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Internet of Things in intralogistics

Energy Efficiency monitoring of belt conveyors using Digital Twins

MASTER'S THESIS

to achieve the university degree of

Master of Science
Master's degree program: Production Science and Management

submitted to

Graz University of Technology

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Graz, May 2019

AFFIDAVIT

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ACKNOWLEDGMENTS

I would like to thank my supervisors, Ass. Prof. Dipl.-Ing. Dr.techn. Norbert Hafner and Schadler, Michael, Dipl.-Ing. BSc.
Meetings and discussions with supervisors helped me and steered me in the right direction.

I would also like to thank other colleagues and students working on similar projects for cooperation and exchange of opinions.

Finally, big thank to the TU Graz and Institute of Logistics Engineering for giving me the opportunity to write about challenging topic for Master Thesis.

ABSTRACT

Digitalization and automation are the main aims of most companies nowadays. In recent years, material flow systems and their industrial development have been characterized by challenging objectives – e.g. increasing energy efficiency, miniaturization and flexibility of the design, improvements of performance as well as higher system availability. Digitalization and automation become the main and the most important focus of the companies in the area of Industry 4.0. Development of Internet of Things, Industrial Internet of Things (IIoT), Cloud computing for further connectivity of systems are great challenges with high potential. With the technology field programmable gate array (FPGA) modules can be developed that serve as an edge-node for powerful automation systems. Anyway, there is a lot of space for improvements. Full integration of versatile systems into IIoT has not been achieved yet. For example, a combination of FPGA, Industrial Internet of Things, Cloud storage and control systems can be used as a concept. Data control of most material handling systems is still not integrated into IIoT. Flexible monitoring of the systems' Key Performance Indicators (KPI) is therefore only available in a limited rang. This master project and its documentation serve to propose a system that makes use of the fundamental concepts. Four fundamental concepts that are investigated are the Internet of Things, Cloud database management and analytics, FPGA-controllers and the basics of data transmission. The system task is to monitor KPIs based on real-time data. Using Microsoft Azure Cloud, data can be analyzed and corrective actions can be applied to the system. The use case of the master project is monitoring the energy efficiency and the behavior of the belt conveyors using Digital Twins.

Keywords: Digitalization, Automation, Internet of Things, Industrial Internet of Things, Cloud computing, Industry 4.0, Energy efficiency, Digital Twins, Belt conveyor

ZUSAMMENFASSUNG

Digitalisierung und Automatisierung sind heutzutage die Hauptziele der meisten Unternehmen. Materialflusssysteme und deren industrielle Weiterentwicklung sind in den letzten Jahren von herausfordernden Zielen geprägt – z.B. die Energieeffizienz zu erhöhen, die Miniaturisierung und Flexibilisierung des Designs, erhöhte logistische Leistungserbringung und erhöhte Verfügbarkeiten. Die Digitalisierung und Automatisierung wird zu besonders wichtigen Aufgaben der Unternehmen, unter dem Überbegriff Industrie 4.0. Die Entwicklung und Anwendung entsprechender Technologien wie Internet der Dinge, Industrielles Internet der Dinge (IIoT), Cloud Computing zur Vernetzung der Systeme, Sammlung und Bereitstellung der Daten sind Herausforderungen mit großem Potenzial. Mit der Nutzung von z.B. Field Programmable Gate Arrays (FPGA) können Module entwickelt werden, die als sogenannte Edge-Knoten wesentliches zu leistungsfähigen automatischen Systemen beitragen. Es gibt viel Raum für Verbesserungen und Aufgaben der vollständigen Integration. Als Lösungsbeispiel wurde ein Konzept aus FPGA, industriellem Internet der Dinge, Cloud-Speicher und Steuerungssystemen entwickelt. Die Gerätesteuerung vieler Materialflusssysteme ist noch nicht vollständig in das IIoT integriert. Die flexible Überwachung des Betriebes und die Echtzeit-Analyse von Key Performance Indicators (KPI) der Systeme ist daher eingeschränkt. Diese Masterarbeit und die zugehörige Dokumentation sollen dazu dienen, ein System vorzuschlagen, das grundlegenden Konzept-Anwendungen zeigt. Vier betrachtete grundlegende Konzepte sind das Internet der Dinge, das Management und die Analyse von Cloud-Datenbanken, FPGA-Lösungen von Industriesteuerungen und die wesentlichen Aspekte der Datenübertragung. Die Kernaufgabe des konzipierten Systems besteht darin, auf der Grundlage der Istdaten-Überwachung, dem Benutzer KPI bereitzustellen. Unter Nutzung der Microsoft Azure Cloud werden die Daten der Gerätesteuerung ausgewertet und Eingriffsmöglichkeiten in das System ermöglicht. Das Usecase-Szenario der Masterarbeit ist die Überwachung der Energieeffizienz eines Förderbandsystems, auf Basis einer Digital Twin Lösung, sowie die Ableitung des Verhaltens des Förderbandsystems.

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IoT	Internet of Things
IIoT	Industrial Internet of Things
KPI	Key Performance Indicator
M2M	Machine to Machine
RFID	Radio Ferquency Identification
WSN	Wireless Sensor Network
IP	Internet Protocol
MCU	Microcontroller Unit
OPC UA	Open Platform Communications Unified Architecture
MQTT	Message Queuing Telemetry Transport
SMQTT	Secure Message Queuing Telemetry Transport
MAX	Measurement and Automation Explorer
FPGA	Field Programmable Gate Array
SQL	Structured Query Language
NI	National Instruments
DSP	Digital Signal Processing
SDO	Standard Development Organization
QoS	Quality of Service
CSR	Corporate Social Responsibility
EEI	Energy Efficiency Indicators
NAS	Network Attached Storage
ADC	Analog to Digital Convertors
DAC	Digital to Analog Convertors
PLM	Product Lifecycle Management
CPS	Cyber Physical System
C2PS	Cloud based Cyber Physical system
SaaS	Software as a Service
P2P	Peer to Peer
ROC	Representative Operation Cycle
CoAP	Constrain Application Protocol
SOA	Service Oriented Application

ReST	Representative State Transfer
CoRE	Constrain REST Environment
TPC	Transfer Control Protocol
UDP	User Datagram Protocol
HTTP	Hypertext Transfer Protocol
NFC	Near Field Communication
LTE	Long-Term Evolution
HLS	High level Synthesis
DTUs	Database Transaction Units
SSMS	SQL Server Management Studio
W_L	Logistic performance
E_{In}	Electrical energy input
λ	Throughput
l	Length of belt conveyor
L_F	Distance
T_N	Operation period
T_i	Percentage of time values
t_i	Percentage of time
I_n	Total input after a given operation period
i_n, i_{n-1}	Instantaneous inputs by proximity sensor in successive periods
t_n, t_{n-1}	Instantaneous operation periods, time between two successive inputs

1 Introduction

1.1 Rationale

Nowadays, digitalization and modernization are the main goals of every industry. From the economical point, digitalization and modernization will give fewer costs in every aspect of work, and from the technical side, we should get better effectiveness and efficiency.

Digitalization has focus by the technical side in three areas. The first area is “IT and software”, this area includes artificial intelligence, mobile applications, and cloud technologies. The second area is “Networking”, include cyber-physical systems for Industry 4.0 and Internet of Things. The third area is “Robot and sensor technology”.

Modernization and digitalization related to logistics have the logistic trends in terms of “basal”, “global”, “customer” and “economic” trends. Basal trends are technological and organizational evolution (for example RFID). Global trends are for example growing of corporate social responsibility (CSR). Customer trends are requirements, services and individualization. Economics trends are for example autonomous trends.

Not directly involved in this research but speaking about “Human Factor” also have effect on entire digitalization and modernization. The human factor plays the most important role. To be in trend is very important that companies invest in education from which workers will gain knowledge and will be able to handle new technologies like everything connected with IoT, IIoT, Industry 4.0, Digital Twins and other related fields. Otherwise, without the right knowledge is very hard to follow the trends. A human can decide on his own using knowledge and skills gotten from education gained through theoretical or practical work. In that way of looking, a human has an unlimited possibility of solving problems, creativity, and resourcefulness, which machines don’t have. Because of skills human still can use better than machinery, a human is an important fact in cyber-physical systems. (Brümmerstedt, Beek, & T. Münsterberg, 2017)

Production environment in its entirety dramatically changed last years. Mass customization faces more and more with pressure and market oscillations. To survive, companies must accept changes of modernization and digitalization very fast with minimal costs and high tolerance to further changes. (Gregor, Haluska, & Fusko, 2016)
As we are speaking about modernization and digitalization, it's important to say that modernization has a big impact on some traditional things and a very good term that can describe everything is "industrial religion". WVS (World Value Surveys) evidence gave clear information about massive cultural changes of traditional values, everything is connected with the modernization of the world, of course in the meaning of industry. (Inglehart & Baker, 2000)

Digitalization is of very importance to processing, storage, and transmission of data. It is because it allows all kind of information in different classes to be carried with the same efficiency. (Pisani, 1985)

1.2 Aim and objectives of the Thesis

The main purpose of the Thesis is monitoring of energy efficiency of the belt conveyors using Digital Twins. The project proposed system will rely on multidisciplinary fields integration of subsystems through different fields like Internet of Things (IoT), Industrial Internet of Things (IIoT), digitalization, software development, energy management, cloud computing, electronics prototyping, and data communication. In the same way, the project aims at investigating the impacts of Industry4.0, Digital Twins and IoT to the improvement of intralogistics system through systematic analysis and synchronizations of all system under study.

1.3 Scope of the Thesis

All of the following tasks and subtasks are very important to the project development:

a) Familiarization with the terms Internet of Things (IoT), intralogistics and Digital Twins in their respective field of interaction and working to improve the automation in the intralogistics industry.
b) Research according to the digitalization of machinery. Serves to establish how digitization promotes intralogistics by revolutionizing data acquisition systems and process as well as speeding data acquisition in intralogistics.
c) Detailed definition of Internet of Things (IoT), Industrial Internet of Things (IIoT), Industry4.0, Digital Twins, Cloud Computing and other relevant topics. Wide scope and understanding of the field will help in coming up with a multi-disciplinary system to address the needs of intralogistics all the way from data acquisition, processing communication and visualization.
d) Comparison of IoT-platforms and M2M-protocols. This will form the main part of the communication system by providing pathways along which data forms from one unit to the other or from one section to another. From sensors to a microcontroller, microcontroller to network adapters and finally into or out of Digital Twin platform.

e) Conceptual design for energy efficiency of belt conveyors using Digital Twins. This will provide an effective design strategy that implements a system that is a digital pair of the actual system, enhancing data communication, cloud services use, material transport throughput measurement in real time as well material use in relative to electrical power consumed providing an avenue for effective monitoring and design.

1.4 Formulation of Research Questions

This thesis will serve to study and propose a system that revolves around Internet of Things, Industry4.0 aspects, Digital Twins among other related aspects and subset such as data communication, data analytics as well as digitization and material control optimization. This exposes the research to shift more to system interaction and development of a hybrid system that at end serve the following key purposes.

- Improving data collection and reliability through communication in real time as well as the cloud storage system.
- Monitoring of the system and help in the optimization of the facility and monitoring of the key aspect of the energy system.
- Provide anytime and anywhere data access.
- Improving intralogistics performance.

In this regards the following research question arises:

1. How the aspects of the Internet of Things and Digital Twins are helping and improving intralogistics in modern-day automation systems?
2. How can the aspect of the Internet of Things and Digital Twins help in improving energy efficiency in intralogistics?
3. How do we optimize the system by usage through design and implementation of a system built on Internet of Things, Digital Twins and Industry 4.0 aspects?
4. How unique is the system in handling big data, improving reliability and optimize the system usage?

1.5 Structure of the Thesis

The structure of the Thesis is the way of scientific work with defined chapters. In each chapter, the reader will get knowledge and a clear idea of what is important for the fields this project is dealing with.

Chapter 1: Introduction about digitalization and modernization in general, point out the things important to understand present and future in a right way. Description of the aim of the thesis.

Chapter 2: This chapter is based on the literature review. Explanation of intralogistics and other important terms like Internet of Things, Industrial Internet of Things, Digital Twins, Industry4.0, among others.

Chapter 3: Research methodology. The basic procedure for system development. Mainly the design criteria, procedures, and planning schemes are accentuated. This chapter provides an effective route to conceptual design.

Chapter 4: Base on the conceptual design. System and component connection, links, block diagrams, analytics, and mathematical modeling have been handled here. Formulation of the main project building blocks is shown as well as systematics configuration steps.

Chapter 5: Giving an overview of how the system is supposed to behave, what it should output or achieve. Conclusion regarding experience during the writing and investigation of relevant topics, as well as suggestions for future work.

2 Literature Review

This chapter focusses on literature in reference to the field of study. All relevant literature that forms the basis for the conceptual framework is reviewed. From intralogistics, trends in industrial automation, conveyor systems, data communication among other related fields creating a research gap as well as the way to conceptual framework build up.

2.1 Intralogistics

Material and information flow remain predominant factors. This simply because of the great need of facilitating production processes for material flow while aiding production control and monitoring for the case of the information flow leading to the constant need for optimizing, integrating, automating and managing the two fields in what has been termed as intralogistics.

Intralogistics there can be seen as a multidisciplinary field encompassing a diversity of core competencies that includes process engineering and analysis, strategic planning and logistics designs, automation, material handling technologies, database design and integrations, operational monitoring and reporting, information technology systems, remote monitoring, industrial, mechanical and electronics engineering among other related sub-disciplinary in the same field.

Over the years the field has undergone a series of transformation with more functionalities added to the field as well as improving the existing functionalities to improve efficiency, material, and data handling capacities. These developments are summarized in Figure 2-1.

Intralogistics solutions often achieve leaps in operational productivity through the integration of material handling and information processing technologies that optimize fulfillment processes and better utilize both equipment and labor resources, whether they are applied to manual, mechanized, or fully automated system configurations. (G.Karting, B.Grosel, & N.Zrnic, 2012)

As Figure 2-1 is showing it is important to note that true intralogistics solutions go beyond just the implementation of tools and component technologies that guide distribution center and fulfillment center operators through specific tasks like receiving, picking, and shipping. They also go beyond the mechanization of processes such as storage and retrieval, packaging, and sorting.

In reference to modern day material handling in most industrial processes, intralogistics plays a major role in promoting material movements, energy efficiency improvement through energy efficiency and management system. Functionality can be attached to it, reduce time and cost of operation as well as reducing material wastage and damage with conveyor belts and drives plays a wide role in material transport. (G.Karting, B.Grosel, & N.Zrnic, 2012)

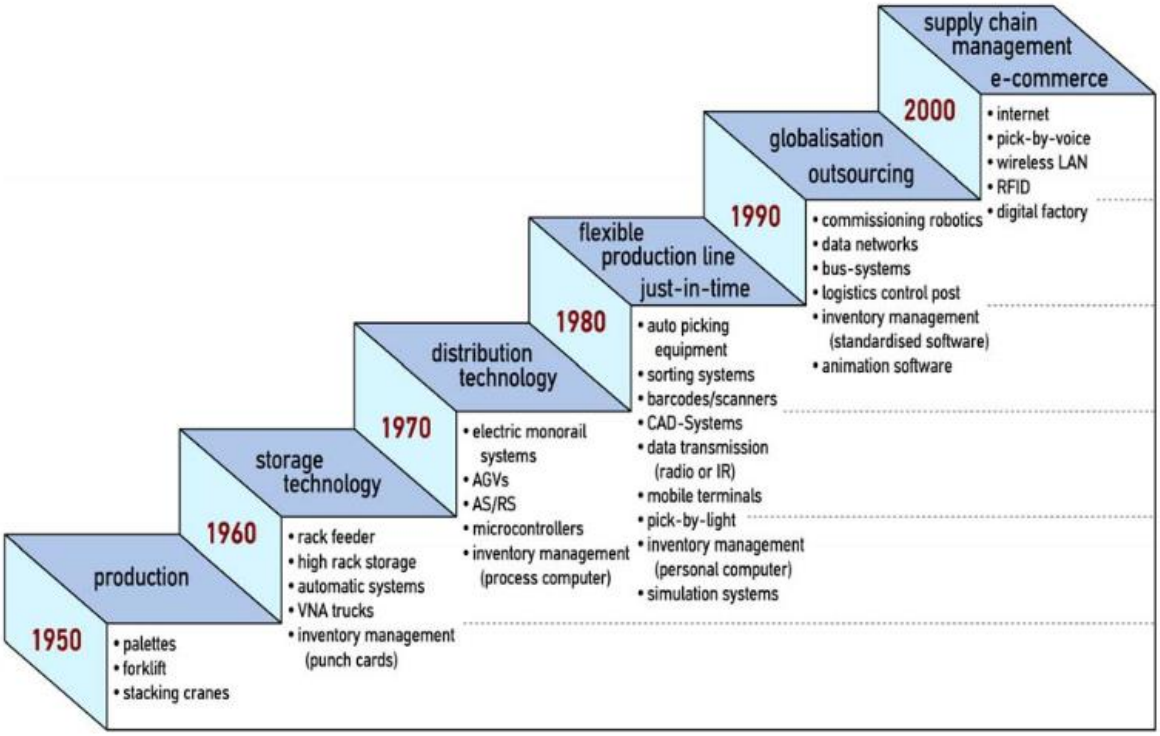


Figure 2-1: Evolution of intralogistics (G.Karting, B.Grosel, & N.Zrnic, 2012)

2.2 Industry4.0 in Intralogistics

2.2.1 Digitalization, Automation and Industry4.0

Reduction of the costs and time from every perspective is depending mostly on digitalization and automation, because of the increasing in the production efficiency. Therefore, Industry4.0 has a big influence on logistics. IoT, IIoT, sensors, Artificial Intelligence (AI) and Big Data are helping in digitalization supply chain and to make automation of logistics. Smart solutions are the result of implementation all of these. Logistic4.0 is dealing with manufacturing logistics processes and intralogistics. Implementation of Logictic4.0 is making processes faster and cost-effective. Modularity of intelligent logistics and smart solutions, a company can customize and push digitalization and automation in the right way. With the right implementation of digitalization and automation performances of the company will increase, like avoid bottlenecks. (Emans, 2019)

Companies should have to establish intralogistics processes to get better sustainability and also a reaction to the variability of products, operating costs, lead times and market changes. As nowadays a number of equipment and machinery is much bigger than before, modern management systems are built to control and monitor all of it. (Emans, 2019)

Intralogistics digital transformation pushed by Industry4.0 is divided into three stages (Emans, 2019):

1. Standardization and Formalization of Internal Logistics Processes
   Mostly is based on visualization of work. To visualize every work operation, automatic data collection should support evaluations into the company based on labor, inventory and other focuses of the company.
2. Dynamic Manufacturing Logistics
   The second phase should be a collection of the information on the bigger scale to generate demands for transport of material and current inventory status.

3. Self-Governing Intralogistics

   As the last step, intralogistics is automated for necessary actions and is shown according to the needs. Machinery can exchange data in real time.

Technological advantages of Industry4.0 (A.Gilchrist, 2016):

- Analysis of operational data is possible because of ubiquitous network connectivity, data volume, and cloud storage.
- Capability for analysis. Product development is requiring good analysis. With better analysis also a product is better.
- Better connection between machine and human.
- Transfer of digital data to real-world usage.

Four characteristics of Industry4.0 are (A.Gilchrist, 2016):

1. Manufacturing acceleration – business operations, using the manufacturing technologies, sometimes innovative but sometimes the old ones.
2. Horizontal integration – the making of the global network.
3. Vertical integration – using of cyber-physical systems. Connection and network for smart things, product and factories.
4. Through engineering – entire value chain, the life of a product is tracked from the start until the end.

2.2.2 Internet of Things (IoT)

The term Internet of Things is best described as a network where machines are capable to communicate together. Prediction is that Internet of Things will achieve around 26 billion units until the 2020 year. Internet of Things will be used and already is used by many companies to improve production, maintenance, design, workflow, and more other things, including costs. (Tayagi & Sharma, 2018) Internet of Things simple explanation is shown in Figure 2-2 where is possible to see what Internet of Things is purpose is to be.

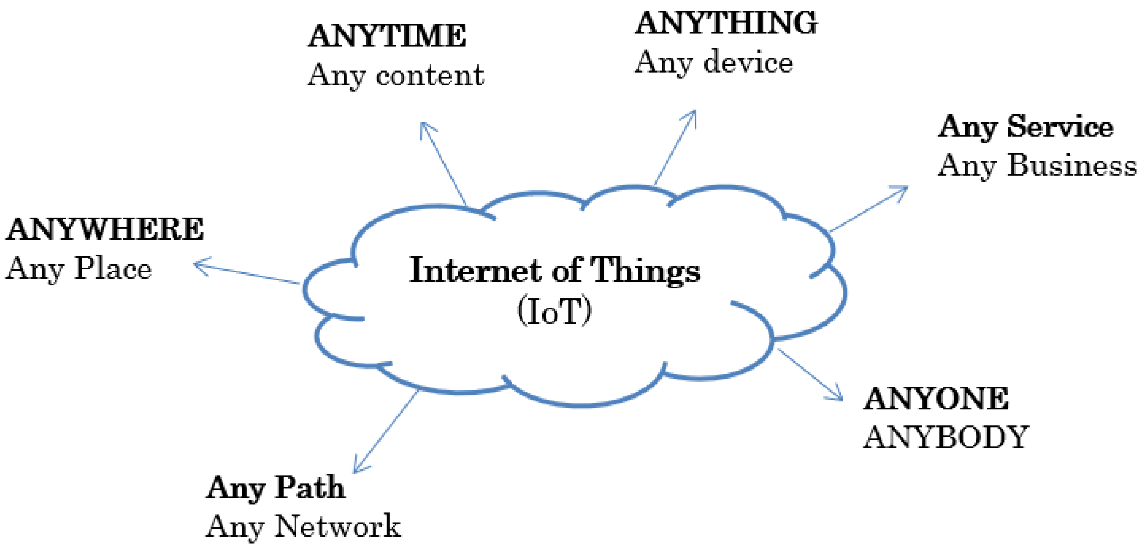


Figure 2-2: Internet of Things description (Tayagi & Sharma, 2018)

Currently, the most widely used Internet of Things technologies are (Lee & K.Lee, 2015):

1. Cloud computing

   It is the Internet of Things technology where on request is possible to get access to a pool of resources. Resources can be a different type, like software information, networks, computers, servers. Resources can be supplied as Infrastructure of Services (IaaS) and Software as a Service (SaaS) Cloud computing can provide the ideal solution for handle large amount of data and as well process that data to where is requested.
2. Wireless sensor network (WSN)

   Often is used together with Radio Frequency Identification (RFID) for better tracking of the system or different things. Wireless sensor networks are basically used in cold chain logistics where is needed to transfer temperature sensitive items but is also used for tracking and maintenance.
3. Radio Frequency Identification (RFID)

   Is allowing automatically identification by using the tag, waves and a reader. Tags contain data and there are three types of tags. Passive tags are working with energy transferred from the reader. Active tags possess own battery and can contain an external sensor. Semi-passive tags have batteries and on that way microchip receives power.

4. Internet of Things application software
   Some industries develop specific Internet of Things application software with user specific application. Such a type of applications has to ensure that the message will be received on time. For example, during transport, some companies have to monitor temperature, humidity and other for them relevant things.

Internet of Things generally could be used in lot of fields into the company. Some of those fields are control and monitoring of the system, Big Data handling and sharing of information. As this project is oriented on monitoring of energy efficiency, monitoring by using Internet of Things will be described more in details into next chapters.
With monitoring of the system as well we have to collect all of the data from past and present to the future forecast should be predictable and possible to react if there are any issues, optimization of the system is one of the main goals. Monitoring also allows workers to track the performance of the system anytime. From data received through sensors and actuator, human should be able to make the right decision. With real-time data received there should be increased customer satisfaction and behavior, but also changes on the market with reference to intralogistics. (Lee & K.Lee, 2015)

Types of Internet of Things technologies (Lee & K.Lee, 2015):

1. Network – until the 2010 year, base was only on sensor technology. After the sensor technology, there are new approaches in this field. Delay tolerant networks, network location by sensors, hybrid technologies and self-organized sensors. Until the 2025 year, expectation is to have network cognition, that network will learn and repair by its own.
2. Algorithms and Software – at the begging of 2010 already started with the Internet of Things oriented approach, Sensor networks, sensor middleware, and localization of algorithms. In the future is expected that software

will enable better communication between humans and things and that Internet of Things will be applicable to everybody and everything.

3. Hardware – in early starts of the Internet of Things, hardware was based on RFID tags and sensors, NFC and sensors for mobile phones. Nanotechnology and new materials are already in use but in the future is an expectation that nanotechnology will be more represented in this field.
4. Data Processing – first is used for quality of services and serial processing. Afterwards data processing of energy and frequency, as well as context-aware processing of data. In the future is expected more of optimization. Advances for optimized data will help users to make clear and faster decision in time critical for big data applications like environmental monitoring or smart manufacturing.

Challenges of Internet of Things (Lee & K.Lee, 2015):

1. Privacy challenge: protecting of privacy will be the main issue here and how to be sure that users will accept all what Internet of Things will offer. According to Trustee, only 22% of users agreed with the Internet of Things and benefits.
2. Data management: At the moment, architecture is not strong enough to handle a large amount of data.
3. Chaos challenge: The innovation of Internet of Things is much faster than other innovations. One of the challenges also will be to find and define the right standards for all innovations in this field.
4. Security challenge: Firewalls and intrusion prevention systems will be the solution for this challenge, as devices of the Internet of Things are not using the encryption in a way of security.

Mentioned technologies belong to specific fields and are shown in value chain are shown as in Figure 2-3.

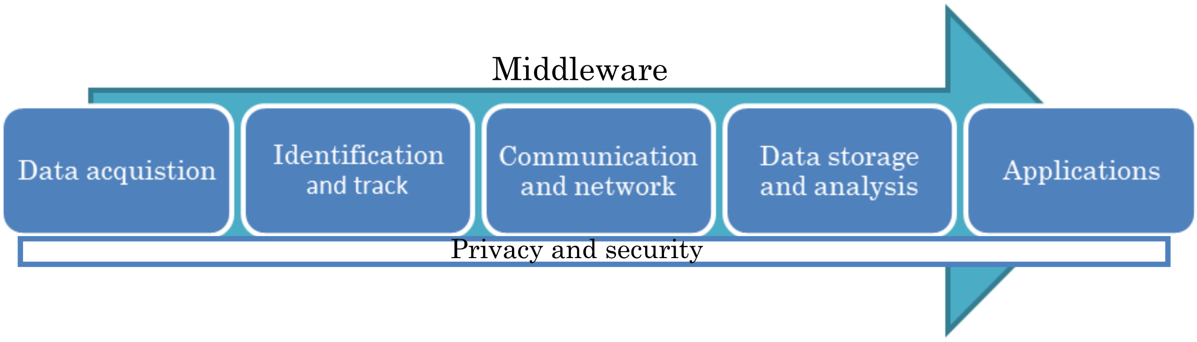


Figure 2-3: Value Chain of Internet of Things (Lodewijks, Li, & Pang, 2016)

Internet of Things was born as the result of different ideas and visions. Figure 2-4 is showing those ideas which created Internet of Things and what Internet of Things present today.

From the Figure 2-4 is possible to see three main visions of Internet of Things:

- The "Things Oriented" Vision is a vision where Internet of Things is viewed as virtual objects or smart physical things, which have a set of technologies to realize everything needed. According to this vision, there are three main characteristics: anything identifies itself, anything communicates and anything interacts. Every object is calling Smart Object and each of those Smart Objects have communication functionalities. If there are more Smart Objects system is seeing as a dynamically distributed network. Some key features in this field are that devices should be heterogeneous, devices should be monitored and autonomous, data should be standardized and security must be at a high level. (Lodewijks, Li, & Pang, 2016)

- The "Internet Oriented" Vision is the vision which allows communication to become standardized, so in that case, can be spread all over the world. Internal Protocol (IP) is used as the network technology for connection of the object. If there are expectation and tasks for an object to share information it should be in the same "language". The term "Internet-0" has seven principles. Every device with Internet-0 should use IP, all devices can work independently, simple communication, bits are used, big bits can stay in the same shape, device use standards. (Lodewijks, Li, & Pang, 2016)

- The "Semantic Oriented" Vision is part where the main focus is on connecting, interconnecting, searching, storing and organizing of the information. The major challenge here at the moment is still how to convert the amount of data into needed information which should be understandable for the user. (Lodewijks, Li, & Pang, 2016)

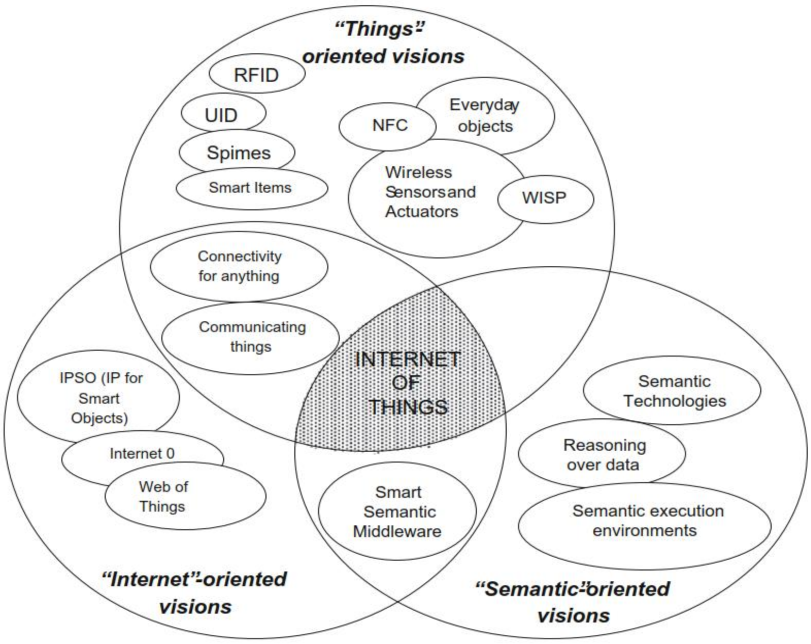


Figure 2-4: Ideas and visions created Internet of Things (Lodewijks, Li, & Pang, 2016)

<u>Comparison of IoT-platforms</u>

To stay competitive, most of the companies already started to switch to cloud services. These days the market is dynamic and with using cloud services companies as well can have better control of data handling, a connection of the systems and as well other production movements. On that way security, production and efficiency could be improved. This need for digital transformation have been followed by a couple of Cloud services. The most popular ones are Microsoft Azure, Google and Amazon Web Services (AWS). From these cloud

platforms, AWS is the one with the longest-serving period, over 13 years. Microsoft Azure and Google bump into the market very fast and have gained high momentum last years. Microsoft Azure becomes very fast the leader. (Watts, 2018)
Microsoft Azure until now gained a lot of trust from customers because of the lower pricing, high data security and additional functions added to it. Microsoft Azure could fit to use in all kind of companies which are willing to start with cloud service. (Cloud Computing Comparison 2019: AWS vs Azure vs Google, 2019).

ASW has four main features that are offered to the customer. They are storage and content delivery, database, compute services and networking. On the other side, Google is offering Google App Engine, open source cloud environment, robust data analysis, big data tools, security via encryption, cloud storage RESTful service to store and retrieve of the data and migration assistant. Microsoft Azure Cloud platform has features that are more flexible to the promotion of artificial intelligence as well as forecasting of machines behaviour. Mostly these features are building of the website by using programming languages, migration assistance, SQL database, machine learning, windows server and Linux virtual machine integrations, virtual machine possibilities supported by tools which include resource manager and cloud services. (Watts, 2018)

Microsoft Azure Cloud platform is selected because of more adaptive features including endless integration, machine learning, flexibility in some fields as well as flexible paying, and other benefits. Beside mentioned features, other major reasons for the selection of the Microsoft Azure Cloud platform are (Lauria, 2017):

- High availability: Since Microsoft Azure is attached to Microsoft products, it is available and promotes high redundancy on a global scale. It provides service level agreements of 99.95% that fit most business operation to the higher capacity that most businesses can't outstrip.
- High security: Microsoft Azure is strongly focused on security. It is equipped with strong cybersecurity controls and Azure is the leader in IaaS security. As the platform is secured, also the customer is protected. Security and this level of security are very important as everyday threats to

security are growing. User-friendly interface for protection is provided by Azure, like a password or multi-factor authentication.

- Scalability: Very useful and friendly for a customer for huge cloud data services like in intralogistics. This is a good point for the use in the conveyor system that has ON and OFF operation cycles. In this case, the customer is paying only when the platform is in use.

Microsoft Azure requires expertise to be sure that each part is working efficiently and together. The mistake from the administrator or person involved in the operation with the platform potentially can cost a company thousands of euros yearly. (Lauria, 2017)

2.2.3 Industrial Internet of Things (IIoT)

General Electric (GE) gave name "Industrial Internet" for Industrial Internet of Things, some others like Cisco gave the name Internet of Everything. Also, Industry4.0 is sometimes put into the equal sign with Industrial Internet of Things. (A.Gilchrist, 2016)
IIoT is often used in Industry4.0 context as Industry4.0 is forth industrial revolution with focus on cyber-physical systems, big data, automation and other applications of Industry Internet of Things. (Sadiku, Yonghui, Cui, & Musa, 2017)

The wide growing of Internet of Things is making a big impact on industries and homes. IIoT is referring to the industrial environment and IIoT has the possibility to combine intelligent machines, predictable analysis, and human-machine interface. With the human-machine interface, productivity, efficiency, and reliability are improved. (Sadiku, Yonghui, Cui, & Musa, 2017)

Common architecture of the IIoT is possible to see on the Figure 2-5.

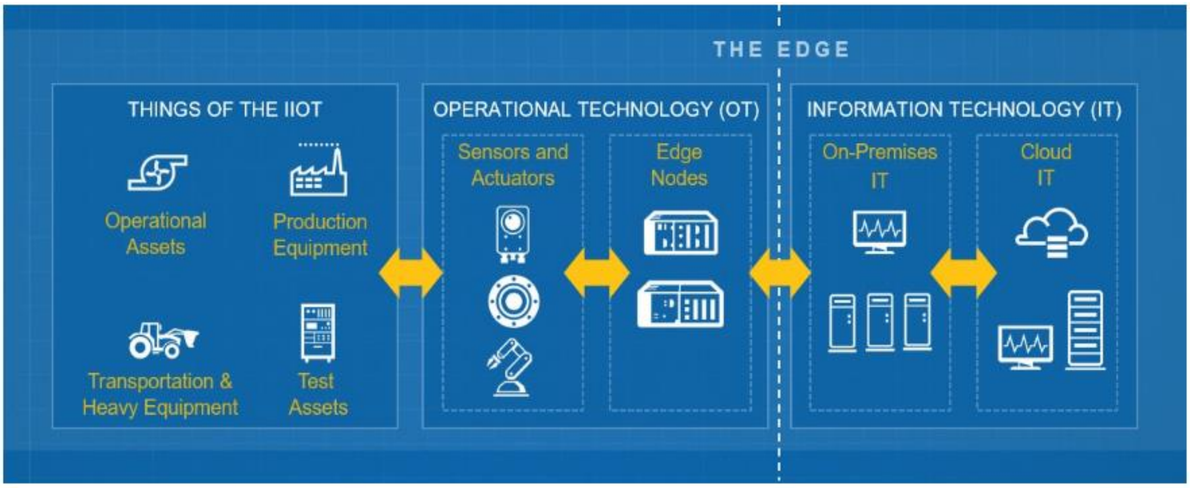


Figure 2-5: Industrial Internet of Things (A Practical Guide for Connecting LabVIEW to the Industrial IoT, 2019)

The largest market of IIoT is manufacturing, as well, manufacturing is the largest type of the industry where IoT is trying to be implemented in its entirety. Smart production in this field is consisting of large connected systems of parts, material, tools, machines, and logistics where machinery can communicate with each other and with the human. IIoT connections are driving to harmonization of the technology, in case of this project, harmonization of the conveyor belt system. The second largest market is transportation with the aim to optimize public transport, to reduce costs during the transport, as well as implementation in airlines and railway industries. (Sadiku, Yonghui, Cui, & Musa, 2017)

Because of the benefits like decreasing the costs, energy efficiency monitoring, energy management, processing devices and connection of the sensors, an adaption of companies to IIoT is very fast. Sensors can read a data and be connected to Compact RIO chassis. The device can send the data in real time to the cloud platform like Azure. Into the cloud, data will be stored and analyzed. But, all IoT devices have to be checked often and updated with the latest patches, in terms of security. (A Practical Guide for Connecting LabVIEW to the Industrial IoT, 2019)

2.2.4 Digital Twins

Digital Twins have to simulate in totally every relevant behavior of process or product during its life cycle from physical to virtual shape and is part of Product Lifecycle Management (PLM) as shown by Figure 2-6.

Digital Twin in the lifecycle of the product must be part of connectivity, modularity and autonomy. More into detail every one of these fields is in a relationship with Digital Twin, like product design, production planning and execution, the intelligence of production, optimization, and engineering. (Post, Groen, & Klaseboer, 2017)

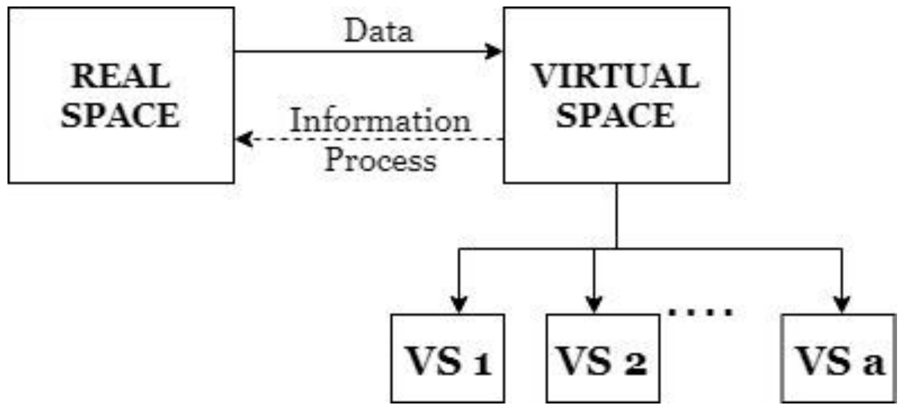


Figure 2-6: Conceptual idea for Product Life Cycle Management (Vickers & Grieves, 2017)

Because of tremendous possibility to progress Digital Twins are getting more attention every day, how in industry, also to be implemented in normal life functions. Gartner confirmed that Digital Twins are the top technology trend in 2017 and 2018 year. Digital Twins between physical objects and virtual models have two ways of mapping. From small parts to big parts, shop floor or whole factory, everything can be in consideration of Digital Twins. Digital Twins can be separated into three categories: Unit, System and System of System (SoS), it is shown in Figure 2-7. System category is the integration of multiple unit categories, which cooperate. The System of System is when more system categories are working together and build System of System. (Qi, Tao, Zuo, & Zhao, 2018)

Three dimensions are extended to five dimensions structure as follows (Qi, Tao, Zuo, & Zhao, 2018):

1. Objective entities have to finish tasks regarding inputs and outputs.
2. Virtual models are showing physical entities in a digital way and can change the lifecycle of physical entities.
3. Integration of different requests like management, optimization, control.
4. Data fusion is Digital Twin core driver by including physical, virtual and service data.
5. The connection of four dimensions, ensure optimization and real-time relations.

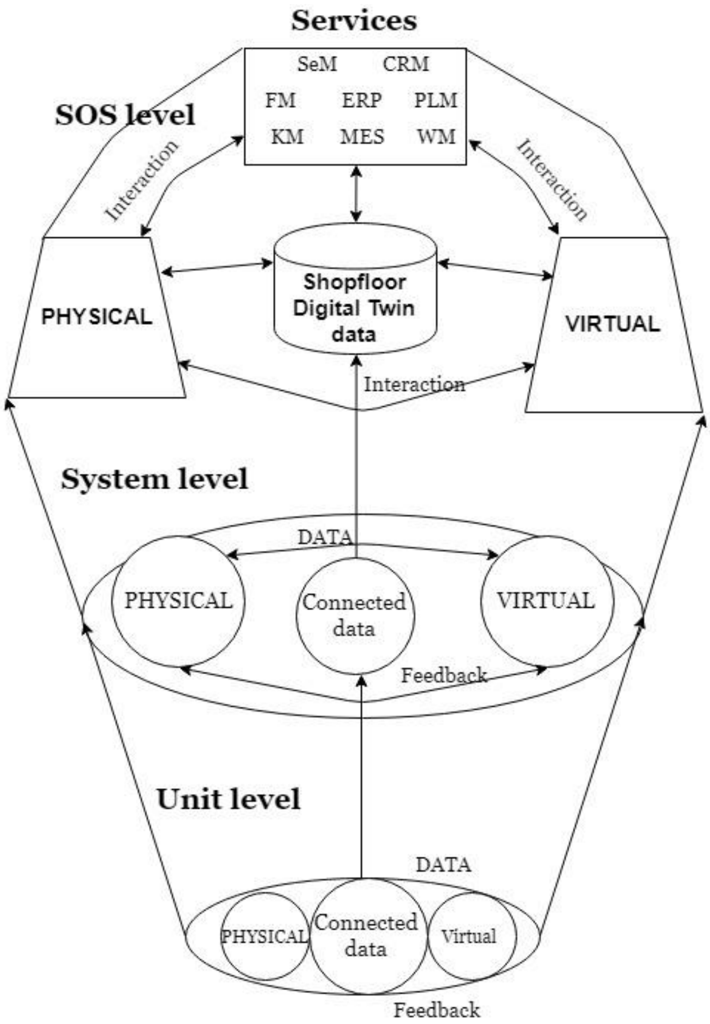


Figure 2-7: Unit, System, System of System (Qi, Tao, Zuo, & Zhao, 2018)

Data and models are the major parts of Digital Twins. With using Digital Twins, it is important that that model can be shared by all users and to have accordingly data analysis. Internet as a solution for users to have access to Digital Twin and the possibility to work with it. The first step and the very important step is establishing of the template which consists of information. That information for a physical object includes some basic things like name, address, ID. Also, the information template includes Quality of Service like costs, time. As well, capacity, real-time conditions, input and output. (Qi, Tao, Zuo, & Zhao, 2018)

Information template is described by data attributes (Qi, Tao, Zuo, & Zhao, 2018):

PO = {Basics, QoS, Cap, Status, Input, Output}
Basics = {type, name, ID, address, delivery time...}
QoS = {time, cost, trust, reliability…}
Cap = {parts, size, precision…}
Status = {health, load…}

PO = Physical Object
QoS = Quality of Service
Cap = Capacity

Virtual Model can also be described as the data attribute. Virtual Model can be used by multiple users and that's the difference from a physical object. Beside creators, also users can reduce cost and time. The owner is who has the ownership. QoS is showing the performance of the models and Input and Output always are different, depending on the mode.
Data is one of the most important parts of manufacturing. But because of a lot of standards and a lot of protocols and ways for communication it is hard to describe the data. In the formulation, data is described with providing who owns it, where data is collected, identification of data and data abstract as the data value. (Qi, Tao, Zuo, & Zhao, 2018)
Figure 2-8 is showing technology services, test services, model services, equipment services and others. From the figure is easy to understand connections and correlations.

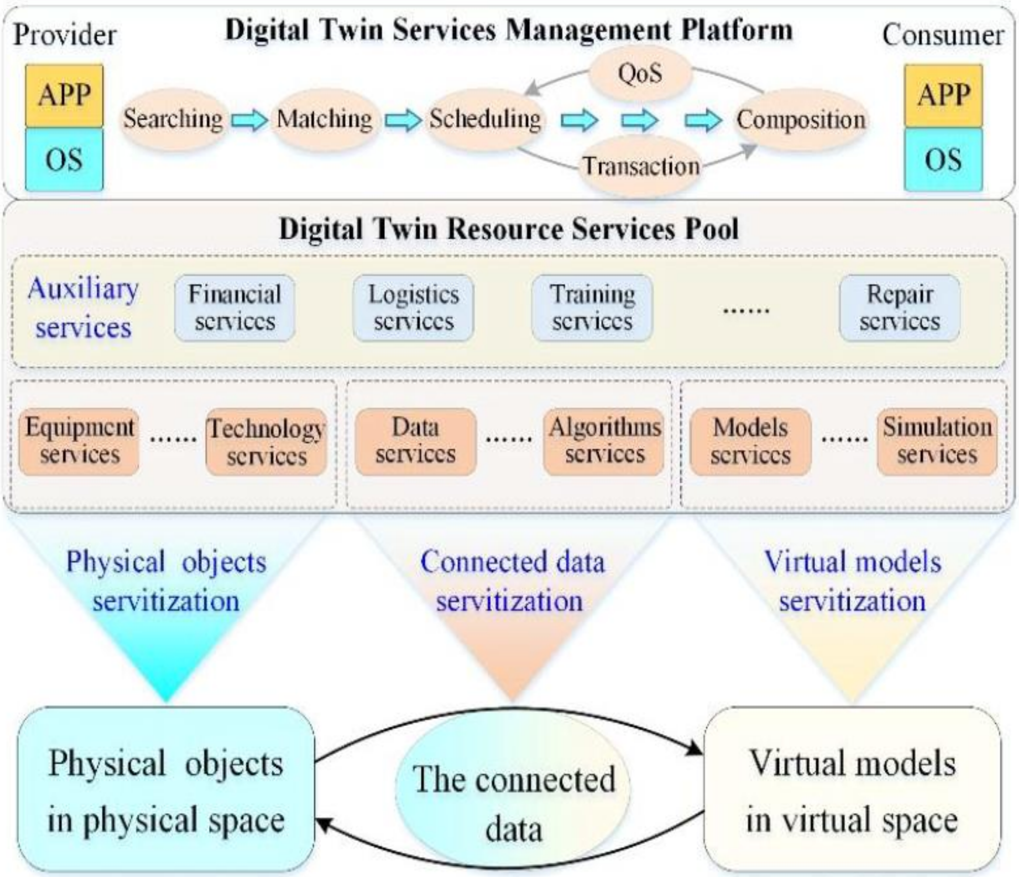


Figure 2-8: Digital Twin application and management (Qi, Tao, Zuo, & Zhao, 2018)

As Digital Twin is required a big amount of data, and it should rely on the technologies that facilitate wide data pipelining, huge processing speed and storage volumes. Prototypes should be replaced with virtual models, with other words with using Digital Twins, shown in Figure 2-9. Virtual costs should be significantly lower that physical costs. (Vickers & Grieves, 2017)

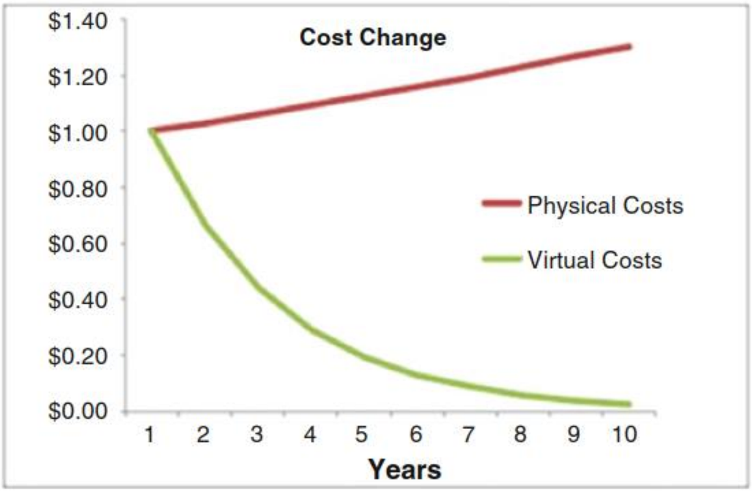


Figure 2-9: Physical vs Virtual Costs (Vickers & Grieves, 2017)

Cyber-Physical Systems (CPS) are transformative technologies to manage connected systems between physical assets and calculation capabilities. CPS could be further developed for managing Big Data and for improving the connectivity of machines with the aim to create more intelligent and self-adaptable machines. As well, integrating CPS would transfer factories to Industry4.0 factories with a lot of economic potentials. CPS 5-level structure got name 5C and it is the guideline to develop CPS, as shown in Figure 2-10. Two main components of CPS are the connection that ensures real-time data acquisition from the physical world and feedback from the cyber world, and, data management and analytics together with calculation capacity from the cyber world.

As shown in Figure 2-10 the first level is Smart Connection. Data can be measured with sensors or gained from other types of system. This stage has two important factors where the various type of data should be considered and selection of the right sensors. The second level is Data-to-information conversion where important information has to be gathered from the data. The third level is the Cyber level and this level is acting as a central information hub. When data is collected and important information gathered, specific analytics should be used to get out even more information about the situation. This is important for measurement and behavior prediction of the machine. In this project, the monitoring and predictive analysis are for belt conveyor system. Cognition is the fourth level, where the graphical view will help the user to gather knowledge about the monitored system. As the last level is Configuration, and it is feedback from the cyber world to the physical world. This is acting as oversight control to make machine self-adaptive and self-configure. (Lee, Bagheri, & Kao, 2014)

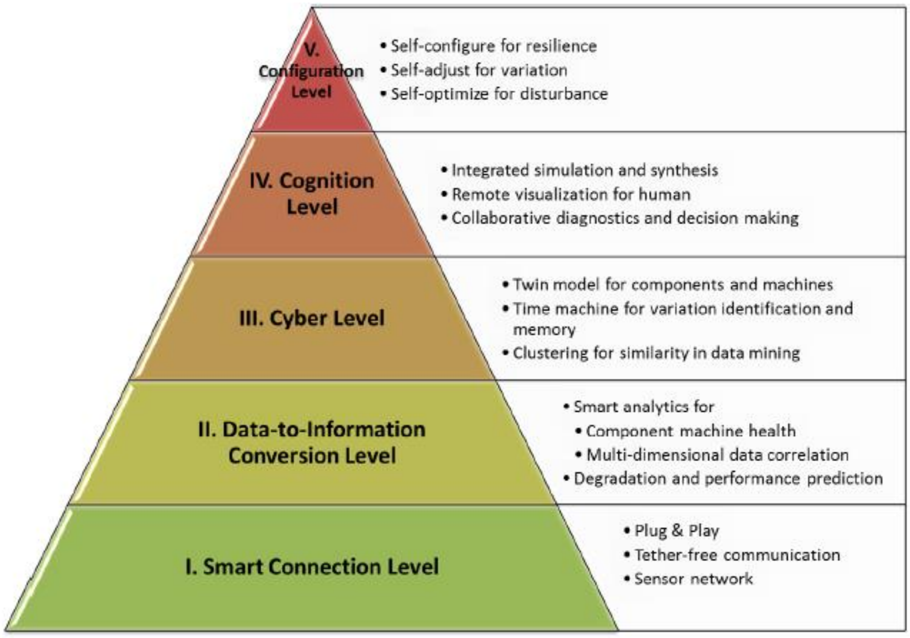


Figure 2-10: 5C architecture to implement CPS (Lee, Bagheri, & Kao, 2014)

Cloud-based Cyber-Physical system (C2PS) is the system where every physical thing is following the hosted cyber thing in a cloud. C2PS architecture is shown in Figure 2-11. (Alam & Saddik, 2017).

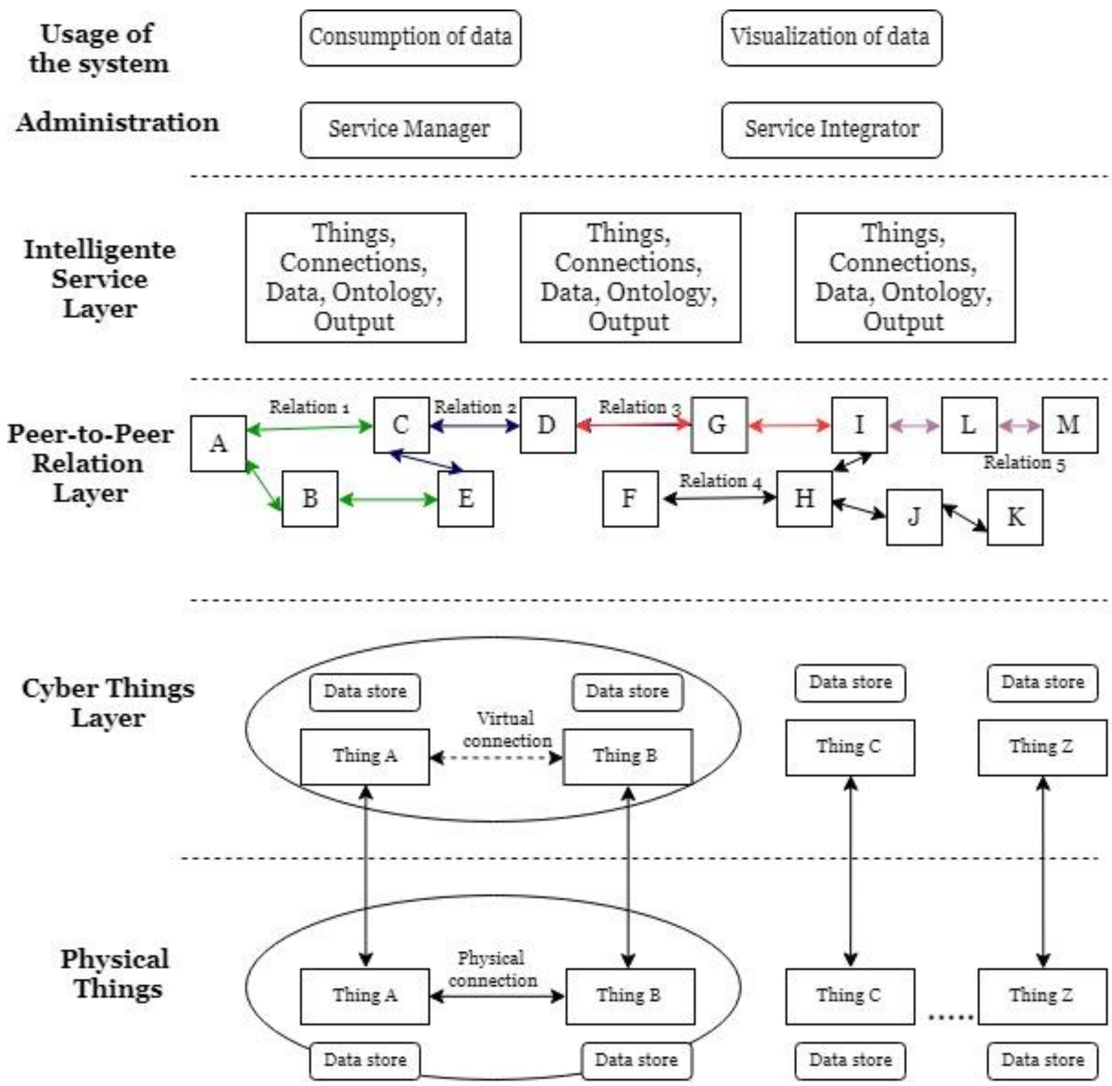


Figure 2-11: C2PS architecture (Alam & Saddik, 2017)

The assumption in C2PS is that every independent system is working with other systems to achieve aims where networks are ubiquitous. All other systems are connected to Digital Twin in the cloud. If physical word changes then sensor have to update the status to digital twin in the cloud. Physical Thing or Cyber Thing is with ID identified. For the example like IPv6, UPC, EPC. With middleware sensor, the owner can control the policy of private. Every communication group created by the owner, is identified with Relation ID. Peer-to-peer Relation Layer is useful for communication groups. Entire data which can be useful for improvement of Quality of Service (QoS) are stored in Data Center (cloud-based). This builds every increasing architecture that cascaded from one level to another as in Figure 2-10. There are mobile smart things and stationary smart things. Can be combination two mobile things, one stationary and one mobile thing, mobile thing and cloud directly or stationary thing and the cloud directly. The physical architecture usually relies on electronics hardware, several systems of sensors and actuators and specialized programs control that aids synchronizations and Human-machine communication as shown by Figure 2-12. Actuators and sensors are connecting the physical world with the cyber world. Physical systems are collecting information from a sensor from the real world and send them to the digital twin through communication technologies. (Alam & Saddik, 2017)

The digital sensor is with Analogue to Digital Converter (ADC) and without ACD is an analogue sensor. If the actuator has Digital to Analogue converter (DAC) it is the digital actuator. Nowadays, both, sensor and actuator more often come with Microprocessors as they are able be built in direction of smart factory things. There is a couple of ways how to connect sensors to the actuator. (Lee & Seshia, 2017)

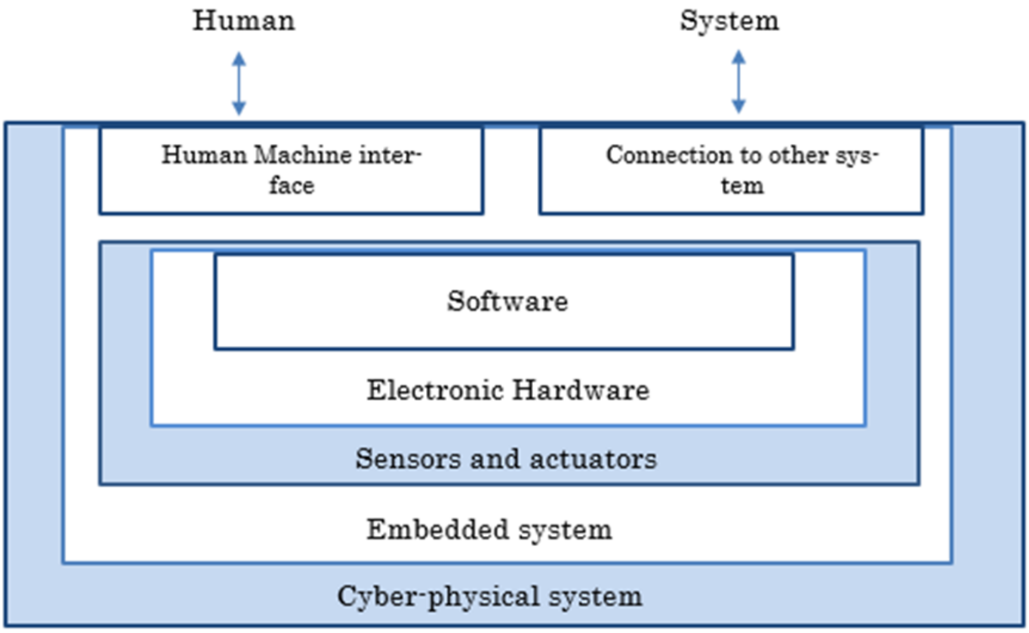


Figure 2-12: Communication between machine and human by using CPS (Brettel, Friederichsen, Keller, & Rosenberg)

<u>Microsoft Azure</u>

Azure Digital Twins is the IoT service that is building models of the physical environment and showing it in a digital way. Azure Digital Twins is helping to create intelligent graphs to model the relationships and interaction between power, space, devices, and throughput. The service is helping also to build real connection experience between the digital and physical world. With Azure Digital Twins, data could be tested for example by using proximity sensors and power measuring. (Seto, et al., 2018)

Azure Digital Twins accelerates the time-to-value of spatial intelligent solutions and reduces development complexity and costs. Azure Digital Twins in the context of other IoT services is shown in Figure 2-13. (Seto, et al., 2018)

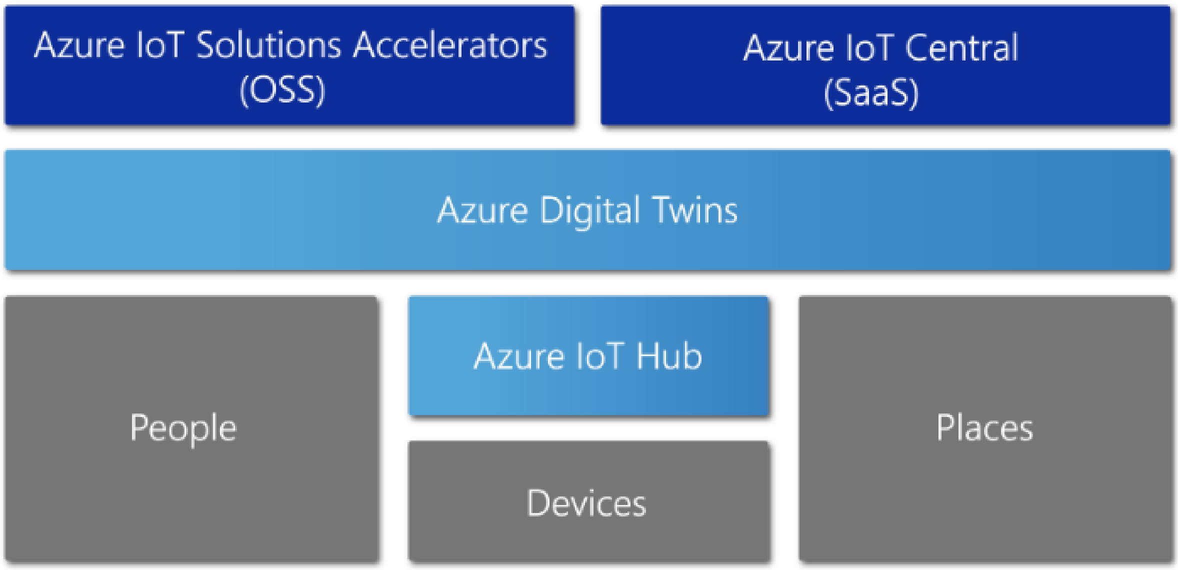


Figure 2-13: Azure Digital Twins (Seto, et al., 2018)

Azure Digital Twins includes the following capabilities (Azure Digital Twins, 2018):

a) Spatial intelligence graph - this is the virtual representation of the intralogistics system. Therefore, helping in the modeling of the relationship between microcontroller, sensor and measuring instruments. It is allowing the organization to build solutions that can improve throughput, energy efficiency, and space utilization.

b) Twin object models - this also offers pre-defined scheme and protocols of the device, which are aligned to the solution and need to make it more simply and accelerated.

c) Advanced compute through user-defined functions - customization of the functions that are sending actions or notification to the endpoints which are based on incoming telemetry messages.

d) Role-based access control and Azure Active Directory - Secure access control. Also, the ability to make specific actions.

e) Multitenancy - building of the solutions that are scaling and replicating to more tenants. Also, nested tenancy capabilities to ensure data is isolated.

Azure Digital Twins benefits for usage are:

- Predicting of maintenance needs for the design of intralogistics system, like belt or motor drives.
- Analyzing the real-time energy requirements for belt conveyor and help with the energy efficiency monitoring.
- Optimization the usage of the belt conveyor system.
- Real time data visualization and control.
- Real time parameter visualization and availability.

2.2.5 Data Management and Communication

Data management, security, communication, control, and optimization could be as an integral part of IoT and Industry4.0 characterization presented in chapters 2.2.1 to 2.2.2 but due to the complexity of the field, it is presented on its own.

Concept of Big data

Improvements in supply planning and also the quality of the product are providing the best benefit of Big Data for manufacturing. Big Data is providing the in-infrastructure for transparency in material handling industries, and that is the way to see some uncertainties like availability of components. Predictive throughput as the applicable approach for almost near zero downtime is requiring a big amount of data and some of the advanced predictive tools for the systematic process of data to transfer into useful information. The conceptual design of packet handling or predictive material is beginning with data acquisition of the different type of sensory data like packet per unit time, current, voltage and controller of data. Big amount of data from sensory and of historical data is creating big data. These big data are acting as input into predictive tools and strategies like Prognostic and Health Management. (Sriramoju, 2017)

Big Data and IoT are working connected. Data received from IoT devices is providing the map of the device connectivity. IoT is as well adapted to collect of the sensory data which is used in manufacturing. Using Big Data to solve some problems of IT and collecting of data is called IT Operation Analytics. Therefore, it is possible to predict some potential issues or even provide a solution before a problem is created. The number of ways how to apply Big Data analysis to IoT solutions is endless. (Sriramoju, 2017)

Also, Big Data is one of the biggest challenges and it is described as (Lodewijks, Li, & Pang, 2016):

1. Volume
2. Variety
3. Value
4. Velocity

Value chain for Big Data shown at the Figure 2-14, where is possible to see steps needed to get information (Lodewijks, Li, & Pang, 2016):

- Generating data
- Preparation data
- Storing data
- Analyzing data
- Visualization data

Figure 2-14: Big Data Value Chain (Lodewijks, Li, & Pang, 2016)

The first step is to collect data. Preparation of data is important to take all needed steps so processing is done to ensure storage of meaningful data that fit the end user's needs.

Storing of the data, after data is prepared should be sent to a Data storage center. There are two data storage systems, Network attached storage (NAS) and Direct Attached Storage (DAS). The difference is that NAS is via the network where data has access via a union interface and DAS is connected via devices and mostly is used for the small sized data center.

Analyzing of data is part where tools and algorithms should be used. After data is analyzed it has to be represented and showed. For that, the last part is data visualization which is likely to be in graphical shape but the main challenge huge data size that is hard to visualize easily. (Lodewijks, Li, & Pang, 2016)

Data communication and protocols

Protocols are used to updating online servers and taking commands from an application to the actuator. During the experts are trying to build as much as possible IoT to existing technologies, research groups are working on adapting protocols to the IoT. With adapting protocols in the right way, benefits which are achieved are the optimization of the communication. Figure 2-15 is shown communication between the Internet, gateways and the final application.(Karagiannis, Chatzimisios, & Vázquez-Gallego, 2018)

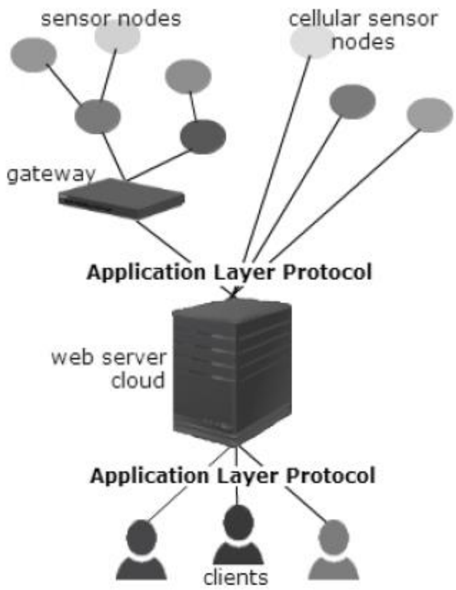


Figure 2-15: Internet of Things architecture protocols (Karagiannis, Chatzimisios, & Vázquez-Gallego, 2018)

As shown in Figure 2-15, Internet of Things consists of three layers: Sensing layer, Network layer, and Application layer.

Sensing layer or perception layer is a layer which collects data like sensors, camera, RFID tags and readers from the device. Sensors or Wireless systems can exchange information between devices. The network layer is using for processing of the information. The main task of this layer is to connect everything together and make possible to share information. The third application layer is the application system to customers and clients. (Sadiku, Yonghui, Cui, & Musa, 2017)

Machine to Machine (M2M)

Machine to Machine (M2M) is the communication between sensors, actuators, computers, devices, machines in one word, with limited human help and interaction. M2M communication is based on two kinds of perception. First one is when machines are connected will be more independent and smart applications can be installed. The second one is that machines connected by the network have more value than only a single machine without touch to other machines. (Chen, Wan, & Li, 2012)

For the better understanding of connections between M2M, Internet of Things, CPS and WSN, correlations are shown in the Figure 2-16,

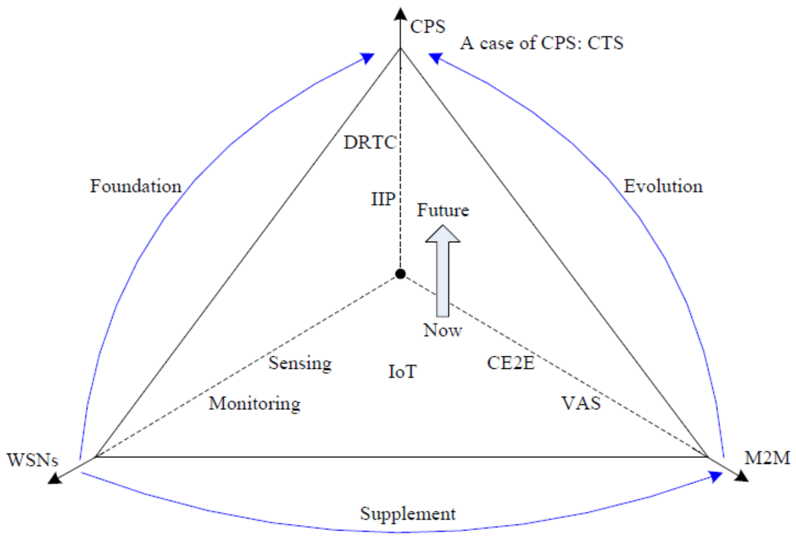


Figure 2-16: Connection between M2M, Internet of Things CPS and WSN (Chen, Wan, & Li, 2012)

Standards regarding M2M networks are defined in five regulations (Chen, Wan, & Li, 2012):

1. Devices, reply and send data
2. Gateway, interworking and interconnection
3. M2M area network, the connection between all intelligent devices
4. Communication between gateway and application
5. Application services

Defined standards for M2M communications depend on many things. Standards Development Organization (SDO) and Telecommunications Industry Association (TIA) are where technical standards are or will be defined. (Chen, Wan, & Li, 2012)

Protocol classes are (Durkop, Czybik, & Jasperneite, 2015):

1. SOA (Service Oriented Architecture) is using to transfer and exchange real-time data in automation systems.
2. REST (Representational State Transfer) has to define constraints to used components. By using REST integration of sensors and actuators is easier. Constrained Application Protocol is example of REST protocol.
3. Message-oriented protocols are supporting data transfer from one to another system. The Message Queuing Telemetry Transport is belonging to this class of protocol.

1. OPC Unified Automation (OPC-UA)

OPC Unified Automation (OPC-UA) is an independent platform which is created for better connection and communication between components of the system from various networks. There are three possible ways of data transmitted with OPC UA, shown in Figure 2-17. (Durkop, Czybik, & Jasperneite, 2015)

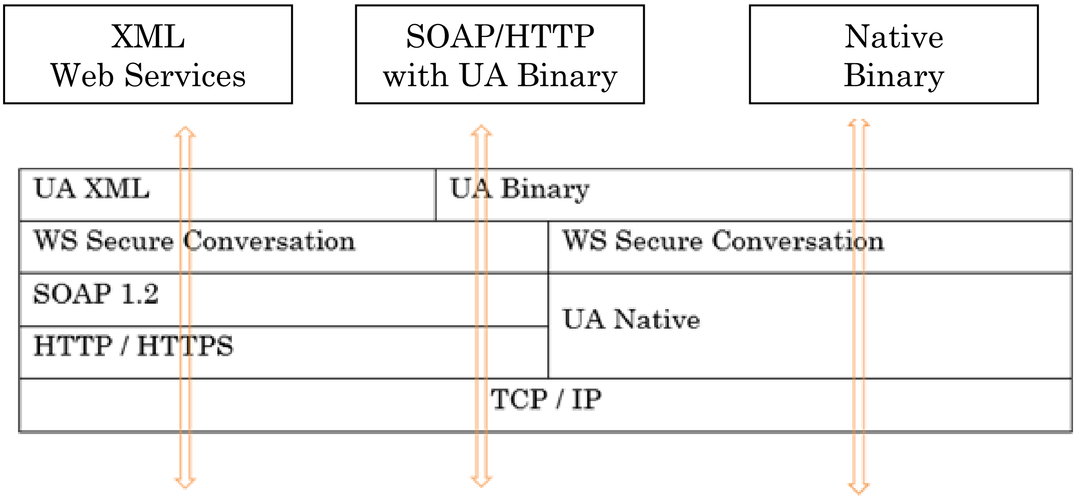


Figure 2-17: OPC-UA data transmission (Durkop, Czybik, & Jasperneite, 2015)

OPC-UA has two protocols for encoding and two for mapping. Data can be encoded in UA XML or UA Binary. SOAP and HTTP are using for transport of the data. For the data resource contained can be used TPC or UA Native. Also, is possible to combine UA Binary with SOAP and HTTP. (Durkop, Czybik, & Jasperneite, 2015)

2. <u>Constrained Application Protocol (CoAP)</u>

Constrained Application Protocol (CoAP) is developed for CoRE (Constrained RESTful Environments). The main goal of CoAP is to develop a protocol for sensor and actuator for integration into Internet Architecture, and CoAP is using REST architecture. UDP is used as the transport protocol and needs to have as less interaction as possible. Also, UDP multi-tasking communication is used and the big advantage of UDP is asynchronous communication from endpoint to endpoint. (Durkop, Czybik, & Jasperneite, 2015)

3. <u>Message Queuing Telemetry Transport (MQTT)</u>

It is designed for the devices with limitation in memory and power. The broker is a connection between two MQTT systems, shown in Figure 2-18. (Durkop, Czybik, & Jasperneite, 2015)

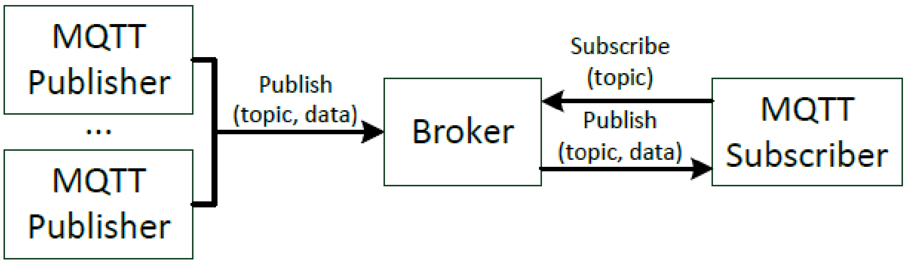


Figure 2-18: MQTT communication (Durkop, Czybik, & Jasperneite, 2015)

Mostly MQTT system contains a lot of devices, like small sensors. The data from the sensor is sent to the broker and at the end, the subscriber will use that data. MQTT is also using TPC like OPC UA. (Durkop, Czybik, & Jasperneite, 2015)

MQTT system using only two bytes and there is no using of additional transport protocols like for example SOAP is using. For message reliability, MQTT has three Quality of Service (QoS) regarding messages, as shown in Figure 2-19. (Thota & Kim, 2016)

- QoS „0“ – at most once. Single transmit with no guarantee that the message will be delivered.
- QoS „1“ – with this level is attempting to guarantee that message is received by recipient.
- QoS „2“ – this is the most secure level of MQTT as this level is attempting that message will be received and decoded.

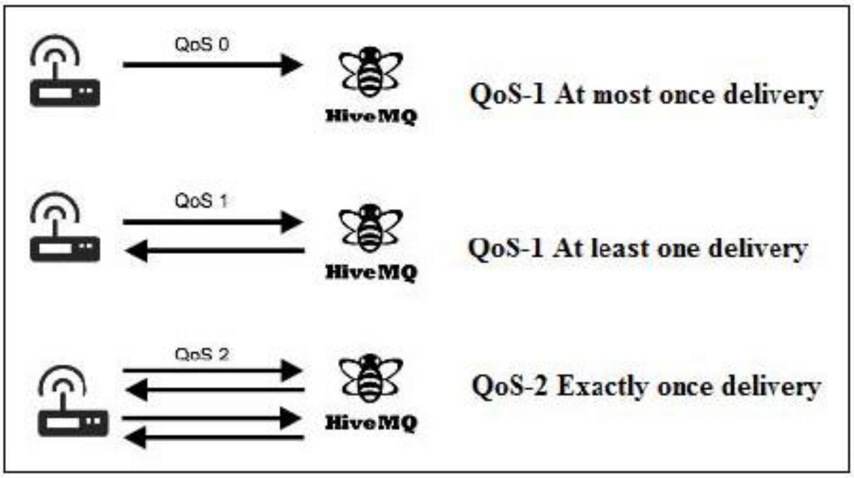


Figure 2-19: Levels of QoS (Thota & Kim, 2016)

The difference between MQTT and CoAP is that MQTT is using Transfer Control Protocol (TPC) and CoAP is using User Datagram Protocol (UDP). As UDP is not good enough CoAP must provide own mechanism confirmable or non-confirmable messages. CoAP is mainly a protocol for sending information between server and clients and is better use in transfer model than event-based. MQTT is used for sending messages between multiple client and servers. Table 2-1 is showing the differences between MQTT and CoAP. (Thota & Kim, 2016)

Table 2-1: MQTT and CoAP differences (Thota & Kim, 2016)

	MQTT	**CoAP**
Layer - Application	Single layered	Single layer and two sub layers (request layer and message)
Layer - Transport	TPC	UDP
Reliability Mechanism	Three quality services	Confirmable and Non-Confirmable Messages
Architectures	Publish Subscribe	Request-Response, Public Subscribe

Benefits of using MQTT are (Thota & Kim, 2016):

a) Time separating: Nodes can be in sleep mode or active mode. The sleep mode is a good way to save energy and reflective the costs. Nodes can accept data only in active mode from the broker. Publisher and subscriber don't need to work at the same time.
b) Space separating: IP address is needed to be shared between the sensor node and broker. Nodes publish information, all data goes through the central server unit or to the broker. Overhead of data is reduced in this way and the number of TPC ports is increased. End nodes have the possibility to operate totally independent.
c) Synchronization separating: Messages are in the storage until they need to be used. With this operating power is saved and repetition of operation is reduced.
d) Security: SMQTT is an extended version of MQTT where S is for Security. Broadcast encryption is used, where one message is encrypted one time and a few customers received the message but in a secure way. publisher and subscriber are registered by broker and security key are provided to them.

Also, besides benefits, MQTT has some disadvantages. The central broker can be one point of failure to the system. Nodes with partial traffic can have lower life. Figure 2-20 is showing MQTT and CoAP in graphically way and how it looks like in practice. (Thota & Kim, 2016)

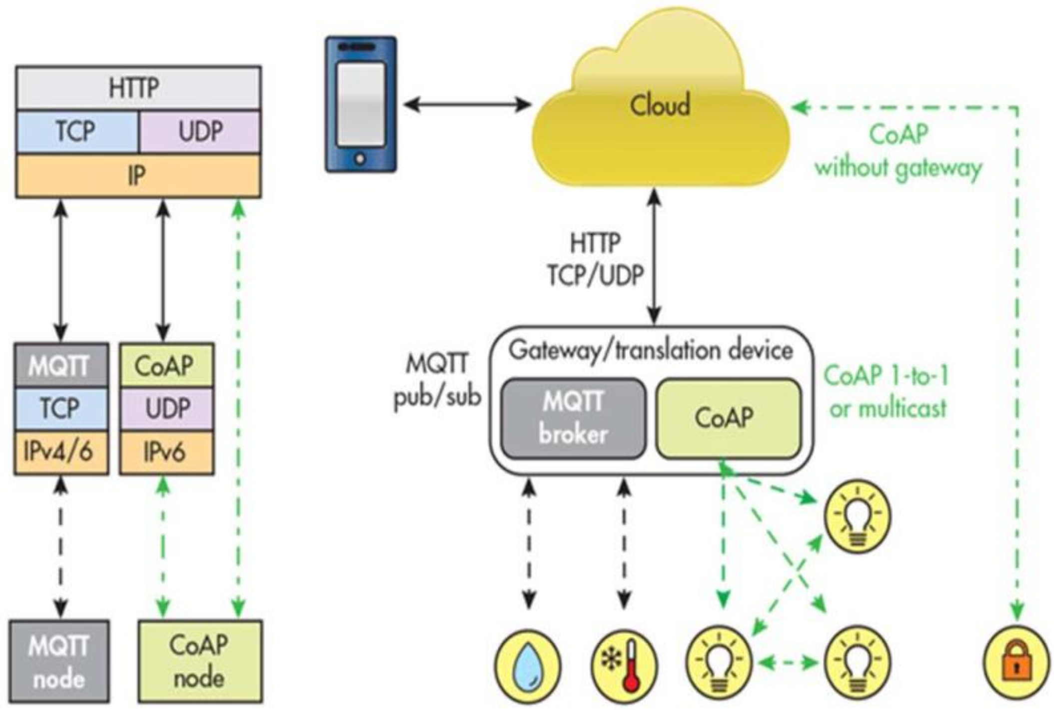


Figure 2-20: Comparison MQTT and CoAP (Thota & Kim, 2016)

Every user can log in and subscribe to nodes of the sensors, and data is published through the nodes. Most data is stored in XML, JSON or CS formats. As well, there are two keys for writing (WRITE key) and only reading (READ key), users can use it with their ID channel. ID channel is divided into eight parts according to an HTTP request. (Thota & Kim, 2016)

2.3 Energy Efficiency of Belt Conveyor Systems

TU Graz, Institute of Logistics Engineering possess couple types of the conveyors. For this project belt conveyor with rigid support (2m) is chosen. Figures 2-21 and 2-22 are showing the photo and the schema of belt conveyor at TU Graz, ITL.

Figure 2-21: Belt conveyor with rigid support 2m (Lottersberger & Hafner, 2016)

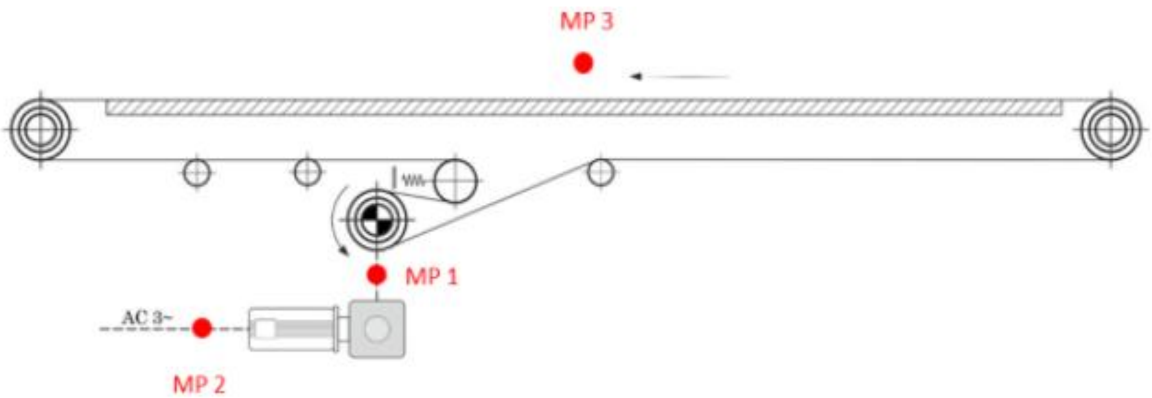


Figure 2-22: Belt conveyor schematic (Lottersberger & Hafner, 2016)

Efficiency is characterized as output divided by input and it is shown with Equation 2-1, (Lottersberger & Hafner, 2016),

$$\eta = \frac{\text{output}}{\text{input}} \qquad \text{Equation 2-1}$$

Expression for Energy efficiency is defined by Equation 2-2, (Lottersberger & Hafner, 2016),

$$E_{eff} = \frac{\text{process output}}{\text{energy input}} \qquad \text{Equation 2-2}$$

Energy Indicators are one of the major points in the context of energy efficiency. Energy Indicators should be calculated by Equation 2-3, (Lottersberger & Hafner, 2016)

$$e_x = \frac{1}{E_{ff}} = \frac{E_{In}}{W_L} \qquad \text{Equation 2-3}$$

e_x – Energy demand of process
E_{In} – Energy input
W_L – Logistic performance

From Figure 2-23 is possible to see measure points where all relevant losses are identified, and it showing typical measurement result on the belt conveyor.

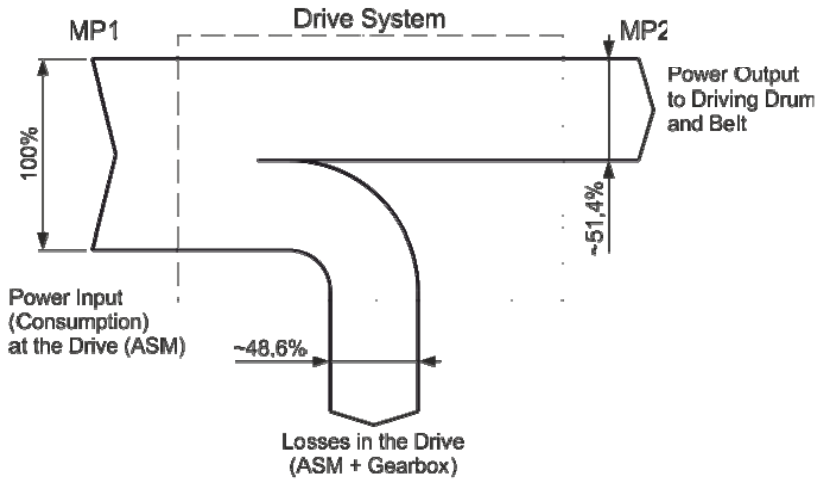


Figure 2-23: Measurement results on belt conveyor – power flow diagram in stationary state (Lottersberger & Hafner, 2016)

As costs are higher with using more energy, it is important to find the right and relevant factors to save as much as possible energy. Major goals should be achieved to get good enough energy efficiency. (Stöhr & Hafner, 2017)

Energy Efficiency Indicators (EEI): first is needed to take into consideration conditions of the conveyor before, considered nominal load, turndown, no load and standby. It is defined with Representative Operation Cycle (ROC). With the given condition shown in Figure 2-24, energy demand is function of as power measurement. (Hafner, Lottersberger, & Jodin, 2013)

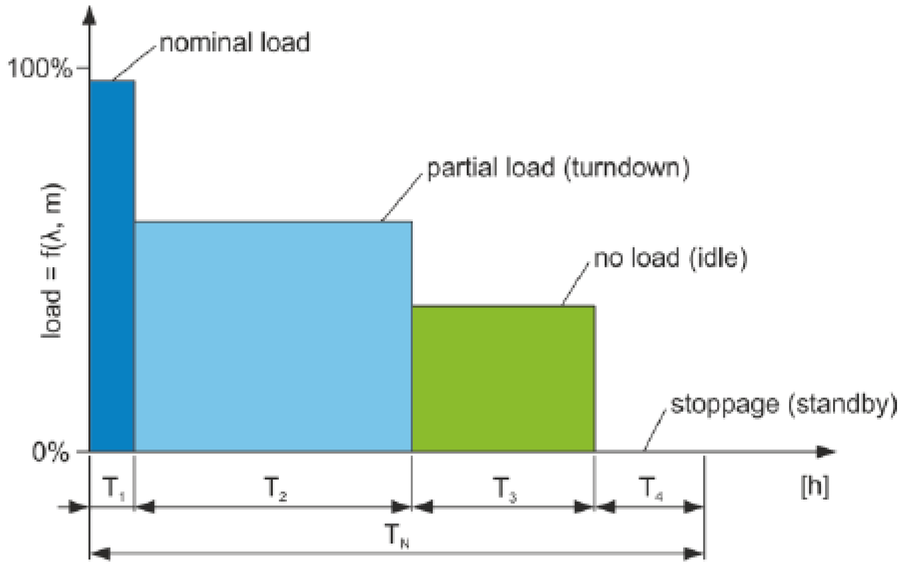


Figure 2-24: Representative Operation Cycle (ROC) (Hafner, Lottersberger, & Jodin, 2013)

Four types of operation in relation to tasks and power consumption are existing. Nominal load is when lines are moving the loads. Actuators and controllers are in work. Partial load is also possible. No load, the machine is running and waiting for the loads and energy is wasted. Machine is not working and it is on standby. (Hafner, Lottersberger, & Jodin, 2013)

Process steps of determining EEI are (Hafner, Lottersberger, & Jodin, 2013):

1. Preparation:
   - Nominal load, classification of the system
   - Determinate load conditions with reference to ROC and parameters
   - Testing of measurement system
2. Measurement:
   - Electrical power determination according to ROC
3. Analysis:
   - Energy Consumption calculation
   - Logistic Performance calculation
   - Energy Efficiency Indicator calculation
   - Evaluation of the results
   - Documentation of the result

Every time, Energy Efficiency Indicators must be under defined standardization as that's the only way which can guarantee the right equivalence. (Hafner, Lottersberger, & Jodin, 2013)

Application of Internet of Things in belt conveyors systems has a very simple idea at the start but from the idea, it is a lot of things which should be correlated to get the appropriate work. Rigidly supported rollers should be connected to the network and at any time we should know what is happening. For example, if there are some problems with the conveying system, the maintenance team will be informed. (Lodewijks, Li, & Pang, 2016)

2.4 Research Gap

Combination of the literature analysis with the IoT, Digital Twins, and Industry4.0 aspects is playing a major role in the development of the modern intralogistics solution. The solution could improve the system throughput, energy efficiency and as well improve handling of the data and optimization of the system performance. Because of that, the development of the intelligent system that is helping to optimize the usage of the conveyor belt system by improving throughput is preferred. Besides that, handling of Big Data on the right way is very important for the improved system.

Most of the time, systems are taking not enough focus on the throughput over time, the factor which can't accurately focus on the energy use in the intralogistics system.

For example, acquiring the throughput over the entire period, like the entire day, can't guarantee that material handling has achieved the optimal performance.

The system could consume a big amount of energy which doesn't transport any of the units. As a result, this is contributing to the basic ineffectiveness of the system. At the end of the running period, the obtained throughput is normally the function of the entire period of the time, but not the time when the system is doing useful work, which is the factor that results with the wrong data.

So there is a need to develop a system that will count for throughput at the running period and which will give accurate data. The accurate data will enable the right energy management of the conveyor belt system and therefore increase of the efficiency.

The predictive study is based on the sensor data which could also be used to provide energy forecasting and as well to help in the conveyor belt system optimization and utilization of time and space, all connected to Azure Digital Twin.

3 Research Methodology and Design

This chapter serves to present how the conceptual framework and the entire solution to the problem under study will be solved. Figure 3-1 is showing the idea for conceptual design and key engineering scopes covered by the system. Because the system is still ideal, it means still not practically implemented, it is only the systematic procedure in reference to the component selection, material science, and development phases.

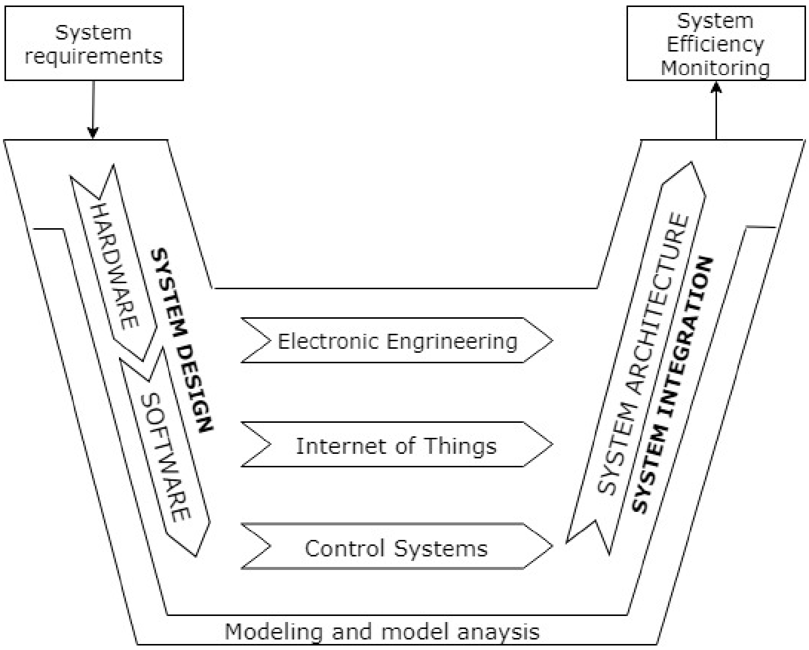


Figure 3-1: Key engineering scopes covered by the system

3.1 Development planning and scheme

Development of the final system architecture and the whole plan is started with the idealization of the model and with definition of the requirements and specification helps in selection of the right components for the system. Afterward, the subsystem is defined and its results are blocks which are connected for the final architecture. Figure 3-2 is showing the development scheme.

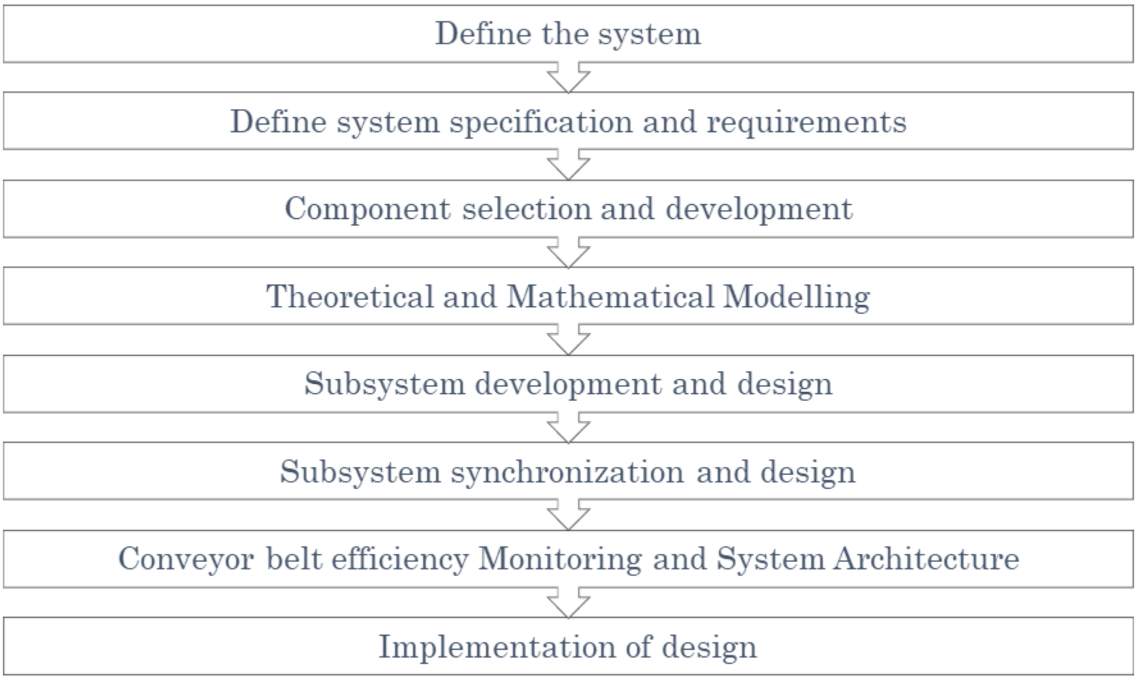


Figure 3-2: Conveyor belt efficiency monitoring system development scheme

3.2 System requirements

Real-time data communication, cloud networking, and electronics development are the things on which system depends on. The reliability and integrity accuracy of the system depends on network reliability, the integrity of sensor, speed, and measuring instrument between other connected components. The basic function of the device is monitoring a parameter that contributes to system efficiency related to logistics performance and electric power, relay data to Microsoft Azure database and executes analytic functions and as a result to get multiple parameter displays of the data.

The system must have the following specifications:

- For handling a large data in the waiting queue as well as data in real time for sensors and input device, and relay high integrity data to the server, high processor speed is needed to have.
- For real-time communication high-speed data is recommended.
- Data acquisition is part of low power usage. Consumption low power is increasing power efficiency. Measuring instruments and sensors should have the highest sensitivity for an optimal response for optimal performance, early failure detection, and higher throughputs.
- Compatibility, all used components have to be compatible with MCU, and this is increasing the reliability.
- Highly persistent systems that can handle vibration and resist mechanical abrasion.

Effective performance on any automated system will depend on the hardware and software design and interactions, Internet of Things, digital design, Digital Twins and software synchronizations to reach the goal.
In intralogistics design and development, most of the technologies are depending on measuring devices of voltage, current, power, parcel per unit time, so it is also the case in this project. Depend on the technologies that have embedded design and lot of possibilities such as programs compatibility, reprogrammable ability, real-time communication and easy way to adjust. This form, most of MCU is

sourcing from different manufacturers, in this project National Instruments are preferred.

3.2.1 National Instruments Microcontroller

NI has built several microcontrollers in several series. The most popular is the family of cRIO series. The usage of NI instruments reduces much of the strain work in interfacing and system integration by offering a quick route to digital twin implementation. It has many subsets of programming languages that have available libraries for any selected component with its range or family of its product.

Compact Rio 9068 chassis

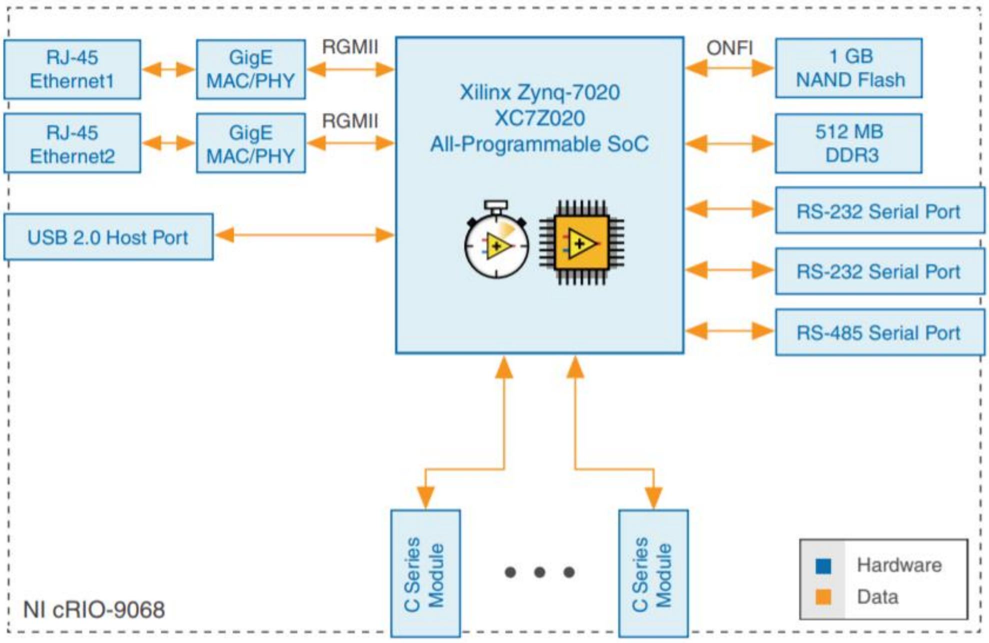


Figure 3-3: cRIO-9068 chassis (NI cRIO-9068, 2016)

This is the embedded Real-Time Controller with Reconfigurable Field-programmable Gate Array (FPGA) for C Series Modules. It is the center of all data acquisition coordination, serving to connect the data collected from the sensor or measuring instruments involved in linking to the database or server. In Figure 3-3 is shown cRIO-9068 chassis. (NI cRIO-9068, 2016)

The measurements include counting, edge counting, pulse width, and semi-period. Depending on the selected model all of these can trigger the states of the counter. For the device details and characterization more is written in Appendix A.

3.2.2 Measuring Instruments

Measuring instruments include measurements tools for analyzing system drives, power capacity and controlling circuities in the system. With this is possible to see total power consumed by belt conveyor per unit time. Total electrical power input is the most basic efficiency parameter for efficiency evaluation, which is dictating the efficiency of the belt pulley and performance of logistics. For voltage measurement is chosen NI 9244 and for current measuring NI 9246. Both measuring instruments are directly inserted on the Compact RIO chassis.
NI is providing an almost complete set of software and hardware. cRIO-9068 is easy to interface with any other component or measuring instrument. It has eight slots which could be used for connection of physical instruments or sensors. In this case, NI 9244 and NI 9246 are inserted. Because of FPGA, cRIO-9068 can be customized to the needs of the user but at the same time, this microcontroller is very fast. Beside eight slots, cRIO-9068 also has the possibility with Ethernet and USB cable from which sensor can be connected or even to get better communication for data.
NI has the complete set of their own software. LabVIEW from which it can also be used for IoT development. Thus, these gadgets provide wide selection ranges for programming.

NI 9244 instrument for Voltage measurement

Figure 3-4: NI 9244 (NI 9244 Datasheet, 2016)

NI 9244 is use for voltage measurement because of high values of voltage involved, the NI 9244 is shown in Figure 3-4. This measurement instrument offers single or three phase measurement configuration.

Connection ability and supported by Compact DAQ and Compact RIO, this instrument is very easy to interface with NI instrument via screwed connections which are available at chassis of supported hardware components, which is providing measurements for both single phase and three phase system connected by star-delta or delta-star topologies. More specifications about the instrument are in Appendix B. (NI 9244 Datasheet, 2016)

NI 9246 instrument for Current measurement

Figure 3-5: NI 9246 (NI 9246 Datasheet, 2015)

NI 9246 is use for current measurements, the instrument is shown in Figure 3-5. NI 9246 is operating at 22 Arms, its input module is a three-channel 22 Arms module designed for supporting direct ring lungs connectivity on three phase high current measurements of 5A current transformers (CTs). Every channel is solo isolated without dependency for other channels or ground. Every input signal of the NI 9246 is isolated and connected to AC, simple with a single 24-bit ADC and connections. More specifications of the measuring instrument are in Appendix C. (NI 9246 Datasheet, 2015)

3.2.3 Sensing device

Sensors which are applied in intralogistics are normally responsible for throughput determination. This means that packet or parcel is passing through to the given point over the unit time. Because of that, sensors are relying on Microprocessors for processing of the signal and in that way is possible to get needed data. The proximity sensor has been chosen for this situation and it is using optical properties, and normally it has a wide range of usage. Principle of proximity sensor work is when the path of the light ray is blocked by the passing object it counts one object, and consecutive rate of blocking gives a number of objects transported per unit time.

Infrared Yocto-Proximity sensor

The Yocto-Proximity sensor is USB proximity sensor, shown in Figure 3-6. This sensor uses a simple principle. The sensor part is emitting infrared light and measuring reflection on the objects near. Color is very important with working with this sensor, and the performance of the sensor is depending on that. Mat and black object can be detected up to the ~2cm. The white object can be detected up to ~10cm. This sensor also can give some estimation of visible and infrared light. The measurements are readable via USB or can be stored on the device internal storage for later review. Yocto-Proximity is designed in the way that it is possible to remove the sensor from the USB, which is giving more opportunities for placement of the sensor itself. More specifications are shown in Appendix D. (Yocto-proximity, n.d.)

Because of the ability to be connected as USB, this sensor was selected as it simple to interface to cRIO-9068 chassis via the USB interface.

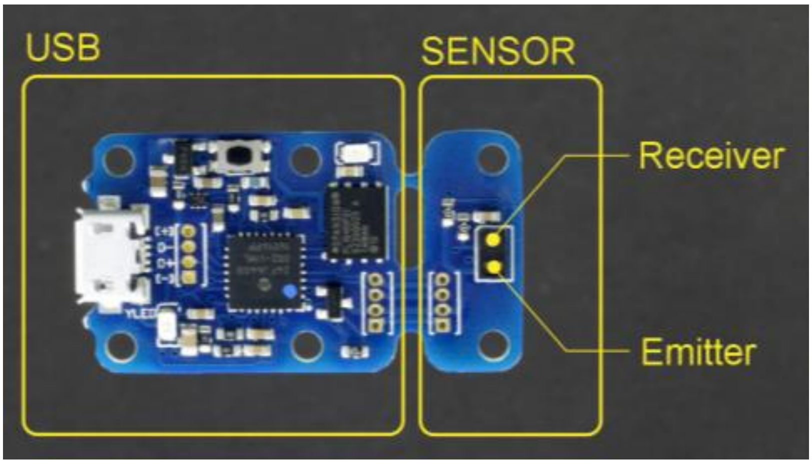


Figure 3-6: Yocto proximity sensor (Yocto-proximity, n.d.)

3.2.4 Software selection

Software synchronization is necessary as a guide to data processing, to provide effective analog sensor input data in real time and to enable corrective feedbacks. Because of the wide spectrum of sublanguages of NI based software, LabVIEW is used.

LabVIEW

LabVIEW is used for the graphical programming of the system. It will enable the design of the virtual part and the subsystem of the conveyor system and will set up virtual measuring instruments which display the main system parameters like voltage, current, and throughput. It helps to develop measurements, control units which are using graphical icons to show the flow from the points. LabVIEW will also have a big role in the integration of hardware like chassis, sensor and measuring instruments with providing built-in libraries for the analysis and visualization.

Add-ons of LabVIEW that should be in use are:

- LabVIEW Real-time

LabVIEW Real-Time Module is an add-on component of the LabVIEW Development System. After the installation of the LabVIEW Real-time will compile LabVIEW graphical code and optimize it for the real-time target. LabVIEW Real-time

Module will help in developing and implementation of the application to all NI real-time hardware like cRIO-9068. (LabVIEW Real-Time Module, 2018)

- LabVIEW FPGA

Combined graphics of LabVIEW and LabVIEW FPGA Module is used to show graphical development of Field Programmable Gate Array (FPGA) chips on NI Reconfigurable I/O hardware goals. With LabVIEW FPGA Module will be possible to create FPGA VIs on the main computer (Windows platform), it will help to LabVIEW and implement the programmed code into cRIO-9068. Creation of embedded FPGA VIs is also possible, it combines direct access to I/O by user LabVIEW logic, in the way of defining sensor and measuring instruments attached to the cRIO-9068. (LabVIEW FPGA Module, n.d)

Measurement and Automation Explorer (MAX)

Measurement and Automation Explorer (MAX) is providing access to National Instruments devices and system. (Measurement & Automation Explorer, 2019)
It has the role to support NI 9244 and NI 9246 in the configuration for the right way synchronization. MAX is also creating the path for the data to the proximity sensor to be sure that value is in the time domain when it was taken.

With the usage of MAX is it possible:

- The configuration of the NI 9246, NI 9244, proximity sensors and LabVIEW.
- Viewing of the devices and instruments connected to the system.
- Updating the NI software.
- Execute system diagnostics.

NI RIO driver software

The driver software is supporting the proximity sensor, and measuring instrument connected to the cRIO-9068 microcontroller. (NI CompactRIO Device Drivers, 2018)
The software will support graphical visualization and programming. Possibility to show a graphical view of the whole system and as well a code can be generated to the system for enabling fast data communication and feedback from cRIO-9068.

3.3 System design

The system is combining the multidisciplinary view:

- Internet of Things (IoT)
- Electronics design
- Analytics

The electronics schematic design is dependent on electronic working. All components are chosen from the side of National Instruments (NI). The chassis makes the base for the entire data synchronization, including the sensors and energy monitoring, selected NI power measuring chassis are directly inserted into cRIO-9068 chassis. LabVIEW is used to synchronize data input and output.

For the connection, the data which is streamed from the cRIO to Microsoft Azure database, there is a need for strong data linkage. Analytics in data processing is managed by the equations that are mostly a function of system input to get the necessary output data which are stored in the database.

Software and hardware will interact in the field of the application with the goal to synchronize other correlated fields of the system. Control and the embedded system will find the application useful especially in feedback, data control and corrective actions that tend to promote system reliability, integrity and reducing the failure rate. Electronic engineering field is the biggest field of the operation in the system which is based on the fact that the final system will be the bulk of electronics. The usage of the electronic instruments like NI instrument, sensors, and chassis are an integral part of the system. The system interaction is summarized by Figure 3-7.

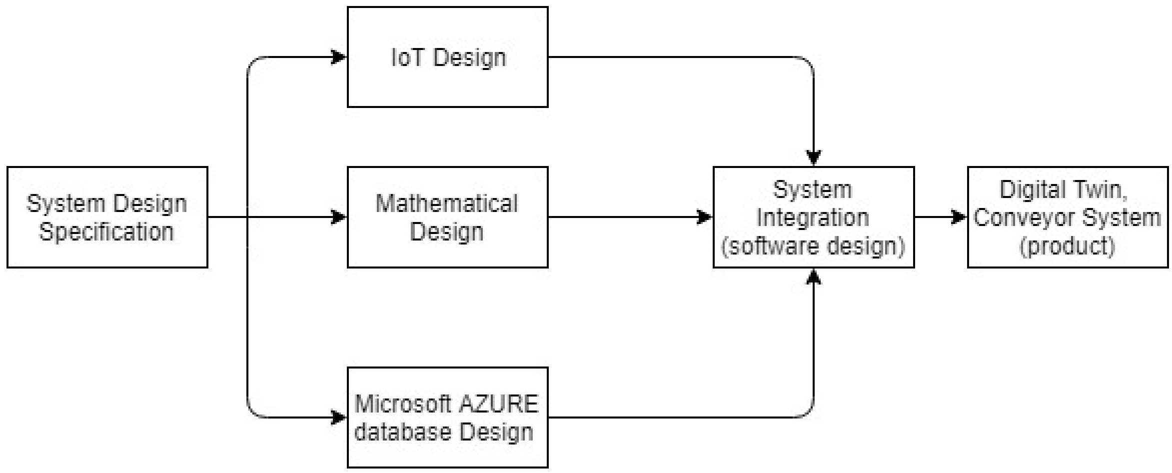


Figure 3-7: Design flow layout

4 Conceptual design

Conceptual design of the research is a guide for the future project implementation. From the theoretical part of the research are given instructions how it should be implemented and every field needs to be checked, put into the real shape and usage.

4.1 Mathematical model of the system and KPI analysis

Performance and accuracy of the data depends on the equations, which control the system. Combination of the multiple systems are controlled differently and it should be taken into consideration. Most of the input is already defined. Inputs are incorporated in the system equation and feed into system governing code to get the necessary control. To get the key data which is important for better control and monitoring of the process, it is necessary to develop the main equation.

The key fundamental performance parameters that define the system KPIs calculated includes:

- Throughput (Λ)
- Electrical power input (P_i), drive speed (n) and transmitted power (P_t)
- Defining different conveyor state
- Length of conveyor (l)
- Logistic performance (W_L)
- Conveyor loading (L_c)
- Power conversion and energy losses
- Efficiency of the system (η)

All of the mentioned parameters are with the equation and linked directly to the system input (time, current, voltage, packet counts). Converting this to meaningful data, inputs must go through a processing system to achieve the goal of the belt efficiency. Everything is starting from the user, followed by data feed in the equation and afterward analytics, processing, and storage of the final values, as well as visualization. The Figure 4-1 is showing the process from the input to the output including data collection parameters, processing and analytics and output at the end.

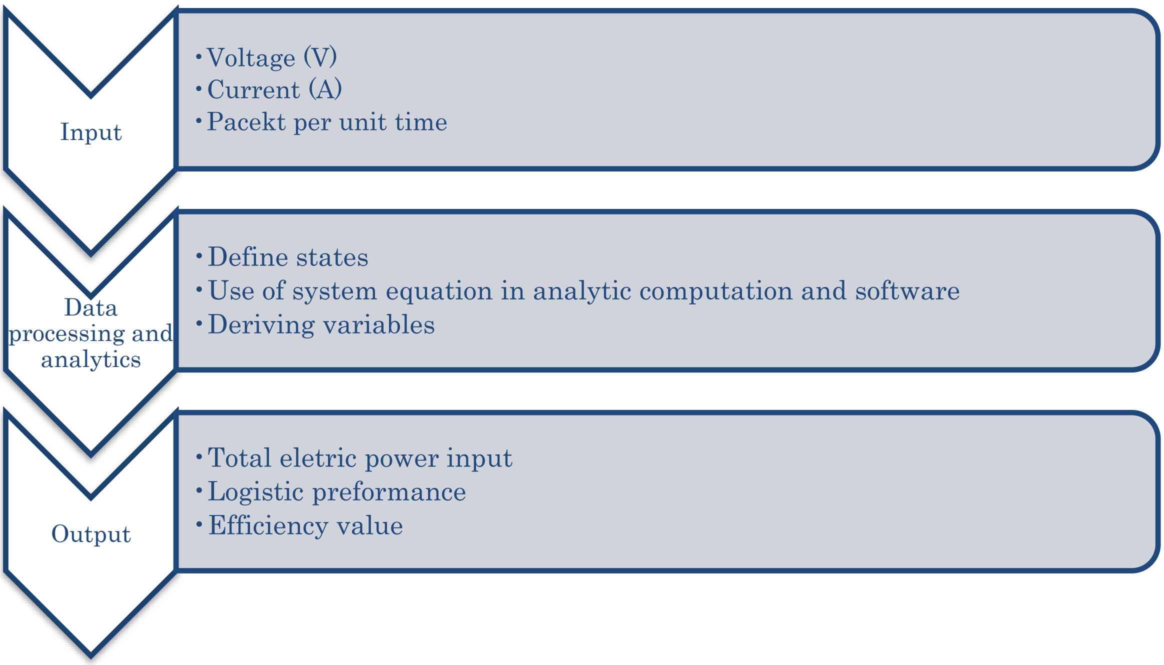


Figure 4-1: Data collection, processing and output flow governing the system dynamics

4.1.1 Throughput

Throughput is directly defined as a number of packets passing through the conveyor at a given time.

This is possible to get as the input of proximity sensor module to which relies on cRIO chassis directly from the conveyor operation. The number of counts per given periodic operation is giving the system throughput.

Throughput is defined by Equation 4-1,

$$\Lambda 1 = \frac{\text{Promimity sensor input to Microcontroller}}{\text{Operation time}} \qquad \text{Equation 4-1}$$

$\Lambda 1$ – Throughput

Microprocessor gets its input regarding the number of light ray blockades that passing objects caused. Therefore, the number of blockades is a representation of the number of the object passing at the point in the operation time. Operation time can be specific to the user as it can decide it to use the whole day, hourly or in minute intervals. For convenience, it is considered of great benefit to discretize throughput in a way that one could view throughput at any given period of time.

In any given operation time then the system throughput can be shown as the Equation 4-2,

$$\Lambda 1 = \frac{\mathrm{i_n} - \mathrm{i_{n-1}}}{\mathrm{t_n} - \mathrm{t_{n-1}}} = \frac{\mathrm{I_N}}{\mathrm{T_N}} \qquad \text{Equation 4-2}$$

T_N – Operation period

I_N – Total input after a given operation period

i_n, i_{n-1} – Instantaneous inputs by proximity sensor in successive periods

$t_n\ t_{n-1}$ – Instantaneous operation periods, time between two successive inputs

Equation 4-2 is the fundamental equation that is governing throughput and therefore the total packet transport over a given operating period is given by an incremental count of input to the microcontroller cRIO-9068.

4.1.2 Operation time

Conveyor operates four states of operation. Four states of operation are (Lottersberger & Hafner, 2016) :

- Full load: definition of the full load is by the periodic time when the system throughput is at its maximum limit. The belt conveyor is fully loaded and can exhibit the maximum number of packets per unit time. Because of the maximum load, power consumption is at the maximum.
- Partial loading: the second possible state is when the conveyor is not loaded fully, only partially.

- No load state: the conveyor has no load but it is still working.
- Stoppage state: the last possibility of the state is when the machine is at rest state.

4.1.3 Electrical input

Electrical power is the input to the system, consumed by sensors, drives, and controls. Measuring instruments should not consume any power, and loss of power by equipment is considered as insignificant power consumption. Drive converted electrical power of the system into mechanical energy. The energy is undergoing a series of conversion, by using system gears to be sure that velocity of the belt is still inferred acceptable limits.

The characteristics of the belt conveyor are described in Table 4-1,

Table 4-1: Characteristics of belt conveyor

Drive type	Drive train specifications	Mechanical specification
Belt conveyor with rigid supports	WA20DRS71S4	Omega drive belt arrangement
No frequency convertors	Power: 0.37kW at unity power factor	
Belt length: 2m	Speed: 90 rev/min	
	Torque: 29 Nm	
Standard: IE2: Rigidly connected to mains, Spiro plan gearbox connected hollow design.		

The power input to the system is obtained by reading the value of NI 9244, NI 9246 and the energy input to the system responsible for driving conveyor, by Equation 4-3,

$$\text{Pi} = \text{NI 9246 input} \cdot \text{NI 9244 input} \cdot \text{power factor} \quad \text{Equation 4-3}$$

Speed conversion of the system will ensure that the velocity of drives will meet the velocity requirements of the belt conveyor. Using the drive with higher speed control is the best regarding the ability to adjust the speed directly from the motor drive. Anyway, not all energy is converted because of some losses like belt resistance or friction, this is resulting in the impossibility of energy input and output. Main losses are from copper losses and from the asynchronous motor drive, gearbox losses and bearing, friction and reactive forces on the conveyor and moving or sliding part. (Efficiency and losses in electric motors, 2015)

Energy flow in the system is showing how energy is lost from the electrical system through mechanical conversion to result in final energy value that accounts for system efficiency. Two criteria could be used to get the total power consumption of the conveyor belt. The first method is, to sum up, gotten power from individual components, drive, and control. Based on the representative operation cycle (ROC), average power consumption P_i is measured for each operating state.
Multiplying the power of any given state, with the corresponding percentage of time from the load specter, the energy input is the result. The energy demand is specific to the conveyor and is indicating the quantity of the energy which is necessary to fulfill requirements of the material handling function. (Hafner, Lottersberger, & Jodin, 2013)

Energy input is given by Equation 4-4 (Lottersberger & Hafner, 2016)

$$E_{In} = T_N \cdot \sum_{i=1}^{n} P_i \cdot t_i \qquad \text{Equation 4-4}$$

E_{In} – Energy input

P_i – Power input

T_N – Operation time

t_i – Percentage of time

4.1.4 Logistics performance

Logistic performance is possible to see from the product sum of packets transported in a distance and unit of time. In the system code, logistics performance will be given by multiplying proximity sensor output module with the total distance passed. Considering long terms of this parameter, multiplying of the output of counter by 2 meters since this is the maximum of transport distance of the conveyor belt for this project.

Equation 4-5 is showing for individual packet, as follows,

$$W = Y \cdot \mathrm{l}$$ Equation 4-5

Y = Yocto-proximity sensor input value
l = Conveyor length

For total packets the logistic performance is given by Equation 4-6 is as follows,

$$W_L = Length\ of\ transport \cdot \sum_{\mathrm{i=1}}^{\mathrm{n}} \mathrm{Y}$$ Equation 4-6

W_L = Logistic performance

The equation is considering throughput, specific distance and period state which is shown in Equation 4-7, (Hafner, Lottersberger, & Jodin, 2013)

$$W_L = \sum_{i=1}^{n} \Lambda_i \cdot L_F \cdot T_i$$ Equation 4-7

Λ_i = Throughput
L_F = Distance
W_L = Logistic performance
T_i = Percentage of time values

4.1.5 Energy Efficiency Indicator (EEI)

Energy Efficiency Indicator is the ratio of mechanical output which is responsible for conveyor working and total input power to the belt conveyor system. Simply, can be defined as the ratio of the output of the system and the total input of the system, shown with the Equation 4-8, (Hafner, Lottersberger, & Jodin, 2013)

$$\eta = \frac{\text{Net output from the conveyor system}}{\text{Total input power to the conveyor system}} \qquad \text{Equation 4-8}$$

With the only definition and the equation between input and output it is not possible to get the correct efficiency rate. The main equation about this is leading to defining the efficiency of the system with using of energy efficiency indicators which are defined as ratios of logistic performance and total electrical input. The form is defined as the result of consideration of the logistic performances, EEI. EEI is calculated from the logistics performance of the product of counts units transported over a given distance during a period of time. The product then serves as the output of the system with the electrical energy as input. Then EE1 is the ratio of the energy input and logistics performance. (Hafner, Lottersberger, & Jodin, 2013)

This can be simplified by Equation 4-9 (Hafner, Lottersberger, & Jodin, 2013)

$$\mathrm{EEI} = \frac{\mathrm{E_{In}}}{\mathrm{W_L}} = \frac{\sum_{i=1}^{n} \mathrm{P_i} \cdot \mathrm{t_i}}{\sum_{i=1}^{n} \Lambda_i \cdot L_F \cdot \mathrm{t_i}} \qquad \text{Equation 4-9}$$

EEI – Energy efficiency indicator

W_L – Logistic performance

E_{In} – Electrical energy input

All parameters calculated strongly depend on the length, Yocto-proximity sensor input, electrical power input and time. In throughput calculation, the input to the system is directly picked as count read by the counter over a given period.

In the diagram shown in Figure 4-2, all the interactions of the system are shown by following the main equations.

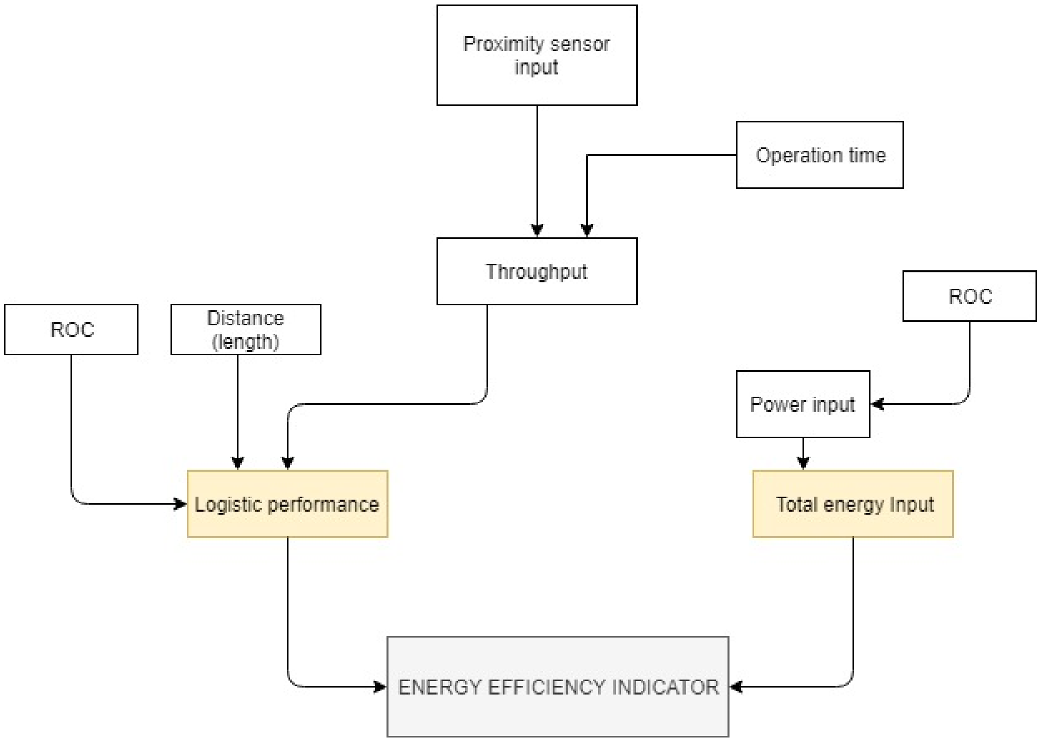


Figure 4-2: System parameter interactions

4.2 Subsystem development

The conveyor belt system consists of these blocks:

- Control, powering units
- Data Acquisition Systems
- Storage Unit
- Data Processing Unit, Microprocessor Unit

The system can be subdivided into three major blocks shown by Figure 4-3 which describe the major components in each subsection as well as path of the data flow from one unit to another.

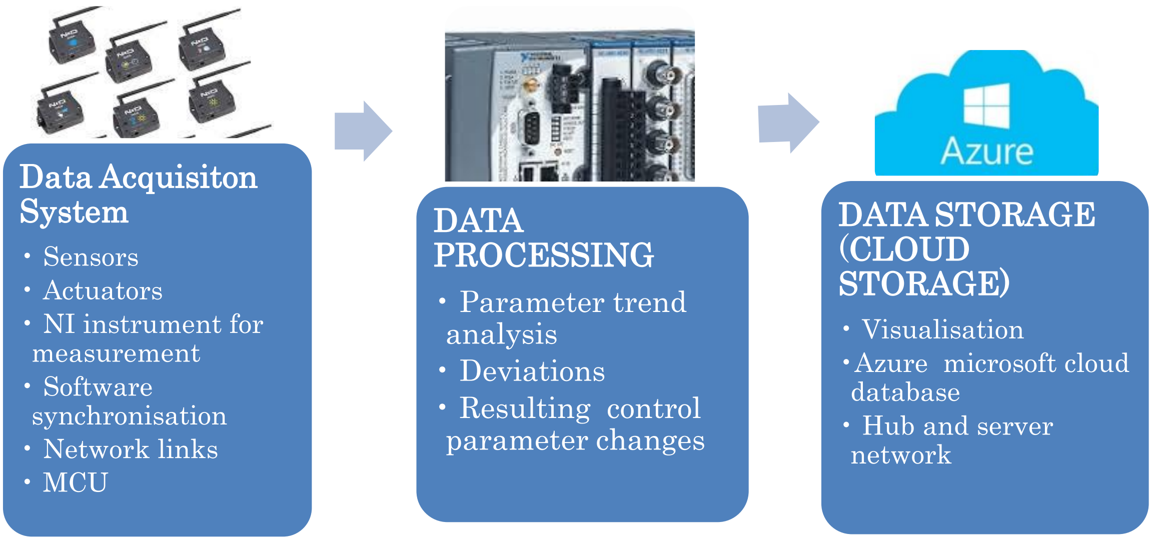


Figure 4-3: Major block describing the design system, information and data flow

The starting point is data acquisition form from the sensor and measuring instruments which are inputs to the system. As there is the availability of real-time clock configuration present in the cRIO-9068, in this case, there is no need for an external counter or real-time clock. Afterward, data is processed by a series of microcontroller instruction to yield requested data output which is based on the system equations. The final process data is being sent to the Azure Cloud database with a graphical visual representation of efficiency over time. The structure is shown in Figure 4-4 as the major block describing the design system, information, and data flow.

NI 9244, NI 9246 and Yocto-proximity sensor feed the data to cRIO-9068 microcontroller unit for processing. This data includes the voltage, current, and counts processed as throughput after data processing. Processed data is then streamed to the Azure cloud database where are analyzed.

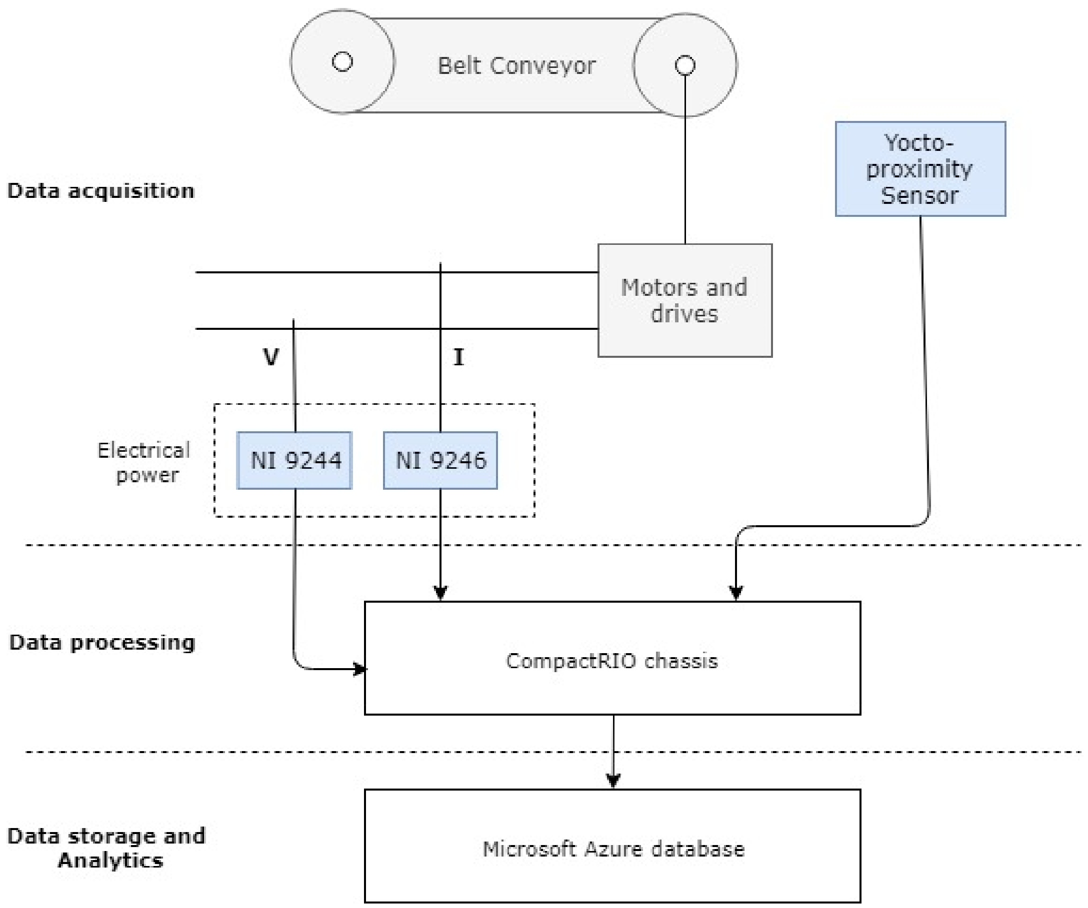


Figure 4-4: Data flow and component connection in data acquisition subsystem

4.2.1 Data Acquisition System

This unit is built of a Yocto-proximity sensor, NI9244 and NI9246 (measuring instruments) and their controls and power units. Parameter control and measuring are based on the fundamental inputs which are needed to the system and which help in the calculation of the efficiency.

The important input to the system includes:

- Voltage (V), Current (I) and Power (P)
- Throughput, packet per unit time
- Unit time for belt conveyor run

The data that has got to the system is relayed to the cRIO-9068 chassis by transmission network. The bus connection system as a transmission network is used to relay data for processing. The system is represented as in Figure 4-5.

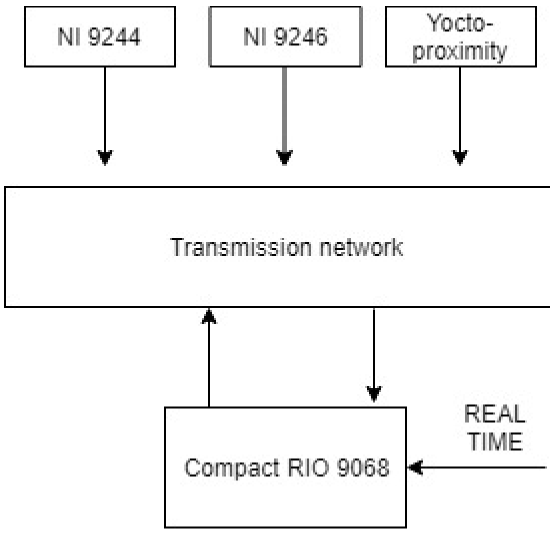


Figure 4-5: Data relying on acquisition unit to Microcontroller cRIO-9068

All data processing is done as per mathematical modeling showed in Chapter 4.1. The system equations in Chapter 4.1 are integrated into the system through the software development phase and therefore become an integral part of the execution phase. Because that all equations directly or indirectly are a function of the three-fundamental inputs throughput, electrical power (voltage and current) and the time.

The process is running at the processing unit located with the Compact RIO chassis and it is direct executed and transferred to cable Ethernet adapter which connect it to cloud services.

Components connection interface

1. Yocto-proximity sensor connection to cRIO-9068

The Yocto-proximity sensor is directly interfaced to cRIO-9068 chassis via USB 2.0 cable (type A - micro B). Afterward, will be fed to digital counter available in the NI chassis through software (MAX) synchronization in real-time.
The proximity sensor is shown in Figure 4-6 and it is powered directly by the same chassis from where it is inserted. (Yocto-proximity, n.d.)

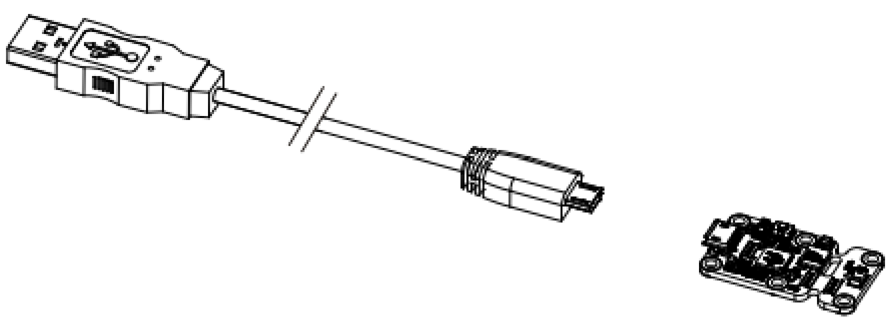


Figure 4-6: USB 2.0 and Yocto-proximity sensor (Yocto-proximity, n.d.)

2. NI 9244 and NI 9246 connection to cRIO-9068

Installation of I/O Modules, in this project NI 9244 and NI 9246 into cRIO-9068, have to follow the next steps (CompactRIO Reconfigurable Embedded Chassis, 2009):

1. The first step is to be sure that NI 9244 and NI 9246 side power not connected to the NI module. If the system is in a safe place, the chassis power can be ON when NI modules installed.
2. Classify the NI modules with the module slot in the chassis. The slots are from 1 to 8, left to right.
3. Grip the latches and insert NI 9244 module on its place into the module slot.
4. Press hard on the NI module connector side, latches should be locked to the module into place.

5. First four steps should be the same to install NI 9246 or any other additional module.

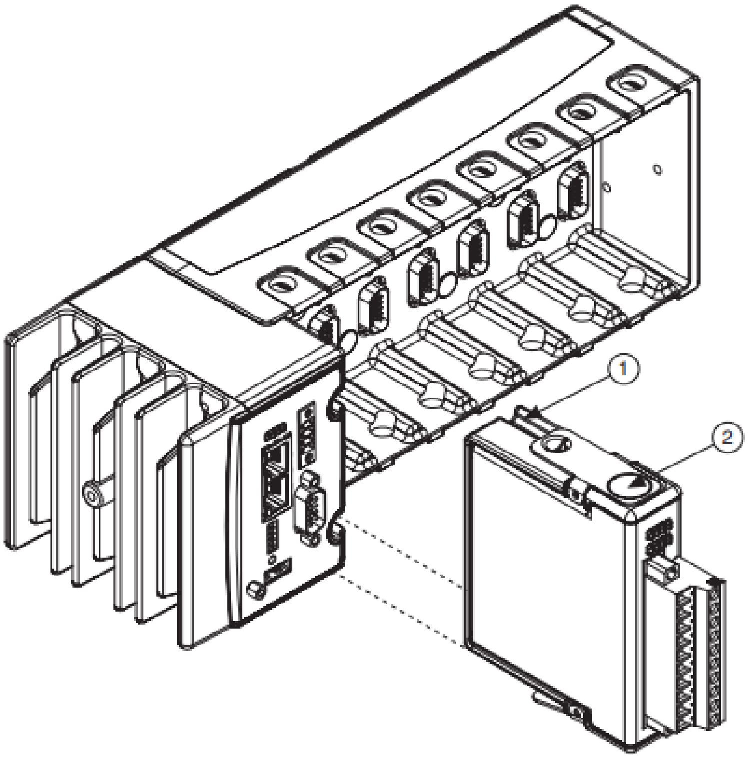


Figure 4-7: Installation of the NI measuring instruments to cRIO-9068 chassis (CompactRIO Reconfigurable Embedded Chassis, 2009)

As showed with the Figure 4-7, number 1 is the insertion groove and number 2 is the latch.

4.2.2 Data Processing Unit

Data processing is done according to mathematical modeling and analytics. The equations of the system are integrated into the system via software development phase and become an integral part of the execution phase. The equations are directly or indirectly function of the three main inputs. These inputs are throughput, voltage, and current.

LabVIEW is playing the important role of supporting the data processing by execution of user functions according to the system equation. The input data follows the path showed in Figure 4-8, for better control and process monitoring.

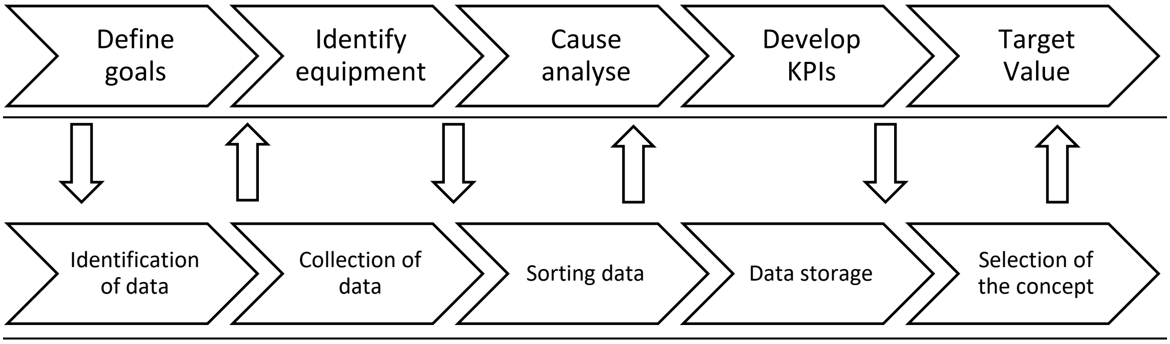


Figure 4-8: Data flow sequence

4.2.3 Data Transmission and Storage System

The data is transmitted from sensor through Compact RIO chassis to the Azure cloud storage. Figure 4-9 shows sequential data flow in the entire designed system.

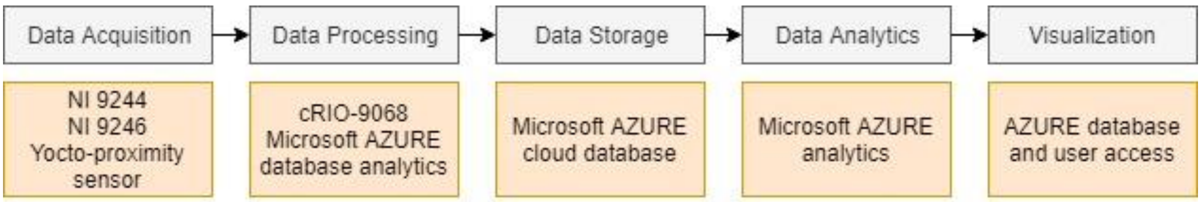


Figure 4-9: Data flow of the system

Microsoft Azure Cloud database is linking two systems in a network. Serves to connect data sources from cRIO and the end user subscribers. Power, time and current are first transmitted to the cRIO, which conditions the input signal and undergoes processing to yield meaningful data in reference to power, throughput, and time. The cRIO-9068 is acting as a broker to linking the raw sensor data to Azure Digital Twin and database as shown in Figure 4-10.

The current, power, voltage, logistic performance and EEI are relying directly on the Ethernet to network adapter. Before being passed wirelessly to the Gateway hub of the Microsoft Azure database in a continuous packet for storage and ana-

lytic Key Performance Indicators (KPIs) displaying the cRIO. Acting as data publisher by pushing data packet for cloud storage and therefore can be idealized to play both broker and publishing role in the telemetry system.
The transmitted data is the message to the telemetry transport and means a wide stream of data sampled periodically by the system over a unit of time.
MQTT will be implemented using standard HTTP calls within LabVIEW. NI Alliance Partners, as well as community versions of such implementation, exist on the LabVIEW Tools Network. (A Practical Guide for Connecting LabVIEW to the Industrial IoT, 2019)

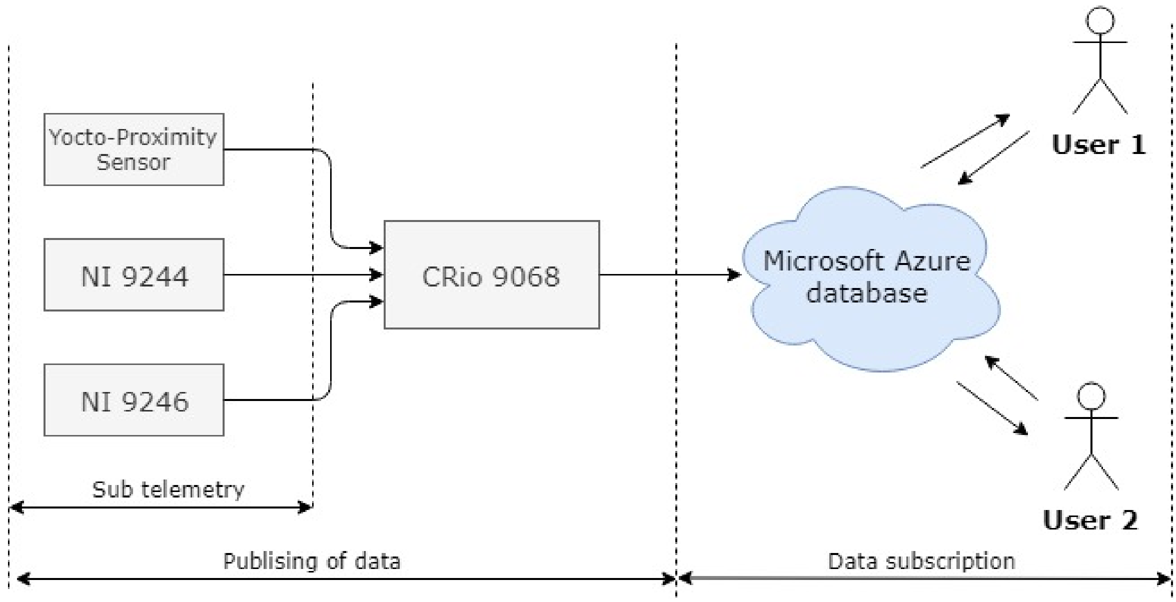


Figure 4-10: Message query transport telemetry for proposed system

<u>System links and Data flow</u>

The final architecture is obtained by synchronizing all developed subunit resulting in a single subsystem. All different blocks working together form the belt conveyor system monitoring by relying on the Internet of Things (IoT).
For effective operation, a control unit has been added to the system ensuring data communication and feedback system is possible to the system.
For the start, all subsystems are first registered to obtain database access Identification (ID), this is helping in the definition of the data path and identification of different inputs and commands for getting a given data stream way from the

hub. It means that the data from a given sensor is acting on its self for conditioning all along, through the processor to the database to yield required properties such as time and digital signal processing, that means that data is streamed continuously through the microcontroller to the server system to the database. Connection and configuration of the device configured to Azure database is providing a safe pathway creation and the direct data stream from sensors to cRIO device and later on to the database.

The arrival of the data packets at IoT Hub is the first directed for the time event calculation which ensures that the data is analyzed and presented as a graphical representation or any other visual representation for direct visualization of the user. After performed effective computation at Analytic center, the data will follow in two routes. The first route will involve direct storage to the database. Data and visual graphics are the streams to the database for storage in real time archives files for easy process take place when there is urgent data storage and is known as a path for data streaming and storage system. In the second route, the data is placed under the event hub which ensures streamlining of data sequentially based on time.

Instreaming of this data from the event hub will need to be connected to the Azure cloud service network which connects it to Azure cloud storage. These paths can be used simultaneously depending on sensor data traffic and the need for feedback. The secured route becomes more effective in tracking system error since the event hub easily can identify the unknown type of data and therefore eliminate or discard, which provided data integrity, accuracy, and security of the data.

The cloud service will connect the data streamed from the event hub and store it directly to the Azure Cloud database systems.

If any data error is detected by the system, the error signal will be generated and transmitted via Microsoft Azure Cloud service to the gateway hub. Based on an event associated with the error message the message or data error is passed to the gateway hub.

The hub is using the error and restores back the event ID to be sure about the proper identification of the error to trace back the sensor or measuring instrument it was sourced from. The error message could be over or under voltage, current or power, packet count failure, real event configuration failure. With the event identified a corrective signal is passed from cRIO to the sensors and measuring instruments to correct the signal restoring back to normal operating ranges of value. A feedback loop is playing an important role in ensuring the system run effectively and under specified environment ensuring that the system with high accuracy and improving its reliability. Data loss is also associated with the system because of the mechanical vibration, physical noise is mitigated ensuring only valid data is streaming from the data sensor and measuring instruments, processing unit cRIO chassis and the cloud Azure database. This is summarized by Figure 4-11.

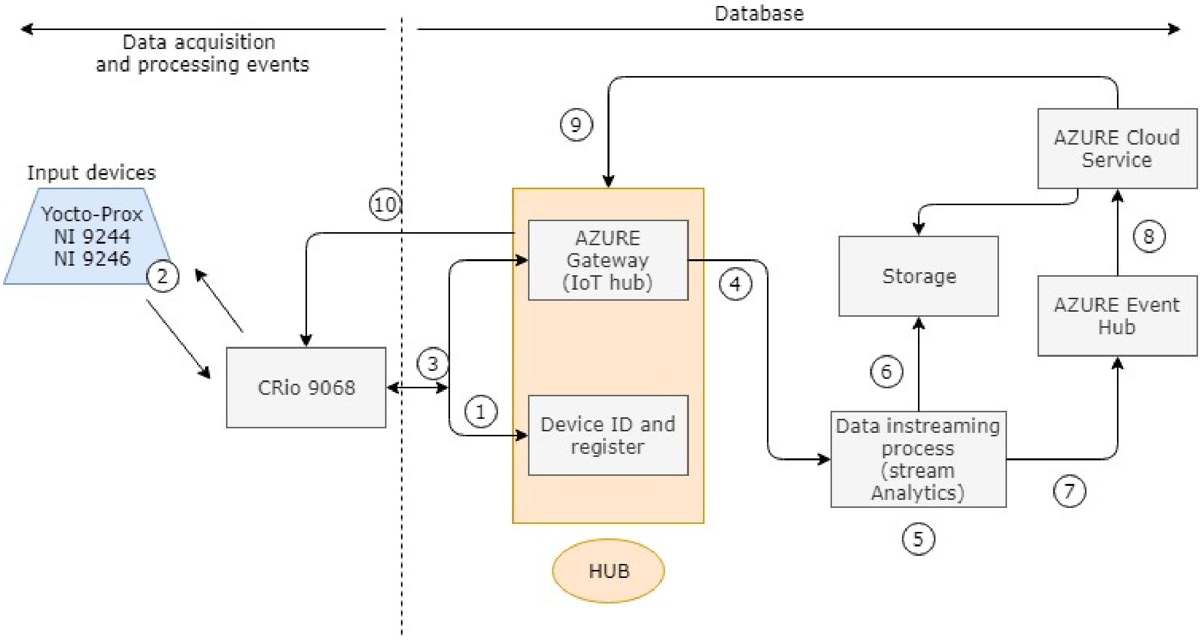


Figure 4-11: Data flow, system interlinks and communication systems of the entire model

1. Register Yocto-proximity sensor NI 9244 and NI 9246 getting device communication port or access link which is used ID. This is simply to configure the device to allow data communication and analog reading at microcontroller.
2. Configure sensors and measuring instruments to cRIO9068.
3. Data is sent from the sensor to Azure IoT Hub.

4. Microsoft Azure Cloud Gateway gives Azure IoT Hub access input to stream analytics functions of Azure.
5. Data sensor is analyzed using stream analytic query.
6. Data storage is taken to cloud account for permanent storage purposes or for back up access.
7. Data from the analytic is sent to Azure Event Hub.
8. Reading data from Azure Event Hub (subscription).
9. The feedback loop for corrective action to Hub.
10. Alert and feedback to the sensor for corrective action.

Database creation

For creation of the AZURE database first step is to register or log-in to the Azure portal. Steps are following Figure 4-12, Figure 4-13 and Figure 4-14.

To create a database next steps should be followed (Phadke & Rabeler, 2019):

1. Create a resource
2. Select database, and after that select SQL database
3. Create SQL database, fill in the form which appeared

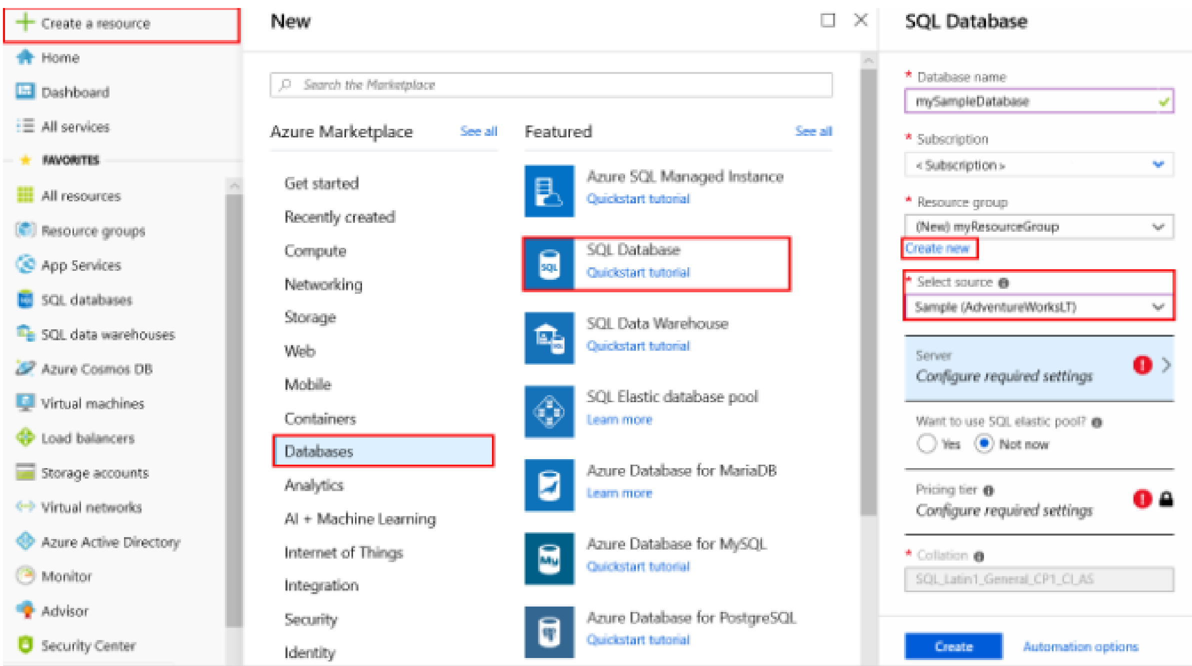


Figure 4-12: SQL database window (Phadke & Rabeler, 2019)

4. Under Server, click Create New
5. Fill in the Server form

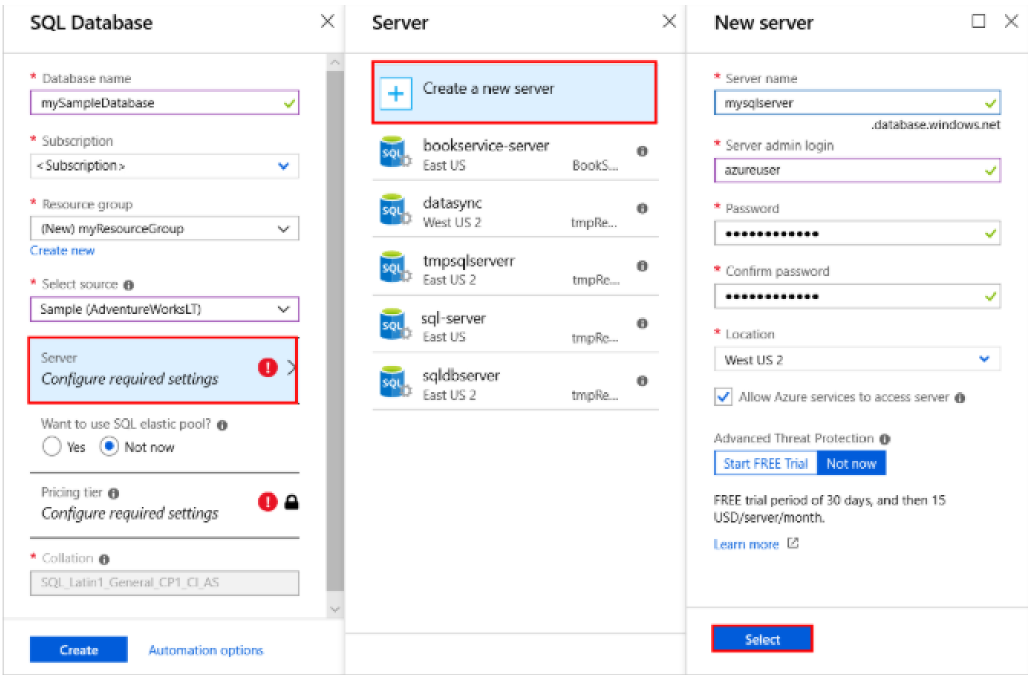


Figure 4-13: SQL database server form (Phadke & Rabeler, 2019)

6. Choose pricing tier and check amount of Database Transaction Units (DTUs) and storage availability.
7. In the SQL database form click APPLY.

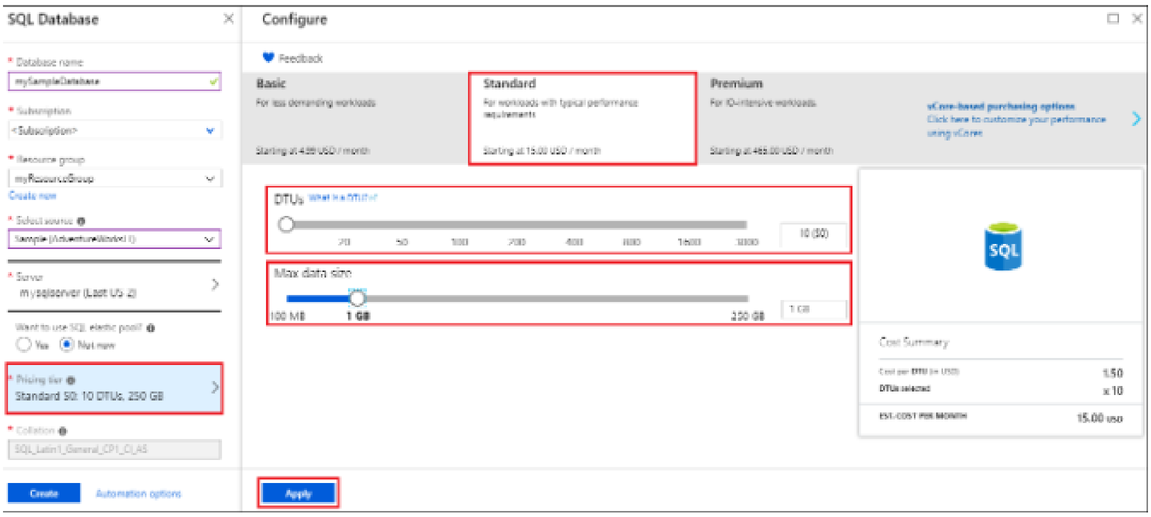


Figure 4-14: SQL database final form (Phadke & Rabeler, 2019)

Configuring cloud database, IP creating and Access

Configuration AZURE database

For configuration, the database, SQL Server Management Studio (SSMS) could be used to connect to the Azure database server. It is possible to create tables on SSMS or export existing tables. Open SQL Server Management Studio. Following procedure should be followed to connect the database to the Azure database server (Rabeler, et al., 2019).:

1. Open SSMS and connect to Server
2. Enter all needed information in the form, showing in Figure 4-15.

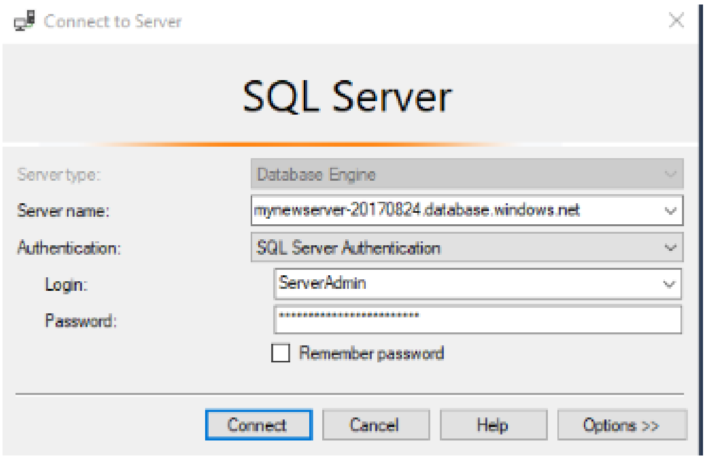


Figure 4-15: SQL database creating interface (Rabeler, et al., 2019)

3. Select options and select mySampleDatabase
4. Click connect, like it is showen in the Figure 4-16

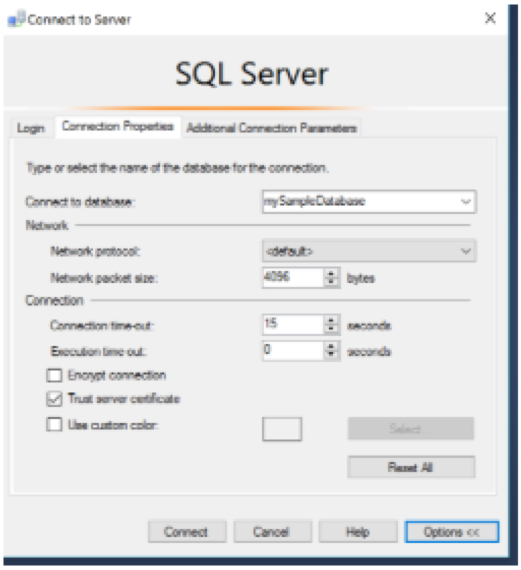


Figure 4-16: SQL connection and configuration of settings (Rabeler, et al., 2019)

5. The last 5th step, to view all database objects in the window Object explorer, expand Databases and expand mySampleDatabase, as shown in Figure 4-17.

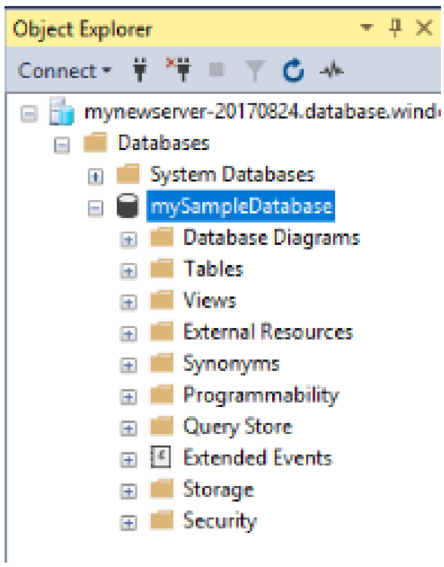


Figure 4-17: Object Explorer (Rabeler, et al., 2019)

IP Creation

At the server level your database creates a firewall to prevent external connection of applications to the server or server databases. To enhance external connection to database an IP address rule is added to the firewall created. This rule is what is used to access by local IP address to the database.

Below is the procedure of creating the rule for the SQL database firewall (Phadke & Rabeler, 2019):

1. Click on SQL database once deployment is complete then select the database you created from the list. The details of your database will appear.
2. Click set server firewall to open the firewall settings.
3. To add the Current IP to a new server-level firewall rule click Add client IP address. The server-level IP firewall rule could open the 1433 port for several or one IP addresses.
4. Click save. The server-level IP firewall rule will be created for the current IP address on the SQL database.
5. Click OK and close the settings for the firewall.
6. This IP address is able to bypass the firewall. It is possible to use SQL Server Management Studio to connect the server to its databases.

Access

Access control to Azure database is by firewall rules which control the user's access to data and actions. The users, therefore, need the authorization to prove who they are. Access to the database is granted by the firewall according to the IP of the request. The firewall of the client computer must allow TCP port 1433 for TCP communications. AZURE provides two types of authentication which are SQL authentication and Azure active directory. SQL authentication uses username and password to allow access to the database as the admin.

The azure active directory uses active directories managed identities and is designed for interconnected domains. To use this, you need to create another admin known AD admin who is able to do all that a server admin can do. Authorization is managed by role membership or object-level permissions which defines the user's capability in the database and what they are able to do. (Azure SQL Database, n.d)

4.3 Hardware and software integration

With the interface data encoding and decoding is possible, converting the analog signal and possibility of discreetness of information to user-friendly data. Data received from the data acquisition system are directly connected to CompactRIO chassis. Not like with the processors, FPGA is parallel in nature so different process operation doesn't need to have to compete for the same resources. Every processing task is assigned to a dedicated section of the chip and can work autonomously without influence from other logic blocks. The result is that the performance of one part of the application is not affected when more processing is added. Figure 4-18 and Figure 4-19 are showing interactions and effective synchronization.

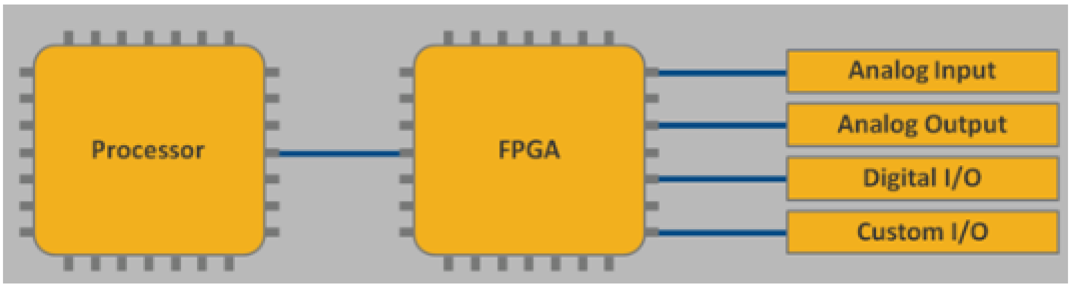


Figure 4-18: Software, FPGA and input interactions (Programming Techniques for Embedded Systems, 2013)

With FPGA module and the communication from proximity sensor and measuring instruments, hardware-software data interchange interface is enabling data processing. With the conversion and with the coding of the FPGA module, data is analyzed by the combination of effective work of NI LabVIEW FPGA. LabVIEW FPGA interface is making possible to use I/O modules from LabVIEW FPGA VIs. Modules (MAX) used in LabVIEW FPGA interface, directly under the target item in the Project Explorer window and the I/O channels show up as FPGA I/O items under the FPGA target. To access to the I/O channel, configure the FPGA I/O Nodes in the FPGA VIs. The LabVIEW FPGA interface will use LabVIEW FPGA programming if there is a request to add more flexibility or to customize the application. With usade the cRIO system LabVIEW FPGA module will have to be installed in the host computer. (LabVIEW FPGA Module, n.d)

Set up of the project for Compact RIO system

When the setup of the hardware is done, Compact RIO controller power ON. Projects in LabVIEW are using to group LabVIEW files and files not specific to LabVIEW, as well as create specifications and deploy or download the files. After the project is saved, LabVIEW creates the project file with the extension lvproj. which includes references to files, configuration information, deployment information, and others.

As well, the project should be used to work with the FPGA, Touch Panel, Digital Signal Processors (DSP).

To set up the project, next steps have to be followed:

1. Launch LabVIEW.
2. In the window Getting Started, under Targets, select FPGA Project. On another way: Tools -> FPGA Module -> FPGA Project.
3. Click **GO.**
4. On the page, Create New LabVIEW FPGA Project, select Compact RIO Reconfigurable Embedded System. After that click Next.
5. Important is that Discover existing system is selected, click Next.
6. On the page New Compact RIO FPGA Project, the controller that is used, select. After this click, next.
7. Uncheck Launch FPGA Wizard and click Finish.
8. Select File -> Save Project and save the project as conveyorbeltsyst. lvproj.
9. A typical project window explorer is shown by Figure 4-19.

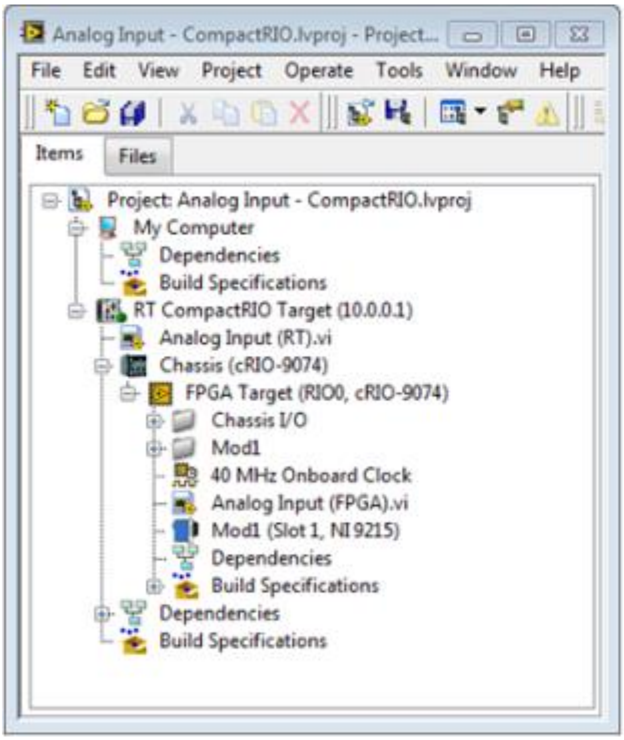


Figure 4-19: Project window explorer outlook (Programming Techniques for Embedded Systems, 2013)

4.4 Final Arhitecture of the system

The final system architecture is represented by Figure 4-20. System devices are including NI9244, NI9246 and Yocto proximity sensors primarily forming data acquisition discussed in Chapter 4.2.1 interact with external world enabling conversion of corresponding physical quantities into analog signal processed by the microcontroller unit to yield useful data to the users. These devices are interacting with the cRIO-9068 and LabVIEW software for control process and monitoring which serves to control the data acquisition process while cRIO-9068 and LabVIEW are enabling data processing. Data processing starts by ADC which is followed by processing by user function defined by the function presented in Chapter 4.1.

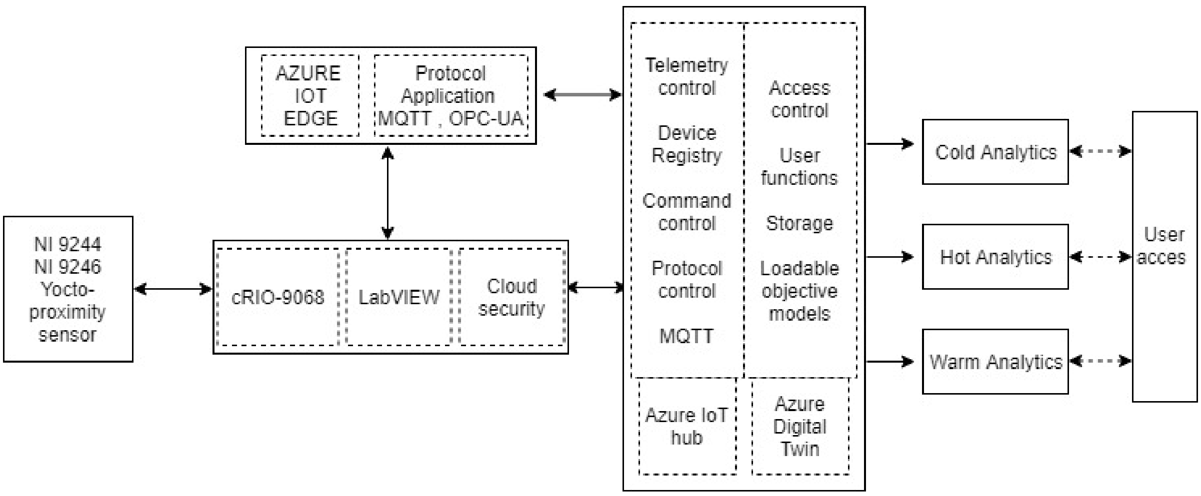


Figure 4-20: Working of the design system module

As a central coordinator of the data acquisition and processing the cRIO-9068 is starting with the data transmission to serve and provide the data to the system to improve data integrity as well as for cloud communication. Therefore, the data is streamed from cRIO-9086 to IoT Edge by using MQTT / OPC-UA facilitating host computer (server) to cRIO-9068 communication.

From Hub, identification is done, creating data paths for all major parameters throughput, power and time. The hub afterward enforces control over telemetry transport through gateway and proxy control.

In Digital Twins, user access control is enhanced which provides user communication and data access.

From here data can be accessed in three forms (Gibson, 2012):

1. Cold Analytics - user asks information over the historical data. The user is there given access to archived data of the system..
2. Hot analytics - user gets access to real-time data control. This is helpful in real-time data trend analysis, monitoring, and control of the system which is usually made by Azure stream analytics.
3. Warm analytics - user asks control to access time series data storage, this could be storing data as a function of time. For example, throughput vs time, power usage vs time, utilization factor changes. This is enabled by the Azure time series.

The data can be available to the user through various access action and mechanism which includes data search or Office 365 access, but it should be available only after integration.

5 Conclusion and Future Work

This chapter is providing a conclusive summary of the designed work and as well the suggest future improvements with focus to the conveyor belt system or another addition facility that would improve the system further.

5.1 Conclusion

Since the implementation is a future deal, the only conclusive pathway can be drawn to push forward for such development and further research.
The project is built for Internet of Things and their applications through usage of Digital Twins. Through Digital Twins users have the possibility to analyze and visualize the conveyor belts system performance, and it helps in close monitoring, control and cloud storage of the industrial volume data.
Improved conveyor belt system is built with National Instrument (NI) components and there is an expectation that the system is more integral providing control, data communication, and signal conditions required from the system to implement fast data processing. The use the of Azure Cloud database from Microsoft was selected to act as a reference to the design work which is a representation of the data services important for Industrial Internet of Things application and the right way study, development, and implementation of Digital Twins.
The interface of virtual control from Digital Twin design is used to show all Key Performance Indicators with the analysis.
Key Performance Indicators data is shown as a function of time by generating relevant infographics of the system changes which should be easy for the user to view conveyor system performance. The infographics should come in the form like the graphs. The data processing is operated by the system equation written in Chapter 4.1. The direct analysis can be viewed from the Azure database system during any given period which depends on the users need. The designed Digital Twin design will show all transitions and state of conveyor operation, also visualization of the belt conveyor system and all associated components attached to it. This should include virtual control of motor drives to power the belt conveyor

movement. Digital Twins and Internet of Things are playing the major role in their different perspective, making the manufacturing and material handling easier for the user. Internet of Things, therefore, can be seen as a drive to data acquisition, data communication, and database management which promote the right tracking record of any material handling facility. Real-time data handling helps in real time monitoring which is improves production efficiency. Internet of Things has also proved effective in improving system reliability by ensuring data processing and analysis that will see the production of quality data. For example, availability to differentiate system throughput as a function of only full load and partial loading state from the stoppage and idle state is of importance to the improving system accuracy and reliability. In addition, it provides information on energy use and helping in the system energy which could improve system efficiency by the running system during full or partial load. Internet of Things and Digital Twin will further increase the product life cycle monitoring, reducing system failure rates through controlled monitoring and visualization of real-time data as well as early failure detection by evaluating system performance. Big Data handling and visualization will also help in quick performance evaluation of the material handling facility enabling forecasting which helps in improving on actual system to adjust to new condition, improve or reduce shortage. Internet of Things and Digital Twins help in rapid data acquisition monitoring and analysis as well as providing a control mechanism in which the conveyor belt system can be modified. Therefore, focus and orientation are on the conveyor belt system visualization and analytics more than physical design of the belt conveyor, though it can virtually represent the physical conveyor belt.

Digital Twin provides a wide scope for increasing the system parameter visualization and close monitoring. It improves data management control and quick data access. Because of the Big Data and fast communication, Internet of Things can help in the aspect of intralogistics by providing more efficient method of data handling. The endless data stream can be stored for the system with unlimited access, anytime and anywhere, especially when connected to web services such as the company's website. Data from NI instruments and proximity sensor can be col-

lected, processed and streamed to the server increasing data access from any location. The greater aspect of Azure Digital Twin system helps in building a model that can provide analytics and forecasting of data helping data control and intralogistics management. With the control and monitoring of throughput and also power help analysis, energy use, overall system performance. This leads to a better understanding of energy use and as a result helping correlate throughput to the power leading to better to energy efficiency and power use insights. Telemetry transport with MQTT will allow users to connect endless counts of NI 9244, NI 9246 and proximity sensor to multiple location. This promotes the control or data acquisition over a wide area regardless of the multiple inputs as the data can be effectively queried to the database effectively due to adequate capacity by MQTT to support multiple devices. The system together with the system data flow, interlinks, and communication is well shown into the Chapter 4, which is serves as a guide for further steps developments.
Azure Digital Twin will make possible to view infographics as well as system virtual representation with controlled parameter like power or throughput of multiple conveyor systems clearly showing aspect of every performance. Implementation of this system, therefore, would reduce inaccurate data conclusions by users as it provides accurate data given as a function of running time. Other than operation time, reduce labor and time incurred in monitoring, increasing access to data as well as providing predictive analysis of the system.

This system should be the early version of a conceptual framework of Digital Twin for the conveyor belt systems and it requires implementation in the real world.

5.2 Future Work

Most of the work is realized by the suggested conceptual design of Digital Twin for visualization and monitoring of the conveyor belt efficiency. Still, there is a lot of space requisite for future studies and analysis in this field, especially the implementation of the proposed system. The project should be a strong reference point for development in industrial application and this step should improve production efficiency, reducing power loss, facilitate mass production and also improve the data management and control.

In other design application, the device should be adjusted with the storage system to ensure data back up whenever there is communication loss. Then, the saved data can be sent or streamed back to the Azure database system whenever the network is back. This provides uninterrupted data streaming and avoiding unnecessary data loss. The system design should be able to sense network loss or resumption to restore data streaming to the Microsoft Azure database. Future studies should be more oriented in making the system more intelligent and work independently without any human interference.

REFERENCES

A Practical Guide for Connecting LabVIEW to the Industrial IoT. (2019, March 19). Retrieved from National Instruments: http://www.ni.com/en-rs/innovations/white-papers/17/a-practical-guide-for-connecting-labview-to-the-industrial-iot.html

A.Gilchrist. (2016). *Industry 4.0.* Berkeley,CA: A press.

Alam, K. M., & Saddik, A. E. (2017). C2PS: A Digital Twin Architecture Reference Model for the Cloud-Based Cyber-Physical Systems,. *IEEE Acess*, 2050-2062.

Azure Digital Twins. (2018, September 24). Retrieved from Microsoft Incorporation.com: https://azure.microsoft.com/en-us/updates/azure-digital-twins/?cdn=disable

Azure SQL Database. (n.d). Retrieved from Microsoft Azure: https://docs.microsoft.com/en-us/azure/sql-database/

Brettel, M., Friederichsen, N., Keller, M., & Rosenberg, M. (n.d.). How Virtualization, Decentralization and Network Building Change the Manufacturing Landscape: An Industry 4.0 Perspective.

Brümmerstedt, K., Beek, H. M.-V., & T. Münsterberg. (2017). Comparative analysis of synchromodality in major Europen seaports. *Digitalization in martime and susteinable logistics: city logistics, port logistics and sustainable supply chain management in the digital age*, 59-76.

Chen, M., Wan, J., & Li, F. (2012). Machine-to-Machine Communications: Architectures, Standards and Applications. *KSII Transactions on Internet and Information Systems*.

Cloud Computing Comparison 2019: AWS vs Azure vs Google. (2019, March 06). Retrieved from Fullscale.Io: https://fullscale.io/cloud-computing-comparison-2019-aws-vs-azure-vs-google/

CompactRIO Reconfigurable Embedded Chassis. (2009, January 09). Retrieved from National Instruments: http://www.sal.wisc.edu/PFIS/docs/rss-nir/archive/public/Product%20Manuals/ni/ni-911x-manual.pdf

Durkop, L., Czybik, B., & Jasperneite, J. (2015). Performance evaluation of M2M protocols over cellular networks in a lab environment. *International Conference on Intelligence in Next Generation Networks* (pp. 70-75). IEEE transactions.

Efficiency and losses in electric motors. (2015, March 24). Retrieved from Groschopp: https://www.groschopp.com/efficiency-and-losses-in-electric-motors/

Emans. (2019, February 22). *INTELLIGENT INTRALOGISTICS: 3 STAGES OF IN-PLANT LOGISTICS AUTOMATION*. Retrieved from Ansoft Emans: Smart Industry Solution: https://www.anasoft.com/emans/en/home/news-blog/blog/Intelligent-Intralogistics-3-Stages-of-Automation

G.Karting, B.Grosel, & N.Zrnic. (2012). *Past, state-of-the-art and future of intralogistics in relation to megatrends,.*

Gibson, D. (2012, June 1). *Big Data Hot, Warm, or Cold.* Retrieved from IBM, Big Data and Analytics Hub: https://www.ibmbigdatahub.com/blog/your-big-data-hot-warm-or-cold

Gregor, M., Haluska, M., & Fusko, M. (2016). Model of intelligent maintanance systems. *Proceeding of 26th International Symposium* (pp. 1097-1101). Viena: DAAAM International.

Hafner, N., Lottersberger, F., & Jodin. (2013). EFFICIENCY INDICATORS FOR BENCHMARK AND IMPROVEMENT OF ENERGY EFFICIENCY ON AUTOMATEDMATERIAL FLOW SYSTEMS. *Proceedings in manufacturing systems*.

Inglehart, R., & Baker, W. (2000). Modernisation ,culture change and persistence of Tradational values. *American Social review journal*, 19.

Karagiannis, V., Chatzimisios, P., & Vázquez-Gallego, F. (2018). A survey on application layer protocols for the Internet of Things. *Trans. IoT Cloud Compute journal*, 48-50.

LabVIEW FPGA Module. (n.d). Retrieved from National Instruments: https://www.ni.com/en-rs/shop/select/labview-fpga-module

LabVIEW Real-Time Module. (2018, March). Retrieved from National Instruments: http://sine.ni.com/psp/app/doc/p/id/psp-515/lang/en

Lauria, J. (2017, December 06). *Microsoft Azure Pros and Cons: Cloud Services for Businesses*. Retrieved from iCorps technologies: https://blog.icorps.com/pros-and-cons-microsoft-azure

Lee, E. A., & Seshia, A. S. (2017). *Introduction to Embedded Systems - A Cyber-Physical Systems Approach.* MIT Press.

Lee, I., & K.Lee. (2015). The Internet of Things (IoT): Applications, investments, and challenges for enterprises. *Business Horizons*, 431-440.

Lee, J., Bagheri, B., & Kao, H.-A. (2014). A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems. *Manufacturing Letters*, 6.

Lodewijks, G., Li, W., & Pang, Y. (2016). An Application of the IoT in Belt Conveyor Systems in Internet and Distributed Computing Systems. 340-351.

Lottersberger, F., & Hafner, N. (2016). Intralogistics Systems – Optimization of Energy Efficiency. *FME Transactions journals*, 256-262.

Measurement & Automation Explorer. (2019, March 26). Retrieved from National Instruments: https://knowledge.ni.com/KnowledgeArticleDetails?id=kA00Z000000P9KBSA0&l=en-HR

NI 9244 Datasheet. (2016, April 16). Retrieved from National Instruments: http://www.ni.com/pdf/manuals/376131a_02.pdf

NI 9246 Datasheet. (2015, May 15). Retrieved from National Instruments: http://www.ni.com/pdf/manuals/376372a.pdf

NI CompactRIO Device Drivers. (2018, May). Retrieved from National Instruments: http://www.ni.com/download/compactrio-device-drivers-may-2018/7321/en/

NI cRIO-9068. (2016, June). Retrieved from National Instruments: http://www.ni.com/pdf/manuals/376007b_03.pdf

Phadke, S., & Rabeler, C. (2019, February 25). *Azure SQL Database*. Retrieved from Microsoft Azure: https://docs.microsoft.com/en-us/azure/sql-database/sql-database-single-database-get-started

Pisani, J. (1985). Mass communication Theory. *Journal of Advertising*, 62-63.

Post, J., Groen, M., & Klaseboer, G. (2017). *Physical Model Based Digital Twin in Manufacturing Process.*

Programming Techniques for Embedded Systems. (2013, September 17). Retrieved from National Instruments: http://www.ni.com/newsletter/51831/en/

Qi, Q., Tao, F., Zuo, Y., & Zhao, D. (2018). Digital Twin Service towards Smart Manufacturing. *Procedia CIRP*, 237-242.

Rabeler, C., Stein, S., Gollnick, J., Goldman, P., Miller, A., Nevil, T., . . . Koudelka, M. (2019, March 25). *SQL Server Management Studio*. Retrieved from Microsoft Azure: https://docs.microsoft.com/en-us/azure/sql-database/sql-database-connect-query-ssms

Sadiku, M., Yonghui, W., Cui, S., & Musa, S. (2017). Industrial Internet of Things. *International Journal of Advances in Scientific Research and Engineering*, 12-17.

Seto, J., Gerard, A., Thurman, P., Stanciu, A., Kshirsagar, D., Fosmark, T., & Vogel, M. (2018, December 14). *Overview of Azure Digital Twins*. Retrieved from Microsoft: https://docs.microsoft.com/en-us/azure/digital-twins/about-digital-twins

Sriramoju, S. B. (2017). *INTRODUCTION TO BIG DATA: INFRASTRUCTURE AND NETWORKING CONSIDERATIONS.* Warangal India: Horizon Books.

Stöhr, T., & Hafner, N. (2017). Energy Efficiency Calculator Model to Optimize Intralogistics Systems Material Flow Systems (MFS).

Tayagi, D., & Sharma, S. (2018). International Journal of Research in Engineering, IT and Social Sciences. 48-50.

Thota, P., & Kim, Y. (2016). Implementation and Comparison of M2M Protocols for Internet of Things.

Vickers, J., & Grieves, M. (2017). Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems in Transdisciplinary Perspectives on Complex Systems. In S. F. F.-J. Kahlen, *Digital Twin:* (pp. 85-113). Springer international publishers.

Watts, S. (2018, June 5). *AWS vs Azure vs Google: Complete Guide to Cloud Platforms for the Enterprise*. Retrieved from BmC blogs: https://www.bmc.com/blogs/aws-vs-azure-vs-google-cloud-platforms/

Yocto-proximity. (n.d.). Retrieved from Yoctopuce: http://www.yoctopuce.com/EN/products/usb-position-sensors/yocto-proximity

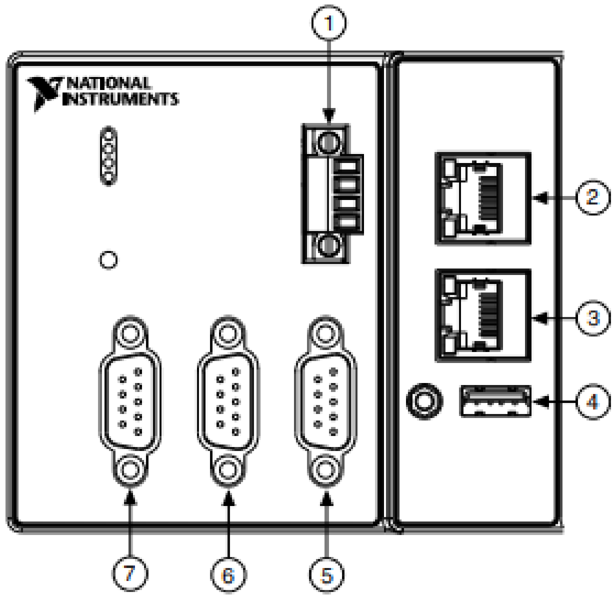
APPENDICES

APPENDIX A - NI cRIO-9068

Startup Option	Description
Force Safe Mode	Rebooting the cRIO-9068 with this setting on starts the cRIO-9068 without launching LabVIEW Real-Time or any startup applications. In safe mode, the cRIO-9068 launches only the services necessary for updating configuration and installing software.
Enable Console Out	Rebooting the cRIO-9068 with this setting on redirects the console output to the RS-232 serial port. You can use a serial-port terminal program to read the IP address and firmware version of the cRIO-9068. Use a null-modem cable to connect the RS-232 serial port to a computer. Make sure that the serial-port terminal program is configured to the following settings: • 115,200 bits per second • Eight data bits • No parity • One stop bit • No flow control
Disable RT Startup App	Rebooting the cRIO-9068 with this setting on prevents any LabVIEW startup applications from running.

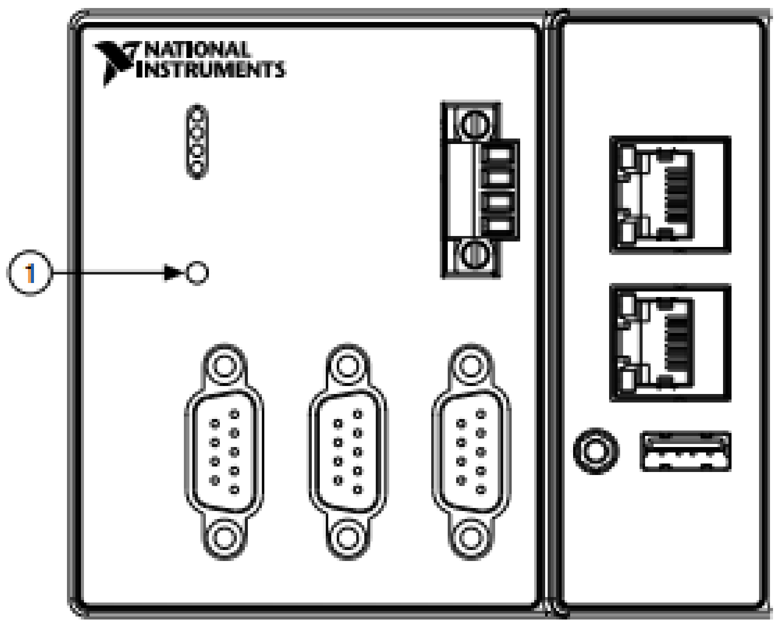
Startup Option	Description
Disable FPGA Startup App	Rebooting the cRIO-9068 with this setting on prevents autoloading of any FPGA application. **Note** When you reset the cRIO-906x controller either programmatically or by using the RESET button, you also reset the FPGA. All FPGA I/O lines are tri-stated after a reset, and will enter predefined states once loaded.
Enable Secure Shell (SSH) Logins	Rebooting the cRIO-9068 with this setting on starts sshd on the cRIO-9068. Starting sshd enables logins over SSH, an encrypted communication protocol. **Note** Visit *ni.com/info* and enter the Info Code `openssh` for more information about SSH.
LabVIEW Project Access	Rebooting the cRIO-9068 with this setting on enables you to add the target to a LabVIEW project.

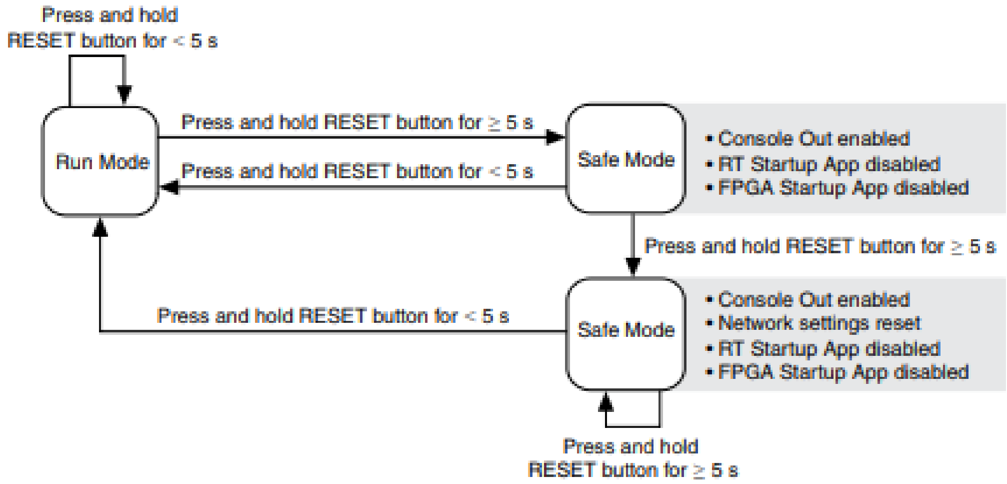
Ports and connection



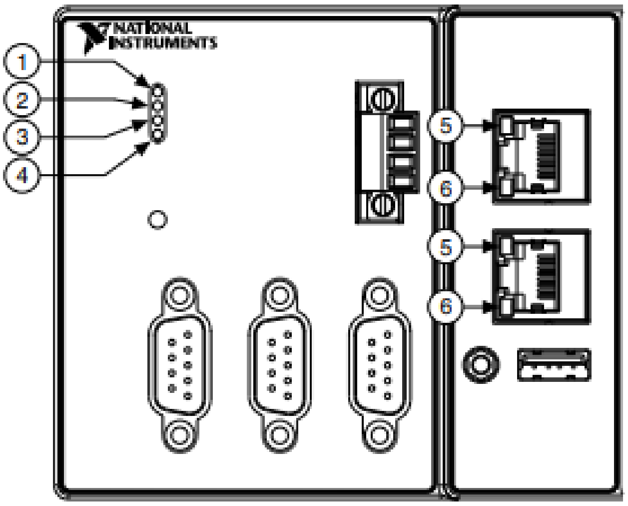
1. Power Connector
2. Ethernet Port 2
3. Ethernet Port 1
4. USB Host Port
5. RS-485 Serial Port
6. RS-232 Serial Port
7. RS-232 Serial Port

Reset





LEDs



1. Power
2. Status
3. User1
4. User FPGA1
5. ACT/LINK
6. 10/100/1000

LED Color	LED Pattern	Indication
Green	Solid	The cRIO-9068 is powered from the V1 input.
Yellow	Solid	The cRIO-9068 is powered from the V2 input.
—	Off	The cRIO-9068 is powered off.

LED Pattern	Indication
Blinks twice and pauses	The cRIO-9068 is in safe mode. Software is not installed, which is the factory default state, or software has been improperly installed on the cRIO-9068. An error can occur when an attempt to upgrade the software is interrupted. Reinstall software on the cRIO-9068. Refer to the *Measurement & Automation Explorer (MAX) Help* for information about installing software on the cRIO-9068.
Blinks three times and pauses	The cRIO-9068 is in user-directed safe mode, or the cRIO-9068 is in install mode to indicate that software is currently being installed. This pattern may also indicate that the user has forced the cRIO-9068 to boot into safe mode by pressing the reset button for longer than five seconds or by enabling safe mode in MAX. Refer to the *Measurement & Automation Explorer (MAX) Help* for information about safe mode.
Blinks four times and pauses	The cRIO-9068 is in safe mode. The software has crashed twice without rebooting or cycling power between crashes.
Continuously blinks	The cRIO-9068 has not booted into NI Linux Real-Time. The cRIO-9068 either booted into an unsupported operating system, was interrupted during the boot process, or detected an unrecoverable software error.
On momentarily	The cRIO-9068 is booting. No action required.
Off	The cRIO-9068 is in run mode. Software is installed and the operating system is running.

User Led

LED	LED Color	Description
USER1	Green	Use LabVIEW Real-Time to define the USER1 LED with the RT LEDs VI. For more information about the RT LEDs VI, refer to the *LabVIEW Help*.
	Yellow	
USER FPGA1	Green	Use the LabVIEW FPGA Module and NI-RIO Device Drivers software to define the USER FPGA1 LED. Use the USER FPGA1 LED to help debug your application or retrieve application status. Refer to the *LabVIEW Help* for information about programming this LED.
	Yellow	

Ethernet Led

LED	LED Color	LED Pattern	Indication
ACT/LINK	—	Off	LAN link not established
	Green	Solid	LAN link established
		Flashing	Activity on LAN
10/100/1000	Yellow	Solid	1,000 Mbit/s data rate selected
	Green	Solid	100 Mbit/s data rate selected
	—	Off	10 Mbit/s data rate selected

APPENDIX B - NI 9244 DATASHEET

The NI 9244 is a C series analog input module that offers three channels for measurements between the signal and the neutral channel, and the neutral channel provides measurements between the neutral terminal and the chassis ground. With this configuration, you can connect single- or three-phase measurement configurations such as WYE and delta. If you are developing power monitoring, metering, or quality analysis applications, consider the NI LabVIEW Electrical Power Suite, which is compatible with both NI CompactRIO and CompactDAQ systems.

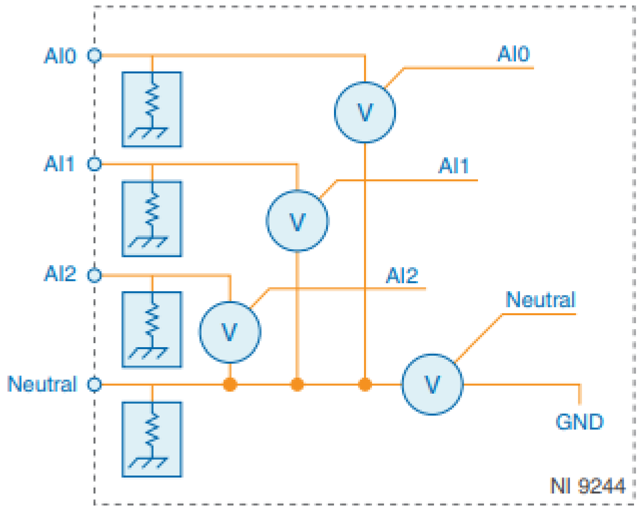
Kit Contents	• NI 9244 • NI 9244 Getting Started Guide • NI 9968 4-Position Screw-Terminal Connector • NI 9969 Strain Relief and Operator Protection

<u>C series high voltage analog input module comparison</u>

C SERIES HIGH VOLTAGE ANALOG INPUT MODULE COMPARISON

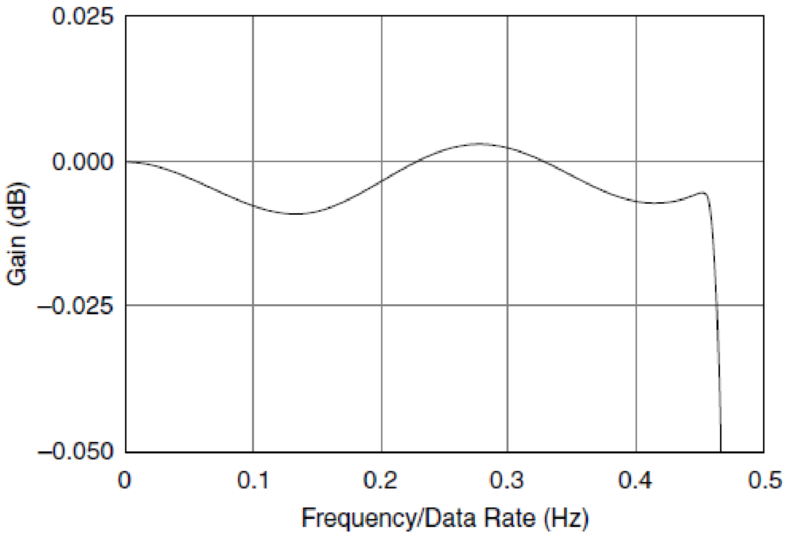
Product Name	Signal Levels	Channels	Sample Rate	Simultaneous	Input Noise	Connectivity	Isolation/Safety Voltages
NI 9221	± 60 V	8	800 kS/s	No	0.7 LSB RMS	DSUB Screw-Terminal Spring-Terminal	Ch-Earth ground 250 Vrms, CAT II (Screw/ Spring Terminal) ± 60 VDC, CAT I (DSUB)
NI 9225	300 Vrms	3	50 kS/s/ ch	Yes	2 mVrms	Screw-Terminal	Ch-Ch 600 Vrms, CAT II
NI 9229	± 60 V	4	50 kS/s/ ch	Yes	320 µVrms	Screw-Terminal BNC	Ch-Earth ground 250 Vrms, CAT II (Screw-Terminal) ±60 VDC, CAT I (BNC)
NI 9242	250 Vrms L-N 400 Vrms L-L	3 AI 1 Neutral	50 kS/s/ ch	Yes	3 mVrms	Screw-Terminal	Ch-Earth ground 250 Vrms, CAT III
NI 9244	400 Vrms L-N 690 Vrms L-L	3 AI 1 Neutral	50 kS/s/ ch	Yes	6 mVrms	Screw-Terminal	Ch-Earth ground 400 Vrms, CAT II, or 300 Vrms CATIII at 5,000 m altitude

Input Circuitry



- Each channel on the NI 9244 provides an independent signal path and ADC. Each terminal has the same input impedance to ground.
- The NI 9244 returns the voltage between each AI terminal and the Neutral terminal as well as the voltage between the Neutral terminal and the chassis ground.

Typical Passband Response for NI 9244



Input Characteristics

Scaling coefficient	118,911 nV/LSB
Number of channels	4 analog input channels
ADC resolution	24 bits
Type of ADC	Delta-Sigma (with analog prefiltering)
Sampling mode	Simultaneous
Internal master timebase (f_M)	
Frequency	12.8 MHz
Accuracy	±100 ppm maximum
Data rate range (f_s) using internal master timebase	
Minimum	1.613 kS/s
Maximum	50 kS/s
Data rate range (f_s) using external master timebase	
Minimum	390.625 S/s
Maximum	51.2 kS/s
Data rates (f_s)[1]	$\frac{f_M \div 256}{n}$, n = 1, 2, …, 31
Input voltage range (AIx-to-Ground, Neutral-to-Ground, AIx-to-Neutral)	
Typical	997.5 Vpk
Minimum	992 Vpk
Overvoltage withstand	800 Vrms continuous, 1000 Vrms for 1 s
Surge withstand	8 kV (1.2 µs/50 µs)
Input coupling	DC
Input impedance, AIx-to-Ground and Neutral-to-Ground	2 MΩ

Power requirments

Power consumption from chassis	
Active mode	332 mW maximum
Sleep mode	50 µW maximum
Thermal dissipation	
Active mode	652 mW maximum
Sleep mode	320 µW maximum

Physical characteristics

Screw-terminal wiring	
Gauge	0.2 mm ^{2} to 3.0 mm^2 (24 AWG to 12 AWG) copper conductor wire
Wire strip length	7 mm (0.28 in.) of insulation stripped from the end
Temperature rating	90 °C minimum
Torque for screw terminals	0.5 N · m to 0.6 N · m (4.4 lb · in. to 5.3 lb · in.)
Wires per screw terminal	One wire per screw terminal
Ferrules	0.25 mm^2 to 2.5 mm^2
Connector securement	
Securement type	Screw flanges provided
Torque for screw flanges	0.5 N · m (4.42 lb · in.)

Safety Voltages

Maximum working voltage, channel-to-earth ground	
Up to 2,000 m altitude	
Continuous	400 Vrms, Measurement Category III
Up to 5,000 m altitude	
Continuous	400 Vrms, Measurement Category II or 300 Vrms, Measurement Category III
Division 2 and Zone 2 hazardous locations applications	
Channel-to-earth ground	300 Vrms, Measurement Category III

Shock and Vibration

Operating vibration	
Random (IEC 60068-2-64)	5 g_{rms}, 10 Hz to 500 Hz
Sinusoidal (IEC 60068-2-6)	5 g, 10 Hz to 500 Hz
Operating shock (IEC 60068-2-27)	30 g, 11 ms half sine; 50 g, 3 ms half sine; 18 shocks at 6 orientations

Enviromental

Operating temperature (IEC 60068-2-1, IEC 60068-2-2)	-40 °C to 70 °C
Storage temperature (IEC 60068-2-1, IEC 60068-2-2)	-40 °C to 85 °C
Ingress protection	IP40
Operating humidity (IEC 60068-2-78)	10% RH to 90% RH, noncondensing
Storage humidity (IEC 60068-2-78)	5% RH to 95% RH, noncondensing
Pollution Degree	2
Maximum altitude	5,000 m

Indoor use only.

APPENDIX C - NI 9246 DATASHEET

3 isolated analog input channels, 50 kS/s per channel simultaneous sample rate

22 Arms continuous, ±30 Apeak input range, 24-bit resolution (AC signals only)

Designed for 1 A/5 A nominal CTs

Up to 300 Vrms Channel-to-Earth and 480 Vrms Channel-to-Channel CAT III isolation

Ring lug connectors for up to 10 AWG cables

-40 °C to 70 °C operating temperature, 5 g vibration, 50 g shock

The NI 9246 current input module is a three channel 22 Arms module designed to support direct ring lug connectivity to three-phase high-current measurements of 1A and 5A current transformers (CTs). The NI 9246 is optimized for power, energy, and industrial applications that require continuous AC measurements up to 22 Arms, ±30 Apeak, and withstand over 1250 Arms for one cycle.

The safety features, certifications, input ranges, overvoltage ranges, and connectivity will help engineers with applications such as:

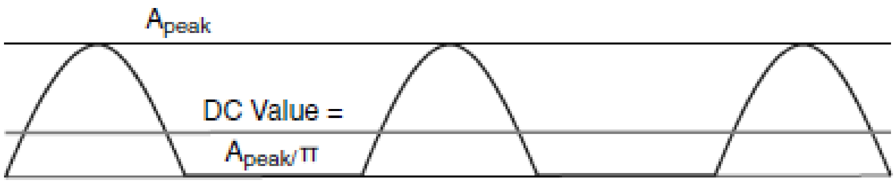
- Power quality monitoring and metering
- Utility pole-mounted smart switches
- Utility pole-mounted smart grid reclosers
- Substation merging units
- Industrial machine measurements
  - Health monitoring
  - Predictive maintenance and prognosis
- Phasor Measurement Units (PMUs)
- General purpose AC current testing

C series current input module comparison

C SERIES 9227, 9246, 9247 CURRENT INPUT MODULE COMPARISON

Product Name	Channels	Input Coupling	Input Noise	Measurement Range		1 s Withstand	Isolation	Connectivity
				Continuous	Instantaneous			
NI 9227	4	DC	0.4 mArms	5 Arms	10 Arms ±14 Apeak	10 Arms	CAT II 250 Vrms Ch-Ch	Screw Terminal
NI 9246	3	AC	0.25 mArms	20 Arms	20 Arms ±30 Apeak	500 Arms	CAT III 480 Vrms Ch-Ch	Ring Lug
NI 9247	3	AC	2.250 mArms	50 Arms	100 Arms ±147 Apeak	500 Arms	CAT III 480 Vrms Ch-Ch	Ring Lug

Half-wave Rectification of a Load, Resulting in DC offset

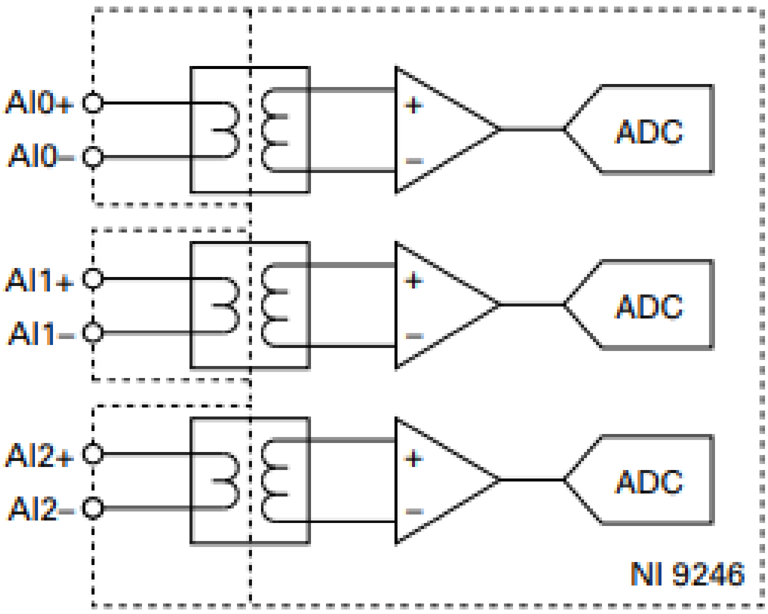


Power requirements

Power consumption from chassis
Active mode .... 0.7 W max
Sleep mode .... 25 µW max

Thermal dissipation (at 70 °C)
Active mode .... 2.0 W max
Sleep mode .... 1.5 W max

Input Circuitry



Input characteristics

Number of channels	3 analog input channels
ADC resolution	24 bits
Type of ADC	Delta-Sigma (with analog prefiltering)
Sampling mode	Simultaneous
Instantaneous measuring range	
Minimum	±30.6 A
Typical	±31.25 A
Typical scaling coefficient	3.7253 µA/LSB
Operating input rating	22 Arms
Overcurrent withstand rating	50 Arms continuously; 100 Arms for 10 seconds, not to repeat more than once in 30 minutes; 500 Arms for 1 second, not to repeat more than once in 30 minutes; 1250 Arms for 1 cycle (20 ms), not to repeat more than once in a minute
Input coupling	AC
Input impedance	0.2 mΩ
Internal master timebase (f_M)	
Frequency	12.8 MHz
Accuracy	±100 ppm max
Data rate range (f_s) using internal master timebase	
Minimum	1.613 kS/s
Maximum	50 kS/s
Data rate range (f_s) using external master timebase	
Minimum	390.625 S/s
Maximum	51.2 kS/s

Data rates (f_s)

$$\frac{f_M \div 256}{n}, n = 1, 2, \ldots, 31$$

Passband frequency	10 Hz to 0.453 · f_s
Passband flatness[1]	
10 Hz to 6 kHz	±0.1% (±0.01 dB)
6 kHz to 22.5 kHz	±1.5% (±0.13 dB)
Alias-free bandwidth	0.453 · f_s
Stopband frequency	0.547 · f_s
Stopband attenuation	95 dB
Input noise	
1 Hz to 25 kHz bandwidth (f_s= 50 kS/s)	0.25 mArms
25 Hz to 75 Hz or 30 Hz to 90 Hz bandwidth[2]	0.035 mArms

Physical characteristics

Connector wiring

Gauge .... 2.58 mm^2 (10 AWG) stranded core wire with an insulated ring terminal

Screw specifications

Screw size 6-32

Maximum screw length .... 5.08 mm (0.200 in.)

Ring/Spade terminal

Maximum width .... 9.525 mm (0.375 in.) of ring lug

Recommended torque .... 1.4 N · m (12 lb · in.)

Weight .... 248 g (8.75 oz)

Safety Voltage

Maximum working voltage, channel-to-earth ground

Continuous

Up to 2,000 m altitude .... 300 Vrms, Measurement Category III

Up to 5,000 m altitude .... 150 Vrms, Measurement Category III or 300 Vrms, Measurement Category II

Maximum working voltage, channel-to-channel

Continuous

Up to 2,000 m altitude .... 480 Vrms, Measurement Category III

Up to 5,000 m altitude .... 300 Vrms, Measurement Category III or 480 Vrms, Measurement Category II

Withstand

Channel-to-channel .... 3510 Vrms, verified by a 5 s dielectric withstand test

Channel-to-earth ground .... 3510 Vrms, verified by a 5 s dielectric withstand test

Shock and Vibration

Operating vibration

Random (IEC 60068-2-64) .... 5 g_{rms}, 10 Hz to 500 Hz

Sinusoidal (IEC 60068-2-6) .... 5 g, 10 Hz to 500 Hz

Operating shock (IEC 60068-2-27) .... 30 g, 11 ms half sine; 50 g, 3 ms half sine; 18 shocks at 6 orientations

Enviromental

Operating temperature..-40 °C to 70 °C
(IEC 60068-2-1, IEC 60068-2-2)

Storage temperature...-40 °C to 85 °C
(IEC 60068-2-1, IEC 60068-2-2)

Ingress protection...IP 40
(with power plug attached)

Operating humidity..10% RH to 90% RH, noncondensing
(IEC 60068-2-56)

Storage humidity (IEC 60068-2-56)..................5% RH to 95% RH, noncondensing

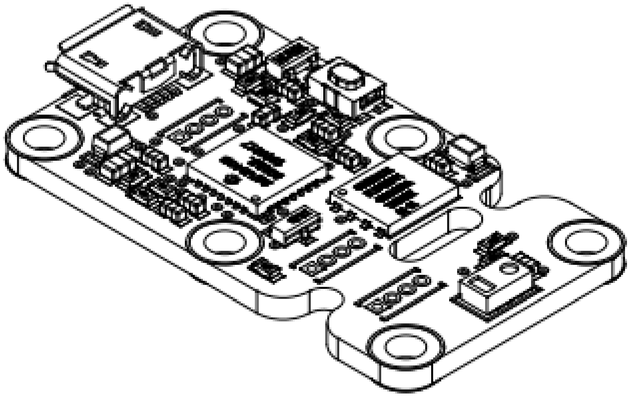
Pollution Degree..2

Maximum altitude..5,000 m

Indoor use only.

APPENDIX D – Yocto-proximity sensor

The Yocto-Proximity is a 35.5x20mm electronic module allowing you to detect the presence of object up to about ten centimeters away. As the detection is performed through the reflection of an infrared beam, the maximum measurable distance varies between 20 and 100mm, depending on the capacity of the detected object to reflect an infrared beam.



The Yocto-Proximity module

The Yocto-Proximity is not in itself a complete product. It is a component intended to be integrated into a solution used in laboratory equipments, or in industrial process-control equipments, or for similar applications in domestic and commercial environments. In order to use it, you must at least install it in a protective enclosure and connect it to a host computer.

Yoctopuce thanks you for buying this Yocto-Proximity and sincerely hopes that you will be satisfied with it. The Yoctopuce engineers have put a large amount of effort to ensure that your Yocto-Proximity is easy to install anywhere and easy to drive from a maximum of programming languages. If you are nevertheless disappointed with this module, or if you need additional information, do not hesitate to contact Yoctopuce support:

Protective enclosure

The Yocto-Proximity should not be used without a protective enclosure, because of the accessible bare electronic components. For optimal safety, it should be put into a non-metallic, non-inflammable enclosure, resistant to a mechanical stress level of 5 J. For instance, use a polycarbonate (e.g. LEXAN) enclosure rated IK08 with a IEC 60695-11-10 flammability rating of V-1 or better. Using a lower quality enclosure may require specific warnings for the operator and/or compromise conformity with the safety standard.

Maintenance

If a damage is observed on the electronic board or on the enclosure, it should be replaced in order to ensure continued safety of the equipment, and to prevent damaging other parts of the system due to overload that a short circuit could cause.

Identification

In order to ease the maintenance and the identification of risks during maintenance, you should affixate the water-resistant identification label provided together with the electronic board as close as possible to the device. If the device is put in a dedicated enclosure, the identification label should be affixated on the outside of the enclosure.

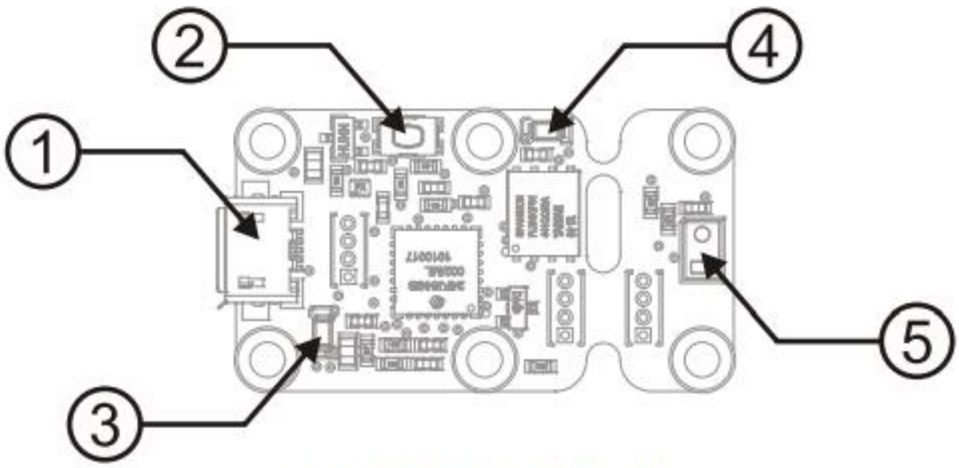
Application

The safety standard applied is intended to cover laboratory equipment, industrial process-control equipment and similar applications in residential or commercial environment. If you intend to use the Yocto-Proximity for another kind of application, you should check the safety regulations according to the standard applicable to your application.

In particular, the Yocto-Proximity is *not* certified for use in medical environments or for life-support applications.

Environment

The Yocto-Proximity is *not* certified for use in hazardous locations, explosive environments, or life-threatening applications. Environmental ratings are provided below.



1: Micro-B USB socket 4: Detection led
2: Yocto-button 5: Sensor
3: Yocto-led

Yocto-button

The Yocto-button has two functionalities. First, it can activate the Yocto-beacon mode (see below under Yocto-led). Second, if you plug in a Yocto-module while keeping this button pressed, you can then reprogram its firmware with a new version. Note that there is a simpler UI-based method to update the firmware, but this one works even in case of severely damaged firmware.

Yocto-led

Normally, the Yocto-led is used to indicate that the module is working smoothly. The Yocto-led then emits a low blue light which varies slowly, mimicking breathing. The Yocto-led stops breathing when the module is not communicating any more, as for instance when powered by a USB hub which is disconnected from any active computer.

When you press the Yocto-button, the Yocto-led switches to Yocto-beacon mode. It starts flashing faster with a stronger light, in order to facilitate the localization of a module when you have several identical ones. It is indeed possible to trigger off the Yocto-beacon by software, as it is possible to detect by software that a Yocto-beacon is on.

The Yocto-led has a third functionality, which is less pleasant: when the internal software which controls the module encounters a fatal error, the Yocto-led starts emitting an SOS in morse [1]. If this happens, unplug and re-plug the module. If it happens again, check that the module contains the latest version of the firmware, and, if it is the case, contact Yoctopuce support[2].

Current sensor

Each Yocto-module is able to measure its own current consumption on the USB bus. Current supply on a USB bus being quite critical, this functionality can be of great help. You can only view the current consumption of a module by software.

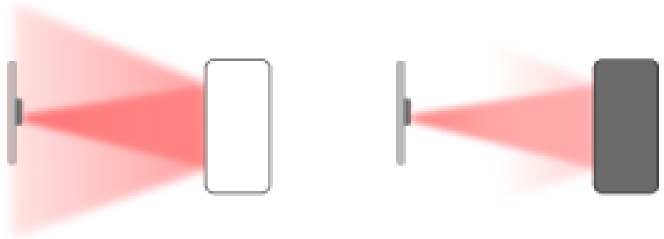
Serial number

Each Yocto-module has a unique serial number assigned to it at the factory. For Yocto-Proximity modules, this number starts with YPROXIM1. The module can be software driven using this serial number. The serial number cannot be modified.

Limitations

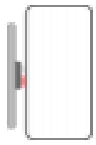
This very simple working principle implies some limitations that you must understand well to be able to make the most of the Yocto-Proximity.

Maximum detection distance
The Yocto-Proximity works by emitting an infrared light and by measuring the quantity of this infrared light that is sent back to it by a potential object. The quantity of light received by the sensor therefore depends on the distance between the sensor and the object, but also on the reflective powers of the said object. In other words, a white object is detected from much farther away than a black object. The Yocto-Proximity can "see" a white object from about 10cm away, while a dull black object is seen only from about 2cm. Therefore, we discourage you to use the Yocto-Proximity as a distance sensor.



The values sent back by the Yocto-Proximity also depends on the color of the detected object

Minimum detection distance
On the RPR-0521RS sensor used by the Yocto-Proximity, the infrared led and the detector are spaced at about 2.5mm. If an object is too close to the Yocto-Proximity, typically less than 4mm, there is less infrared light that manages to reach the detector, and this biases the measures. Because of this, an object pressed against the sensor is simply not seen because the reflected infrared light cannot reach the sensor.



Objects too close to the sensor can be problematic

Micro-USB hub

If you intend to put several Yoctopuce modules in a very small space, you can connect them directly to a micro-USB hub. Yoctopuce builds a USB hub particularly small for this purpose (down to 20mmx36mm), on which you can directly solder a USB cable instead of using a USB plug. For more details, see the micro-USB hub information sheet.

YoctoHub-Ethernet, YoctoHub-Wireless and YoctoHub-GSM

You can add network connectivity to your Yocto-Proximity, thanks to the YoctoHub-Ethernet, the YoctoHub-Wireless and the YoctoHub-GSM which provides repectiveley Ethernet, WiFi and GSM connectivity. All of them can drive up to three devices and behave exactly like a regular computer running a *VirtualHub*.

1.27mm (or 1.25mm) connectors

In case you wish to connect your Yocto-Proximity to a Micro-hub USB or a YoctoHub without using a bulky USB connector, you can use the four 1.27mm pads just behind the USB connector. There are two options.

You can mount the Yocto-Proximity directly on the hub using screw and spacers, and connect it using 1.27mm board-to-board connectors. To prevent shortcuts, it is best to solder the female connector on the hub and the male connector on the Yocto-Proximity.

You can also use a small 4-wires cable with a 1.27mm connector. 1.25mm works as well, it does not make a difference for 4 pins. This makes it possible to move the device a few inches away. Don't put it too far away if you use that type of cable, because as the cable is not shielded, it may cause undesirable electromagnetic emissions.