Developing Intelligent Machines with Smart Sensors for a Smart Factory

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Abstract- Smart sensors present a novel solution to the advancement of machines in a factory. Smart sensors take input from the physical environment and use the resources available to perform functions that are predefined upon detection of specific input and then process data before passing it on. This paper presents a detailed analysis of use of a smart sensor (temperature sensor) in a hydraulic fuel tank of a milling machine. This research has also collected a lot of information about application of smart sensors. A model of voice recognition system in a vending machine is also presented in this paper. Moreover, the case study presented in this paper proposes the solution to the overuse of hydraulic fuel (liquid), which eventually increases the lifespan of a machine. The paper also presents information about the role of smart sensors to form a smart factory. The result of the research done has presented many theories that will facilitate in future research in smart sensors.

Index Terms- Smart Factory, Industry 4.0, Smart Sensors, Cyber Physical System

I. INTRODUCTION

The performance boundaries of machinery are ever-expanding, and the components and processes involved in the combustion stage are no exception. In this information age, expectations on machine behavior has been increasing simultaneously along with information technology. Utilization of many smart components has been made in order to enhance the performance of each and every aspects of machine. Information from every sector possible are being embedded in present machineries. Trying to make the living easy, mankind has made it more difficult as numerous developments took place regarding appliances used in developing the world.

Automation has been a major topic of concern during this information age, as humans are not capable of performing actions as effectively as machines itself. Moreover, AI (Artificial intelligence) has taken over the world. So, smart factories have taken over the traditional factories in many manufacturing companies.

The developments in technologies have completely changed the world. Smart factories are the main pillar in making the vision of "anytime anywhere production" a reality– which means, smart factories are flexible and reconfigurable to support a large array of production processes and the products are smart enough to control their own production [1].

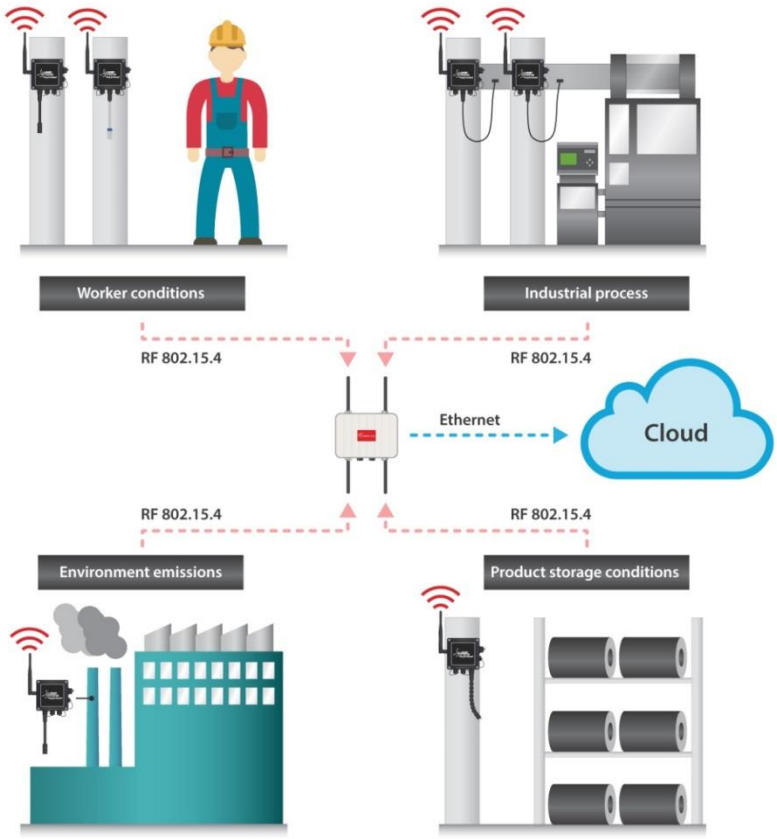

Figure 1 A smart factory system

Smart factories are a reality now. Smart factories help in reducing maintenance costs and ensuring quality in the manufacturing process. For example: Nowadays, furniture be configured on the Internet. People can freely select, combine, and ordere the dimensions, design elements and the type of wood they want. The customer order reaches the production system and the machines via the Internet. Intelligent sensors are embedded in the machines so that the controller can parameterize appropriately for the particular product and then automatically produce the desired piece of furniture. Using a closed loop feedback system, production, inspection, packaging and dispatch all take place according to the individual order – and without any manual interventions. This waw, the customer receives their personal one-off piece at the price of a mass-produced item.

II. Literature Review

Smart Sensor is a technique developed in the 1970's. During that time, processing capabilities was very far from the complexity needed in advanced warning systems and infrared surveillance. It was because of the enormous amount of noise/unwanted signals emitted by operating scenario especially in military application. Thus, this led to the development of smart sensors. The smart sensors technology was still restricted within a close military environment, finally exploding in applications and performances in the 1990s [2].

Smart Sensors are widely used in manufacturing industry these days. Research paper by Dargahi [3] includes the most recent advancements in the design/manufacturing of various tactile sensors. The paper also includes the applications od smart sensors in different industries. He presented the application of smart sensors in different fields like: medical, agricultural/livestock and food, grippers/manipulators design, prosthetic, and environmental studies. Robert [4] presented the reflections of structured working groups that are concerned with the problem of the definition of smart sensors and actuators. He also presented about the integration of these components into industrial processes. The concept of integrated smart sensors (ISS) is described by Huijsing [5]. When sensors and circuits are combined in microelectronic chips with standardized digital bus output, the concept is called ISS. The paper analyzed the fact that large-scale sensor applications can only be made economically feasible if the sensors are ISS.

With the development in technologies and globalization, local industries are challenged by products from all around the world. This has pushed the manufacturing sector to its next transformation – predictive manufacturing. In order to become more competitive, manufacturers need to embrace emerging technologies, such as advanced analytics and cyber-physical system-based approaches, to

improve their efficiency and productivity. [6] For manufacturing industries to be up-to-date with the existing technology, smart sensors must be installed in the industries.

Smart factory is a concept that came into light due to the globalization of manufacturing industries. Many factors led to the development of the concept: smart factory. Lucke [7] enlisted some of those factors:

- Trend in manufacturing systems design- sustainable design, ubiquitous manufacturing, emergent synthesis, service engineering, value creation, cost engineering, and so on.
- New applications for manufacturing systems – medical, life-science, optics, NEMS, etc.
- Intelligent use of advanced methods and new materials – new manufacturing process technologies, high-hardness materials, bio-medical materials, etc.
- Integration and control for new machines – compound machine tools, rapid prototyping, printing process integration, etc.

In agreement with Giachino [8], increase in the availability and numerous application of cheap sensors have allowed people to explore beyond their imagination the usage of smart sensors. In order to meet the designer's requirement, more advanced sensors are being developed. Sensors have been more enhanced in performance and cheaper as the production efficiency has been increasing simultaneously.

Sim [9] explains that new approach towards on-board computation and wireless communication capabilities has made quite a contribution in making the cost of smart sensors with reasonable price resulting more practical use on large civil structures as well. Also in accordance with J -M Favennec [10], technological advancement in the field of microelectronics has a huge impact on the innovation of intelligent sensor.

B. F. Spencer Jr [11] has analyzed how the Microprocessor and wireless communications equipped with smart sensors has the power to alter the vision on the monitoring and controlling the infrastructures around us. And as researched by him, a 2002 National Research Council report illustrated that the use of networked systems of advanced computers and sensors throughout the world could be able to dominate the human civilization.

In accordance with K Najafi [12], Smart sensors can be explained as those sensors which hand over analog or digital signals after receiving the input signal in various form, addressing and transferring data through a bidirectional digital bus and controlling and computing of the data generated by the sensors.

More emphasis can be paid to wireless smart sensors as well because, as according to Al-Ali [13], it is getting more popular in tele-monitoring, tracking, automation, and other industrial places. Wireless sensors are basically just a sensor without wires which are powerful enough to collect data regarding velocity, pressure, temperature, and so on which are very useful parameters in order to proceed in fields that work with cyber physical systems. Measurements from various channels and adjustments to support decision making can be performed using these sensors.

In accordance with IEEE 1451, Gervais-Ducouret [14] explains that smart sensonrs are the sensors with small memory and standardized physical connection which allows the communication with the microprocessor and the data network. According to Gervais – Ducouret himself, smart sensors are basically a combination of sensors which conducts signal manipulates embedded algorithms and has digital interface.

Not only in industrial areas, smart sensor has been playing quite a role in human kind and its health as well. As Quazi [15] explains, sensors capable of detecting emotions generated by human has been developed which are based on physiological parameters received by the sensors. Sensors are being capable of monitoring heart rate, skin conductance, and human temperature constantly. The signals gained by the sensors are then stored in the memory for further analysis and increase the probability by detecting obvious patterns. Many algorithms has been developed in order to reduce the error using clustering techniques and regression. Till now, the results have been fruitful and shows a positive potential in monitoring the physiological parameters.

In Laguerre neural network-based smart sensors for wireless sensor networks, as said by Patra [16], a wireless sensor network equipped with motes, which are simply nodes which communicates with other nodes from the data collected by the sensors. Since it is important for the sensor to provide the information as accurate as possible, careful attention shall be paid in harsh environments. And in order to accomplish that, Laguerre neural networks (LaNN) is used to adjust the nonlinearity automatically, and provide linearized sensor output regardless of the harsh environment. According to Robert [17], smart sensors and smart actuators are getting common in both daily lives as well as in industrial environments.

Previous researches in smart sensors have provided us with many information needed to perform this research. With the technological advancement, traditional machines are being replaced or updated to smart machines. As presented in the previous researches done by many researchers, smart machines are being developed with a lot of improvement in smart sensors.

III. METHODOLOGY

3.1 Smart Sensors

A sensor is a device that is capable of responding to a stimulus and produces an electrical signal that corresponds to the stimulus. Traditional sensors provide output signals which have to be interpreted further to understand what the sensors are registering. A smart sensor consists of a sensing element, a signal processor, and a microprocessor all coupled into a single system. [18] Traditional sensors are a part of an open feedback system, where the sensor does the required action, as predetermined, regardless of the present system. Whereas, smart sensors are a part of a closed feedback system, where the sensor only does the required action, in consideration to the present system.

The basic architectural components of smart sensor node is shown in figure 2. Changes in parameters are sensed by sensing unit, digital signals are generated by signal conditioning circuitry from electrical signal. Analog to digital conversion is performed and this input is given to processing units or application programs. Task processing is done by memory unit and communication with base station or sensors or sinks in Wireless Sensor Network (WSN) is done by transceivers. [19]

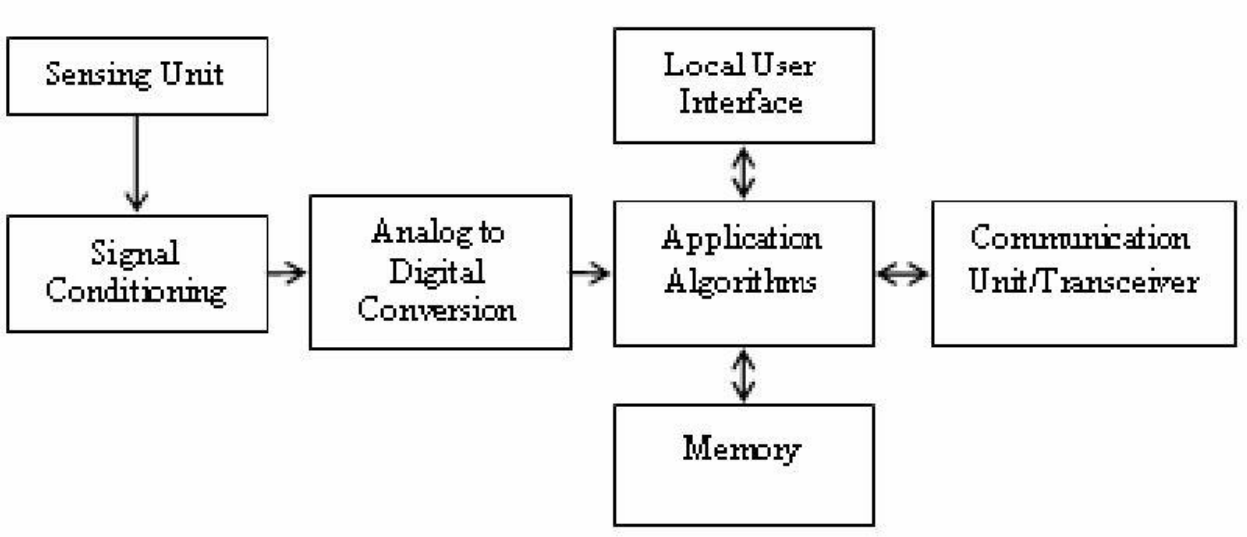

Figure 2 Basic architectural components of a smart sensor node

Smart sensor is a very important aspect for Industry 4.0. Use of smart sensors can ensure the Cyber Physical System (CPS) to be possible. CPS in a manufacturing system helps to attain the maximum performance of a system. New concepts such as Industrial Internet, Internet of Things (IoT), Cloud Based manufacturing and Intelligent manufacturing are designed for this digitally animated image and are usually accompanied by the concept of the Fourth Industrial Revolution or Industry 4.0 vision. All structures, internet and support technologies, human and machine agents, materials, products, production lines and processes, serve as the backbone to create new organizational boundaries and process the intelligent, connected and elegant value of the latest technological developments.

The advantages of smart sensors in manufacturing can be found in three categories, process monitoring and diagnostics, condition based monitoring, and product quality monitoring. [20] Smart sensor are able to recognize any deviation from the normal process parameters and take necessary control action. They also monitor the performance of periodic or continuous measurements on parameters that are used indicate the condition of a component. With the help of smart sensors, quality control of parts is also less time consuming.

Smart sensors are those sensors that hold embedded microprocessors and, hold the potentiality to monitor, examine and maintain a particular system. In other words, a smart sensor is a device that takes input from the physical environment and uses built-in compute resources to perform predefined functions upon detection of specific input and then process data before passing it on.
Smart sensors not only enable more accurate and automated collection of environmental data, but also have less erroneous noise amongst the accurately recorded information. These devices are used for control mechanisms and monitoring in a wide variety of environments including battlefield reconnaissance, smart grids, exploration and a great number of science applications. The smart sensor is also a crucial and integral part of the Internet of Things (IoT). Smart sensors can be implementated as one of the components of a wireless sensor and actuator network (WSAN) whose nodes can number in the thousands. Each of those nodes are connected with one or more other sensors and individual actuators as well as sensor hubs.

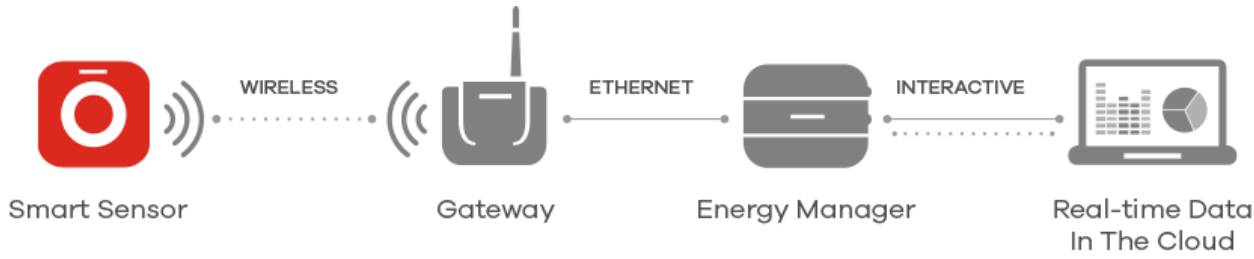

Figure 3 Smart sensors system

The smart sensors have wider intelligence ability when compared to the traditional sensors. This is the main difference between the traditional sensors and smart sensors. The common function of a normal sensor is to sense information and then transform it in the form of electrical signals. The normal sensors have three main parts which are

- Sensing element (Transistor, Capacitors, and Photo Diode etc.)
- Conduction of signals and processing
- Sensor Interface

3.2 Applications of Smart Sensors

Communication: Smart sensors are used to convey or exchange certain information. This is one of the basic applications of smart sensor as they provide information about possible thing that they are sensing.

Multi Sensing: Smart sensors are versatile They can sense more than one physical quantity or chemical reaction and then even transfer the electrical signals to the desired place.

Computation: Smart sensors can perform calculations to obtain a variable or deviation from the stipulated measurements. Even during extreme weathers or high temperatures, this is easily adapted by the sensors.

Self-Calibration: Smart sensors are different from traditional sensors mainly because of this reason. Traditional sensors cannot readjust themselves when initial adjustments were made during the input. Whereas, the sensors that have smart sensing abilities with the integral component microprocessors can make sure that the self-calibration property of the sensor is attained at the right moment with the right value.

Some examples of Smart sensors include: Optical sensors, accelerometer, Infrared detection array, integrated multi sensor etc.
Sensor node is a part of a smart sensor network. Energy efficiency in every parts of sensor network is very crucial for long network lifetime. Nodes in the sensor network cooperates and spreads the data processing task and sends the processed information to sinks. For reducing the overhead of power supply of each and every node, Radio Frequency Identification (RFID) chips with no batteries are developed. Sensors are used to monitor different parameters related to lighting conditions, noise levels, humidity, vehicle movement, soil makeup, mechanical stress levels, presence or absence of certain type of objects and other properties. [21]

3.3 A model of smart machine: Voice Recognition System in a Vending Machine

Implementation of voice recognition system in mobile phones are very common these days. Voice recognition system is one of the major breakthrough in information age. It has made its place in various fields including office, security system, and most commonly, cell phones.

It is a universal truth that oral communication is faster and convenient than any other ways. Whenever there is a presence of some uncertain events in front of us, our mouth is the one to play the primary role. According to some informal survey, it is seen that people are more prone to use voice recognition system for the task to be accomplished quickly than using hand gestures.

Time saving is the primary objective of a vending machine. Not only time, but by eliminating the shopkeeper and introducing automation, space can be saved as well. And in this developing world, each square inch of space is vital. It has been several years since vending machine has come into use. And throughout the years, various progress has been made in the way vending machine process.

In previous years, it had a different mechanism than it has now. Some of them were, when the payment has been tendered, a product was proceeded to the customer by:

- The machine releasing it in order for the product to leave its current position by opening of the compartment which might have been located at bottom of the compartment (like a small door).
- Unlocking of a door or drawer or turning of a knob.

In most of the cases of vending machines, products need to be prepared on spot. For example, coffee, or some other beverages. Much enhancement has can be seen now. As there are just simple buttons these days. And the payment procedure has taken a new level already, which is payment through cell phones using some simple application. Similarly, a progress can be made when ordering or choosing the product the customer desires.

As the customer or a pedestrian is felt in front of the vending machine by ultrasonic sensor, a microprocessor can be programmed and installed in the machine along with the speaker to greet the customer and letting the customer become aware that the machine is operating. After an input is given by the customer with his voice, the inbuilt voice recognition module takes the input and advances on the next step. Which is checking whether the voice matches the required frequency pattern of the words they need to say. After recognizing the pattern, machine does the operation, which is asking the customer for his final decision, i.e. asking ("Are you sure you want to order, for eg. Espresso"). After the second question, the customer as to answer for the one last time, which is saying yes or no. After receiving the required answer, the Machine asks the customer to complete the payment in order to make the required product, or to release the required product from the vending machine.

IV. Case Study: Temperature sensor embedded milling machine

Milling machines are used to remove material from a workpiece by advancing the cutter into the workpiece at a certain direction. The cutter can also be held at an angle relative to the axis of the tool. Milling covers a wide variety of different operations and machines, on scales from small individual parts to large, heavy-duty gang milling operations. It is one of the most commonly used processes for machining custom parts to precise tolerances.

Milling machines often consists of different mechanical parts. And new generation milling machines are embedded with numerous electronic parts as well. Some of the electronic system poses open loop control system while some has closed control system. Statistical data can be generated with the installed sensors and computer. The data might include running temperatures, vibrations, inner viscosity, and so on. There happens to be a number of sensors and actuators in the new generation's machines. Hydraulic system in the milling machines are one of the most important part. Specifically, hydraulic cylinders. Temperature sensor can be used to get some sense of the temperature of the hydraulic oil and the condition of the oil as well as the operating performance.

4.1 Smart sensors in milling machine

First of all, when it comes to milling machines, there are several factors that are required to be taken into consideration. Geometry and loading scenarios commonly employed in mechanical testing of materials are , a)tension, b)compression, c)indentation hardness, d)cantilever flexure, e)three-point flexure, f)four-point flexure and g)torsion. To perform all these actions, many things are required.

There are various equipments used for mechanical testin. The equipments range from simple, hand-actuated devices to complex, servo-hydraulic systems that are controlled via computer interfaces. A universal testing machine is a general purpose device that are used in common configurations. Modern test machines fall into two main categories: electro (or servo) mechanical (often employing power screws) and servo hydraulic (high-pressure hydraulic fluid in hydraulic cylinders). Digital, closed loop control (e.g., force, displacement, strain, etc.) along with computer interfaces and user friendly software are common. Different types of sensors are used to monitor or control force (e.g., strain gage-based "load" cells), displacement (e.g., linear variable differential transformers (LVDT's) for stroke of the test machine), and strain (e.g., clip-on strain-gaged based extensometers). Moreover, controlled environments can also be applied through self-contained furnaces, vacuum chambers, or cryogenic apparatus. Depending on the information required, the universal test machine can be configured to provide the control, feedback, and test conditions unique to that application. Even in this machine test, a hydraulic cylinders are used.

In this case, a hydraulic fluid in the hydraulic cylinders tend to last far longer than the fluid in the actual milling machines. As in the case of milling machines, the milling process is done more frequently and more number of times. Which means the operation or run time is much longer, which tend to heat up the fluid inside the cylinder. As the heat increases, the fluid inside the hydraulic cylinder loses its viscosity. And over time, as the viscosity of the fluid decreases, the smoothness of the system decreases and heats the inner surface resulting in small particles to erode. As this process keeps on going, replacement of the fluid must be done in order to run the machine smoothly and last longer.

But the problem in this scenario is that the operators are unaware of the time of replacement of the hydraulic fluid in a milling machine as it is one of the less frequently used equipment. So we need to figure out when to do such checkups and replacements.

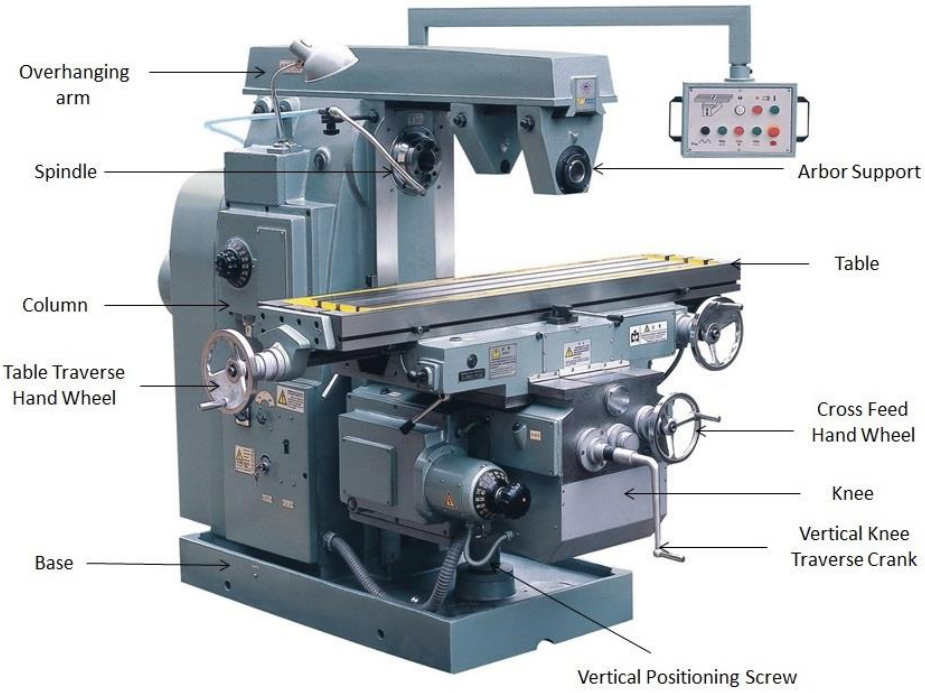

Figure 1 Milling Machine and its parts

4.2 Temperature sensor in hydraulic cylinder

Although timely servicing can be considered but when it comes to running the machine in a perfectly mannered way, strict checkup must be performed. One of the way to figure out the time to replace the hydraulic fluid is by taking statistical data over time to ensure that each part is being monitored. And that can be accomplished by using temperature sensor in the hydraulic cylinder.

By installing a temperature sensor in the hydraulic cylinder, data on the temperature can be noted down. Under normal working condition, it gives normal reading. Which means, the temperature goes on increasing as the machine is operating. Under many runs, lowered viscous fluid erodes the internal part of the hydraulic cylinder resulting in more heat generation and deformation in the system. Heat gets generated more because of the minute particles which are produced during the operation of the machine and internal heat. If these things are neglected, more heat will be generated and finally result in system failure.

By installing temperature sensor, the operator will be notified of the condition of the machine. The operator can observe the data and make technical analysis on when the hydraulic fluid and the filter must be replaced. Sensor which will be connected in a microprocessor will be pre-programmed in such a way that as the mean temperature reaches a certain value for certain duration, it will inform the operator or the factory. For example, let's say under normal working condition, the mean temperature goes from 80 degrees to 120 degrees, which has a mean of 100 degrees. So the fluctuation happens in the standard mean deviation of 20. The same data can be taken into account. So as the fluid gets old, the temperature in the system tends to increase because of some particles inside it which has been further burned because of the heat itself. So when the time goes on increasing, after several thousand hours of operation, the temperature graph shifts from the mean of 100 to 120 or more. But for this example, let's say the mean becomes 120 degree Celsius. In this case the temperature increase can be seen. So as this value is recognized by the processor, by using if and else case in the programming, the operator can be made alert by using some communication devices or switch or some sort of actuators. The basic idea is to notify the operator about the situation using sensor and a program through the processor.

If in some case the operator does not desire to replace and check the fluid condition by himself, CPS (Cyber Physical System) can be implemented. By doing this, the machine manufacturer can be directly informed about the situation or the condition of their machine and they themselves can come and do the entire servicing including replacement of hydraulic fluid.

V. CONCLUSION

Analysis of the case study presented in this paper gave a conclusion that a machine can run in a perfectly mannered way when smart sensors are used. Smart sensors like temperature sensor, pressure sensor, or motion sensor can be embedded in a machine to enhance the performance of a machine. This paper is mainly focused on the study of the smart sensors and their role for a factory to be a smart factory.

Additional research will be required to better understand the complex spatial and temporal characteristics of the smart sensors. More researches should be done in embedding different sensors to make machines smart, thus making a factory smart.

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