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Turning a Legacy Robot to Collaborate to Fit in Industry 4.0 Demands

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Introduction

Robotic machinery and programmable logic controllers (PLCs) have been the workhorse of industrial manufacturing for a long time [1]. The emergence of industry 4.0 has revolutionized the progressive manufacturing, however there are many industrial sites that rely on their working legacy programmable machinery, yet. Replacement of these legacy machinery with industry 4.0 compatible equipment is very costly and perhaps many of the industrial manufacturing sites cannot afford a sudden shift to industry 4.0. Accordingly, a transitional model is required until complete shift to industry 4.0.

Industry 4.0 targets important objectives, such as improvement of production efficiency, increase of production speed, enhancing the production reliability and quality for better customer experience, production automation, and integration of manufacturing and supply-chain [2]. Machine to machine (M2M) and machine to environment (M2E) communication are two requirements for production automation and production efficiency improvement. Therefore, turning the legacy non-collaborative robotic machines to collaborate with the environment and the other machines is one of the important changes that is needed to adapt these legacy machines to industry 4.0 [3,4]. For this purpose, each machine needs to be equipped with sensing and proper communication facilities to have a meaningful sense of the environment and the other working machines. For this purpose, sensors such as proximity sensors, accelerometers, vision sensors and cameras, temperature, gas, humidity and dust sensors, etc. might be considered. The higher reliability of wireless over wired communication due to the absence of cables and connectors and its mobility, makes wireless communication more desirable in most of the cases. Accordingly, wireless sensor platforms with their small formfactors are proper candidates for sensing the work environment. The variety of possible wireless technologies such as IEEE 802.11 WiFi [5], IEEE 802.15.1 Bluetooth [6], narrow-band internet of things (IoT) [7,8], LoRa [9], 4G and 5G [10] are just among the possible solutions for wireless access. The variable signal performance and data rate, and co-channel interference among the co-existing non-coordinated network users is one drawback of using contention-based wireless systems. To avoid this problem, NB-IoT, 4G and 5G technologies are suggested for sensitive applications.

To share the sensor observations with the robot controllers, a direct or indirect communication link is needed to be formed. Due to the absence of this link, using a cloud-based internet of things (IoT) service is one possible solution as an intermediary service to share the sensor's data with the robot controller unit. Adding a programmable network interface to the legacy robot controller unit allows to access to the sensors' data that are stored over the cloud, and these data can be used to control the robot's motion based on the collected data.

The rest of this paper is organized as follows. In the next section the problem statement will be given, where it follows with the proposed solution and methodology. Then, the four implementation phases of the proposed solution will be discussed. Finally, the experimental result from the implementation of the proposed system will be presented.

Problem statement

Industry 4.0 influence in manufacturing sites is getting prevalent, worldwide. However, there are a large number of working legacy robotic machines that have no sense of their working manufacturing environment. These robotic machines need essential change to be compatible with Industry 4.0 requirements. For instance, they need smart sensing, computation and communication capabilities, where it would be difficult to augment in their legacy structure.

Recent advances in information technology, computational intelligence, sensing and communication, however have provided this opportunity to renovate the legacy machines so that they can collaborate with their work environment. Cloud computing, machine learning, low-power wireless communication technologies and smart sensing are among the technology advancements that allows industry to define a transitional solution and let the legacy machinery be used for a longer time until complete replacement for original industry 4.0 systems.

This paper reviews the process of an experimental work in adapting a non-collaborative robot arm to collaborate with the environment as one step towards adapting legacy robotic machinery to industry 4.0. For this purpose, the emerging technologies such as cloud computing, internet of things (IoT), machine learning algorithms, and distributed wireless sensing have been used [4].

Methodology

Before discussing the methodology for the introduced problem, let’s look at the definition of industry 4.0 and its requirements. Several definitions have been given for industry 4.0 in literature, however a simple definition for it would be the emerging automation technology by involvement of modern technologies, such as machine to machine communication (M2M), industrial internet of things (IIoT), machine learning algorithms, etc. by adding smart sensing, cognitive computation and communication to the industrial platforms and systems, in order to improve production efficiency, delicacy, safety, etc. with minimal involvement of human-beings [11].

The legacy robotic machinery lacks majority of the assumed requirements of industry 4.0, and they normally have no sense of the work environment or the other working machines to collaborate with. Increase of the production efficiency and safety demands collaboration with the environment, where it needs smart sensing, cognitive computation and communication. Smart sensing is the feature that allows the working robot arm to get a correct sense of its work environment. Cognitive computation is what it needs for filtering of the sensors’ data and fusing them together for a meaningful outcome; and communication is required to connect the added sensors in the work environment to the computation unit and the robot arm.

Legacy robotic devices suffer from lacking of understanding of their work environment. In this paper, cloud computing and internet of things are introduced as technology interfaces between legacy robotic devices and the environment or the other machinery in work area. Wireless sensor platforms that can sense the changes in work environment share their sensor observations with the robot control system by storing the information over the cloud. A replacement for the robot control system that has networking capability can read the sensor’s data from the cloud and controls the motion of the robot, accordingly.

This in-progress project was implemented in four phases that will be discussed throughout the manuscript. These phases are i) planning for the required sensing and communication, ii) design approach for data storage and visible cognitive computation, iii) using an industrial hardware platform with networking facilities that will be substituted with the conventional robot arm controller, iv) selecting a proper programming language to control the robot arm accordingly. The procedure of the experiment in this paper is with the criteria of having a limited budget and using the scalable devices and algorithms.

The limitations of the proposed approach such as latency, possibility of fault occurrence and its compatibility with variety of the legacy machines will be discussed later in another paper and solutions will be postponed for future work. The proposed approach is comparable with the open source robotic concept that was introduced in the past recent years and may even be combined to it under a more general definition and expected capability. In this project one MECA-500 mini robot arm was used for implementation of the approach.

Implementation phases

i) Communication and sensing

One necessary requirement for collaboration between the robot arm and the environment and possibly the other machines is smart sensing. Varity of sensors for detection of proximity, motion, distance, touch, color, material type (metal or non-metal), gas presence, pressure, speed, range, etc. can be imagined to add to the work environment. One or more types of these sensors send their sensor observation for processing and data logging in database. The communication device that is usually wireless transmits the sensor’s data to be stored in a database. Luckily, there are easy to program and cheap microcontroller boards with several wireless communication capabilities that may be used for indoor or outdoor applications. The sensors are directly attached to the microcontroller board to send their collected data to the data processing center via any one of its available wireless communication means.

For this project, after extensive investigations, ESP 8266 microcontroller with WiFi access capability was selected. One ultrasonic sensor that could detect the presence of an object in its vicinity, was directly attached to the microcontroller board to form a wireless sensor platform. Based on measurements, the ultrasonic proximity sensor could detect the presence of objects and persons in the range of 5-m with 1-cm accuracy. Figure 1, represents the assembly of the wireless sensor on prototyping board.

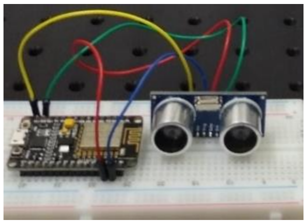

Figure 1. The assembly of the wireless sensor platform

ii) Sensor observations' data storage and cognitive computation

As mentioned, the sensor observations are used for cognition of the environment and controlling the motion of the robot arm in accordance with the needs. For instance, if an approaching person or machine is within a specific zone of the robot arm, then its instantaneous speed changes accordingly, for instance to drop any risks of collision. However, due to lacking of connectivity between the legacy robot arm and the sensor platforms, a cloud-based IoT service is used for data storage, visualization, data filtering and cognitive computations.

Data storage can also be done by building on-site database, where it would be much more secure, much faster to reach with low latency and has immediate access to on-site data to process and visualize. Network of things (NoT), which is a replacement for IoT was first introduced by researchers at National Institute of Standards and Technology (NIST) had been developed with this purpose [12]. However, using the available cloud-based IoT services is easier to use, and most of the times faster to setup with several available service options in formation of the service's outcome.

Due to the limited time and budget of the project and also complications caused by COVID-19 situation, using a cloud-based IoT was selected for this project. In searching for the possible options for the cloud-based IoT services, several service providers were considered, where Table 1, in next page represents a portion of them. As Table 1, shows the service features of these service-providers are listed based on data visualization, supported protocol for data collection, the database type and also security options. Moreover, the simplicity of access to the service and also simplicity of service setup, and last, but not the least the service expenses are the other important factors in selection of the proper IoT service provider.

MATLAB is of the common technical software that is known as "language of technical computing" and is used in variety of fields of engineering and science. The reliable and tested toolboxes of MATLAB in variety of fields such as data visualization, data filtering, machine learning, etc. are among the major positive aspects of it. This software is used in most of the academic institutions and is used and taught in variety of courses and projects. One of the IoT service provider candidates among the listed service providers is Thingspeak, an affiliated company of MATHWORKS, the producer of MATLAB that allows to add MATALB codes for processing the collected data over the cloud and it has variety of data visualization options. The free educational account with limited data rate (one data transmission in every fifteen seconds) and also its low-cost academic account with acceptable data collection rate (one data transmission per second) are the other noticeable features of this cloud-based IoT service-provider. Thingspeak introduces authentication option for security purpose.

Security has always been one major concern for online services and cloud computing has also the same weakness. Variety of security options have been proposed or implemented for cloud security. Implementing cloud intelligent agent (CIA) is one these proposed security options that allows the data owner dynamically change the security key in the process of data collection and filtering [13]. The observation and tracking of the access to data are among the other features of CIA that improves its performance.

Table 1: List of potential Cloud-based Internet of Things (CIoT) service providers

Comparison of IoT Platforms					
IoT Sevice Provider	***Vender***	***Security***	***Protocols for data collection***	***Data Visualization***	***Database***
ThingSpeak	Mathworks	Basic Authentication	MQTT and HTTP	Yes	---
Google Cloud IoT	Google	Asymmetric key authentication over TLS 1.2	MQTT and HTTP	Yes	MySQL, PostgreSQL, SQL Server, and HBase to other traditional databases
IBM Watson IoT	IBM	FIPS 140-2 Level 4	MQTT and HTTP	Yes	--
AWS IoT Analytics	AWS	FIPS 140-2 Level 3	MQTT and HTTP	Yes	Ad hoc or Scheduled SQL
Countly	Countly	GDPR, HIPAA and COPPA	HTTP	Yes	MongoDB
ThingsBoard	ThingBoard	Basic Authentication	MQTT, CoAP, and HTTP	No	Cassandra
Thing+	Daliworks Inc	Basic Authentication	MQTT	Yes	--
AT&T IoT Platform	AT&T	Basic Authentication	HTTP	Yes	--
SensorCloud	Lord	DoD (SRG) Impact Levels 2 and 4 and 5, DFARS	HTTP	Yes	FDBS
Axonize	Axonize	Basic Authentication	MQTT and HTTP	Yes	--
Cumulocity IoT	Software AG	ISO 27001, DSS and other standards	HTTP	Yes	MySQL,
Ubidots	Ubidots	X-Auth-Token	HTTP, MQTT and TCP/UDP	Yes	--
Apache iota	Apache	Basic Authentication	HTTP	No	--
Murano IoT (Exosite)	Exosite	ISO 27001, DSS and other standards	HTTP	Yes	--
GroveStreams	GroveStreams	Basic Authentication	HTTP	Yes	--
Knowi	Knowi	Basic Authentication	MQTT and HTTP	Yes	MySQL, SQL Server, MongoDB

iii) Industrial hardware platform as replacement for robot controller

Robotic machinery such as robot arms are usually connected to a robot controller that interfaces between the computer, in which programs the robot and the other common hardware pieces such as teach pendant and emergency stop button. Legacy robotic arms have low flexibility and are tightly rely on their proprietary robot controller unit. Using programmable logic controllers (PLC) to store the program codes of a routine of a robot has been addressed in some references for specific robot brands, however the approach cannot be generalized for all types of robots. Moreover, PLCs have limited or no networking access and to access to internet, they need to be accompanied by a network grade access point.

In order to control a robot arm based on the collected data from the work environment, it is required that the robot controller has continuous access to internet and to the cloud-based IoT website. The legacy robot controllers and most of the PLC types do not have such internet access options. To overcome this issue, in this project a programmable automation controller (PAC) was used. PACs have network access options and normally they can control a number of PLCs in their domain and support multiple communication protocols via the embedded ports in their hardware structure.

In this project a PAC is used as a substitute for the robot arm controller. After extensive research and based on the available budget limitations, one unit of AMAX-5580 PAC from Advantech Co. Ltd. was purchased with the awarded fund in 2020. This PAC that is illustrated in Figure 2, has been designed for IoT applications. The PAC supports several communication protocols, such as serial communications via RS-232, RS-485 and USB; IP-based Ethernet communication; WiFi wireless; and communication via 5G cellular also is expected to be added to its future generation.

(a) Connected AMAX-5580 unit in experiment

(b) AMAX-5580 with EtherCat modules (Courtesy of Advantech Co. Ltd.)

Figure 2. AMAX-5580 PAC was used in this project as the substitute for the robot arm controller and network interface

AMAX-5580 collects the most recent data from the online database over the cloud-based IoT in order to adjust the speed of move of the robot arm. For this experiment, MECA-500 robot arm from Mecademic Inc. was used. The AMAX-5580 was replaced with the computer that controls the normal operation of the robot arm. In conventional operation mode, a computer controlled the motion of the robot arm, either by a web-browser as software interface or a running script code. Figure 3, illustrates the general layout for control of robot arm based on the collected data from the sensor observations using the directly attached PAC to the arm.

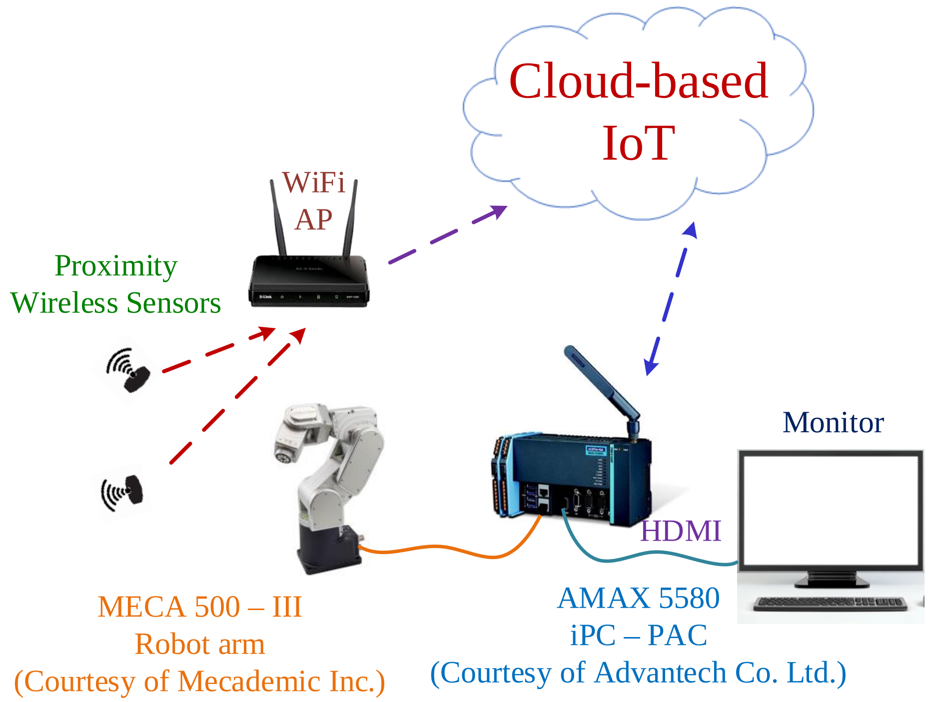

Figure 3. Connection layout of the proposed robot arm collaboration with the work environment using the collected data from the sensor observations

iv) Programming language for control the robot arm

As the PAC is responsible for access to the collection of the sensor observations that are stored over the cloud, a program code is required to be executed to collect the relevant data. The code gets the IP address of the IoT web site and the related data channel. In selection of the programming language, several programming languages were reviewed and their potential for web-based application and simplicity of use were considered as measures of selection. Among the reviewed programming languages, there were visual Basic, C and C++, Java, C#, and Python, where Python was selected due to its potential and its ease of web-based programming.

In writing the program code to control the attached robot arm, the code frequently checks for the most recent update in the environment data from the cloud-based IoT site. Then, it modifies the motion speed of the robot arm accordingly to avoid incidents with human-beings or other objects in its neighborhood.

Experimental work

The proposed scheme was developed in the defined robot arm control layout framework that has been illustrated in figure 3. The directly attached ultrasonic sensor to the wireless enabled microcontroller, collected the distance information to the approaching object. This information was wirelessly sent over the cloud-base IoT site via the WiFi access point, located in the neighborhood of the wireless sensor. The collected data over the IoT site was recorded and visualized. Figure 4, illustrates the collected data from the proximity sensors for a period of time.

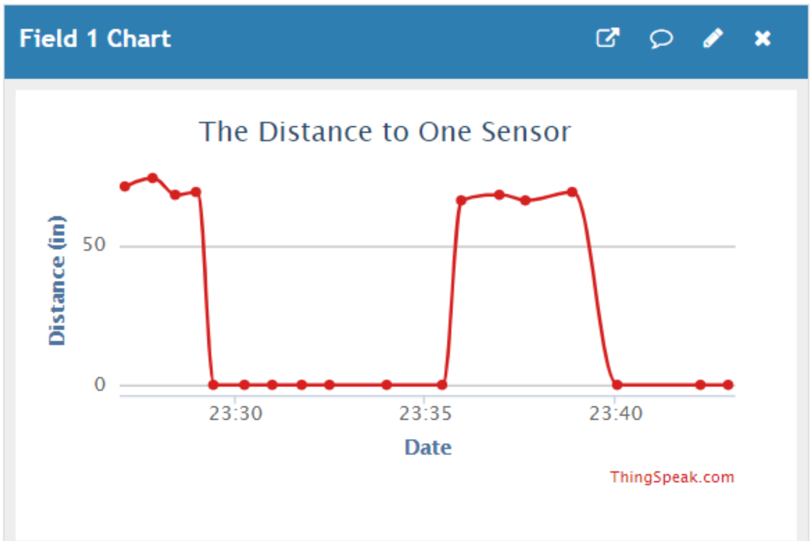

Figure 4. Collected data from the wireless proximity sensors is visualized over the cloud-based IoT site

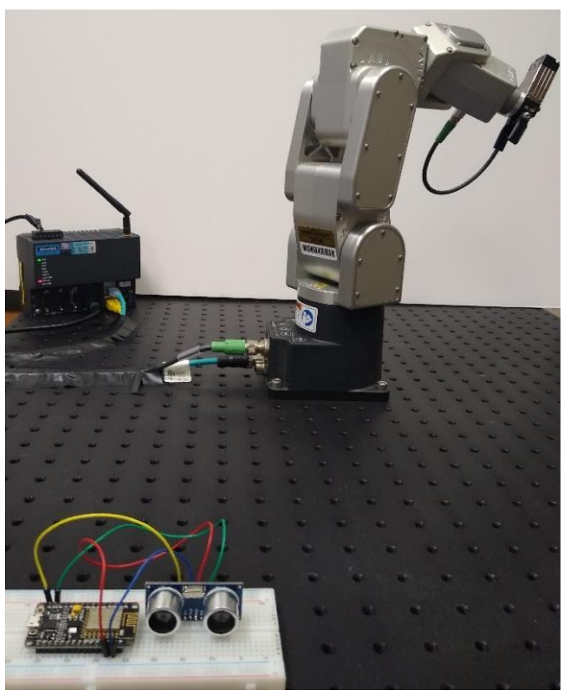

Figure 5. A system assembly for the proposed solution

AMAX-5580, the attached PAC to the robot arm via Ethernet cable (CAT-X) checks for the most recent data from the IoT site and it modifies the motion speed of the robot arm accordingly, based on the detected distance zones of the approaching object. Figure 5, illustrates a system assembly for the proposed solution.

Conclusion and Future Work

A cloud-based internet of thing approach is proposed and implemented for making a legacy robot arm collaborate with the work environment. Ultrasonic proximity wireless sensors collected the environment data and stored it over the IoT site. AMAX-5580, a programmable automation controller (PAC) that is directly attached to MECA-500 robot arm periodically checks for any data update and modifies the motion speed of the robot arm to avoid any incidents in the work environment. Experimental results show that the proposed approach works well as one collaboration instance with the work environment, where the idea in general can be extended to collaboration between two or more robotic machines.

As future work, problems such as reduction of data transfer latency, and using network of things (NoT) instead of IoT will be considered. Other aspects of the proposed solution such as involvement of open-source robot operating system needs more investigation.

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