VŠB – Technical university of Ostrava

Faculty of Electrical Engineering and Computer Science

Department of Cybernetics and Biomedical Engineering

Návrh a implementace přístupu prediktivní údržby v laboratorním mechatronickém systému
Design and Implementation of Predictive Maintenance in Mechatronic System

2019 **Prabhu Doss Arul Doss**

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Faculty of Electrical Engineering and Computer Science
Department of Cybernetics and Biomedical Engineering

Diploma Thesis Assignment

Student:	**Prabhu Doss Arul Doss**
Study Programme:	N2649 Electrical Engineering
Study Branch:	2612T041 Control and Information Systems
Title:	Design and Implementation of Predictive Maintenence in Mechatonic System Návrh a implementace přístupu prediktivní údržby v laboratorním mechatronickém systému
The thesis language:	English

Description:

1. Describe constructional and functional properties of the laboratory mechatronic system.
2. Analyse available IoT platforms suitable for industrial applications.
3. Review of data analytic tools available in IBM Bluemix and MindSphere platforms.
4. Design of control application of mechatronic system connected to selected IoT Platform.
5. Implementation of selected data analytic tools in selected IoT Platform.
6. Verification and testing of created applications.
7. Conclusions.

References:

[1] GREENGARD, Samuel. *The internet of things.* Cambridge: MIT Press, 2015. ISBN 978-0-262-52773-6.
[2] GILCHRIST, Alasdair. *Industry 4.0: The industrial internet of things.* New York, NY: Springer Science Business Media, 2016. ISBN 978-1-4842-2046-7.
[3] ADRYAN, Boris. OBERMAIER, Dominik. FREMANTLE, Paul. *The technical foundations of IoT.* Boston: Artech House, 2017. ISBN 978-1-63081-251-5.

Extent and terms of a thesis are specified in directions for its elaboration that are opened to the public on the web sites of the faculty.

Supervisor: **doc. Ing. Jiří Koziorek, Ph.D.**

Date of issue: 01.09.2018
Date of submission: 30.04.2019

VYSOKÁ ŠKOLA BÁŇSKÁ-TECHNICKÁ UNIVERZITA OSTRAVA Fakulta elektrotechniky a informatiky 1D16

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I hereby declare that this master's thesis was written by myself. I have quoted all the references I have drawn upon.

Ostrava, April 30, 2019 ……………………………….

I would like to thank doc. Ing. Jiří Koziorek, Ph.D for help, factual comments on the work and his helpful approach during the elaboration of my thesis.

Abstract

This project monitors the performance of a mechatronic device in a cloud platform called IBM Cloud. If the monitoring value reaches a certain condition, then it will automatically alert the user to call for maintenance duty by doing predictive learning analysis. The goal of this project is to create a cloud application for the data from the mechatronic system to perform the predictive maintenance operation in real time using machine learning tools such as SPSS modeler, streams flow, Watson studio and Watson IoT platform. This is achieved by sending the mechatronic system data through IoT2040, which is an interface that transforms data from S7-1500 PLC to IBM cloud by using Node-Red programming. The SPSS model is created by training the sample data using a neural network framework and connected with mechatronic system data in Streams flow. Then the streams flow analyses the data in Real-time and shows the alert in the Dashboard. This alert signal is sent back to PLC to generate a maintenance alert in the system before it affects the mechatronic system.

Keywords

IBM Cloud, Machine learning, Predictive maintenance, Node-Red, SPSS Modeler flow and Streams Flow.

Abstraktní

Tento projekt sleduje výkon mechatronického zařízení v cloudové platformě IBM Cloud. Pokud monitorovaná hodnota dosáhne určité podmínky, pak bude automaticky upozorňovat uživatele, aby požadoval o údržbu, a to pomocí prediktivní analýzy učení. Cílem našeho projektu je vytvořit cloudovou aplikaci pro data z mechatronického systému pro provádění prediktivní údržby v reálném čase pomocí nástrojů strojového učení, jako je modeláře SPSS, Streams flow, studio Watson a platforma Watson IoT. Toho je dosaženo zasláním mechatronických systémových dat skrze IoT2040, což je rozhraní, které transformuje data z S7-1500 PLC do cloudu IBM pomocí programování Node-Red. Model SPSS je vytvořen trénováním dat vzorku pomocí neuronové sítě a propojen s mechatronickými systémovými daty v Streams flow. Pak Streams flow analyzuje data v reálném čase a zobrazuje výstrahu v řídicím panelu. Tento výstražný signál je odeslán zpět do PLC, aby generoval výstrahu údržby v systému předtím, než ovlivní mechatronický systém.

Klíčová slova

IBM Cloud, Strojové učení, Prediktivní údržba, Node-Red, SPSS Modeler flow a Streams flow

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List of symbols and abbreviations used

IOT-Internet of Things

PLC-Programming Logic Controller

AWS-Amazon web services

IBM-International Business Machines

AI-Artificial Intelligence

SPSS-Statistical Package for the Social Sciences

TIA-Total Integrated Automation portal

HSC-High-Speed counter

S7-Step 7

IO-Input/Output

API-Application Programming Interface

CDN-Content Delivery Networks

VPN-Virtual Private Networks

IaC-Infrastructure as Code

SQL-Structured Query Language

CLI-Command Line Interface

Modbus RTU-Modbus Remote Terminal Unit

OPC UA-OPC Unified Architecture

OS-Operating System

mPCIe-Peripheral Component Interconnect Express

LED-Light emitting Diode

MQTT-Message Queuing Telemetry Transport

DC Motor-Direct Current Motor

IaaS-Infrastructure as a Service

PaaS-Platform as a Service

SaaS-Software as a Service

AWS-Amazon Web Services

CRM-Customer Relationship Management

EC2-Elastic Compute Cloud

EC2-VPC-Elastic Compute Cloud- Virtual Private Cloud

GUI-Graphical User Interface

PHP-Personal Home Page

VB.Net-Visual Basic .Net

C&R Tree-Classification and Regression Tree

MLLib-Machine Learning Library

SD-card-Secure Digital card

GB-Giga Byte

RAM-Random Access Memory

IP address-Internet Protocol address

Device ID-Device Identity document

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1. Introduction

Predictive maintenance in mechatronic systems is done by processing and analysing the data from any data point or data source in real time and maintaining the system immediately before the problem occurs by generating an alert signal. In this thesis we have done the Predictive analysis by using IBM SPSS module, the world's leading statistical software, which is helpful in figuring out business problems and research problems by using ad-hoc analysis, hypothesis testing, and predictive analytics. IBM SPSS module is available in Desktop version and IBM Cloud version. We used IBM cloud version in which we sent the data from mechatronic system and high-speed counter and then analyzed it in real time by using Streams flow. Predictive maintenance is done in Mechatronic system by sending the data from the production line. We also send high-speed counter data which acts as a sensor to perform predictive maintenance with integer values. If the high-speed counter exits the limit the alert is triggered by the predictive maintenance application. The counters play a role in the mechatronic system by analysing high-speed counter data in IBM cloud and giving us the probability of analysing different integer data from different data points like pressure sensors, temperature sensors, humidity sensors, vibration sensors or any other sensors by using the knowledge obtained from this project. [1][21]

1.1. Applying Predictive maintenance in Mechatronic systems

We applied predictive maintenance in mechatronic systems by creating an application in IBM Watson IoT platform to collect the data from High speed counter and mechatronic system, then we analyzed that data by using the IBM Watson Studio tools. Mechatronic systems consist of a combination of Mechanical, Electrical, Telecommunication, control and computer science technologies. In this thesis we used the High-speed counter and laboratory production line as the Mechatronic systems data in which the predictive maintenance is performed. Every data point in the Mechatronic system needs to be maintained or controlled before a problem arises. This prevents the loss of productivity in Mechatronic systems. In order to improve the productivity, the data from the device is turned into a predictive maintenance signal (alert) to control or trigger the maintenance process. These predictive maintenance signals are created by doing predictive analysis on IBM studio by using Machine learning, Streaming analytics, and SPSS modeler tools. We have created this predictive maintenance signal and showed it in IBM Watson Studio application. This helps us to predict the problem in the Mechatronic system immediately and helps us to create a maintenance process in real time. This avoids the time delay due to maintenance and even protects the mechatronic system from getting damaged. [1][19]

1.2. Implementation of Predictive maintenance in Mechatronic systems

Predictive maintenance is implemented by using an IBM cloud platform which is made possible by the Industry 4.0 revolution. The mechatronic system is a production line connected with sensors. The input to these mechatronic systems is controlled automatically based on the output of the sensors. The performance of the systems and quality of the end product are measured by maintenance sensors such as vibration monitoring sensors, temperature sensors, pressure sensors, etc. These maintenance and quality sensors send the data to a cloud database to monitor the data in real time from anywhere. In an IBM Watson studio, the data is analyzed by web applications. Predictive analysis of mechatronic systems is done by setting alerts based on data values. If the analyzed data exceeds the limit value then the system is maintained, which prevents complete system failure, maintains quality of the outcome, monitors the production line and maintains the efficiency of the mechatronic system. With the result of the maintenance the user will achieve greater productivity and quality of the product from the production line. In this thesis, we are going to connect the high-speed counter data points and data points from the laboratory production line with the IBM Watson IoT platform where the data is collected from mechatronic systems and predictive analysis is done by analyzing the data using streams flow and SPSS model in the IBM Watson studio application. As we proceed, we will answer the following questions: How do we connect mechatronic devices? What are the different IOT platforms for industry application? What are the problems in cloud computing platforms? And lastly, how can we automatically predict maintenance with predictive analysis in IBM streams flow? [1][20]

1.3. IBM Cloud

IBM Cloud is an all-in-one cloud platform that has both public, private, and hybrid environments. One can build their own platform with a collection of advanced data and AI tools. One may also receive help from experts while they explore the vast capabilities that IBM Cloud offers us. IBM Cloud improves a company's production rate by reducing the cost and time that comes from system failure. Upgrading this mechatronic system with IBM Cloud creates a huge increase in the productivity and helps companies grow.

1.3.1 Implementation of IBM Cloud

IBM Cloud allows the user to control and visualize big data information which is collected from different IO modules, PLC, sensors, and physical equipment status. In order to start up this project, we needed a web browser and an IBM Cloud account. The data is sent to the IBM Watson IoT platform in arranged or non-arranged form. IBM Cloud has a streams flow analytics tool that analyzes data and uses it to predict when the system will need to be maintained.

This data is collected by an interface called Node Red, a programming tool for linking hardware devices, APIs, and online services such as IBM Cloud Services. In order to connect devices (for example, the siemens S7-1500) with Node Red we need to use Simatic IoT2040. IBM Watson studio analyzes the data from the system with a time stamp.

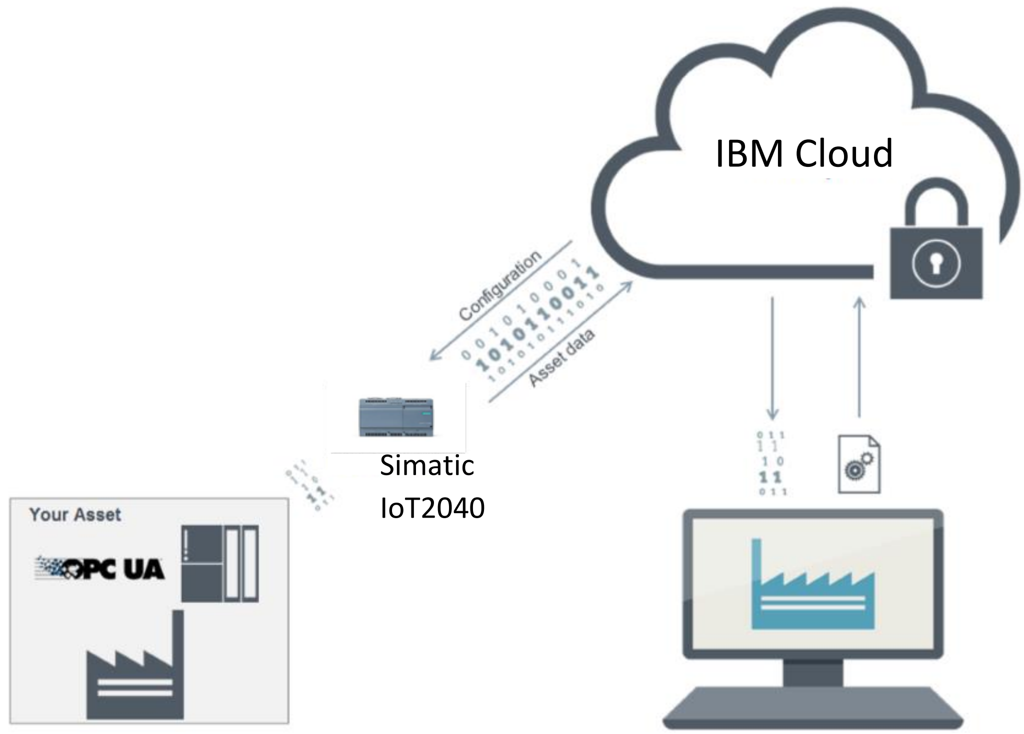

FIGURE 1: IMPLEMENTATION OF IBM CLOUD IN MECHATRONIC SYSTEM [22]

1.3.2 Usage of IBM Cloud

IBM Cloud platform enables access to other IBM (and non-IBM) tools and services like IBM Watson and IBM Cloud Functions for computing without a server. The IBM Cloud Catalog has over 170 services across categories, including:

- **Computing resources** including bare-metal servers, virtual servers, serverless computing and containers, on which enterprises can host their workloads.
- **Networking services** such as load balancers, content delivery networks (CDN), virtual private networks (VPN), tunnels, and firewalls.
- **Storage** offers like object, block, and file storage for data.
- **Management tools** to watch cloud deployments, such as those for log analysis, automation and Infrastructure as Code (IaC).
- **Security options** Including services for activity tracking, identity and access management and authentication.
- **Data management** Providing SQL and NoSQL databases, and data querying and migration tools.

- **Analytics** offering data science tools such as Apache Spark, Apache Hadoop, and IBM Watson Machine Learning, and analytics services for streaming data.
- **Artificial Intelligence (AI)** Using IBM Watson to deliver services such as machine learning, natural language processing, and visual recognition.
- **Internet of Things (IoT)** Including the IBM IoT Platform, which provides services that connect and manage IoT devices, and analyzes the data they produce.
- **Mobile Accessibility** enables a development team to build and monitor mobile applications and their back-end components.
- **Developer Tools** Including a command-line interface (CLI), as well as a set of tools for continuous delivery, continuous release and application pipelines.
- **Blockchain**, a software-as-a-service offering to develop apps, enforce governance and monitor a Blockchain network.
- **Integration** offering services to integrate cloud and on-premises systems, or various applications, such as API Connect, App Connect and IBM Secure Gateway.
- **Migration** providing tools to migrate apps to the cloud like IBM Lift CLI and Cloud Mass Data Migration.
- **VMware** enabling migration of VMware workloads to the cloud**.**[2]

1.4. Assets

Assets is a device from which the data is transfered to IBM cloud via IoT interface. In this project we used the IoT2040 as IoT interface. Industry 4.0 revolution makes the path open for each industrial device to become smart and intelligent by using different tools from Cloud platforms. An asset which we used in this project is Siemens S7-1500 PLC, which is connected with a High Speed counter and mechatronic systems by using Tia Portal PLC programming and then the PLC is connected with IoT2040 by using Putty. IBM Watson IoT platform is connected with IoT2040 by using Node-Red. Node-Red is installed in the IoT2040 by using Putty. Node-Red is started by typing its IP address on a web browser. In this way the connection between the IBM Watson IoT platform and the asset is achieved.

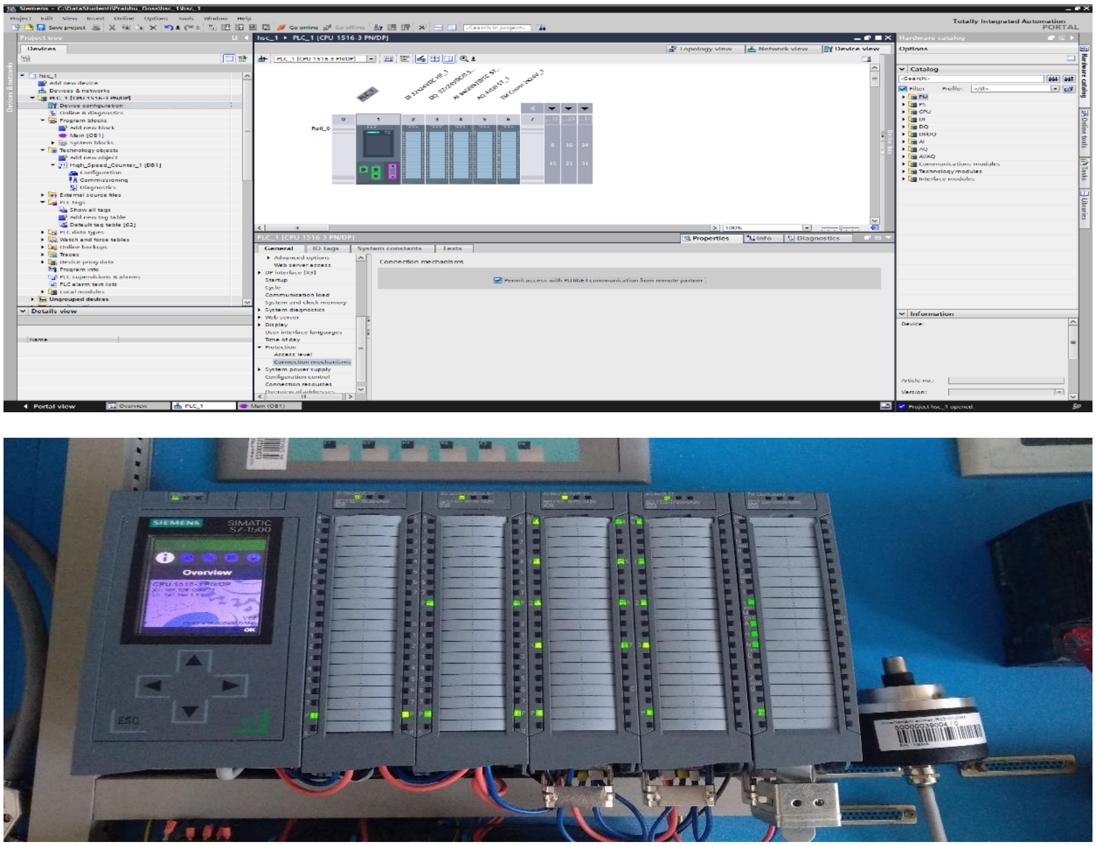

FIGURE 2: S7-1500 PLC WITH HIGH-SPEED COUNTER

1.5. IoT2040

IoT2040 is a reliable, open platform device used for processing, transmitting and training data from mechatronic system. It is used as a gateway between IBM cloud and S7-1500 PLC. IoT2040 supports different communication protocols such as Modbus RTU, OPC UA. Open source application examples and libraries are helpful to connect IoT2040 with IBM Cloud. Yocto Linux is used as OS. [3]

FIGURE 3: SIMATIC IOT2040

1.5.1. Benefits of ToT2040

a) Highly flexible connection options

- Various on-board interfaces for simple connection
- Simple and very flexible options with Arduino Shields and mPCIe cards

b) High degree of quality for continuous operation in industrial environments

- Designed for continuous operation at surrounding temperatures up to 50 °C and tough environmental conditions
- It comes with the diagnostics LEDs

c) Constant response and performance for industrial applications

- Battery-backed real-time clock for setting data to relevant time stamp
- Intel Quark X1020 processor including x86 standard response and security feature such as Secure Boot [3]

1.6. IBM Watson IoT Platform

IBM Watson IoT Platform is a managed, cloud-hosted service that makes it simple to get a value from IoT devices. Watson IoT Platform and its additional add-on services are its Blockchain service and its analytic service which enable businesses to retain and explore data for devices, equipment, and machines, and discover insights that can drive better decision-making. Connectivity between IBM Watson IoT platform and IoT2040 by using Node-Red allows the data to be put in cloud storage. [4]

1.6.1. Connecting IBM Watson IoT Platform and IoT2040

- We created a **new connection** between the IBM Watson IoT platform device and IoT2040 by following these steps:
- Connection is done by creating an **IBM Watson IoT application**, and then a new device is created in device section.
- After the device is created the **API key and Authentication token** are noted separately, since it is shown only once during the creation of the device.
- After that the IBM Watson IoT device is connected to PLC through **Node-Red interface**.
- Node-Red consists of **IBM Watson IoT Platform nodes** which is used to connect the IBM Watson IoT device with PLC through IoT2040.

1.7. IBM Watson Studio

IBM Watson studio is an environment which provides **tools to analyze data** by using streams flow, machine learning and SPSS modeler. IBM Watson studio is connected with the IBM Watson IoT platform to collect data from the asset and **send it to streams flow. Streams flow, SPSS modeler and Machine learning** tools are added to the project which is corrected in IBM Watson studio. IBM Watson Studio helps us to analyze data without even a **single line of code.** [5]

1.7.1. Streams Flow

Building a real-time application is not an easy process. Streams flow makes the process simple and accessible. With a simple user interface, we can easily drag and drop operators to shape, transform, and analyze our data as it flows from inputs to outputs. This allows us to build real-time applications without having to dive deep into complex libraries, programming and tools. We really loved this method because it allowed us to complete this project in days and quickly build and test new data flows and using Streams flow is so easy.

a) Implementation of Streams Flow

- Streams flow helps us to analyse the data from the Watson IOT platform. Streams flow consists of an SPSS model, python model, and cloud function.
- In this project, we used an SPSS model to analyze the real-time data from the asset.
- We used a filter to filter the time-stamp signal from the asset.
- Streams flow helps us to analyze the high-speed counter and mechatronic system data by using SPSS model.
- The SPSS model is created by using an SPSS modeler flow tool in IBM Watson Studio.
- Output of the SPSS model is sent as a Reset value, alert signal or Predictive Maintenance signal to the Target system.

1.7.2. SPSS modeler Flow

SPSS Modeler is a leading visual data science and machine-learning solution. It helps us to achieve desired outputs by changing time to value and it speeds the data scientists' tasks. It is a leading method on IBM for data preparation and machine learning to monitor and analyze the data assets. It is available in the IBM Watson studio application which is used for creating predictive analysis in our project. SPSS modeler also helps us by:

- Giving us the advantage of open source-based innovation,
- Providing data scientists of all skills - programmatic and visual,
- It uses hybrid approach on premises and in the public or private cloud and
- It begins with an easy, simple and small-scale structure for an enterprises-wide governing approach.

a) Implementation of SPSS Modeler flow

- SPSS modeler flow is first trained with a sample data and connected with the real time data through streams flow.
- SPSS modeler is free in IBM Watson studio and easier to use than any other model.
- It is a code-free environment.
- It helps to train data and implement real time analysis.
- SPSS modeler consists of a lot of analytic tools (Note: In this project we used neural net to analyze and predict data).
- Neural Networks offers non-linear data modeling procedures that enable us to discover more complex relationships in our data from device assets.

b) Training Sample data

- Sample Data is created in an Excel file and trained in an SPSS modeler.
- The training is done on an SPSS modeler by connecting sample data with the partition node in SPSS modeler flow.

- The Training partition is set to 50 and the Validation partition is set to 50.
- Partition node splits the sample data into separate samples for the training, testing, and validation stages of model building.
- Next, we added a most important node called neural net, which can approximate a wide range of predictive models with minimal demands on model structure and assumption.
- The target setting on Neural net is set to ync and the Input setting is set to High speed counter data. For mechatronic data target is set to Result and Input is set to sensors output data.
- At last we ran the SPSS modeler flow and obtained a trained SPSS model which is deployed and connected in streams flow.

c) Predicting real time data

- Finally, the deployed SPSS model is connected with the IBM Watson IoT data in IBM steams flow.
- Model inputs are given as per the output scheme from IBM Watson IoT platform node output.
- The output of the SPSS model is connected with debug.
- The predicted value for maintenance control (Nync) is shown in the streams flow matrix page.
- This maintenance control (Nync) value can be used for maintenance alerts by using EMAIL node or can be used as a reset signal for PLC by using MQTT node.[6]

2. Laboratory mechatronic system

The Laboratory system is a module built for students to study and improve their skills in the industrial automation and production line field. This demonstration model is cheaper to build than a real industrial production line, but it can also work as a production line and for predictive maintenance. You can do this by connecting this demonstration model with PLC and by sending data to the cloud database, then by analyzing it. After analyzing the data, the user can predict when to automatically maintain the device before the fault occurs which is the goal of this thesis.

2.1. Types of System blocks in our laboratory model

Laboratory mechatronic system is an example for production line which consists of distribution system, testing system, process system, handling system, sorting system and storage system. The actions done by each system is controlled by sensors and PLC. Each system is explained separately as follows.

2.1.1. Distribution system

Distribution of the product or materials into a production line is an important operation to be performed in order to obtain final product. The distribution system as to make sure that the products are reached correct position at correct time. The motion of conveyor belt is controlled by DC motor in which products are transfer, here we use puckers on the belt which is considered as a product. It also consists of electromagnetic valves, an induction belt speed sensor, a pneumatic pucker with an end position sensor, an optical sensor that detects the puck on the belt, and a stack for nine pucks.

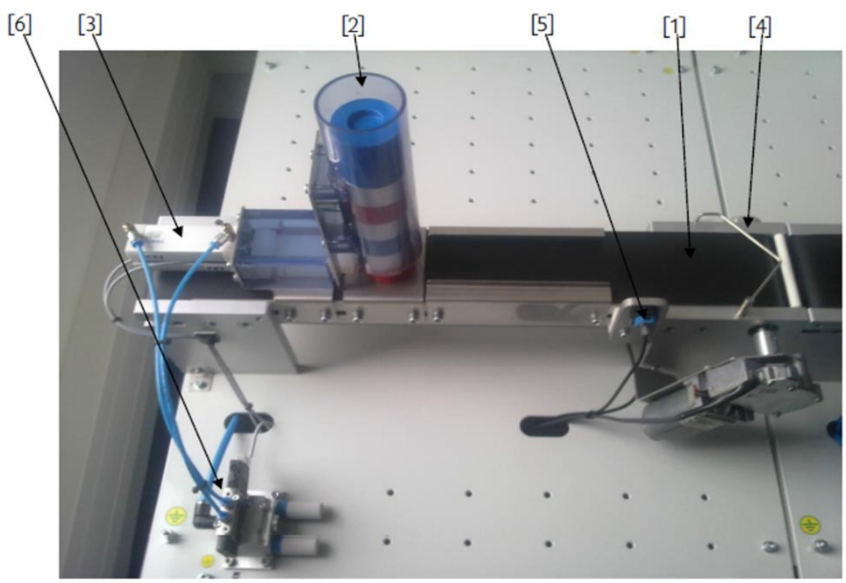

FIGURE 4: DISTRIBUTION SYSTEM

1. Conveyor belt driven by gearbox motor,
2. Vertical stack for nine pucks,
3. Pull-out pneumatic cylinder with end position sensors,
4. Inductive belt rotation sensor,
5. Optical presence sensor on the belt, and
6. Solenoid valve block.

2.1.2. Testing system

The testing system is the next stage system after distribution system, the product from distribution system is checked and sorted. It consists of two conveyor belts according to the properties of the product (puck) the sorting operation is performed. The properties of the products used for sorting are height, colour, and material of puck. After sorting the pucks are made travel in two different conveyor belts depending upon the properties

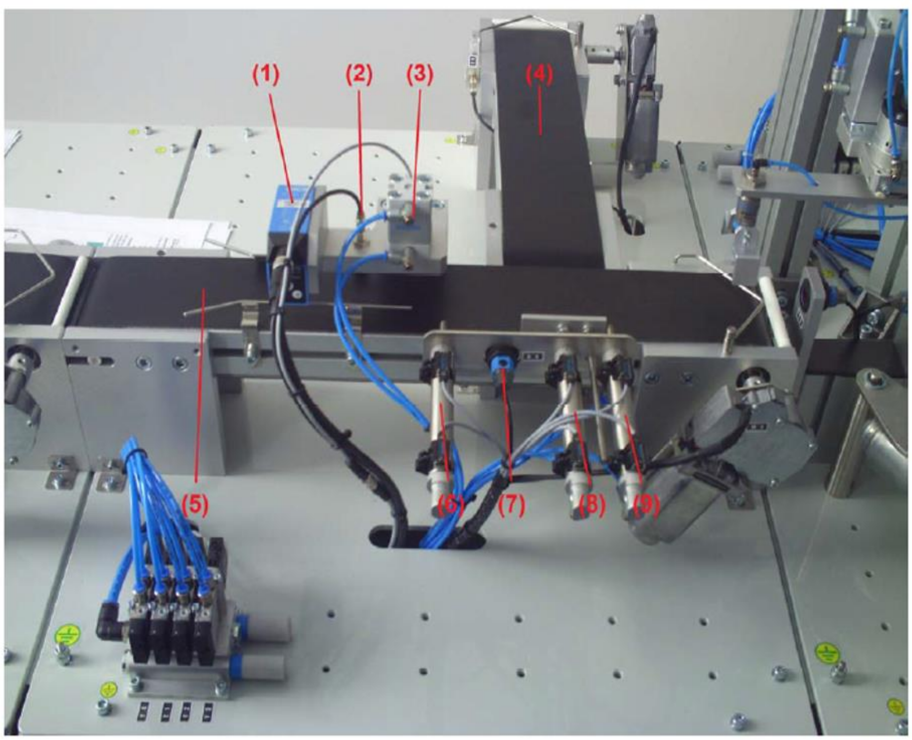

FIGURE 5: TESTING SYSTEM

1. Colour sensor,
2. Magnetic properties sensor,

3. Height sensor,

4. Conveyor belt No.2,

5. Conveyor belt No. 1,

6. Barrier 1 - Retaining for measurement section,

7. Puck presence sensor,

8. Ejector, and

9. Barrier 2 - Retaining for stamping on the conveyor belt No.2.

2.1.3. Process system

The puke from testing system is picked up by using swing dive which moves the product from conveyor belt to process area by using tentacles. The process system consists of carousel which is driven by the motor using a sliding gear, two optical sensors, and a gripping device. The product is taken to the input position by using swing handle with tentacles. The product is processed into certain operations at this area. The product(puck) is drilled, stamped, and cleaned at the process system in order to move to next part of production line. This work is done by using model of a drill, rashes, and spray nozzles.

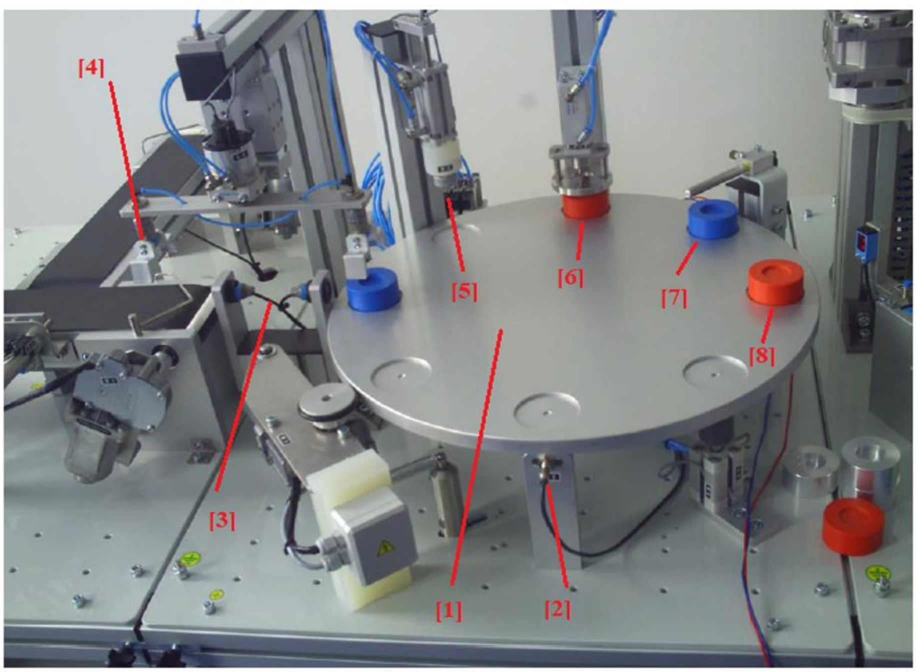

FIGURE 6: PROCESS SYSTEM

1. Motor-driven carousel,

2. Inductive sensor for positioning the carousel,

3. Optical sensors that detect the presence of the object at the loading position,

4. Swing drive that moves the pucks from the loading area to the carousel using tentacles,

5. Pneumatic cylinder with electric motor simulating drilling operation,

6. Pneumatic cylinder with spring mechanism simulating the stamping operation,

7. Perforated pipe reducer valve simulating the finishing process for air cleaning, and

8. Output positions for the next workplace,

2.1.4. Handling system

Handling system is driven by a servo motor which moves the system to its pre-defined positions. The piston tentacles pick the puck from the process system and send it to one of the three slipways which is present between the start and end positions. Handling system sorts the puck according to its colour and material properties.

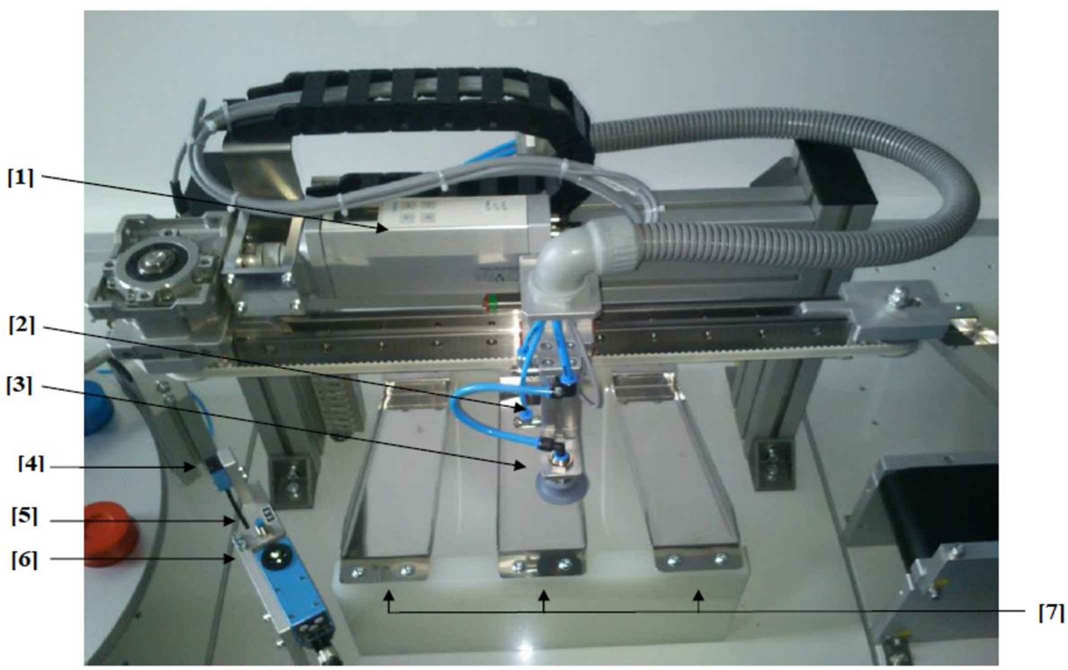

FIGURE 7: HANDLING SYSTEM

1. Actuator for movement of the piston,

2. The suction piston includes two end position sensors,

3. Puff transport bag.,

4. Optical presence sensor at the entrance of the workplace,

5. Inductive sensor of magnetoelectric properties,

6. Colour sensor, and

7. Material separation slides.

2.1.5. Sorting system

The sorting system consists of DC motor to drive conveyor belt in one direction only. In order to sort the Pucks according to colour magnetic sensors are placed at the entrances of the sorting system. The sorting process is done by the help of Position sensors, Pneumatic gates, and Thrusters.

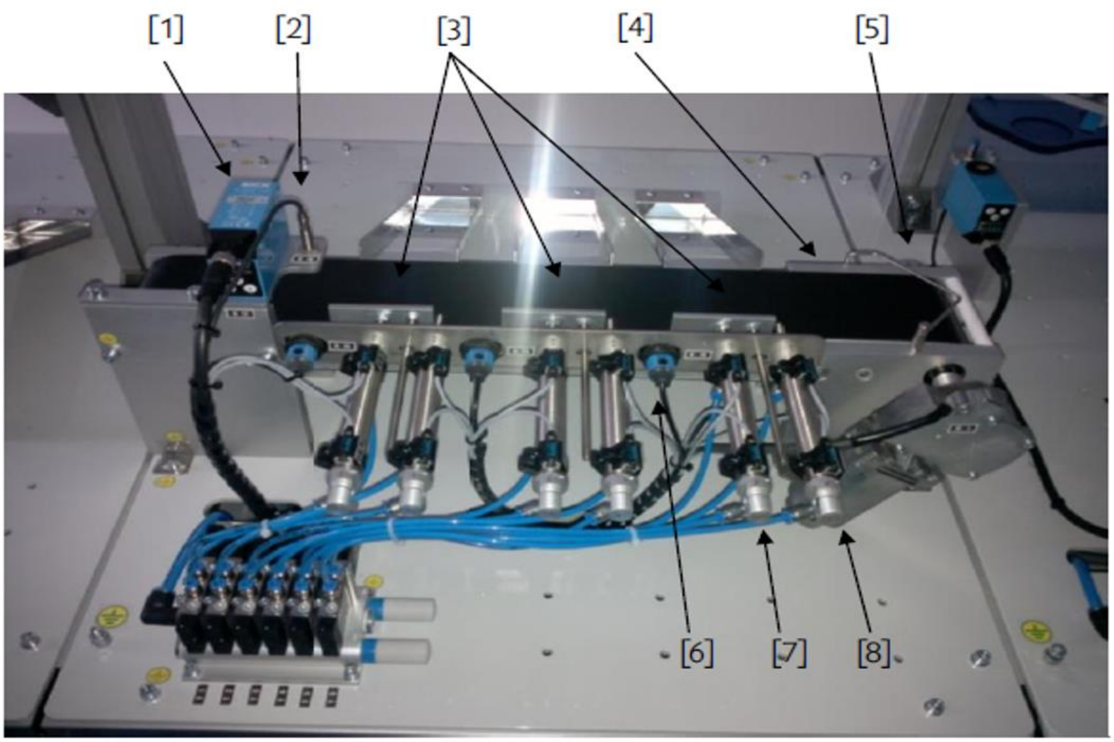

FIGURE 8: SORTING SYSTEM

1. Colour sensor,
2. Magnetic properties sensor,
3. 3 firing blocks,
4. Belt conveyor driven,
5. Inductive belt rotation sensor,
6. Optical presence sensor of the object in front of the rider,

7. Compressor consisting of a pneumatic cylinder with sensors at the end positions, and
8. Derailleur barrier consisting of a pneumatic cylinder with sensors at the end positions.

2.1.6. Storage system

Storage operation is done with the of magnetic and optical sensors which detects the presence of the puck and material properties of the puck. The transfer of the puck is performed by mechanical and pneumatic elements present in the system. The puck goes through three sections before it reaches the warehouse, and they are manipulation, testing, and storage space itself. The puck is first grasped from the belt and then its colour is detected using colour sensor, and at last it is moved to warehouse. The storage area consists of 4 floors and each floor consists of 5 storage spaces for pucks to be stored.

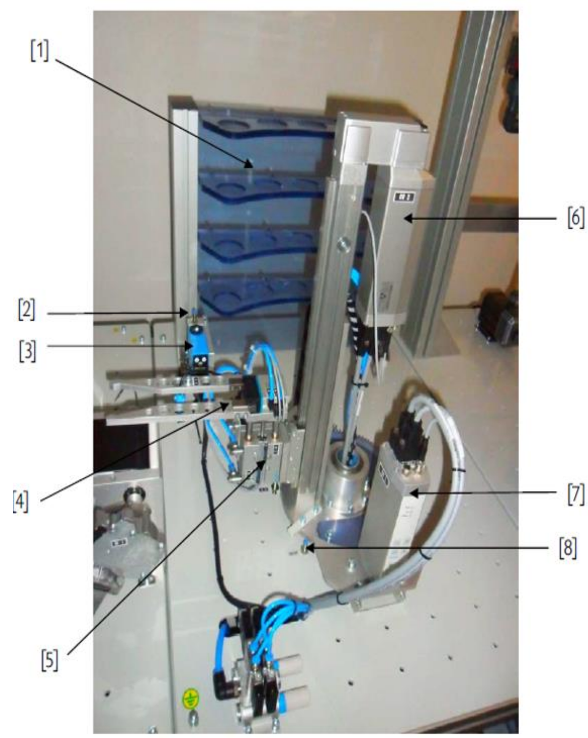

FIGURE 9: STORAGE SYSTEM

1. Warehouse,
2. Magnetic properties sensor,
3. Colour sensor,
4. Pneumatic grip,
5. Pneumatic cylinder,

6. Vertical servo drive,
7. Horizontal actuator, and
8. Horizontal drive position sensor.

3. Analyzing available IoT platforms suitable for industrial applications

3.1. Need of IOT platform or Cloud platform

Cloud computing is the same as a personal computer but the OS, storage and applications all run on the cloud platform. The company which provides this cloud platform will charge the user depending on the amount of time the cloud computing is used. Cloud computing reduces the cost of buying hardware and software for setting up the connections with devices and communicating with it. A larger amount of data can be analyzed in a few seconds using cloud computing with the help of a cloud application like predictive maintenance which we used in our project. This allows the user to go to a new level of updating in his production line or application, and improves felicity, time management, quality, and maintenance.

3.2. Types of cloud services

- **Infrastructure-as-a-service (IaaS):** The most basic category of cloud computing services. With IaaS, you rent IT infrastructure (servers and virtual machines (VMs), storage, networks, operating systems) from a cloud provider on a pay-as-you-go basis.
- **Platform-as-a-service (PaaS):** Cloud computing services that supply an OnDemand environment for developing, testing, delivering, and managing software applications. PaaS is designed to make it easier for developers to quickly create web or mobile apps, without worrying about setting up or managing the underlying infrastructure of servers, storage, network, and databases needed for development.
- **Software-as-a-service (SaaS):** Method for delivering software applications over the Internet, on demand and typically on a subscription basis. With SaaS, cloud providers host and manage the software application and underlying infrastructure, and handle any maintenance, like software upgrades and security patching. Users connect to the application over the Internet, usually with a web browser on their phone, tablet, or PC. [7]

3.3. Limitation of cloud computing

- Downtime is often spotted in cloud computing which results in slowdown of industry application and takes time to analyze the data with a delay.
- Security also plays a major role in cloud computing; all data is stored in the cloud which can be hacked and can cause a huge loss to the company.
- Lack of knowledge forces the customer to go for a high cost software developer.
- Cost of cloud computing is very high which is not affordable by small companies.[8]

3.4. Different cloud computing platforms

There are several cloud computing platforms present in the market to implement industrial application and every platform has advantages and disadvantages. We listed 5 platforms used in industry application and analyzed them in the following paragraphs. We also described why we chose the IBM Cloud platform as the cloud computing platform for our project. Some of the well-known IOT or cloud computing platforms for industrial applications are,

3.4.1. AWS (Amazon web services)

AWS is a leading IOT platform provider for industrial applications and the services offered by AWS are very flexible and secure. They offer the user data analysis, storage, IOT, Cloud computing, etc. Amazon provides its services to companies, governments, and individuals with a massive share of 35%. AWS allows the user to enjoy an entire virtual cluster of the computers which they require. The whole service can be enabled through the internet. The virtual cloud platform of AWS comes with all attributes of a computer such as hardware, pre-loaded application, databases, an operating system, CRM, etc.

a) Limitations of AWS

- AWS comes with a free one-year free trial but still the cost of using the services like predictive analysis are high.
- It comes with a high complex structure with every virtual cloud platform tool, which creates a gap between the user and developer.
- A limitation of Amazon EC2 server - to improve the service we need to pay more.
- Security limitations are the most important set back; AWS limits some of features in EC2-classic and EC2-VPC.
- A technical support fee is paid every month.
- Other cloud computing issues are also found in AWS such as downtime, limited control and backup protection[9]

3.4.2. Google cloud

Google offers a cloud computing solution which is called the google cloud platform. It provides services in all important fields such as storage, AI, Machine learning, industry, IOT, and networking. Google cloud also has tools for cloud security, management, and development. The storage offered by google cloud is extremely dynamic with storage both with SQL (Cloud SQL) and without SQL (Cloud datastore). For hosting the data workload, IaaS or Google Computer Engine basically offers its user a virtual machine instance. PaaS provides the software developers an opportunity to enter the ON-DEMAND hosting as well as the software developer kit for application development which can run on the app engine present on google cloud. All of these services of Google cloud can be contacted through public internet on dedicated networks.

a) Limitations of google cloud

- Support fee is very high and download cost from google storage is expensive (0.12USD per GB).
- Bugs in the Google cloud are very confusing.

- Amazon S3 is better than SDK APIs in google cloud.
- Pricing is higher than Microsoft and IBM. [9]

3.4.3. Microsoft Azure IOT Hub

Microsoft has machine learning, Cloud storage, and IOT devices. Microsoft also has their own operating system which is improved for cloud computing. This lets the user know that Microsoft is intended to give them the whole IOT solution. The pricing of this cloud computing is done in four tiers depending on the amount of data used by the cloud computing devices. If the number of messages is below 8000 per day the service is given for free by Microsoft. It is not so complex to connect and use other Microsoft services, but the user will be asked to pay for the use of other services. A pricing calculator helps the user to calculate the amount of money charged by Microsoft for the required service. In this IOT cloud platform of Microsoft, we can implement the machine learning and data analysis by which other new applications can be built.

a) Limitations of Microsoft azure

- It is difficult to upload custom data to the cloud database.
- Virtual machines contain a longer provisioning time than On-premise.
- Poor management GUI and Tools.[9]

3.4.4. MindSphere

MindSphere is an open IOT operating system which is used to connect to the devices and enterprises to collect data. Mindsphere provides proper connection between products, systems, sensors, and machines. Mindsphere's focus is to connect the user to the generated data by using IOT devices. Mindsphere is made by using open PaaS competences to develop apps for different applications. Mindsphere first launched in 2016 and allowed users to create ecosystems and through that they can develop and deliver industry applications efficiently. This Cloud Platform also allows the user to access the Cloud services of AWS. Mindsphere also includes the attributes such as a safe connection between the software and the hardware connectivity solution.

a) Limitations of Mindsphere

- Siemens is new to the Cloud market;
- It has a lot of setbacks when it comes to predictive analysis and machine learning.
- Mindsphere is not a great choice when it comes to predictive maintenance projects.
- It costs up to 1250 pounds per month to begin predictive analysis for this project.[9]

3.4.5. IBM Cloud

IBM Cloud is a cloud computing solution that basically comes along with PaaS and IaaS together. Because of this the user gets the platform along with the infrastructure or IOT Architecture as services. With IBM Cloud we can easily develop, deploy and get access to the visualization to computer power, networking, and storage through the internet. Depending on the organization's needs the services can be used as private, public or hybrid model. The PaaS of this IOT Cloud platform is based on the open source IOT platforms which are called the Cloud foundry. The developers can utilize the services of these platforms for developing apps, running apps, managing data, and deploying scalable applications for on-premise and public cloud environments.

a) Benefits of using IBM Cloud

- **Capture data in real time**

Process IoT data instantly to identify valuable insights about device behavior and field operations and to notice trends before they influence our outcome.

- **Optimize Operations and Resources**

Reduce Expenses by understanding our IoT devices. This allows us to operate them more efficiently. Visualize our IoT data to plan the operations better, and increase productivity.

- **Increase Revenue**

We use well developed business understanding and two directional communication between end user to modify or improve the services and products to achieve high profit.

- **Analytics Services**

Improve efficiency, increase productivity and communicate with our IoT device data through IoT Platform with the help of analytics service add-on.

- **Blockchain Services**

To Improve belief and transparency we will enable the IoT assets to test provenance and events in a trusted, secure environment with these blockchain services.

- **User friendly platform**

The most easy and friendly platform for us for cloud application is IBM Cloud. It contains Documentation and tutorials for all of its applications. The most important advantage is that it has a Lite version for all tools and that's enough for the students. Implementing the same project in other platforms would take more time and more money for sure. This is the main reason we chose IBM cloud instead of other leading Cloud platforms.[10]

4. Data analysis tools in IBM Cloud and Mindsphere

4.1. IBM Cloud

Big data allows us to do predictive analysis in order to make predictions about the future or events. Predictive analysis gives us a lot of new applications such as social networking, online shopping, emergency alarms, healthcare, mobility, insurance, finance, marketing, etc. Nyce says that we have to use the predictive analysis for finding the risk and probabilities of failure to give an appropriate insurance rate. This method gave an idea to make use of data from marketing records, underwriting records and claims records by sending it through a data cleansing and organizing algorithms. Then this data is ready for the data mining process with the help of some additional external data. The predictive model can be created from the output of data mining. Predictive analysis consists of different statistical techniques ranging from data mining and predictive modeling to machine learning.

Some of the usual servers are hardly keeping up with the huge growth of data in recent years. These servers are very costly to run and maintain. This motivated the industries to turn towards cloud computing which segregates a big task into some small routines through the network automatically and provides an output similar to many servers after calculation which is then analyzed. Cloud services are generally very reliable due to use of multiple redundant copies of data, which allows instant access to the data even in the case of storage drive failure. Current cloud services not only have a lower cost than costly data center management, but also allow users to purchase them anytime and anywhere according to their requirements.

Cloud storages allow users to store and access their data at any time and in any location. The structure of the cloud storage system consists of four important layers: the storage layer, which consists of many storage devices that are located in different regions; the management layer, which implements the collaboration between multiple storage devices; the application interface layer; and the access layer with the task of managing user access to their files and preventing unauthorized use.

IBM Cloud, formerly known as Bluemix, was rolled out in 2016 offering its users both types of cloud computing which are platform as a service (PaaS) and infrastructure as a service (IaaS) from a single console. IBM Cloud IaaS provides the possibility of deploying and accessing virtualized IT resources over the internet. Additionally, IBM Cloud PaaS is based on the open source cloud platform Cloud Foundry which allows developers to use IBM services for creating, managing, running and deploying different kind of applications on both local and public clouds. The main advantage of IBM Cloud is support for many programming languages including Python, Node.js, java, PHP, etc.

Additionally, integration with other IBM tools and services such as IBM Watson and IBM Cloud Functions can be established which creates a comprehensive and powerful tool for users. Some of the IBM tools and services are Compute, Network, Storage, Mobile, Blockchain, Integration, Migration, VMware, Management, Security, Data management, Artificial Intelligence (AI), Internet of things (IoT), Developer tools, Analytics, etc. There are three deployment models for IBM cloud platform. The first one is Public which provides access to virtual servers in a multi-tenant environment. Second are Dedicated deployment models which are single-tenant private clouds that IBM hosts in one of its data centers. The third model is dedicated to IBM Cloud Private which provides deployment as a private cloud in its own data center behind a firewall.[21]

When it comes to predictive analytics IBM offers several tools and services that cooperate with their cloud services. IBM SPSS Statistics comes as a software package which is mainly used for statistical analysis. It is considered one of the world's leading statistical software's which offers advanced statistical analysis, a vast library of machine-learning algorithms, text analysis, open-source extensibility, integration with big data and seamless deployment into applications. SPSS can be driven externally by a Python or a VB.NET program using supplied "plug-ins" which provides endless opportunities for custom solutions.

SPSS modeler flow is used in this project to perform predictive analytics with real-time data. IBM Watson studio consists of SPSS modeler flow to train, analyze and predict real-time data from device assets. The SPSS modeler is trained separately by using a Sample data first and then the data from the high-speed counter or mechatronic system data is sent through the SPSS model.[11]

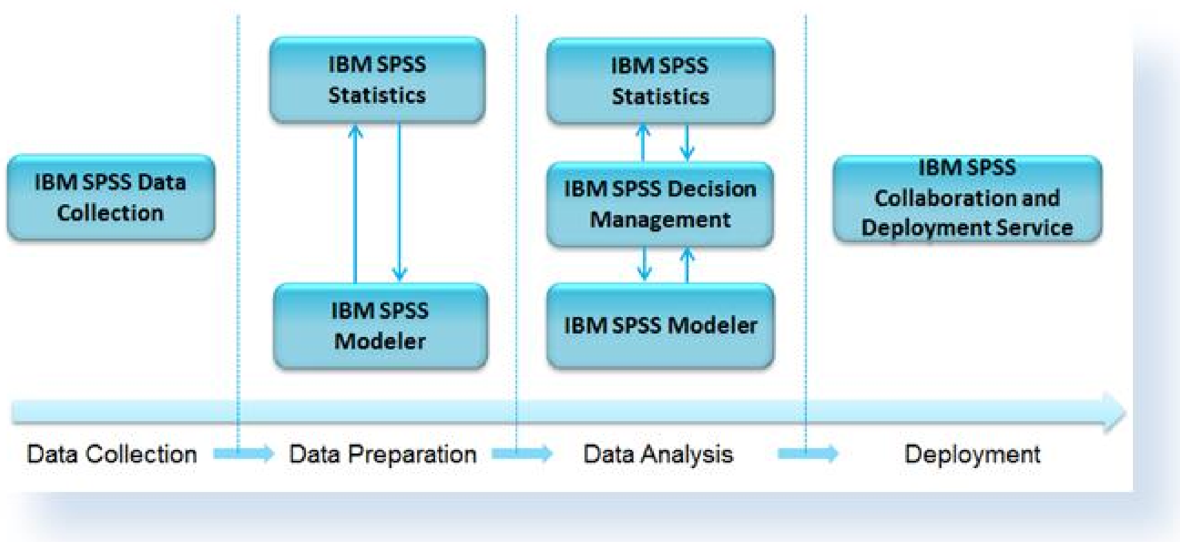

FIGURE 10: SPSS MODELER IN DATA ANALYTICS[21]

Another possibility with IBM cloud is integration with the IBM Watson platform, which includes services such as Watson Analytics, Watson Machine learning, Watson assistance, etc. Watson Analytics is a powerful tool that takes advantages of machine learning and AI technologies combined with natural language querying that is also intuitive and easy to use. The only shortcoming of this platform is lack of real-time data streaming. The real time data streaming problem is overcome by Streaming analytics tools which we have implemented in this project.[11]

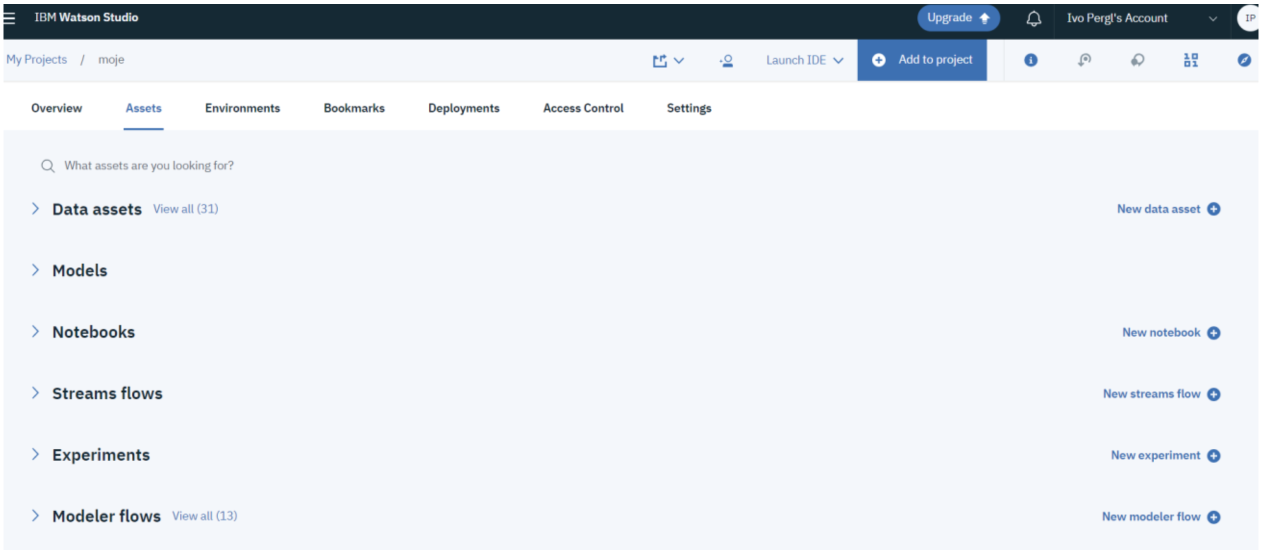

FIGURE 11: WATSON STUDIO

4.1.1. IBM real-time analysis tools

IBM Watson Studio and IBM Watson IoT platform play an important role in Real-Time analysis in our project. The IBM streaming analytics service and IBM machine learning service are used to analyze the streaming data in real time. The data flows through the Streams flow and gets analyzed using an SPSS module connected to the Streams flow. The analyzed data is viewed in the matrix window of the Streams flow. The analyzed data can be used to maintain or control devices. IBM Watson studio also contains MQTT, Python model, Cloud function, Event Streams, alerts and Watson IoT nodes to analyze or control devices. In this project we used SPSS models to analyze the real-time data. This is done by collecting data from the mechatronic system and connected with SPSS models in Streams flow. The SPSS model is trained in SPSS modeler flow. The following paragraph describes the process done in IBM Watson studio to perform predictive maintenance in the mechatronic system.[11]

4.1.2. Data collection

Data is collected from the mechatronic system and sent to IBM cloud to do Real time analysis for managing the quality of production and to perform predictive maintenance to the machine parts. Machine data is sensed by using pressure, vibration, optical, inductive and other sensors. This data can be collected in the IBM Watson IoT platform and then connected with IBM Streams flow to perform real time predictive analysis. IBM Streams flow consists of an SPSS model, MQTT, Filter, Watson IoT platform connection, Debug and other tools for real time analysis. The SPSS model is created using SPSS modeler in which we can train the predictive model and transform the trained model into SPSS model which can be used in IBM Streams flow to perform the trained predictive analysis.

4.1.3. Training of Data

SPSS modeler is used to train the sample data to obtain the predictive maintenance output. The sample data consists of input data which is the possible outputs from the sensors and output data which is the desired output data for the respectable input data. Data is uploaded using the Import option in SPSS modeler. Training is done in SPSS modeler using Modeling tools such as neural net, C&R tree, Random Tree, and other tools. Here we used neural network which is similar to the human brain. Data is processed and filtered using Field and Record operations in SPSS modeler. Output and graph models are used to visualize the data. Data asset Export is used to save the output data. The deploy model is used to create a SPSS model for Streams flow.[11]

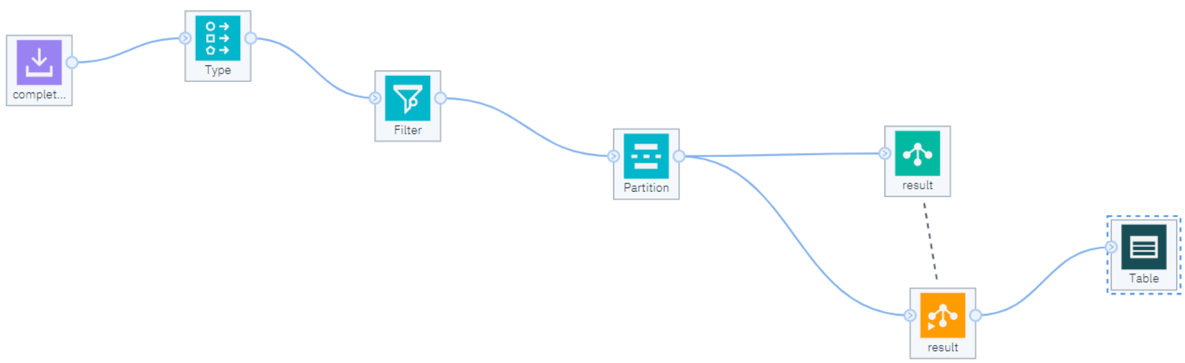

FIGURE 12: SPSS MODEL FLOW

4.1.4. Real-Time analysis of data

The deployed SPSS model is connected with IBM Watson IoT platform data in the streams flow. This allows our production line data to be analysed automatically using an SPSS model. The analysed output is the predicted output for the machines in order to know whether to perform maintenance or not. This output is given as an alert signal. If the alert occurs, the person who is in the maintenance department can make some immediate response to avoid damage in the production line. This alert is obtained by using MQTT messages or Email messages. These MQTT messages can also be sent to PLC or Robotic arm. PLC can control the action of production line by turning off the production line or it can also activate some Robotic arm with Machine learning and Image processing technology. These Robotic arms perform the maintenance automatically after getting activated by PLC by using Deep learning and Image processing concepts.[11]

4.2. Mindsphere

MindSphere is an open IOT operating system which is used to connect to the devices and enterprises to collect data. It is a Siemens Cloud platform. Mindsphere provides good connection between products, systems, sensors, and machines.

4.2.1. Benefits of using Mindsphere

Mindsphere consists of advanced analytics, industrial applications, and an innovative development environment for self-creating applications. Mindsphere uses the Platform-as-a-Service (PaaS) ability with access to AWS cloud services. Mindsphere is a simple and direct cloud platform for building industrial applications. It helps the user to understand the output more efficiently and allows the developer to develop applications with the freedom of selecting the coding language. It also provides the security of user data by using AWS cloud services. Mindsphere is built using the AWS cloud platform, so it has all security features from AWS. Siemens is a leading company in automation industry and Mindsphere is simpler to connect with Siemens devices without any interface. But after seeing the price of predictive analytic tools we changed to IBM Cloud. Predictive analytic tools in IBM are free and it is the best way to do this project.

4.2.2. Possibilities with MindSphere

- We can create user's data analytics and manage them.
- MindSphere Asset Configurator is used to crate, maintain and control assets.
- MindConnect Nano is used to collect data from device assets and transfer it to MindSphere.
- The user can visualize the transferred data in time stamping.
- Control the connected assets and can be operated automatically.
- We can create or use default Mindsphere applications.

4.2.3. Steps to create an application in Mindsphere

Step 1- Subscribe to MindAccess DevOpsPlan – For Cloud Foundry applications: Order and receive a MindAccess Developer Plan from Siemens. This provides you with access to the Cloud Foundry development space. The MindAccess Operator Plan provides you with access to the Cloud Foundry productive space on the Platform. – For self-hosted applications: Order and receive a MindAccess Developer Plan and the outbound traffic upgrade from Siemens for developing and testing the self-hosted application. The MindAccess Operator Plan provides you with access to the productive space on the Platform.

Step 2- Configure your development environment – MindSphere-managed Environment Use Cloud Foundry Command Line Interface or a tool of your choice to prepare your development space. Configure Cloud Foundry as well as separately ordered or included Backing Services like additional data stores or message queues. – Self-managed Environment Configure and use your development environment according to your needs and specifications, possibly provided by the vendor of the environment.

Step 3- Develop your application – According to your needs, create a local development environment by installing appropriate software tools. – Use the Developer Documentation to see how to create an application. – Use MindSphereAPI Reference and API Guide for information on how to make API calls. – Create your application in one of the supported languages.

Step 4- Test and evaluate your application using the tenant on your development space – Register your application as described in the Developer Documentation. Test and evaluate your application as to its technology, functionality, performance, security and user interface with regard to expected content and behaviour. – Use tools and processes to manage application testing. [12]

4.2.4. Predictive Maintenance in Mindsphere

Mindsphere Predictive Learning allows data analyzer to build prediction models through machine learning techniques, which gives access to different companies to optimize product quality and reduce machine failure and other performance problems. By predicting what happens next and when it happens companies can make productive decisions, schedule predictive maintenance and control devices. Mindsphere Predictive Learning allows companies to utilize big data and IoT data to make real time decisions or proactive decisions that will improve the productivity of devices, improve the growth of companies and allow the user to gain a profit.

4.2.5. Trend Prediction Service

The Trend Prediction Service predicts the future value according to time series by using linear and nonlinear regression models. It is a forecasting framework, which is useful for this project in the area of Process & Condition Monitoring.

a) Benefits of the Trend Prediction Service

- Predictive maintenance: Finds the lifetime of the machine or finds the problem in the region of system.
- Monitoring of processes: Predict the fault occurrence in the mechatronic system (e.g. waiting).
- Seasonality and trend removal are useful for preparing data for other analysis tasks.[13]

4.2.6. Predictive Learning tool

The Data Science Workbench with the Predictive Learning Data Science Workbench module gives users access to the Zeppelin notebook for authoring models. Managed instances of Zeppelin notebook are given for exploration, training and visualizing models. These notebooks consist of preloaded deep learning which offers TensorFlow, Kera's and Theano as well as distributed machine learning packages such as MLLib. There are options to configure and select what level of computing power is needed so users can easily explore and build models on big data. But this method of predictive Learning is costly and complicated compared to IBM streaming analytics. Even though Mindsphere has the tools for predictive analysis, there is no lite version for predictive analytic tools. IBM Watson has a Lite version for the creation of control application of mechatronic system. [14]

5. Design of control application of mechatronic systems in the IBM Watson IoT platform

In order to do predictive maintenance in the Laboratory mechatronic system, we used the TIA portal to connect the sensor signal with IoT2040 and then we connected with IBM cloud and performed predictive analysis on the received data from the Mechatronic system. This process is done in three platforms,

- TIA Portal V14.0,
- IBM Watson IoT Platform, and
- IBM Watson Studio

5.1. TIA Portal V14.0 Application

TIA portal is a software used to control the mechatronic system and S7-1500 PLC. This software lets us view data in watch table, control devices by using PLC programming and has the ability to transform data to IBM cloud via IoT2040. The PLC program for mechatronic system and high-speed counter is created by us. We have connected the mechatronic system with PLC S7-1500 by using Profinet cable. The PLC ladder program is created in Tia Portal which controls the mechatronic systems and High-speed counter and before compiling the program we enabled the PUT / GET configuration first to send this PLC signal to the Node-red. This is done by going to enabling Connection mechanisms in Tia portal. This allows the PLC to pass and get data from node-red interface of IoT2040. After setting connection mechanisms we went online in the Tia Portal. After that we went to node-red environment to start connecting these data from PLC and mechatronic system. Node Red is started by installing node red in IoT2040 device.

5.2. IBM Watson IoT Platform application

IBM Watson IoT application is done using the IBM cloud and is created in order to receive data from Tia portal. Connection between IoT2040 and IBM cloud is obtained by using node-red. The following steps have to be done in the IBM IoT platform application:

5.2.1. Connectivity

First, we have created an IBM account and started the IBM Watson Internet of Things Platform service in order to create a connection between cloud and mechatronic system. In the catalog tab we selected the Internet of Things Platform service and then we launched the IoT application by clicking the launch button in the Watson IoT platform service. After that in the IoT platform application, a new device is created in devices block. This device has to be linked with PLC in Node-red interface by typing the IP address and required fields. The node-red interface is configured and installed in the IoT2040. [4]

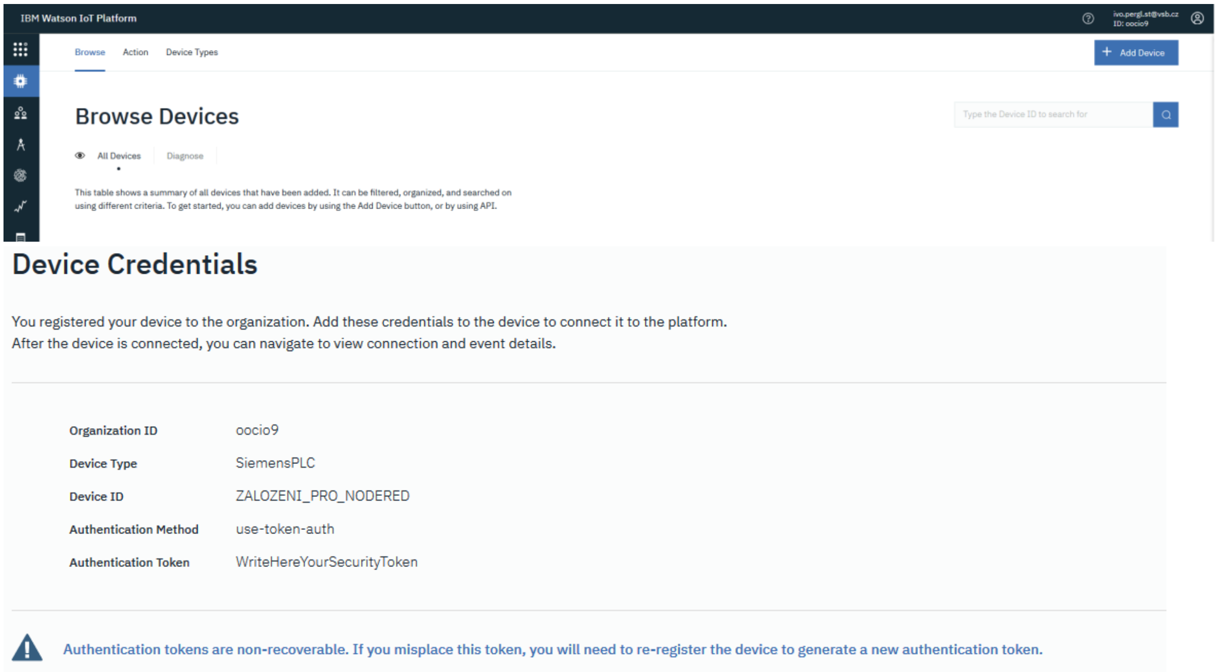

FIGURE 13: CREATE DEVICE IN WATSON IOT PLATFORM

5.2.2. Configuration of IoT2040 and Node-Red

IoT 2040 is connected with IBM cloud through Node-Red. It is an interface between the PLC and IBM cloud. Node red has to be installed in the IoT2040 device in order to connect IoT2040 with IBM cloud. The following components are required for connecting IoT2040 with IBM cloud.

a) Requirements for IoT2040

- Internet connection and the newest internet browsers (like Google Chrome or Firefox) for an online user interface
- Siemens Simatic IoT2040
- Internet connection for the equipment to run Simatic 2040
- Supply of the standard functions of HTTPS for Simatic 2040-HTTP connection for the port 443 (here we will use Node Red)
- Power supply 24V DC
- SD-card with Yocto Linux

- Ethernet Cable
- Node-Red
- IBM account

5.2.3. Specifications and preparation of IoT2040

- Intel Quark X1020 processor
- 1 GB RAM
- 2 X Ethernet interfaces
- 2 X RS232/422/485 interface
- Battery-buffered real-time clock

Preparing the Simatic IoT 2040 Device for the IBM Watson IoT platform to send data is the beginning of data transfer from mechatronic system to IBM cloud. First the IoT2040 device has to be connected with Putty and node-red and IBM Watson IoT interface nodes have to be installed. After installing node-red in IoT2040, node-red can be started by clicking auto start node-red button in iot2000 setup. After that the node-red IP address is typed in the web browser to open the node red flow to connect the IoT2040, PLC, and Mechatronic system with IBM Watson IoT Platform.[3]

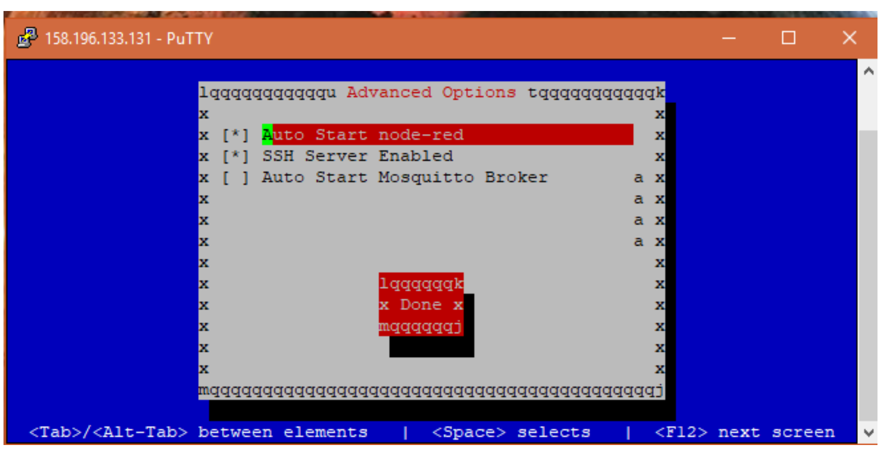

FIGURE 14: NODE-RED AUTO START

In Node red, we created the data connection between S7-1500 and IBM Watson IoT platform through IoT2040. PLC is connected with High-speed counter to sense the count value or connected with the mechatronic system to predict the status of the system and send it to the cloud to do predictive analysis.

5.2.4. Node-Red configuration

a) PLC connection with Node-Red

In node-red we have usable nodes on the left side of the node-red web page. We took the S7 node from the input category. This node block allows us to read individual variables from the PLC. We can connect any data variable with IBM IoT platform. We get to **Node Block Settings** by double clicking on the S7 node which helps us to configure the PLC. The first block in the node block settings is the PLC. Here we set the PLC from which we wanted to read. S7-1500 PLC is configured to this node setting by clicking the edit button and both the IP address and Port address of the PLC are given here. Then variables have to be added in the variable tab to send the data from PLC. At last click deploy to start the data connection between Node-Red and PLC.[3]

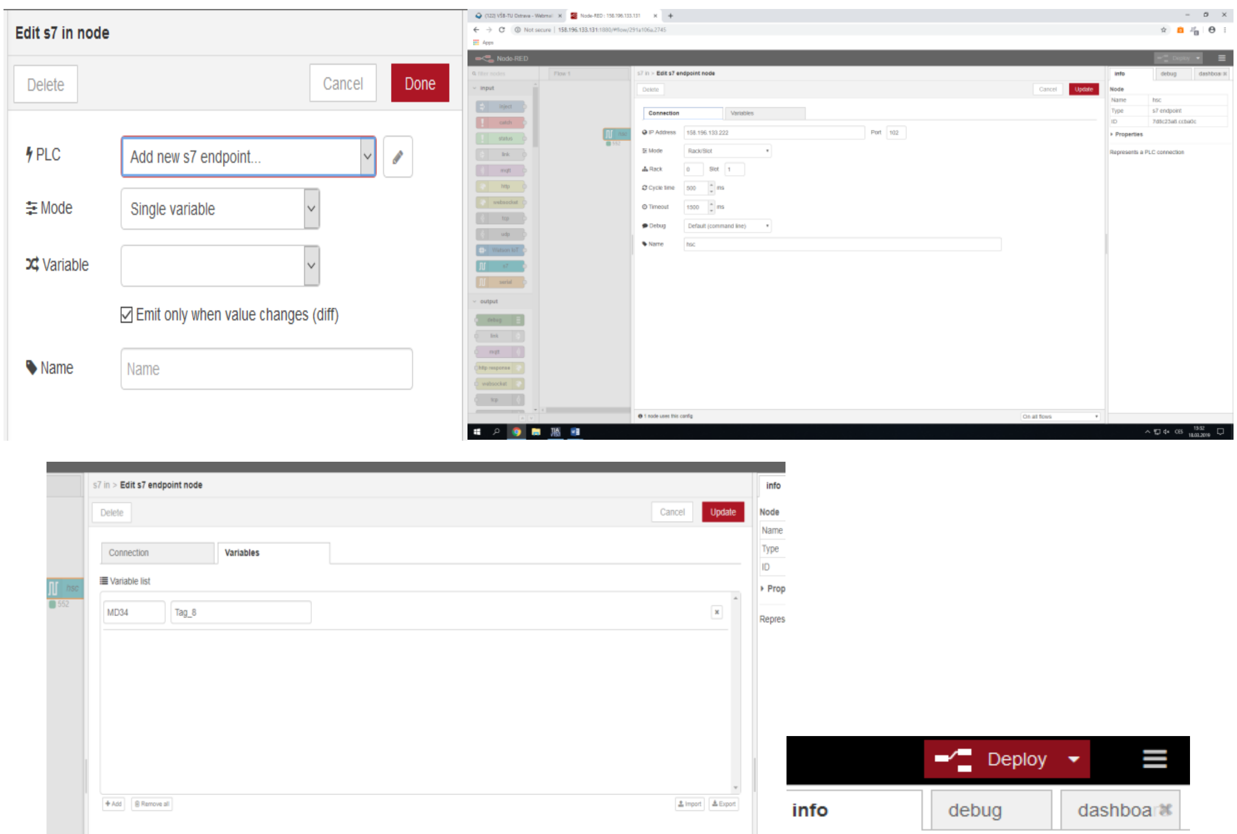

FIGURE 15: CONNECTING PLC AND NODE-RED

b) Watson IoT platform connection with Node-Red

After connecting PLC with node-red we connected the IBM Watson IoT platform device with the Node-red blocks. The Watson IoT platform node is taken from the output category in node red. By using Watson IoT node, we are able to view the Watson IoT node edit window, in which we can configure IBM cloud. The following steps have to be done to obtain it. First choose the IoT device to be connected with node red in Watson IoT platform. On Watson IoT node in node red choose connect option as Device and check "Registered". Then we will add information in the Credentials line. If we have a device profile, we can just select the profile or we can create a new profile directly by using the pencil edit icon. When we click this edit Icon an Edit window for credentials node appears in a new window. Here we fill in the data from our IBM Watson IoT platform, which we have to write carefully. We need to enter following information-**Organization, ServerName:"OrganizationID".messaging.internetofthings.ibmcloud.com, Device type, Device ID and Auth Token.**

After configurating the device with node red, we can choose under which name we will send this data to the IBM cloud by filling in the Event Type. Connect the S7 node and Watson IoT platform node to create a connection between them. This will create the data flow connection. Lastly click Deploy, which will start the link between IBM cloud and PLC data.[4]

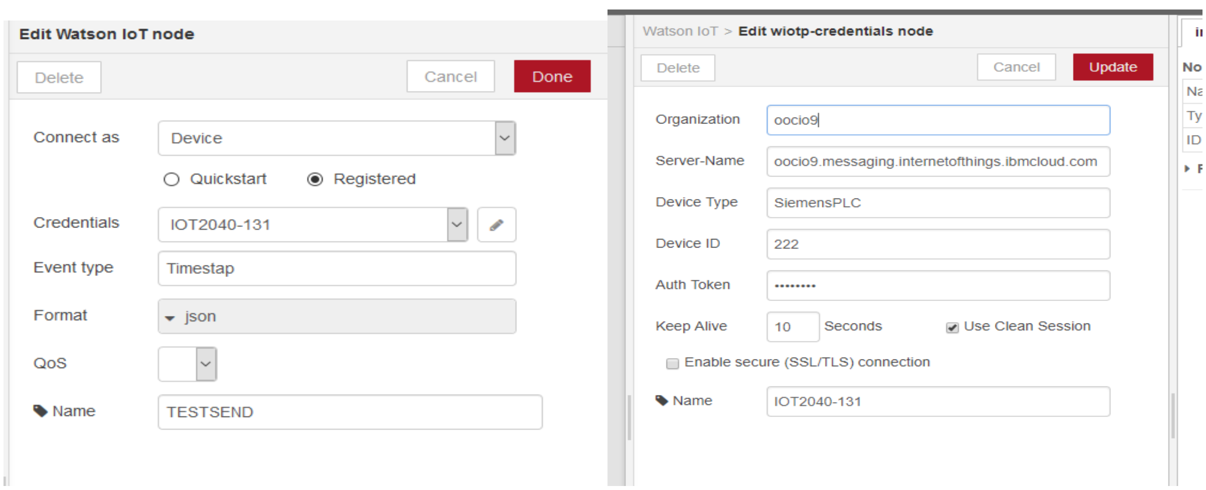

FIGURE 16: CONNECTING WATSON IOT PLATFORM NODE AND NODE-RED

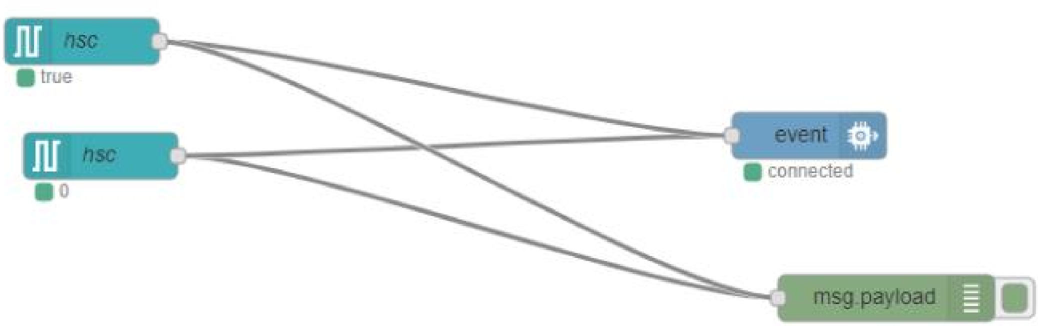

FIGURE 17: CONNECTING WATSON IOT PLATFORM NODE AND S7-NODE OF HSC DATA

5.2.5. Visualization of data in Watson IoT Platform

Visualization of data is an also important feature from IBM Watson Platform. Data can be viewed in real time allowing the SPSS model to analyze data in real time. This data visualization gives a proper understanding of data to the data analyzer or programmer. Understanding the data helps the programmer to think about how to train the SPSS model in order to obtain the desired end result. Visualization in Watson IoT platform is obtained after connecting the S7 node and Watson IoT Platform node in Node-Red. We can then view the data from S7-1500 PLC in the board. In the board we can create any type of plot to view the data by clicking the add new card button in the user overview tab. The create card tab then appears. We could choose any option, but we chose to view our data in line card by selecting line card from the list of cards. After that we need to choose the data which we need to view from the list of data. Then we can configure the card by selecting the tile size. Lastly, we can name the card and choose a color for it. It also shows the details about device type, data transfer rate with respect to time and data history.

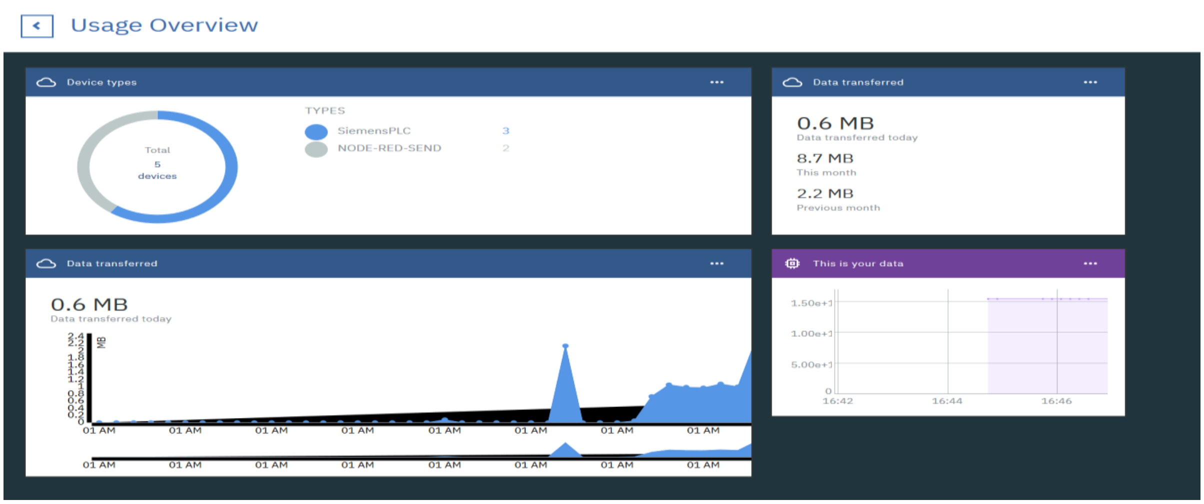

FIGURE 18: VISUALIZATION IN WATSON IOT PLATFORM NODE AND NODE-RED

5.3. IBM Watson Studio

IBM Watson studio helps us to program SPSS modelers for training data to achieve predictive learning. It contains SPSS tools to do Machine learning, Predictive learning, Deep learning and Image processing in real time. The following procedure explains how to connect the Watson IoT Platform and Watson studio. After receiving the mechatronic system data, we can go to the catalog in IBM Cloud and create IBM Watson Studio services, Machine learning services and Streaming analytics services. In order to do the predictive maintenance, we have to create an application in Watson studio and then train an

SPSS model and then connect it with Streams flow. The real time data from IBM Watson IoT platform is connected by dragging the Watson IoT node in Streams flow and connecting it with the SPSS model which is created to connect with Input data from PLC and gives predicted output. The SPSS model is created in SPSS modeler. This predicted output is viewed in the dashboard. The following Chapter gives a detailed explanation of IBM Watson studio and streams flow. The image below is the final visualization of predicted data of the mechatronic system data.[5]

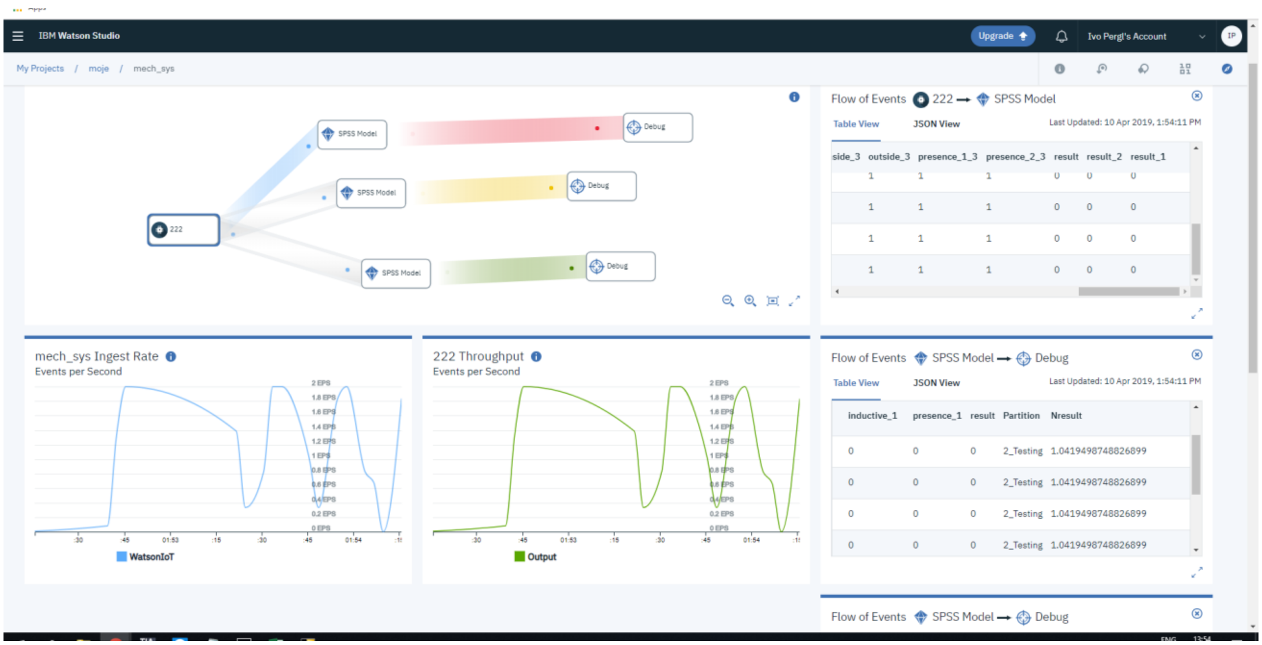

FIGURE 19: FINAL OUTPUT IN THE MATRIX PAGE OF STREAMS FLOW FOR MECHATRONIC DATA

6. Implementation of IBM Watson studio analytics tool using real time data in IBM cloud

Implementation of Predictive learning in IBM Watson studio is the easiest and most time saving method. The IBM Watson studio has a lot of analytical tools for machine learning and deep learning. In this project we used the SPSS modeler in IBM Watson studio for training data and Streams flow for automatic Real-Time analysis.

6.2. Connecting IBM Watson IoT application data and streams flow

Connecting the data from the Watson IoT device to Watson Studio is done by the following procedure. The goal is to implement Streams flow in IBM Watson studio application to analyze data in real time. For that we need to create an IBM Watson Studio application. After creating the connection between the IBM Watson IoT Platform we have to go to the Catalog in dashboard and enable Watson Studio, streaming analytics, machine learning, continuous delivery, knowledge catalog, and Cloud-object storage services. After creating these services start Watson Studio by clicking “Get Started”. After that create a new project by clicking “create a project”. Now we can see a page with options for different application tools. We can click any tool but the best option is Streams Flow. In our project we used the Standard tool because we can add any tool in this application whenever we need to by clicking “add to project” button. We created standard application and injected Streams flow and Modeler flow tools. These tools are used for creating the Predictive maintenance application. [6]

Inside of the project we can add Streams flow by clicking the button “add to project” in the application. Now we should go to the asset and click “new streams flow” and have to create a new asset for our Streams flow project. After clicking on the button, it will be redirected to another window where we can type the streams flow’s name. Then we can just leave everything as the default settings. Then we can click create. After that we have to fill out the application, it will redirect us to another window with the title “Select Source”, now we select the source as “Watson IoT”. When we went to this page click on the button “Add connections”, then the page “Create Connection” will open. Then fill in the following information: Name, Description, Organization, Authentication token, API Key, and then click “Create”. we already have the authentication token and API key from IBM Watson IoT platform. This will start the data communication between Watson IoT platform and Streams flow.

Then click continue, and we will be redirected to the page “Preview Data”. This is where we can see the data flow. Then click “Continue”. Then we will be moved to the page “Select Target” and we can select “Cloud Object Storage”, because we’ve already created this storage so that we could easily connect it. Now we add the connection to “cloud-object-storage-zn", and the file path is created. In our final Streams flow we used MQTT, SPSS model and debug. SPSS model is explained in next paragraph. MQTT is used for sending the alert signal to PLC. Debug is to view the output in the dashboard.

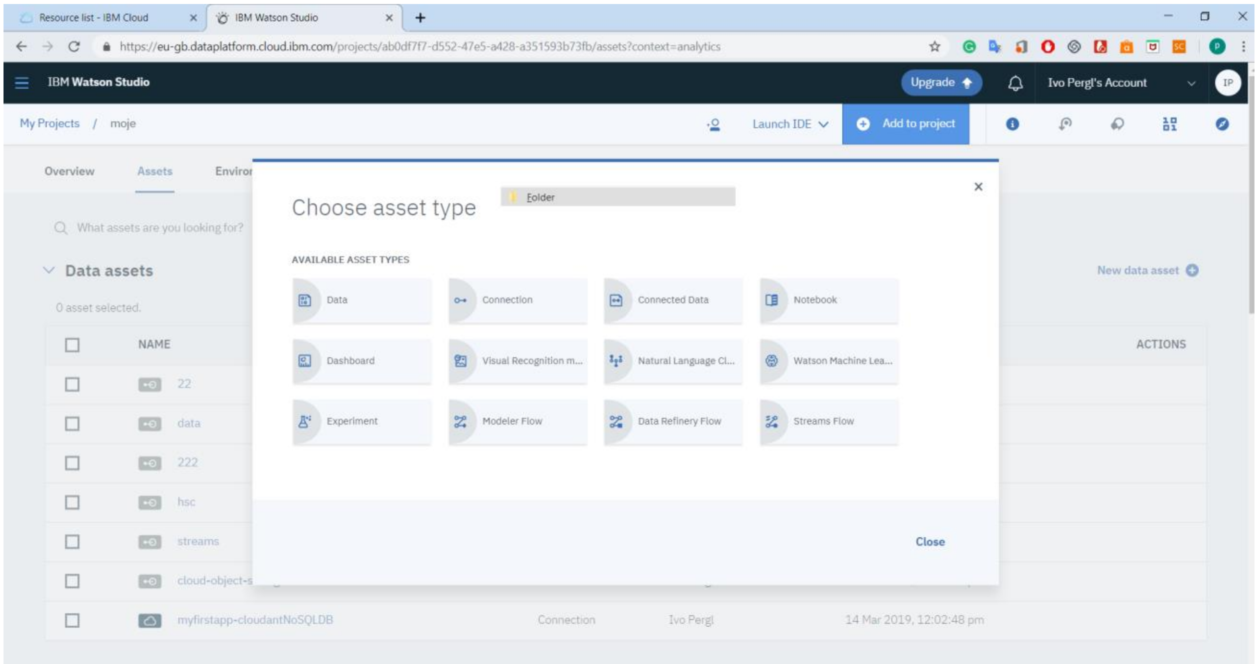

FIGURE 20: TOOLS IN IBM WATSON STUDIO APPLICATION

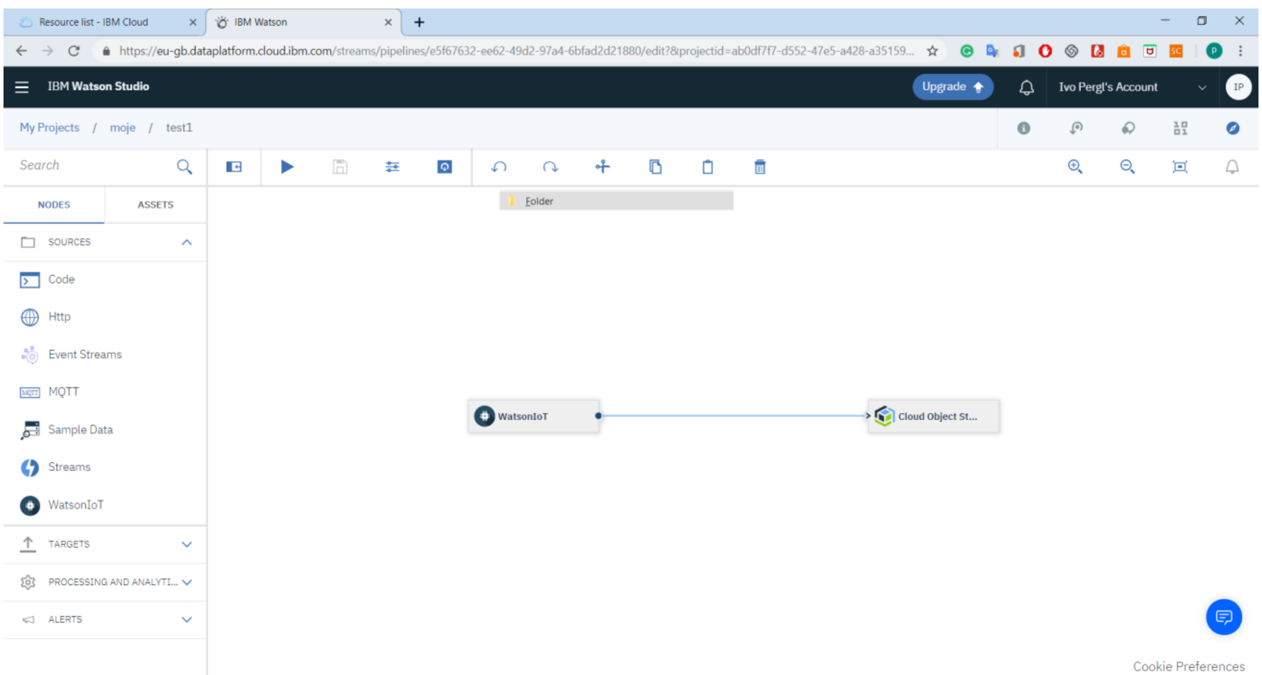

FIGURE 21: IBM WATSON IOT DATA IS CONNECTED IN STREAMS FLOW

This is how we connected the IBM IoT platform data in Streams flow. Then we created the SPSS module for predictive analysis using Module flow by using the "add to project" button. After that we linked it with the streams flow to view and alert the maintenance call. SPSS model creation is explained in the following paragraphs.

6.3. Streams Flow

Streams flow is a flow in which Watson IoT data is connected with SPSS model. It is the tool used to analyze the real-time data in IBM cloud. To implement the IBM Watson streaming analytics tool in the IBM Watson application we need to create an IBM Watson studio application. To create an IBM Watson studio application, we need to go to the dashboard in IBM cloud. After creating the IBM Watson studio application, we can Import a streams flow which is an easy way to bring a streams flow from a different project or Watson Studio instance into our project. We can create a new Streams flow or we can use an example streams flow. We have to use importing when our streams flow needs to run in different locations.

6.3.1. Streams Flow using SPSS model for HSN and mechatronic system data

SPSS model is used for training the data to obtain predictive maintenance using Neural network. SPSS model will remember this trained information while doing real time analysis in streams flow. SPSS model is connected with Streams flow by using SPSS model node. Before connecting the SPSS model, the SPSS flow must be deployed. SPSS flow has to be trained by using a Sample data. This project consists of High-Speed counter data and Mechatronic system data which is sent to streams flow and has been analyzed by using an SPSS model. The data is first trained by using an Excel file containing a sample count value and decided reset value for HSC data and Mechatronic system. This sample data is sent to the Neural network which can approximate a huge range of predictive models with lower demands on model structure and assumptions. The pattern of the relationships is formed during the training process. If a linear relationship between the target and predictors is suitable, the output of the neural network has to be closely matched with the traditional linear model. If a nonlinear relationship is more suitable than traditional linear, then the neural network will automatically approximate the "correct" model structure. Partition node is used to divide the data based on the Training, Testing, and validation partitions.

Sample data is connected to Type node in the SPSS modeler and the input values are read in the type first. If there is additional data coming from the source, we can filter that data by using filter node in SPSS modeler. The output of the filter is sent to the partition and then sent to the Neural network to train and validate the data. After that run the neural network which will generate a gem which is the trained SPSS model to be connected in Streams flow. After that connect Multiplot to the trained SPSS model and view the plot by running it. After that the model is deployed by clicking deploy model. Branch terminal node can be set to Multiplot. Model name is according to the user’s wish, so we named it as final1. After that click save and the SPSS model will be created in the modeler flow asset window. Training process is the same for both HSC and mechatronic system data.

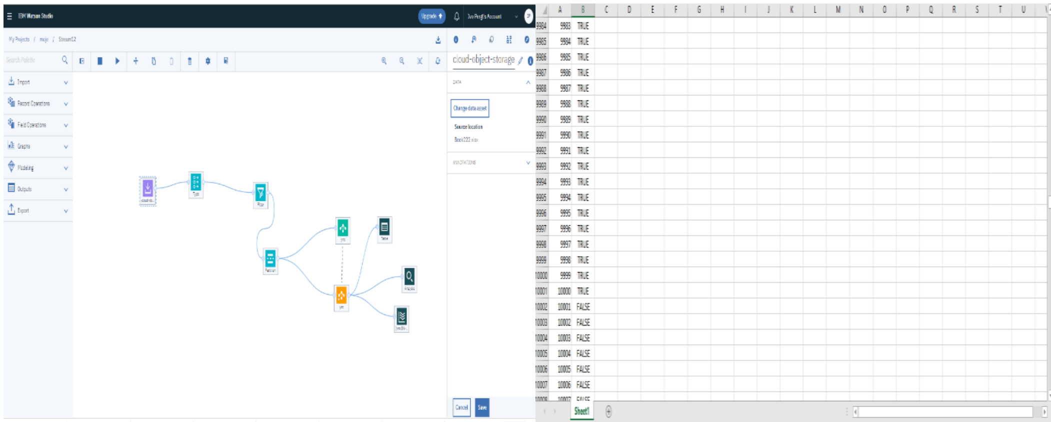

FIGURE 22: TRAINING OF SAMPLE DATA FROM HSC IN SPSS MODEL

6.3.2. Connection of SPSS model in Streams flow

After the training of the SPSS model is completed the deployed SPSS model is connected to the Streams flow by connecting this SPSS model node with the Real-time data from IBM Watson IoT. SPSS model name is given in the node by double clicking on it. Here we give the model the name “final1” which is our trained SPSS model. The input parameters are given next and then the input schema and output schema are connected to the model. The output of the SPSS model is connected to debug and its output is viewed in the Streams flow matrix window. For sending the alert data back to the PLC, MQTT node is used.

SPSS model output schema can be connected to the MQTT node and a message can be sent back to node red which sends the alert signal to PLC. Using this alert signal, maintenance is done immediately before the machine get damaged.[15]

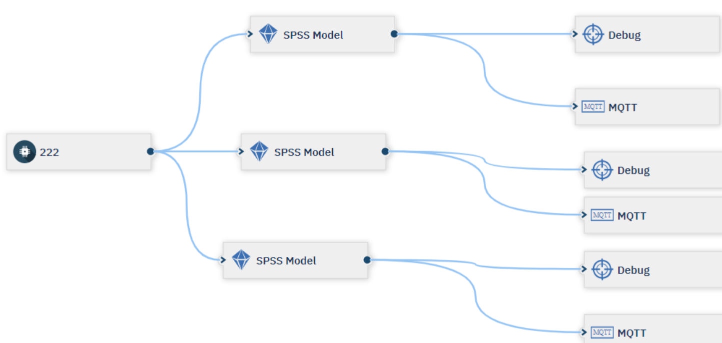

FIGURE 23: CONNECTION OF SPSS MODEL IN STREAMS FLOW WITH MQTT

7. Verification and testing of Mindsphere application

The final output from streams flow is the predicted value by the SPSS model for the High-Speed counter data and mechatronic systems. The predicted value has to fulfill the testing condition by giving the proper result that we need for the counter reset value. In this project we wanted the PLC to receive an alert for the High-speed counter when the count value reaches 10000 and for the mechatronic system when it receives false values for all input values in the systems. The output must reset to zero for High Speed counter data when the count value reaches or exceeds 10000. The output must be set to one when the statuses of all the sensors become false in a system. This has to be tested in the output of the streams flow to confirm that the predicted output is correct.

7.1. Verification in the streams flow matrix page

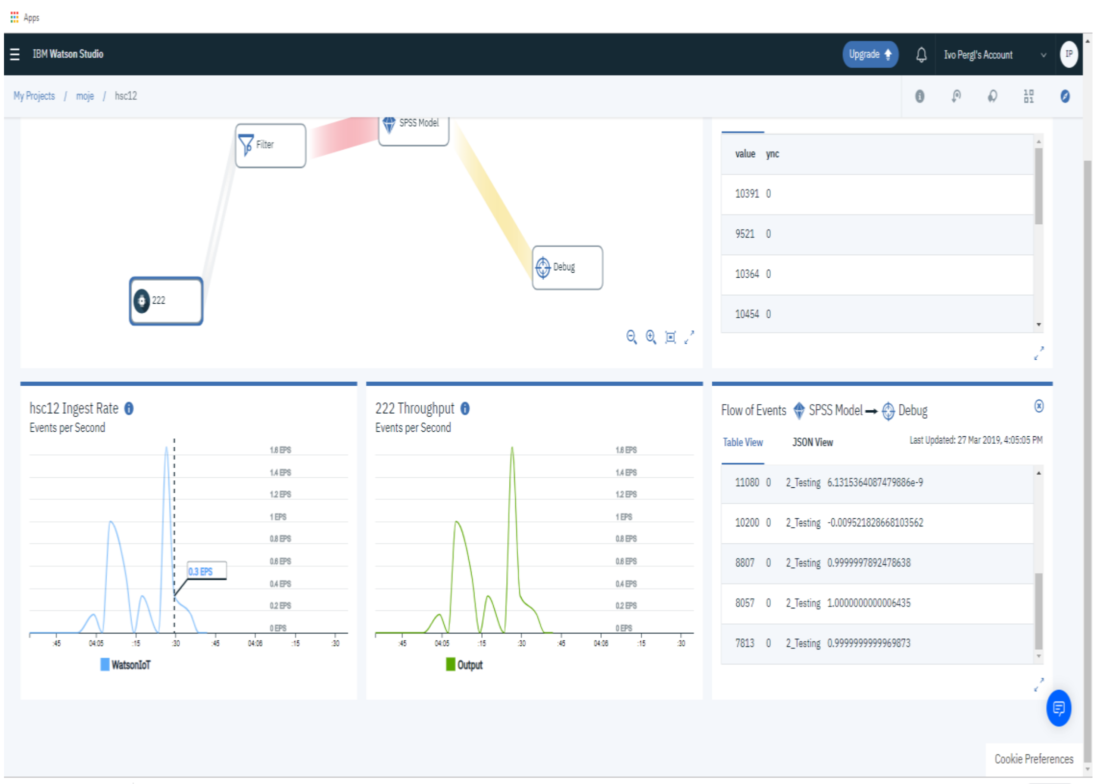

FIGURE 24: FINAL OUTPUT IN THE MATRIX PAGE OF STREAMS FLOW FOR HSC VALUE

The above Output window shows the value of output scheme "Nync" which is changing from 1 to 0 when the count value reaches a value above the limit (10000). This proves that the "Nync" is the predictive output from the SPSS model. The "Nync" value can be transmitted to the device and control the device depending on the limit value. Similarly, we also tested the output from the SPSS model of mechatronic systems. The result values change from zero to one when every sensor in the system goes false.

7.2. Modifying the data in the PLC and IBM Streams flow to have the same datatype

The data sent to the IBM Watson IoT Platform from PLC is Boolean data from the mechatronic system, but the SPSS model cannot accept Boolean data, so we converted the Boolean data into integer data which is the same data type used in the Streams flow. These values can also be found by comparing the flow of data between Watson IoT and Streams flow. Under certain conditions the data can be missing or hacked. IBM gives the most secure and reliable data flow channel to the user. So, the data is the same throughout the entire process in IBM cloud. The data transferred from PLC is first sent to a converter where it changes the TRUE values to "1" and FALSE value to "0".

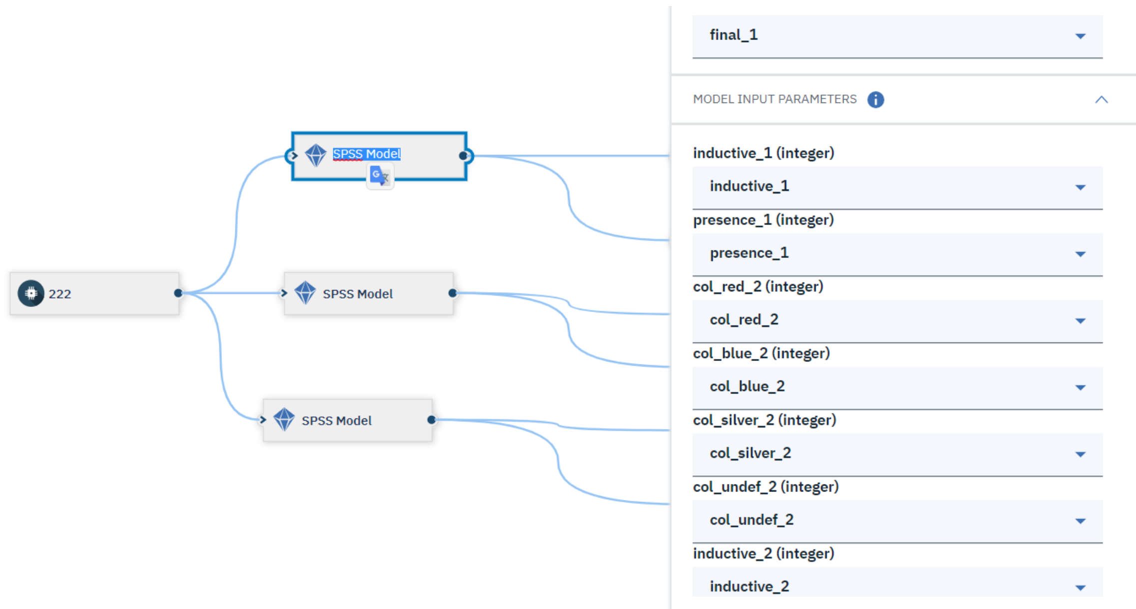

FIGURE 25: SPSS MODEL FOR HSC DATA

7.3. Testing the SPSS model

SPSS view is selected by right clicking on the Neural network gem. Neural Network analytics is used in this SPSS modeler with model evaluation of 0.999, Mean Squared error of 0.000 and ROOT mean square error as 0.018. This allows us to know for certain that the predicted output is correct. The accuracy of this SPSS model is 1.00 which is the maximum level. This can be achieved by improving the sample data. The Sample data must contain repeated values at which the result has to be changed. Sample data must contain a greater number of data samples. Accuracy of the SPSS model is totally dependent on the sample data. A low number of sample data gives less accuracy, whereas a greater number of sample data gives more accuracy. We duplicated the sample data in an excel document multiple times by which we obtained 0.999 model accuracy.

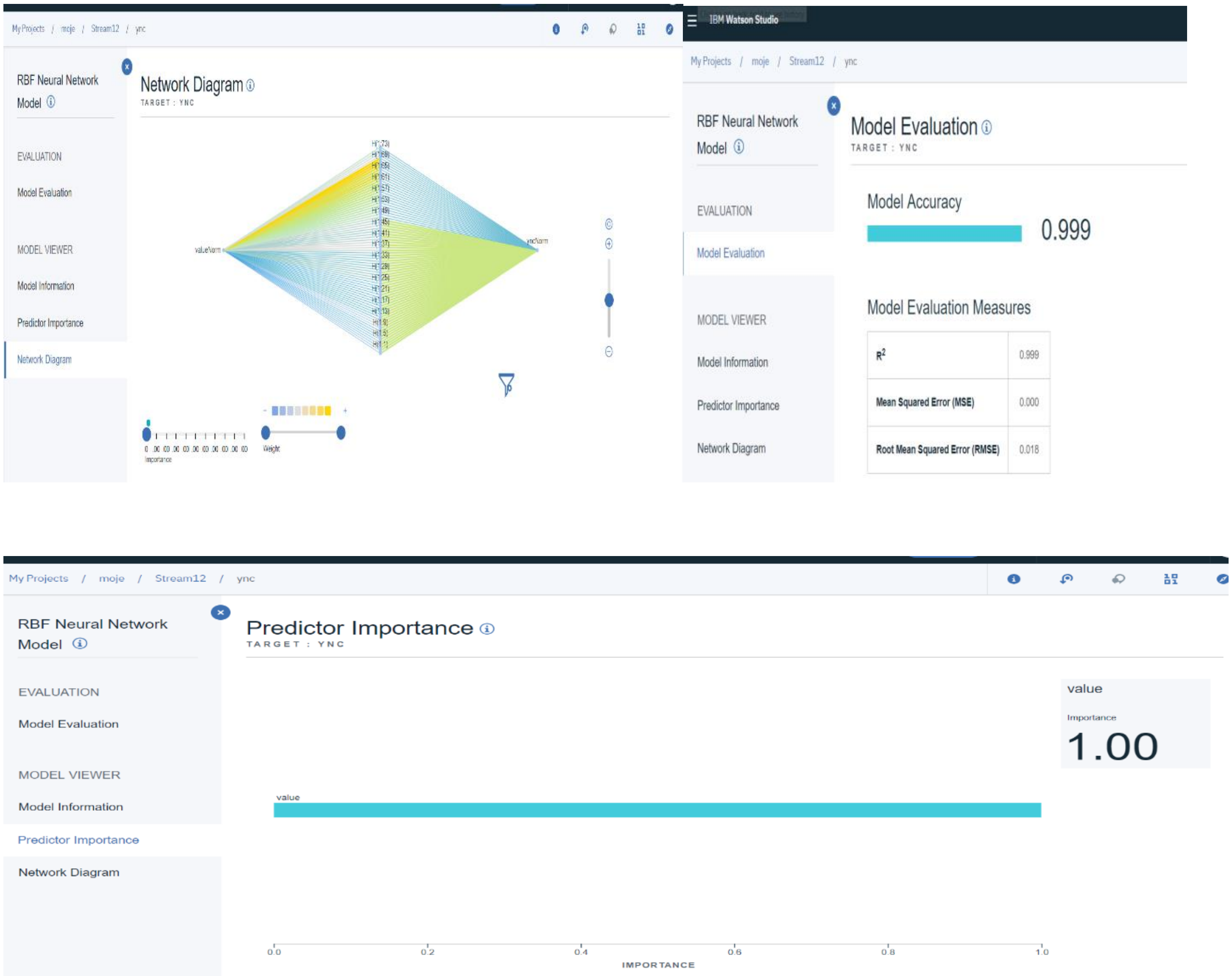

FIGURE 26: SPSS MODEL FOR HSC DATA

7.4. Cloud services and Support

Time delay happens when the IBM cloud undergoes service. At these times we have to contact IBM support to overcome the problems immediately. For the Lite version of IBM cloud support is not available. Therefore, to avoid service or some other problem due to server problems, data downtime, server capacity, storage, and time of data transfer we should upgrade IBM lite version to Standard version or enterprise version, which include IBM support. The Enterprise version gives access to multiple users and offers unlimited viewer collaboration. IBM services are ranked second by TechRadar websites.[16]

8. Conclusion

Mechatronic system and High-speed counter generate real-time data such as the status of the mechatronic system and count value readings through Tia Portal v14. This data is collected by streams flow and SPSS model. SPSS model monitors the count value and the status of the mechatronic system and analyses them automatically in real time. As a result, it predicts the time at which the alert has to be activated by using the training sample data. In this project I kept 10000 count value as the limit in High speed counter value. This limit is predicted by the SPSS model and the predicted output is viewed in the dashboard. The SPSS models of the mechatronic systems predict the false state of the sensors in the mechatronic systems. Whenever one of the mechatronic system's states goes totally false, the SPSS model will generate an alert signal. Hence the Predictive maintenance is performed in mechatronic system data and High-Speed counter data. The predictive maintenance in the mechatronic system can be performed in any data point using sensors, but the data analyzer has to know the limit or use case at which the alert has to be generated. Integer data from any sensor can be analyzed using this SPSS model method and an alert can be generated in Streams flow. For analyzing Boolean data, I converted Boolean data into integer data using PLC programming in order to be analyzed by an SPSS model. The output integer data from streams flow can also be converted back to Boolean using PLC programming.

8.1. Future upgrade

As a result of this project it is possible to transfer real time data from mechatronic system through the cloud and analyse it automatically by using an SPSS model. The output of the SPSS model generates an alert call for maintenance people. Maintenance can be done by robotic arms by using deep learning and image processing concepts. This image processing in real time is made possible by using a SPSS neural network modeler.[17]

Automated maintenance can be made possible by using IBM Watson studio. It is possible to analyze image data in real time by using an SPSS neural network modeler. Because of this, total Production lines can be automated and controlled using AI and machine learning technologies. Robotic arms are controlled by AI instead of humans. This prevents loss of time and human errors, improves quality and accuracy and reduces costs for investors.[21]

All types of data from every possible data point from a real production line system can be connected with the SPSS model and stream flow to achieve automatic analysis for real time data from data points. By automating the maintenance process, the industry 4.0 concept can be achieved in the maintenance department of the industry and also in other processes.

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10. Annexure

a) CD

- Thesis Report (PDF)
- Thesis Presentation (PPT)
- Output Screenshots (images of IBM cloud outputs)
- Project files (Tia portal and SPSS modeler files)