complex Events. Figure 4.14 presents the noise level measurements in the classroom on 28.12.2011. Before we started our implementation, we predicted that noise level would increase during break times and decrease when lecture started. In our institute we have seen that during the break times, the classroom noise level does not change significantly, thus making our sensor irrelevant for our Complex Event. By looking at the figure we can say that noise level has both high and low peeks during the lecture, even when there is no break. Because of this irrelevancy, Electret Microphone sensor prevents us to match the defined event while we can detect them at the right time without the usage of this sensor. We believe that while deciding the members of the complex event, relevant events must be carefully inspected and without complicating the rules the right events must be added as members of the event. More events may be used as alternative rules to deduce the same event or to increase precision of the Complex Event.

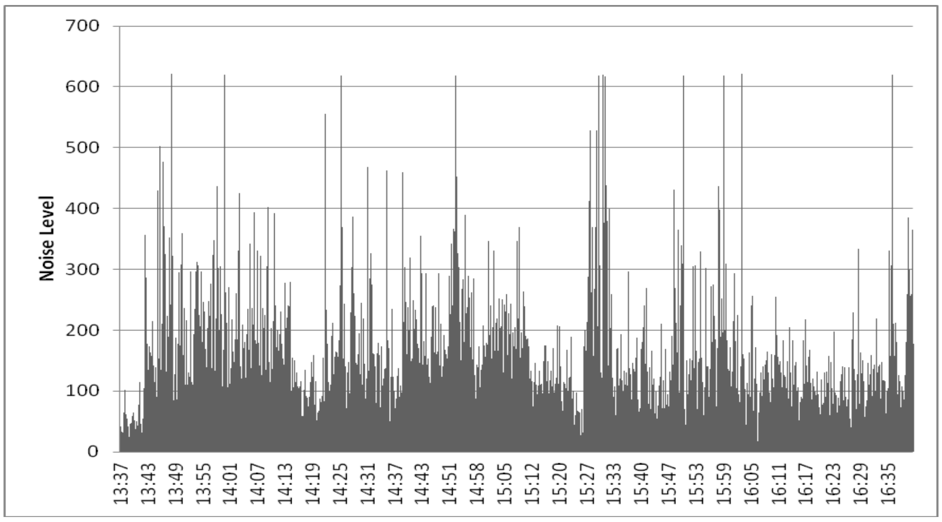

Figure 4.14- Noise Level Measurement in the Classroom

CHAPTER 5

CONCLUSION

This chapter summarizes the study and highlights findings and limitations. It also details the topics which are left out of the scope of this study for future studies.

5.1 Summary of Study

Our aim in this study is to extract high level information using simple readings from the sensors. The rules given in Chapter 4 are implemented using DRL and by inserting the incoming events (sensor readings for our case) to the knowledgebase, where the rules are defined, rules are fired. Without manual input, we let the sensors detect the state changes in the environment, as a result we have an event driven system which is capable of making smart deductions. With our simple sensors and complex event processing technique, we have achieved our goal of making an environment smarter as described in [32]. This result shows us that by using currently available technology, a simple environment can become smarter. Study [31] explains limitation of hardware as a main issue in pervasive computing applications; by using available and inexpensive hardware we claim that it’s possible to construct a smart environment. Figure 5.1 shows approximate values of our hardware costs for the real life implementation. We also present that our approach is feasible to be used with any hardware as data sources with help of our publish/subscribe system. In addition, we have utilized readily available open source software.

RFID Reader and Tags	**Sensors**	**Development Boards**	**Communication Modules**	**Batteries**	**Total**
$90	$55	$240	$125	$50	**$560**

Figure 5.1- Hardware Cost of the Framework

An event-based system with sensors being the event generators is designed and the event processing module of the system is supported by a Complex Event Processing engine. Event generators and event processing engine is loosely coupled with help of an event messenger. The event processing engine is subscribed to the sensors who are publishing the detected events. While study [27] is also using a CEP engine to reason over WSN data, we use a rule based complex event processing engine to correlate the relationships among simple events by using temporal constraints on the rules. The same rule engine is also used in [28] for a medical sensor network. Our designed system is then implemented as a prototype to extract high level information in a classroom environment. Like the architecture defined in [10] our system takes atomic events and by using our CEP engine turns them into business events. Our sensors are Event Originators, while Event Modeler and Event Processing Medium correspond to to our CEP engine component. After successfully completing prototyping, a real life implementation is deployed in a classroom in order to detect Complex Events occurring in that classroom. By looking at the challenges of large area deployments ([38],[39]) we have decided to use a more controlled area in our real life implementation. Eight different types of sensors are placed at four different locations of the classroom to gather simple events. We have also used RFID tags in order to obtain a heterogenic system described as a requirement in [22]. With predefined rules the gathered events are used to deduce Complex Events by using the system implemented. After five different experiments, the system is found to be successful to be able to detect the Complex Events within the same minute of real happening time. The result are obtained with 83,3% success rate.

During the prototyping process, we have seen that the high frequency and high volume of the events may throttle the sink node leading to loss of the events. We have chosen our system to be a centralized one unlike [15], [16]. It's stated in [18] that in a centralized system the event processing is not dependent on the frequency events and also distributed processing needs more power and system requirements on the sensor nodes. We tried to reduce the volume of the events by designing sensors to only send state changes when applicable. While making those changes we took care not to put any logic on the sensor nodes because the aim of the study was to keep all logic in one place. Another point we have observed was the power consumption of the sensor nodes. For this study we have used 4 different sensor nodes with at least 2 sensors attached to them. We have seen some sensors need more power than the power supplied by the development boards. Adding more battery capacity to our sensor implementation was seen necessary. Although we think that decreasing the message volume will decrease the power consumption, using more sensors consumes power of the development boards more quickly. With this study we implement a pervasive computing example in the classroom where the system is running in the background without any input from the users. The event based architecture is found to be suitable because we want the system to automatically check all the rules whenever a new event is detected. By using a publish/subscribe event messaging service, we design our system so that it publishes the events to our subscriber component, the event processing engine. After making necessary changes on our prototype implementation we find out that we can detect our Complex Events with the designed setup.

Study [28] is very similar to our approach; they use a prototype in a hospital environment where RFID is the main data source. We try our approach with a real life application where sensor data, RFID and data from other information systems are equally used. We have completed our real life implementation in a classroom on five different days. We are able to detect our complex events at the same time when they occur in the classroom. While CEP is presented as ill-suited in [29], we claim that it is possible to use CEP technology in pervasive environments to obtain smart environments.

During this implementation, we have seen that volume of events is still a problem even after we have changed our design after the prototyping phase. Some sensors that are used in the implementation have to send all events continuously like PIR motion, electret microphone and proximity sensors. These sensors send events whenever they sense anything in the classroom. This increases the volume of events and leads to loss of events detected. The shortcoming of event loses are already stated in [20]. We propose two solutions for this shortcoming; the first one is putting more logic in the sensor nodes to make them send both state changes and also reminders about their states in a fixed time period. While this solution decreases the volume of events, it also helps missing events to be detected when a reminder is sent. Second solution is to use more sink nodes to be able to deal with the high volume of events. We also suggest using more sensors in the classroom, thus this solution will be beneficial even if the first solution is used. Our complex event rules were dependent on each other. That caused the system to lose all its ability to detect the events if a previous event was not detected. We suggest that by using more types of sensors, we will be able to write more rules that can detect the same complex event which can be used as alternatives to other rules. We also believe more sensor types will help detection of more complex events which are not implemented in this study. We observed that our complex events were detected successfully with relevant simple events by using time constraints between simple events. Increasing the number of sensors will make rules more reliable, but increasing the type of sensors will not affect a simple rule if they are irrelevant for that complex event.

This study was limited to the sensor types and numbers available to us during the implementation phase. We designed our system to support more types of sensors but our sensor selection was limited to the sensors available in the Wireless Lab of METU Informatics Institute. This limitation is stated as a difficulty in pervasive computing applications in [31]. We believe that with more types and number of sensors our system will become more stable and will be able to deduce more Complex Events which are not implemented in this study. The shortage of sensor types led to high dependency on these sensors for our study. Removing any of the sensors from our implementation would cause it to function improperly. During the real life implementation, we use one classroom in the Informatics Institute. Using the system for all the classrooms will be a better practice in the pervasive computing domain. We do not use any actuators in our implementation, even though we have used some actuation rules which only warn about the action to be taken. Our study uses a simple network of sensors which are communicating with the sink node wirelessly, although this setup does not have all the characteristics of a Wireless Sensor Network.

5.2 Future Work

A direction for future studies is to increase the number of sensors and sensor types and to observe the outcomes including the performance evaluations. The computational performance of the system would be evaluated according to events in the knowledgebase and the number of rules that are implemented. Our study shows that with the current setup, a single computer being the event processor we do not need any significant processing power. Our CEP engine removes the events in the knowledgebase when they are not necessary according to their timestamp and the temporal constraints used in the rules. We did not observe any memory problems during this study but with more events and rules the memory usage needs to be examined.

As another study different Complex Event Processing Engines can be used with the system implemented in the classroom and the advantages and disadvantages of them can be expressed. For this study we have chosen a rule based open source complex event processing engine, but by the end of 2011 more CEP engines became available with different mechanisms [61].

The development boards used in this study can be arranged to work like a wireless sensor network by using the newer versions of ZigBee modems that are deployed on boards. Another future study can use a WSN to examine the event dissemination in the current setup. The power consumption statistics and results of development board failures on the network would be observed.

As another venue for future work, different pervasive computing applications can be implemented on our EDA framework. We believe that by implementing this test bed in the Institute, we have made this setup available for future studies. Simple sensor events and also the Complex Events detected by the engine can be used by subscribing to all of them. Also security of the system should be provided to prevent any attacks to the system and to be sure proper messages are received by the subscribers.

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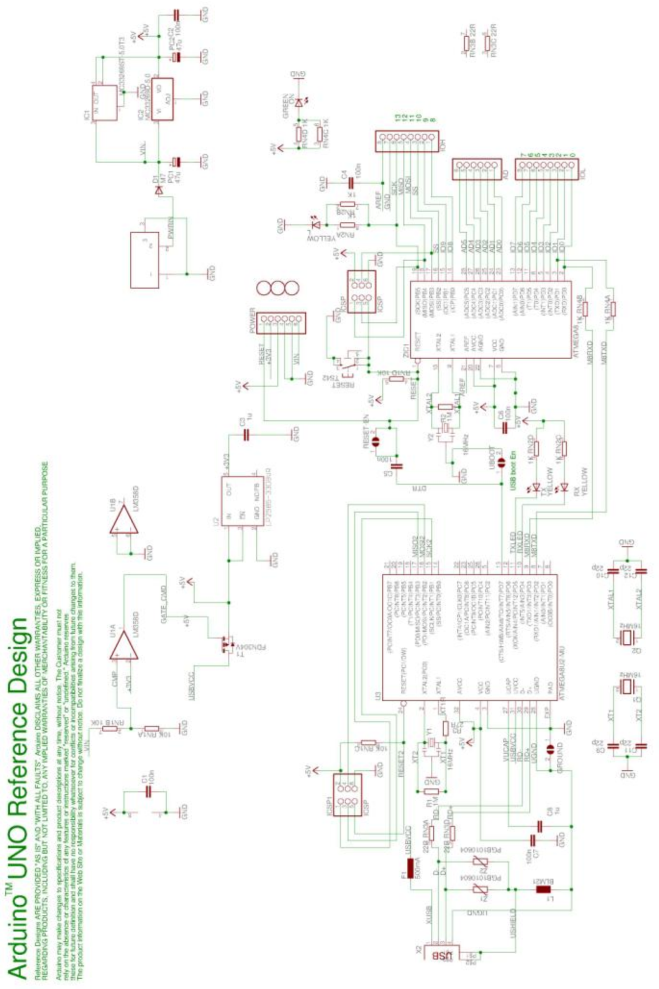
APPENDICES

Appendix A : Sensor Board Schematic For Arduino Uno



Appendix B : Microcontroller Codes

Microcontroller Code -Door

```
/* Uno 5
/* Halleffect,proximity,pressure sensors
/* Used at clasroom door
/* M.Ozge Kaya; Informatics Institute,METU
 */

int hallEffectPin = 8;
int proximityPin = A5;
int opticalPin =A0;
int proximityThreshold = 200;
int proximityReading = 0;
int hallReading = 0;
int hallSwitch=0;
int optical =0;
int lockCounter = 0;
int unlockCounter = 0;
int lockSwitch =3;
int timer = 500;
int alarmPin = A3;
int alarmValue = 0;
long previousMillis = 0;
long interval = 2000;

void setup(){
  Serial.begin(57600);
  pinMode(buzzerPin, OUTPUT);
  pinMode(alarmPin, INPUT);
  delay (3000);
}

void loop(){
  optical = analogRead(opticalPin);
  hallReading = digitalRead(hallEffectPin);
  proximityReading = analogRead(proximityPin);

  //just to slow down the output - remove if trying to catch
an object passing by
  delay(180);
  // Selected Readings
  if (proximityReading >= proximityThreshold) {
    /*If lenght changes(An object passing) ,
    /*I0: Infrared at door.
    /*Send  value 1 meaning there is movement.*/
    Serial.print("I0:1");
    Serial.print("\r");
  }

  /* Detect if door is open or closed
  /* H0: HallEffect at door.
  /* Send 1 for open,send 0 for closed
  /* HallSwitch is used for sending open and close messages fo
r once
   */
```

Microcontroller Code –Door Cont.

```
if(hallReading == 1 && hallSwitch==0){ //Door is open
    Serial.print("H0:1");
    Serial.print("\r");
    hallSwitch=1;
  }
if (hallReading == 0 && hallSwitch==1) { //Door is closed
    Serial.print("H0:0");
    Serial.print("\r");
    hallSwitch=0;
  }

/* Detect if door is locked or not
  /* P0: Pressure at door.
  /* Send 1 for locked,send 0 for unlocked
  /* Counter is used to get last 10 measurement
   */
  if (lockSwitch != 1) {
    if (optical < 900 && lockCounter ==10) {
      Serial.print("O0:1");
      Serial.print("\r");

      lockCounter=0;
      lockSwitch=1;
    }
    else if (optical <900 && lockCounter < 10) {
      lockCounter++;
    }
  }

  if (lockSwitch != 0) {
    if (optical >= 900 && unlockCounter ==10 ){
      Serial.print("O0:0");
      Serial.print("\r");
      unlockCounter=0;
      lockSwitch = 0;
    }
    else if (optical >= 900 && unlockCounter < 10) {
      unlockCounter++;
    }
  }
  /* Detect if there is movement
  /* M0: Motion inside first.
  /* Send 1 for motion
  /* Counter is used to delay 5 secs after every movement
   */

  alarmValue = analogRead(alarmPin);
  unsigned long currentMillis = millis();
  if(currentMillis - previousMillis > interval) {
    previousMillis = currentMillis;
    if (alarmValue < 100){
      Serial.print("M0:1");
      Serial.print("\r");
      }
   }
}
}
```

Microcontroller Code -Outside

```
/* Uno 4
/* Ambient Temp,Photosensor
/* Used at outside
/* M.Ozge Kaya; Informatics Institute,METU
 */

#include <Wire.h>
int tmp102Address = 0x48;
byte res;
int val;
int photoPin =A0;
int photoRead =0;

void setup(){
  Serial.begin(57600);
  Wire.begin();
}

void loop(){
  /* Detect outside temp.
  /* T1: Outside temperetaure
  /* Send every 8 sec.
   */
  Wire.requestFrom(tmp102Address,2);

  byte MSB = Wire.receive();
  byte LSB = Wire.receive();

  int TemperatureSum = ((MSB << 8) | LSB) >> 4; //it's a 12bit
int, using two's compliment for negative

  float celsius = TemperatureSum*0.0625;
   Serial.print("T1:");
  Serial.print(celsius);
  Serial.print("\r");
  delay(4000);
  /* Detect outside ambient light.
  /* L1: Outside light.
  /* Send every 8 sec.
   */
  photoRead= analogRead(photoPin);
  Serial.print("L1:");
  Serial.print(photoRead);
  Serial.print("\r");

  delay(4000);
}
```

Microcontroller Code –Inside Wall

```
/* Uno 3
/* Ambient Temp,Photosensor,Electret Microhpone
/* Used at inside
/* M.Ozge Kaya, Informatic Institute,METU
 */

#include <Wire.h>
int tmp102Address = 0x48;
byte res;
int val;

const int ledPin = 13;
const int electret = A0;
const int photo =A1;
int electretReading = 0;
int photoReading =0;
int electretMax = 0;
int electretMin = 1023;
int electretThresholdHIGH =100;
int electretThresholdMED =50;
int electretThresholdLOW ;
int noiseLevel;
int lastNoiseLevel=50;
long previousMillis = 0;
long interval = 8000;


void setup() {
  Serial.begin(57600);
  Wire.begin();
    //Calibration for Electret
   while (millis() < 3000) {
   electretThresholdLOW = analogRead(electret);
   // record the maximum sensor value
   if (electretThresholdLOW > electretMax) {
   electretMax = electretThresholdLOW;
   }
   }
   // signal the end of the calibration period
   electretThresholdLOW = electretMax;
   Serial.println("Calibration Completed");
   Serial.print("Background Noise Level:");
   Serial.println(electretThresholdLOW,DEC);
}
```

Microcontroller Code –Inside Wall Cont.

```
void loop() {

  /* Detect inside noise.
  /* E0: Inside Noise
  /*
   */
  electretReading = analogRead(electret);
  if ((electretReading >= electretThresholdLOW)) {
  Serial.print("E0:");
  Serial.print(electretReading-electretThresholdLOW);
  Serial.print("\r");
  delay(500);
 }
  unsigned long currentMillis = millis();
  if(currentMillis - previousMillis > interval) {
    previousMillis = currentMillis;
    /* Detect inside ambient light.
    /* L0: Inside light.
    /* Send every 8 sec.
     */
    photoReading=analogRead(photo);
    Serial.print("L0:");
    Serial.print(photoReading);
    Serial.print("\r");

    /* Detect inside temp.
    /* T0: Outside temperetaure
    /* Send every 8 sec.
     */
    Wire.requestFrom(tmp102Address,2);

    byte MSB = Wire.receive();
    byte LSB = Wire.receive();

    int TemperatureSum = ((MSB << 8) | LSB) >> 4; //it's a
12bit int, using two's compliment for negative

    float celsius = TemperatureSum*0.0625;
    Serial.print("S0:");
    Serial.print(celsius);
    Serial.print("\r");
  }
}
```

Microcontroller Code –Inside, Ceiling

```
/* Uno 2 Ic2
/* PIR,Photosensor
/* Used at inside
/* M.Ozge Kaya;Informatics Intstitute,METU
 */
int timer = 500;
int alarmPin = A0;
int alarmValue = 0;
long previousMillis = 0;
long interval = 6000;
int photoReading =0;
const int photo =A1;


void setup(){
  Serial.begin(57600);
  pinMode(alarmPin, INPUT);
  delay (3000);
}
void loop(){
    /* Detect motion
    /* M1: PIR Motion
    /* Send every 2 sec.
     */
  alarmValue = analogRead(alarmPin);
   if (alarmValue < 100){
    Serial.print("M1:1");
    Serial.print("\r");

    delay(2000);
  }

  unsigned long currentMillis = millis();

  if(currentMillis - previousMillis > interval) {
       previousMillis = currentMillis;
    /* Detect inside ambient light.
    /* L2: Inside light.
    /* Send every 8 sec.
     */
    photoReading=analogRead(photo);
    Serial.print("L2:");
    Serial.print(photoReading);
    Serial.print("\r");
  }
}
```

Appendix C : Rules in Drools Rule Language

CE 1: Lecture will be delayed

```
rule "dersGecikecek"
when
            CurrentState(timeOfLecture=="S1") from entry-point
DEFAULT
            CurrentState(numberOfStudents <= 3) from entry-point
DEFAULT ||
            Number( doubleValue < 17) from accumulate(
        SensorEvent(sensorName == "Temp0",$data : data) over
window:length( 4 ) from entry-point classroom,
        average( $data ) ) ||
       $eventA : SensorEvent(sensorName == "Optical0") over
window:length (1) from entry-point classroom
       SensorEvent(data == 1) from $eventA
then
            System.out.println( "DROOLS:Ders Gecikecek");
            Main.sendDroolsJMS("DROOLS:Ders Gecikecek");
end
```

CE 2: Lesson Started

```
rule "dersBasladi"
      when
      not(DroolsEvent(event == "dersBasladi") from entry-point
DEFAULT)
      $eventA : SensorEvent(sensorName=="Hall0") over
window:length(1) from entry-point classroom
      SensorEvent(data == 1) from $eventA
      $state : CurrentState(numberOfStudents >= 6,timeOfLecture ==
"ST",isInstructerThere==true) from entry-point DEFAULT
      then
            System.out.println( "DROOLS:Ders Basladi");
            Main.sendToJMSText("DERS BASLADI","state");
            Main.sendDroolsJMS("DROOLS:Ders Basladi");
            Main.addEventDersBasladi();
            Main.retractEventAraBitti();
            Main.retractEventDersBitti();
end
```

CE 3 :Break given

```
rule "araVerildi"
      when
      not(CurrentState(timeOfLecture=="E15") from entry-point
DEFAULT)
      not(DroolsEvent(event == "araVerildi") from entry-point
DEFAULT)
      not(DroolsEvent(event == "dersBitti") from entry-point
DEFAULT)
      not(DroolsEvent(event=="araBitti") from entry-point DEFAULT)
      $eventB : DroolsEvent(event=="dersBasladi" ) from entry-point
DEFAULT
      $eventA : SensorEvent(sensorName=="Hall0",data == 0,this
after[30m,90m] $eventB)  from entry-point classroom
      $eventD : SensorEvent(sensorName == "Infrared0",data ==
1,this after[1s,120s] $eventA) from entry-point classroom
      then
            System.out.println( "DROOLS:Ara Verildi");
            Main.sendToJMSText("ARA VERILDI","state");
            Main.sendDroolsJMS("DROOLS:Ara Verildi");
            Main.retractEventAraBitti();
            Main.addEventAraVer();
end
```

CE 4: Break ended

```
rule "araBitti"
      when
      not(DroolsEvent(event=="araBitti" ) from entry-point DEFAULT)
      $eventB : DroolsEvent(event == "araVerildi") from entry-point
DEFAULT
      $eventA : SensorEvent(sensorName=="Hall0",data == 1,this
after[5m,30m] $eventB) over window:length(1) from entry-point
classroom

      then
            System.out.println( "DROOLS:Ara Bitti");
            Main.sendToJMSText("ARA BITTI","state");
            Main.sendDroolsJMS("DROOLS:Ara Bitti");
            Main.addEventAraBitti();
            Main.retractEventAra();
End
```

CE5: Lecture Ended

```
rule "dersBitti"
      when
      not(DroolsEvent(event=="dersBitti" ) from entry-point
DEFAULT)
      $eventA : DroolsEvent(event == "dersBasladi") from entry-
point DEFAULT
      ( CurrentState(timeOfLecture=="E15") from entry-point DEFAULT
||
      CurrentState(timeOfLecture=="ET") from entry-point DEFAULT)
      $eventB : SensorEvent(sensorName=="Hall0") over
window:legth(1)  from entry-point classroom
      $eventD : SensorEvent(data == 0) from $eventB
      $eventC : SensorEvent(sensorName == "Infrared0",data ==
1,this after[1s,120s] $eventB) from entry-point classroom
      CurrentState(isInstructerThere==false) from entry-point
DEFAULT
      CurrentState(numberOfStudents <= 3) from entry-point DEFAULT

      then
      System.out.println( "DROOLS:Ders Bitti");
      Main.sendToJMSText("DERS BITTI","state");
            Main.sendDroolsJMS("DROOLS:Ders Bitti");
            Main.addEventDersBitti();
            Main.retractEventAraBitti();
            Main.retractEventDersBasladi();
end
```

CE6: Lecture finished early

```
rule "dersErkenBitti"
      when
      not( CurrentState(timeOfLecture=="E15"))
      not( CurrentState(timeOfLecture=="ET"))
      not(DroolsEvent(event=="dersBitti" ) from entry-point
DEFAULT)
      $eventA : DroolsEvent(event == "dersBasladi") from entry-
point DEFAULT
      $eventB : SensorEvent(sensorName=="Hall0",data == 0)  from
entry-point classroom
      $eventC : SensorEvent(sensorName == "Infrared0",data ==
1,this after [1s] $eventB) from entry-point classroom
      CurrentState(isInstructerThere==false)
      CurrentState(numberOfStudents <= 3)

      then
      System.out.println( "DROOLS:Ders Erken Bitti");
      Main.sendToJMSText("DERS ERKEN BITTI","state");
            Main.sendDroolsJMS("DROOLS:Ders Erken Bitti");
            Main.addEventDersBitti();
            Main.retractEventAraBitti();
            Main.retractEventDersBasladi();
end
```

CE7: Day ended

```
rule "gunBitti"
      when
      $eventC : DroolsEvent(event=="dersBitti" ) from entry-point
DEFAULT
      $eventA : CurrentState(isLastCourse==true)      from entry-
point DEFAULT
      not(SensorEvent(sensorName == "Motion0",data >= 0,this after
[10m,15m] $eventC) from entry-point classroom)
      not(SensorEvent(sensorName == "Motion1",data >= 0,this after
[10m,15m] $eventC) from entry-point classroom)
      Number( doubleValue < 50) from accumulate(
    SensorEvent(sensorName == "Electret0",$data : data) over
window:time(60s) from entry-point classroom,
    average( $data ) )
then
            System.out.println( "DROOLS:GUN Bitti");
            Main.sendToJMSText("GUN BITTI","state");
            Main.sendDroolsJMS("DROOLS:Gun Bitti");
            Main.retractEventDersBitti();
            Main.addEventGunBitti();
            Main.changeCurrentState("false","isLastLecture");
            System.out.println("görevliyi kilit için çağır");

end
```

CE8: Classroom Check

```
rule "sınıfKontrol"
      when
      $eventA : DroolsEvent(event=="gunBitti" ) from entry-point
DEFAULT
      $eventB : SensorEvent(sensorName=="Optical0",this after
[10m,60m] $eventA) over window:length (1) from entry-point
classroom
      SensorEvent(data == 1) from $eventB
      $eventC : SensorEvent(sensorName=="Motion0",data >= 0,this
after [0h,8h] $eventB) from entry-point classroom ||
      $eventD : SensorEvent(sensorName=="Motion1",data >= 0,this
after [0h,8h] $eventB) from entry-point classroom ||
      Number( doubleValue > 50) from accumulate(
    SensorEvent(sensorName == "Electret0",$data : data,this after
$eventB) over window:time(60s) from entry-point classroom,
    average( $data ) ) ||
      not(SensorEvent(sensorName=="Light0",data <= 200,this after
[0h,8h] $eventB) from entry-point classroom) ||
      not(SensorEvent(sensorName=="Light2",data <= 200,this after
[0h,8h] $eventB) from entry-point classroom)

      then
            System.out.println( "DROOLS:SINIFI KONTROL ET");
            Main.sendToJMSText("SINIFI KONTROL ET","state");
            Main.sendDroolsJMS("DROOLS:SINIFI KONTROL ET");

end
```

CE9: Day started

```
rule "gunbasladi"
 when
      $eventA : DroolsEvent(event=="gunBitti" ) from entry-point
DEFAULT
      $eventB : DroolsEvent(event=="dersBasladi" ) from entry-point
DEFAULT
      then
      System.out.println( "DROOLS:Gun Basladi");
      Main.sendDroolsJMS("DROOLS:Gün Basladi");
      Main.addEventGunBasladi();
      Main.retractEventGunBitti();
end
```

AR1: Open the curtains

```
rule "perdeAc"
when
            Number( doubleValue < 500) from accumulate(
        SensorEvent(sensorName == "Light0",$data : data) over
window:length( 10 ) from entry-point classroom,
        average( $data ) ) ||   Number( doubleValue < 500) from
accumulate(
        SensorEvent(sensorName == "Light2",$data : data) over
window:length( 10 ) from entry-point classroom,
        average( $data ) )
        Number( doubleValue > 600) from accumulate(
        SensorEvent(sensorName == "Light1",$data : data) over
window:length( 10 ) from entry-point classroom,
        average( $data ) )
then
            System.out.println( "DROOLS:Dış ortam aydınlık perdeleri
açın.");
            Main.sendDroolsJMS("DROOLS:perdeleri acin.");

end
```

AR2 :Open the lights

```
rule "isikAc"
when
            Number( doubleValue < 500) from accumulate(
        SensorEvent(sensorName == "Light0",$data : data) over
window:length( 10 ) from entry-point classroom,
        average( $data ) ) ||   Number( doubleValue < 500) from
accumulate(
        SensorEvent(sensorName == "Light2",$data : data) over
window:length( 10 ) from entry-point classroom,
        average( $data ) )
        Number( doubleValue < 600) from accumulate(
        SensorEvent(sensorName == "Light1",$data : data) over
window:length( 10 ) from entry-point classroom,
        average( $data ) )
then
            System.out.println( "DROOLS:Dış ortam karanlık  ışıkları
açın.");          //Main.sendDroolsJMS("DROOLS:isiklari acin.");
            Main.sendDroolsJMS("DROOLS:Isiklari acin.");
end
```

AR3 : Open the window

```
rule "camAc"
when
            Number( doubleValue >= 28) from accumulate(
        SensorEvent(sensorName == "Temp0",$data : data) over
window:length( 10 ) from entry-point classroom,
        average( $data ) )
        Number( doubleValue <= 24) from accumulate(
        SensorEvent(sensorName == "Temp1",$data : data) over
window:length( 10 ) from entry-point classroom,
        average( $data ) )
        Number( doubleValue <= 19) from accumulate(
        SensorEvent(sensorName == "Temp1",$data : data) over
window:length( 10 ) from entry-point classroom,
        average( $data ) )
 then
            System.out.println( "DROOLS:İçerisi çok sıcak camı
açın.");
            Main.sendDroolsJMS("DROOLS:Cami acin.");
end
```

AR4 : Run air conditioner

```
rule "klimaAc"
when
            Number( doubleValue >= 28) from accumulate(
        SensorEvent(sensorName == "Temp0",$data : data) over
window:length( 10 ) from entry-point classroom,
        average( $data ) )
        Number( doubleValue >= 24) from accumulate(
        SensorEvent(sensorName == "Temp1",$data : data) over
window:length( 10 ) from entry-point classroom,
        average( $data ) )

 then
            System.out.println( "DROOLS:İçerisi çok sıcak klima
açın.");
            Main.sendDroolsJMS("DROOLS:Klima acin.");
end
```

AR5 : Run heater

```
rule "isiticiAc"
when
            Number( doubleValue <= 20) from accumulate(
        SensorEvent(sensorName == "Temp0",$data : data) over
window:length( 10 ) from entry-point classroom,
        average( $data ) )
        Number( doubleValue <= 22) from accumulate(
        SensorEvent(sensorName == "Temp1",$data : data) over
window:length( 10 ) from entry-point classroom,
        average( $data ) )

 then
            System.out.println( "DROOLS:İçerisi çok soğuk ısıtıcı
açın.");
            Main.sendDroolsJMS("DROOLS:Isıtıcı acin.");
end
```

TEZ FOTOKOPİSİ İZİN FORMU

ENSTİTÜ

Fen Bilimleri Enstitüsü ☐

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YAZARIN

Soyadı: KAYA
Adı : MUAMER ÖZGE
Bölümü : BİLİŞİM SİSTEMLERİ

TEZİN ADI (İngilizce): A Complex Event Processing Framework Implementation Using Heterogeneous Devices In Smart Environments

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