Industrial IoT Gateway with Machine Learning for Smart Manufacturing

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Abstract. Working together is important aspect of future industry. Therefore, technologies like Internet of Things (IoT), cloud computing, SOA give rise to another industrial revolution. We propose here a concept definition, which focuses on data acquisition, integration and predictive control in the industry. The concept consists of industrial IoT gateway, cloud services and machine learning services. We used machine learning to verify our data acquisition solution and we implemented prediction control as a cloud service. Finally, proposed solution will exceed boundaries inside ICS (Information and Control System), improve flexibility, interoperability and test plant prediction control in smart manufacturing.

Keywords: Cloud service · Cyber-physical system · Gateway · Internet of things · Machine learning · Smart manufacturing

1 Introduction

IT is one of the fastest emerging field in the world and it influences a lot of revolution approaches in industry. The well-known industrial approach is Industrial revolution 4.0. The president and chief operating officer in Rockwell, Don H. Davis, Jr. describes industrial revolution principle in the meaning that the driving force behind productivity today isn't working faster, or cheaper, but working together.

Every industry is a heterogeneous system, which consists of many subsystems. Each subsystem consumes and produces data. Data, information and knowledge are the most important attribute in the ICS (Information and Control System). Therefore, working together between subsystems is very important in industry. There are lot of solutions, which solve cooperation in industry. The new approaches improve cooperation with using the newest IT trends. One of the most popular IT trends is IoT that deals with term working together [1,2,3]. IoT is named like IIoT in the industrial field.

Industrial IoT (IIoT) cares about low level devices. These devices produce a lot of data about processes in the ICS floor level. IIoT collects data and improves physical world digital representation of plant floor processes, machines. This representation of physical world is important to monitor, control and plan

ICS floor processes. IIoT plays a key role in fast data acquisition and data processing, what changed the machine-to-machine (M2M) and machine-to-human (M2H) communication in the industry. The artificial intelligence is used in process description and control [3,4,5].

The IIoT data has be transferred into higher layers of heretical ICT system. Plant is wide distributed heterogeneous system. It consists of many different devices with network communication interfaces, which are distributed across a whole plant. The data acquisition is problematic due the different distributed devices and their communication protocols. SCADA (Supervisory Control and Data Acquisition) uses M2M protocols, which are focusing on reliability and speed. The Service Oriented Architecture (SOA) improves the SCADA. The interoperability and flexibility is increased and some parts of ICS can be hosted in cloud, too. Nowadays, data from devices can be easily acquired into cloud system. Then we can use many cloud services for data storing, analytics, remote monitoring, management or control process [4,5,6,7]. As a result, the data acquisition, monitoring and control can be improved with the new IT approaches like IIOT, M2M communication, SOA and cloud. Where the flexibility, interoperability, modularity can improve whole ICS. We focus on data acquisition and better monitoring, control of plant floor processes. We propose data acquisition IoT gateway, which is based on M2M communication, SOA and cloud. We use machine learning to create a prediction model, which is published as a cloud service. This service is consumed by a control service, which uses IoT gateway to collect data from plant floor devices and send control commands to the plant floor devices. Finally, proposed solution will exceed boundaries inside ICS, improve flexibility, interoperability and test plant prediction control.

Paper consists of concept definition, which describes industrial IoT gateway, machine learning services, experimental application of our concept and final conclusion.

2 Industrial IoT and Cloud Services

CPS, IIoT, SOA and cloud are the key to the factory of the future. These technologies open plant floor data to every part of ICS system and help to make system “working together”. CPS and workers are connected together with IIoT and cloud services into one big network [8,9]. Position of CPS, IIoT and cloud services is presented in the Fig. 1.

Plant can be divided into Operational technologies (OT) and Informational technologies (IT). The OT consists of various devices or CPSs, which produce data and connect physical world with its virtual (digital) representation. The IT consists of systems, which consume data, process data and are hosted in cloud. Integration between OT and IT is realized with IIoT [11,12].

The IT is implemented like services in cloud. Services represent data acquisition with device connectivity (buses and queues), analytics (data analytics) and presentation & Business services (mobile and web services, storage, machine learning services, business services (ERP) and third party services).

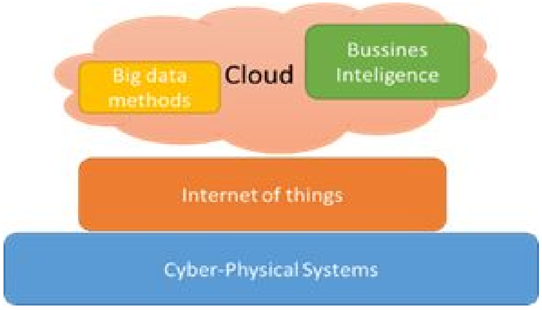

Fig. 1. Industrial connection with IoT, CPS, cloud, and Big data (Source: [10])

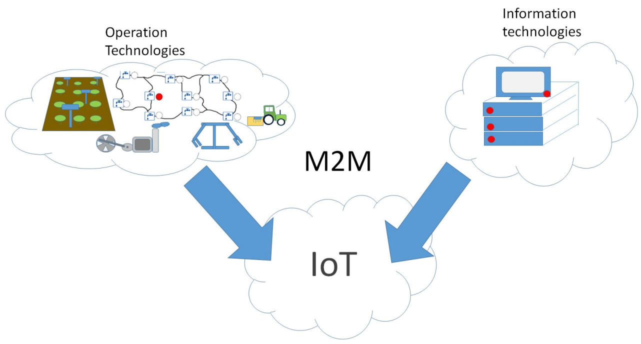

Fig. 2. IT and OT integration

Cloud services help to integrate data and create a digital representation of real processes. With such data acquisition based on IIoT, data can be centralized and processed very fast in the cloud. However, the data acquisition has big influence on service output quality [10]. For example, data analytics results might be evaluated wrong, because data are inconsistent or inappropriately sampled. Therefore, connection to the plant floor devices can be crucial. A lot of devices have specialized communication protocols, what makes data acquisition even more problematic and so exists a lot of field gateways and protocol adaptation solution to overcome this "working together" problem. Aim of this paper is to focus on data acquisition and data preprocessing due better data processing in analytics and presentation & business services

3 Concept Definition of IIoT Gateway and Predictive Control

We designed data acquisition and control concept to our problem. Our concept is presented like an architecture, which consists of OT technology represented by plant floor devices and field gateway. This gateway plays a role of mediator.

Gateway helps to create an abstraction of a real plant floor device network. The abstraction is used for better plant floor data representation without knowing the real network topology. The abstraction helps to implement better M2M communication and better understanding of plant processes. We focus on idea that data from abstraction can be analyzed with cloud machine learning services. This will help us to create predictive control. IoT hub service, stream analytics service and machine learning service represents the IT part. The result from machine learning is a cloud service, which cooperate with control service. This control service represents an adaptive regulator, which is using cloud gateway to control the agents in the OT. Proposed concept is based on SOA, cloud and CPS. We used these technologies to monitor and control of plant floor processes. We used IoT gateway and machine learning to collect data, integrate, monitor, process, analyze, predict, and future control. We divided our concept into two main subchapter IoT Cloud/Field Gateway and machine learning.

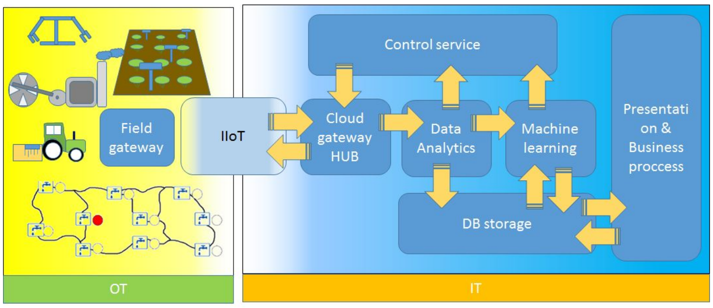

Fig. 3. Proposed architecture of IoT Gateway and Predictive Control

3.1 IIoT Cloud/Field Gateway

It already exists many devices and technologies, which connect individual subsystems to work together. They are called like a gateway or mediator. Industrial router, which is IoT field gateway. This router encapsulates industrial protocols and forwards data through the Ethernet interface. Such devices enable better interactivity with cloud services using M2M communication [10]. This type of gateway is a field gateway. On other hand, it exists software for IoT Cloud Software. The software enables to integrate production machines and processes with cloud service. It has a running instance in the cloud. This type of gateway is a cloud gateway. We focus on the interoperability with cloud services and low plant floor devices, which is based on services. The service interoperability is one of the SOA feature, which reflex the "working together" idea. Cloud services interoperates with relation, nonrelation databases, blob storages, third party services, web services and remote monitoring services. Therefore, the gateway is important in OT and IT integration. The proposed gateway can be implemented like a field gateway or like a cloud service gateway. The gateway concept definition and some results are published in [10]. Our concept helps to integrate network devices and data. It creates consistent and interoperable monitoring and control service between cloud and plant floor devices. The flexibility, interoperability, modularity is inherited from SOA [13]. The machine learning and predictive control are used to predict and control simple and predictable plant process. In our experiment, we selected a slow process due the cloud response time, which we had less than 1.1 seconds. The key role in monitoring and predictive control. Our next step is to improve plant floor device integrity and verified designed IoT gateway.

Today, the cloud system and some services has own graphical interface, which does not require a programming skills. What decreases implementation time and reliability [14]. Therefore, we would like to implement graphical configuration interface in our gateway in the future.

3.2 Machine Learning and Experiment Conditions

Enterprises want to increase performance and work efficiently, which is depending on machine learning and IIoT. Therefore, the data acquisition and integration are important for the enterprise. The machine learning predicts, prescribes and automates process in the plant. The prediction tries to describe behavior of the process in the future while nothing unforeseen will influence the processes. The prescription tries to offer better decisions, which are based on monitoring and recommendations. The automation tries control a monitored process in finding the best solution for each situation in real time. In this publication, we are focusing on the adaptive control with a prediction of the monitored process.

This part of concept receives data from data storage, IoT gateway or databases. The data are spited into train and evaluation set. Then we train model, which is used to predict process. After training and evaluation, we used this prediction model as cloud service. This allows better interoperability with other services in the cloud. The control service is a consumer of machine learning service, which offer process prediction. This prediction is used in adaptive control. The adaptive control is part of control service and its behavior depends on the prediction. The control service is used to control plant floor processes. The service sends control commands to plant floor devices thru the IoT gateway.

4 The Implemented Solution and Evaluation

We used the designed concept and applied it on the plant process. We focused on coke ovens that are one of the first production units in the steelmaking process. Blast-furnace coke or metallurgical coke is produced using the process of dry distillation of black coal in the ovens. For transport, coke needs to be cooled down with right amount of water. It is important to measure humidity in coke. We were not able to measure humidity of coke directly, because the coal is hot and moving. Therefore, we created model where we considered influence of atmospheric temperature on water evaporation from coal. Our experiment was realized in laboratory conditions. This use case is used as a proof of concept and it is not realized in all detail yet.

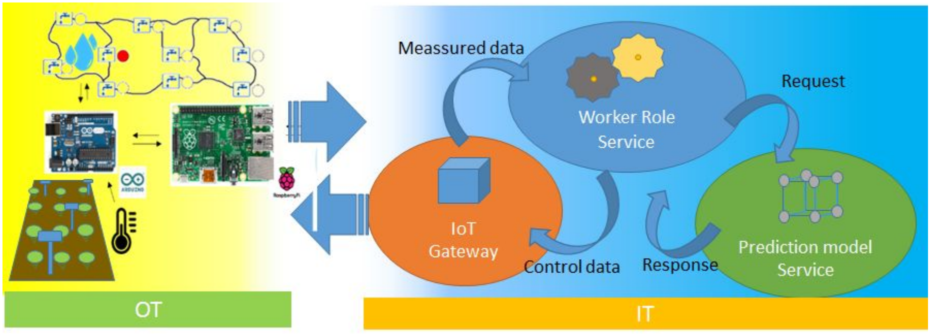

Fig. 4. . Real-time representation of the predictive control solution

We have collected temperature data, integrate with our industry IoT field gateway. The gateway communicates with cloud gateway. The cloud gateway transfers the data to the listeners (cloud service listener). In our experiment, the worker role service is the listener. The worker role service represents a control service in the concept. This service contains an adaptive regulator that control the irrigation systems.

We used nearest weather station which is collecting atmospheric temperatures. We took data from past 3 years and we have built a prediction model. Example of predictions from semi-skilled model is presented on the graph in the **Fig. 5**. The prediction model was deployed like a service in the Azure. This service is consumed by the Worker role service. Worker service has own adaptive regulator, which adapts according the temperature and humidity prediction. The adaptation changes a behavior of the regulator. The regulator can better react on the predicated changes. Temperature and humidity changes can be better handle with regulator adaptation. Robustness and precision of the regulation is based on the prediction. Finally, the control from Worker role service is sent thru the IoT Gateway to the field gateway. This gateway communicates with the irrigation system and control the irrigation.

This proof of concept is more focusing on the architecture. We want to show a cooperation between services, which influences plant floor processes. As a final result, the direct control OT is better to place closer to OT. Our controlled system had a slower dynamics. Measured 1.1 second delay does not have a notable influence in control. Therefore, we could use cloud control service, which represents a plant floor controller.

5 Conclusions and Future Work

The CPS, IIoT, SOA, machine learning and cloud computing are technologies, which improve data acquisition, data integration and changing data into infor-

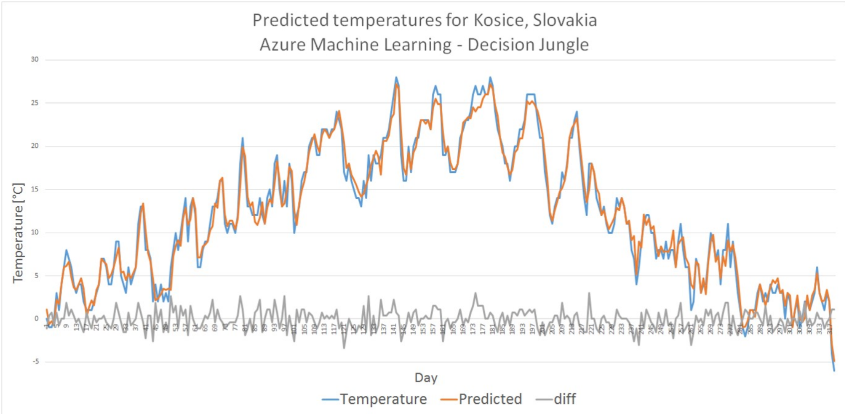

Fig. 5. . Real-time representation of the predictive control solution

mation and then into wisdom [10,11,12,13,15]. We focused on concept, which will improve data acquisition and control for smart manufacturing. We collect data into cloud - Microsoft Azure. We used our industrial IoT gateway, which collects and integrates data. After that, we used weather station data to build a prediction model for atmospheric temperatures. This prediction model was deployed as cloud service. This service is consumed by control service, which contains an adaptive regulator. This regulator adapts according data from service. On the other hand, control service controls plant floor process.

We want to increased industrial modularity, flexibility, efficiency, robustness and realize "working together" idea. Therefore, we have designed an IoT gateway and cloud services. The future work includes artificial intelligence methods and bigger amounts of data acquisition to better predicate and control processes. Our goal is to improve communication between services, machines and plant processes.

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