Are we ready for Industry 4.0?

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Abstract A significant number of manufacturing organisations are showing interest in Industry 4.0 due to the support it can provide for processing and visualising manufacturing data in real-time. Industry 4.0 techniques can be used to provide an assessment of machine condition by detecting and processing internal and external data of critical machine components. Currently, a few Small and Medium Enterprises (SME's) still use ageing and non-computer numerical control, manufacturing assets are operated and maintained without the use of digital technologies to monitor and report operating problems before they occur. Which in return, creates a significant barrier to the implementation of Industry 4.0 applications. In order to facilitate the implementation of Industry 4.0, on ageing, manual manufacturing assets, certain technologies associated with the third industrial revolution, including electronics and information technology, should be examined.

This paper presents the implementation process of an automation system for monitoring and control of a hydraulic press by firstly examining the required electronics and information systems for processing data and secondly by defining the needed tools and techniques associated with Industry 4.0 applications and the related implementation barriers.

Keywords: Industry 4.0; Automation systems; Condition Based Maintenance; Automation system integration

1 Introduction

Through the decades, the manufacturing industry placed a heavy focus on the continuous introduction of technological advancements, aiming to improve production quality, speed, reliability, availability and efficiency indexes. Recently the term Industry 4.0 had emerged gaining significant attention and interest from organisations [1]. The term Industry 4.0 was introduced in 2011 by the German government, placing the foundation stone for the fourth industrial revolution.

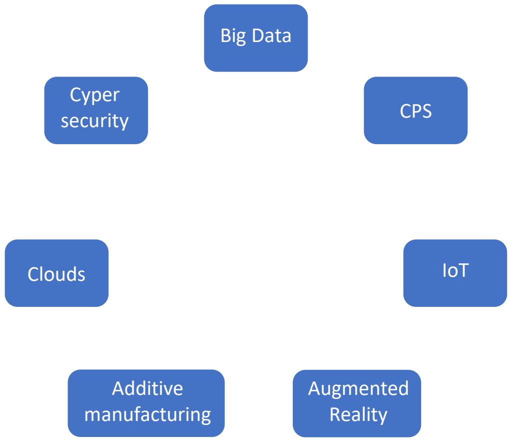
To understand the development of the fourth industrial revolution, the history behind it needs to be understood. The first recognised industrial revolution was in England between the 1780s and the 1870s. The first revolution was based on the introduction of steam enginesas , a different power source than the use of manual labour. . The Second industrial revolution took place from the 1870s to the 1960s in a broader range of countries including England , Germany and the United States. The second revolution involved a wide range of development and advances to Industry. Such advancements included the introduction of Electricity as different power source alongside the introduction of mass production, which triggered the implementation of production lines and automatic operations by using electric circuits to increase productivity rates. Aiming for more advancements in machine control, the Third industrial revolution began in the 1960s and introduced the use of electronic ccontrollers and[c1] computer programs for machine control, aiming to increase productivity and Machine efficiency alongside decreasing the workforce required for operation. The first three industrial revolutions had a significant effect on the manufacturing sector that always targeted simplifying the production process, increasing productivity [c2]with the highest quality within controlled cost. The Fourth industrial revolution (Industry 4.0), introduces digitalisation into the manufacturing sector, Introducing technological advancements in connectivity and data processing techniques [1-3].

Table 1. Industrial revolutions

Revolution	First introduced	Main novelty
1st	1780	Steam engines and mechanical loom
2nd	1870	Electric motors and petroleum fuel.
3rd	1960	Computerised systems and robots in the industrial production
4th	2011	Computers, Internet and automation combined.

Industry 4.0 presents areas of interaction with the manufacturing process from different focuses through the introduction of Cyber-Physical Systems (CPS), the Internet of Things (IoT), Big Data, Cybersecurity, Clouds, Additive manufacturing and Augmented Reality (AR) [4].

Chart 1. Industry 4.0 engines



This new paradigm introduces a new manufacturing environment that includes high connectivity between systems and machine independency in decision-making processes. However, to facilitate the use of the new industrial advancements, significant changes in the manufacturing process and existing machinery must take place, which is associated with the high-cost impact that is not feasible for most manufacturers.

Individual aspects of Industry 4.0 could be integrated with existing manufacturing equipment based on the areas of attention of different manufacturers. Internet of Things (IoT) provides a high level of connectivity and data exchange process between different machines in a local network level or over the Internet. (IoT) Is considered one of Industry 4.0's main enablers for further implementation of different Industry 4.0 technologies. However, (IoT) applications require a minimum level of technology and connectivity that must exist at machines' level prior its implementation [5].

Condition Based Maintenance (CBM), is an advanced maintenance optimisation strategy that uses different sensing tools. Such tools varies between temperature, vibration, pressure, humidity, speed, etc., based on the machine's types to monitor the state of different parts of the system. Sensing tools for CBM developed over the years from using Hand-Held Devices (HHD) to apply checks on a scheduled basis, towards the use of continuous monitoring tool permanently attached to the equipment, continuously collecting data about the Machine's state and condition. Such technology was introduced as part of the third Industrial revolution using sensing devices to continuously send data to the primary computing device, creating a smart system capable of processing data that monitors different parts of the equipment, analyse them, and take the proper actions that suits the manufacturing process [6,7].

Given the significant interest from Small and Medium Enterprises (SME) in Industry 4.0 applications as a condition monitoring enabler, this paper will presents the implementation of an automation system for monitoring and control of a hydraulic press. The application is considered the initial integration phase to adapt the integration of Industry 4.0 technologies. Such work will be carried out by firstly, examining the required electronics and information systems for processing data, by defining the required tools and techniques associated with Industry 4.0 applications and the associated implementation barriers.

2 Literature review

2.1 Industry 4.0

A technological advancement introduced as a complex system aims for connectivity between different devices, collecting real-time data from sensory devices, using machine intelligence to create Machine's decision-making applications based on the collected data analysis [8]. Elements that characterised the fourth industrial revolution were the integration of Information and Communication Technologies (ICT), Cyber-Physical Systems (CPS) and the Internet of Things (IoT) [9]. Continuous improvements in digitisation in the manufacturing process was the main contributor to Industry 4.0 existence [10].

Industry 4.0 aims to facilitate flexible, controlled manufacturing processes with real-time data collection and analysis aiming for improvements on the decision-making process on both strategic and operational levels [11]. Developments in ICT and the availability of affordable sensing tools facilitated their spread around the manufacturing sector, forming interconnected systems [12]. Such systems provide continuous monitoring and machine's control alongside the production processes with continuous updated virtual models about the current status of the Machine and its internal parts [13]. Industry 4.0 was predominantly created by the CPS integration in the manufacturing process as well as the industrial processing using the IoT connectivity [14].

In order to establish efficient Industry 4.0 environment, Frank [15] presented six different principles highlighted as crucial enablers for Industry 4.0 as follows;

Table 2. Industry 4.0 principles

Principle	Description
Interoperability	System, people and information connected to allow information exchange between machines, processes, interfaces and people.
Real-time operation capability	On time data exchange mechanism to enable immediate actions to take place.
Virtualisation	High use of sensor allowing remote monitoring and tracking of all processes.
Decentralisation	with machines allowed to send, receive commands and process information regarding their work cycle forming a decentralised work environment.
Service orientation	The use of service-oriented software architectures in alignment with the Internet of Things (IoT).
Modularity	Allows tasks changing for the machines in an easy and flexible way.

2.2 Industry 4.0 vision

The technological aim of Industry 4.0 is to connect all existing machines in the manufacturing process together in a network of exchanging data, taking decisions and triggering actions independently without any human interaction through decentralised systems creating smarter production processes [8]. The industrial paradigm is described as a result of the improvement of the in digitisation and manufacturing automation linked with various communication methods developed [16]. According to Pereira [8] from different researchers' and companies' perspective, Industry 4.0 vision towards the manufacturing industry included Smart factories and Smart products. Smart, in terms of different researchers' points of view, indicates machine's independence and self-awareness of its own state with real-time communication between it's different sensing and actuation components and other smart machines, deciding and acting independently based on the exchanged data [14]. Additionally, Smart factories are associated with the use of digitisation and the advancements in ICT to create smart machines aware of their own state (self-controlled) and other smart machines connected, forming a smart factory. Addressed as key technological enablers of Industry 4.0, CPS and IoT are considered base requirements for the adaptation and use of Industry 4.0 applications.

Cyber Physical System (CPS). Cyber Physical Systems is an emerging term that is widely used as one of Industry 4.0's key enablers that represents technological advancement in ICT. Based on the interaction between the physical and virtual worlds, CPSs provides machine's self, controlling and monitoring functions, and coordinate the manufacturing process. CPS connects machine's automations systems with programming and analytical software to continuously study the machine's current status and control the operation based on the existing conditions. Monostori [17] described CPS as an embedded system that exchange data in a smart network. When the different CPS systems are connected in a higher-level network, it is frequently known as the Internet of Things (IoT).
Different communication protocols connects different industrial devices together. OPC-UA, MODBUS, PROFIBUS and CANopen are examples of existing protocols. An IoT enabler device, Industrial Gateway, is able to communicate through a wide range of the existing protocols, allowing it to process data from wide range of systems to form into one system [18]. Luis Lino Ferreira [19] presented CPS as a system that consists of the real time levels from the Industrial automation, Field, Direct control and supervisory control levels, with real time data processing software developing more machine's intelligence and on time assessment of collected data by system.

Internet of Things (IoT). A common term that highlights the connectivity between the different actual things and the internet. Continuous developments in computers' interconnections became widely emerged, taking it to the next level of creating smart objects. CPS as an industry 4.0 engine, creates smart systems capable of monitoring and control of its process, taking it to the next level. IoT facilitates the connection between different CPSs in a smart network sharing information together. In addition, IoT adapts wide range of communication protocols that suits the nature of any CPS for data exchanging process [8]. Moreover, integrating all physical objects into the information network assist providing services to the smart objects connected to the internet for information exchanging process [20].

2.3 Industrial automation

Described as the third industrial revolution engine, that is identified as an arrangement of a set of technologies resulted in industrial machines' monitoring and control with minimum human interaction with the process [20]. According to Omer [21], Industrial automation consists of five different levels which are;

Field level. Contains two major areas, sensing devices and actuators. Sensing devices carry out different monitoring applications of the system's different parts using different sensing devices. Actuators, on the other hand, converts the controller's signal into physical output.

Direct Control level. The sensory data and the actuation signals gets processed using generic software. The software process the logic operations by operating on industrial hardware like PLC and Industrial PC.

Supervisory control level. Provides real-time monitoring and control of machines. Supervisory systems can provide variable Machine's setpoints capability, which provides flexibility to the operating conditions.

Production control level. Fully covers the manufacturing operations from production, quality, inventory management and maintenance perspective.

Enterprise control level. Management focused operation for scheduling manufacturing operations.

Field, direct control and supervisory control are real-time machine operation levels. They provide instant feedback and decision-making process within machines. On the other hand, Production and Enterprise control levels are management applications which focus on data processing and analysis for process and services optimisation applications. However, they are not real-time applications like the first three levels.

Advancement in Communication and services technologies resulted in a Service Oriented Architecture (SOA) paradigm. SOA applications link all the Automation systems levels together in a real-time process, providing interoperability and interaction among different industrial levels [22]. OPC-UA is an SOA for industrial automation that focuses on machine-to-machine communication, providing scalability, data automatic buffering, device discovery and security [23].

The current study presents the implementation phase of Automation System on Field, Direct control and supervisory control levels on a hydraulic press machine exists at a Medium size company from the Aerospace Industry. The system aims to use Programmable Logic Controllers (PLC) and Human Machine Interface (HMI) integrating number of sensory devices aiming to implement the foundation for CPS with communications capabilities for data exchanging with supervisory systems or different machines.

2.4 Condition Based Maintenance (CBM)

The development of maintenance strategies over the years has focused on studying a machine's condition, history, its operating conditions, etc., in pursuit of the optimum maintenance schedule for the Machine. Aiming to eliminate breakdowns, excessive maintenance applications and increase availability and efficiency within controlled cost. CBM methods and tools that have been developed had different Analytical and non-Analytical elements to identify and reach the desired output [24].
CBM, presented a new perspective on how to gain more understanding and control of the manufacturing assets internal parts' conditions. CBM relies on modern technology in sensing and identifying the current condition of an asset. Modern technology provides different sensing tools including Vibration, Temperature, Pressure, Noise, etc. These tools suit different machines depending on their criteria and operating condition [7]. Condition monitoring applications in-case of using HHD takes place on a scheduled basis using special sensing tools or on a continuous basis in-case of using fixed sensory devices on the machines. In addition to CBM advantages, it

helps reducing Machine's breakdown rate and downtime using early warning system. CBM can provide a safety measure to warn the operators and stop the Machine when it reaches certain predefined levels of the existing sensory devices. which in return, helps the maintenance team to take the necessary precautions to avoid Machine's breakdown.

According to Shin [7], maintenance is associated with three main aspects that are considered the main pillars that define the necessary maintenance schedule;

1. *Detection*, Occurred failures identification

2. *Prognosis,* failure prediction over a certain time.

3. *Diagnostics,* deteriorating components and/or their root cause identification.

Small and Medium Enterprises (SMEs) experience the ownership of machines with different ages that were bought over the decades[c3]. Such machines have different control systems that vary between manually operated, semi-automated and fully automated systems, with various operation's technologies. To establish a sufficient ground for Industry 4.0 applications to take place, a certain level of technologies inherited from the third industrial revolution, Automation systems, have to exist. Automation systems application is conducted on aged manufacturing asset, Hydraulic press, that lacks for any sort ICT technology for monitoring or control. The hydraulic press under study relies on technology from the second industrial revolution for its operation of using mechanical relays and electrical switches for operation. The applied Automation system is associated with the HMI screen for condition monitoring and control of the press. All the existing control devices that exists on the Machine whether they were buttons, Indicators or switches, are replaced with the suitable alternatives from Automation perspective. Mainly, the press's monitoring and control applications are designed to take place using physical buttons and attached HMI screen.

Fig. 1. Press machine

3.0 Application phases

3.1 Phase 1 investigating

Investigating the hydraulic press understudy in depth. initially, studying the Machine from Mechanical, Electrical, Hydraulic and Control perspective. Mechanical area [c4]included, inspecting the press chassis for any visible cracks or breaks, the ram state and motion with the associated parts, Electrical area included the existing motors, pumps, fans, sensors and switches for their integrity, their specifications and their connections' requirements, Hydraulic area included hydraulic fluid, Directional Control Valves (DCV), fluid lines and the hydraulic operation sequence. Control area, focused on Automation system requirements from Actuators, sensory devices from control and monitoring perspective. Additionally, investigating the quality and integrity of all Machine's parts is essential to ensure the Machine is within the operating condition to ensure the highest safety measures.

3.2 Phase 2 guard system design

As safety is an essential consideration during the Automation system planning phase. Aiming for highest safety precautions, a pneumatic operated, PLC controlled guard door designed for the press, isolating the press machine from any human intervention during operation to ensure maximum safety and security of the press. The door pneumatic position detector fixed inside the pneumatic cylinder for continuous feedback about its locations whether it was open or closed.

3.3 Phase 3 Requirements Identifications

Following studying the press in-depth, investigating all related aspects from an operational requirements point of view, suitable electrical components that facilitates the delivering the designated power for each component of the press were selected. From the Automation control point of view, Selected PLC and HMI screen for machines monitoring and control were selected supporting OPC-UA communication protocol for future integration with other software or systems.

3.4 Phase 4 Monitoring tools

Focusing on having deep monitoring practices about the press's different parts conditions for condition monitoring and early failure detection, existing sensory devices at the Machine were used alongside in addition of extra sensory devices for more insight about different parts of the Machine. For the press under study, Hydraulics’ fluid pressure and temperature sensors originally existed with fixed operation setpoints, without feedback mechanism. Further sensory devices including temperature and detection sensors were selected for addition on the main motor and around the Machine for monitoring the main motor’s temperature and the surrounding area around the Machine. In terms of Machine's condition and operability; differences in pressure or temperature at different parts can work as an indicator of unusual behavior, which if spotted on early stages, failures could be prevented. Monitoring the guard door status is Included in the HMI screen program to increase security level through continuous feedback on its location.

3.5 Phase 5 Programming

PLC and HMI programming were undertaken using Ladder Logic Diagram (LLD) language. System program is the system's intelligence that facilitates machine's self-control and monitoring applications without human interactions. Programming phase creates the machine's operation sequence by controlling the existing actuators, motors in the current cases, based on different sensory data collected from different parts of the Machine. Virtual version of the press was created on the HMI screen, presenting the status of different parts of the press including, hydraulic fluid pressure and temperature, the status of different safety measures regarding including the guard system, the modification ability for the threshold of the different measures undertaken.

4 Results

Studying the Press machine in-depth resulted in an understanding of all the related aspects of the Machine and allowed examining the integrity of different parts individually. Recommendations for the full replacement of the hydraulic sealings, hydraulic lines and hydraulic fluid were presented to ensure high operation quality.

The main barrier faced at the initial stage was the limited background information and data about the press from a technical point of view. Machine's documentation usually includes the different parts of the machine and the required power loads for each motor, pump, valve, sensor, etc. Unfortunately, press’s documentations did not exist as they were never received from the previous machine’s owner. Investigation into all different components and their specifications through the collection of the information plates pinned on each component individually to overcome such issue. Gathering all the required data about every part at the Machine allowed the choice of suitable power supply and connectivity requirements.

The choice of certain models of PLC and HMI was carried out based on suitability to integrate all different [c5]parts of the Machine that included, Different motors, Pump, sensory devices, brakes system, control valves and developed safety system from one perspective, and connectivity capabilities to exchange data between different systems using advanced communication protocol including OPC-UA from another prospective. Programming carried out using LLD language of programming as a simple graphical language chosen due to its ease to use to allow staff future engagement with the Machine in failure detection or development phases. Virtual image of the press was created on the HMI screen for different monitoring and control applications.

Fig.2 presents the Electrical Control panel (ECP) developed for the press machine. Designed specifically based on the Machine's components specifications, ECU connects all machine parts together, sensors and actuators, to monitor and control the Machine's operation cycle. The ECP includes the PLC that controls all associated machine’s parts via a series of connections.

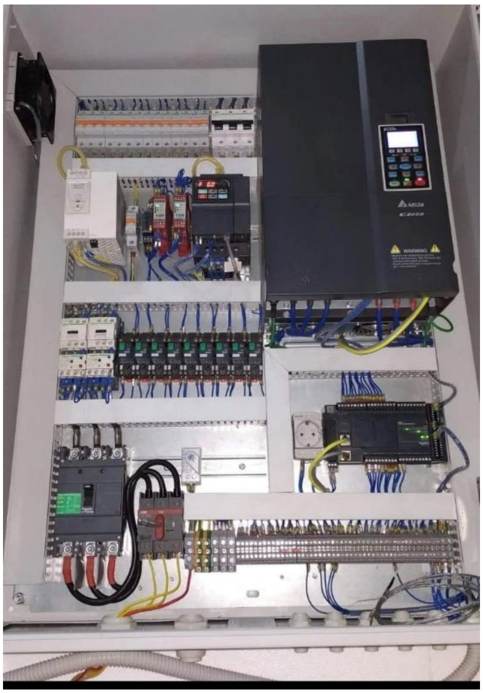


Fig. 2. Developed Control panel

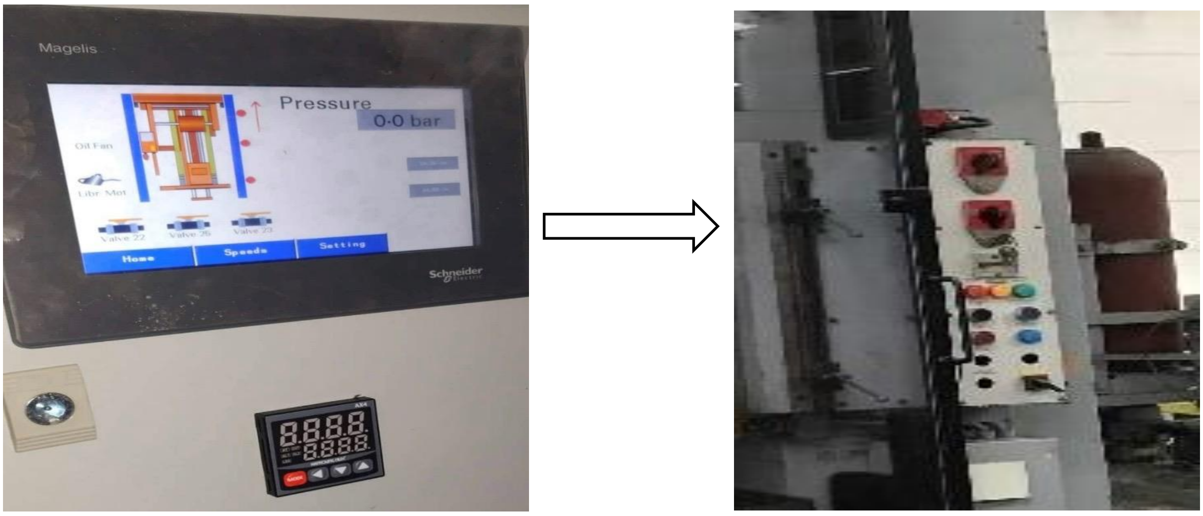


Fig. 3. Integrated HMI screen (left) and old control system (right*)*

Fig 3 presents the replacement of the original control system for the Machine (Right), with the developed HMI screen that facilitates wide range on monitoring and control applications for the press with [c6]operations' conditions that could be customized. The developed system presents continuous feedback regarding the status of the guarding system, the hydraulic system components including, valves actuation and status, hydraulic fluid pressure and temperature and hydraulic ram position. Alarming system monitors the status of all Machine's parts included in the developed system. Two different modes of operations were included, testing mode and normal mode, testing mode is used for maintenance applications by sending feedback about all the different related parts individually using low power and speed. normal mode uses the user-defined pressure and speed data. Fig 4 presents a different page of the program developed shows different indicators of the Machine's parts. In addition, communication setup to Supervisory Control and Data Acquisition (SCADA) or IoT gateway through OPC-UA communication protocol was considered and included in the programming phase for following development phases of connecting the Machine to different systems or apply machine-to-machine connectivity for data exchange.

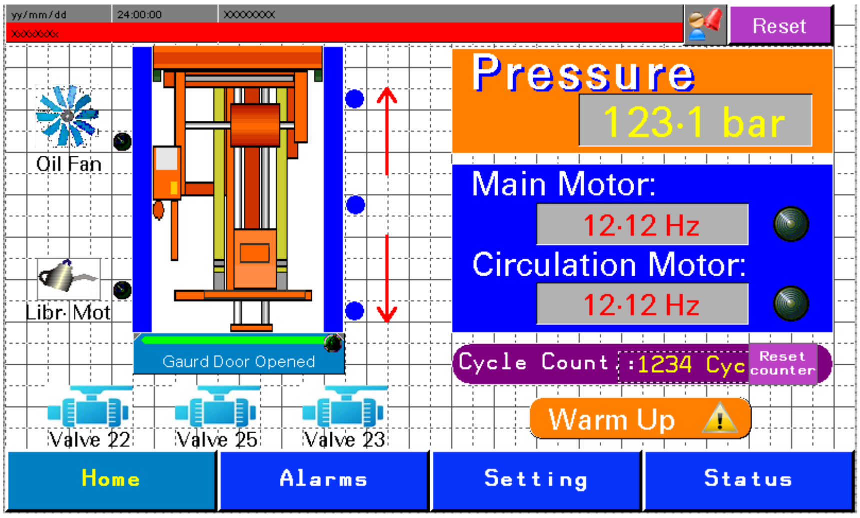


Fig. 4. Developed control system on HMI screen

The image above is the developed system replaced all the existing control and power control systems for the Machine. Figure (3) shows the old and initial control system that existed, and the new developed system using the HMI screen on the left. The developed system facilitated monitoring and control applications for the status of the different actuation positions, temperature, pressure, guard door status, variable pressure and temperature threshold setups for alarming and operation requirements included in the system. The use of HMI screen provides insight of the machine condition with continuous monitoring for the hydraulic pressure and temperature in the system, and ability to change operating conditions based on the required setups rather than one operation setup previously. The system designed and programmed to construct a fully automated system that performs the pressing task individually based on a sequence of checks to ensure suitable operation condition without human interaction.
Pressure and temperature values are stored internally inside the system using storage space for further analysis.

4.1 Application barriers

Initially, data collection phase was extremely delicate process. That was due to the lack of documentation existence, which added further investigations and research about the different Machine's part for proper allocation of the required electrical and control related parts for the Machine. Deep experience level from the engaged staff from different levels was highlighted as almost to non-experience about the machine or automation systems, which created many difficulties across the phases to direct the engaged staff to the right path. The company aimed to designate a low fund for purchasing of the press machine, which resulted in different areas needed refurbishing and examination for quality before carrying out the work.
The low budget in place for the project was limited, which resulted in the use of overseas supplier for the different components. The practice was effective and the project was carried out successfully with much lower price than local suppliers, however, delays in delivery and communication issues were a common issues took place.

5 Future work

The developed system integrated the base requirement for the integration of Industry 4.0 applications. Data analysis programs and communications applications to different systems are now feasible to take place on the system.

6 Conclusion

Interest in Industry 4.0 and its applications in machines' real-time condition monitoring of their internal parts and daya analysis application started to emerge among SMEs [c7]from various manufacturing industries. However, to facilitate the applications of Industry 4.0, a certain level of technologies associated with the third industrial revolution needs to exist in the manufacturing assets. a significant number of aged, manually and semi-automated machines exists on various production sites and have high importance to the organisations. An application for the integration of Automation system in a Hydraulic press at Aerospace components company was conducted using different sensing tools, pressure, temperature, objects presence for continuous monitoring and control applications of the different parts of the Machine using PLC and HMI screen. The system can detect any anomalies in the status of the connected components form the normal conditions using the sensory devices and react by sending alarms and bring the Machine to a stop to prevent breakdowns. The developed system can connect to different data analysis programs for the formation of a full CPS system, and the communication to supervisory systems or different systems for machine-to-machine applications. The implementation of such application could have a positive financial impact only if the machine's is within good operation conditions prior the upgrade. In addition, a sufficient background examination and identification of machine's different parts' specifications and the proper choice of suitable electronics is vital to ensure sufficient implementation. For the consideration of future Industry 4.0 applications, spacing for the associated electronics e.g. Industrial Gateway and Network router, connectivity mediums e.g. Internet cables, Wireless transmitter should be given attention in future planning.

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