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THE INS AND OUTS OF THE INTERNET OF THINGS (IoT) BACHELOR PROGRAM DESIGN

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Abstract: **The Internet of Things (IoT) is becoming an increasingly viable and advanced paradigm that has a tremendous potential to improve productivity. There is a pressing educational demand to introduce more solid and broad programs in IoT at the post-secondary education stream. While most colleges and universities offer courses related to IoT that are taught in computer science and engineering majors, very few have dedicated programs for IoT. Courses such as microprocessors, embedded systems, networking, programming, data science, etc. are usually part of other majors but rarely grouped in a single major at the bachelor level. In this paper, an ambitious, tailored and a new major in IoT is presented. This IoT degree program will be offered in the Management & Information Technology Department at Jubail Industrial College, a prominent industrial college in the heart of Jubail Industrial City, KSA. This paper will explain all aspects of this new multidisciplinary major. After a brief introduction on IoT, we will present the purpose and the learning outcomes of this major, followed by the IoT model upon which a degree plan was designed. IoT core courses and their design rationale will then be explained. Other related bachelor programs and challenges are also presented.**

Keywords: **Internet of Things, Technology Education, Embedded Computing, IoT Technologies.**

I. INTRODUCTION & BACKGROUND

Most of us have heard the phrase "Internet of Things," but many people may not be sure exactly what it means. The basic definition of Internet of Things or IoT is the concept of connecting devices to the internet. "Things" here means devices of all sorts and shapes such as computers, home appliances, smartphones, tracking devices, industrial machines, automobiles, health gadgets, etc. Thanks to advances in microprocessors, communication, and batteries, IoT is rapidly growing as more devices and sensors are added to the computing and communication grid. According to one study by Research Nester [1], the IoT market reached USD 598.2 Billion in 2015 and is expected to reach USD 724.2 Billion by 2023. Cisco's projection [2] of IoT growth to reach 50 Billion devices by 2020 as shown in Figure 1.

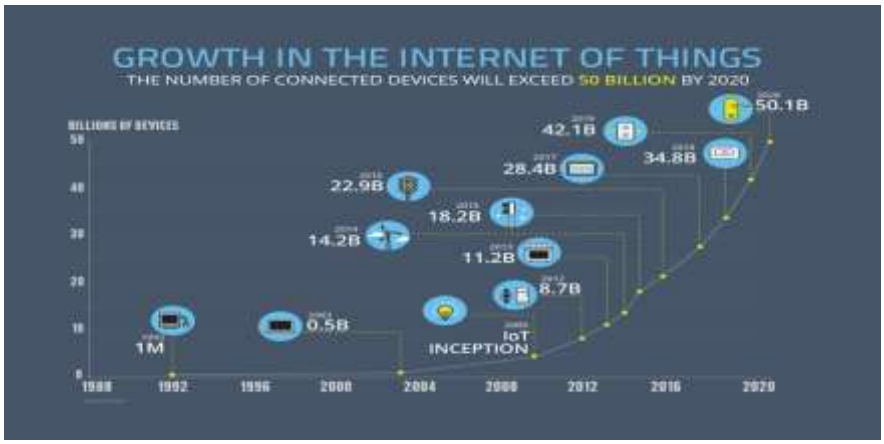

Figure 1: Cisco's projected growth of IoT devices till 2020 (source: NCTA 2018)

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Further, the portal for statistics by [3] is showing the number of IoT devices may reach 75 Billion by 2025 as graphed in Figure 2. A Gartner survey [4] estimated that 40 percent of companies expected that IoT would increase their business revenues in the subsequent three years, followed by a 60 percent increase in the following five years.

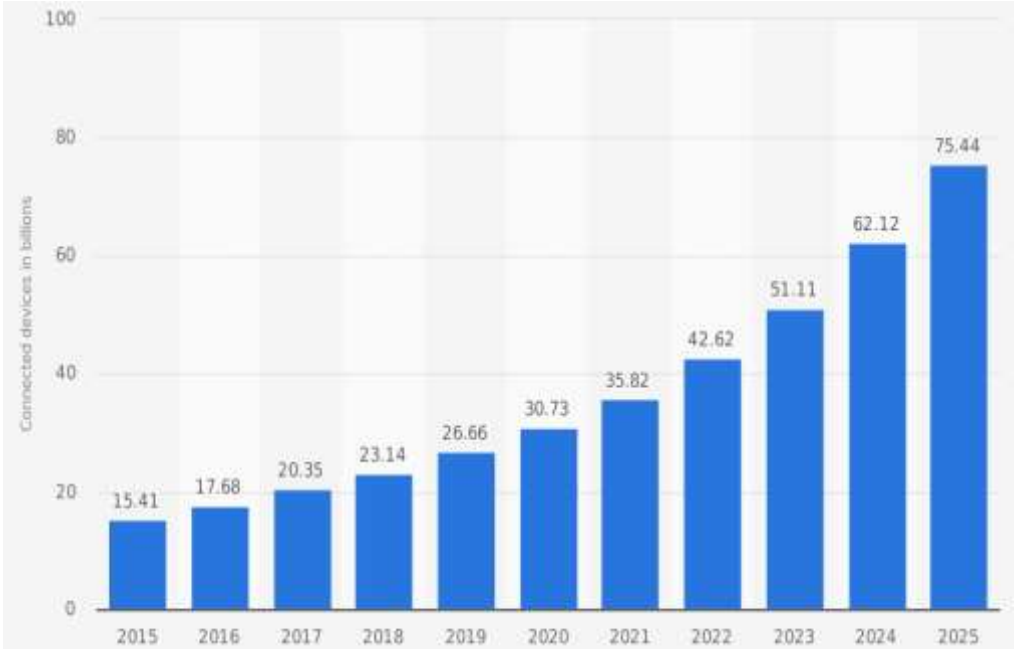

Figure 2: Statista's prediction of IoT devices growth in 2025 (source: [3])

A study by CMO Council [5] found that while most of the big global enterprises expect a considerable impact of IoT on business performance, a significant gap exists between existing market skills and new skills and management thinking are required for the IoT transformation. The study specified that the majority of the surveyed companies have significant gaps in IoT skills about business models rethinking, data integration, analytics capabilities, and technical skills. According to insights by Zebra Technologies [6], currently, there is a shortage of qualified IoT professionals throughout the industry that could continue for the next few years. This shortage is becoming increasingly critical in the areas of DevOps and artificial intelligence. A study by Open University [7] revealed that Britain would face a technical skill deficit because of disruptive technologies such as IoT and Big Data. Not even those skills will be in high demand, but also the talent to manage those skills will be outdated.

It's evident from a study by Citius Minds [15] shows an increase in research trend measured by the rise in patent filing activity. The chart in Figure 3 indicates an increase in patent filing activity in the field of IoT since 2006. Research and Development in IoT are increasing inside the major high tech players such as Cisco, Verizon, IBM, GE, etc. It's needless to say that training and education need to catch up the demand of the much required IoT skills. While the market is growing for those with expertise in IoT systems, courses, certificates, and other degree programs exploring the IoT are in their nascence. Designing an IoT degree program entails teaching several technical and nontechnical subjects. Core topics in an IoT program should include networking, embedded systems, networking, web technologies, security, data presentation and analysis, hardware and platforms. Other subjects such as system integration and faculty development should also be considered in preparing any IoT plan. In this paper, we present a bachelor program design where all IoT skills are taught under one degree. In the next sections we will define the purpose and the learning outcomes of this program, then we present an overview of IoT core subject areas, then the planned IoT core courses and their design rationale. Other aspects such as program uniqueness, depth, breadth, and challenges will be covered in the last sections.

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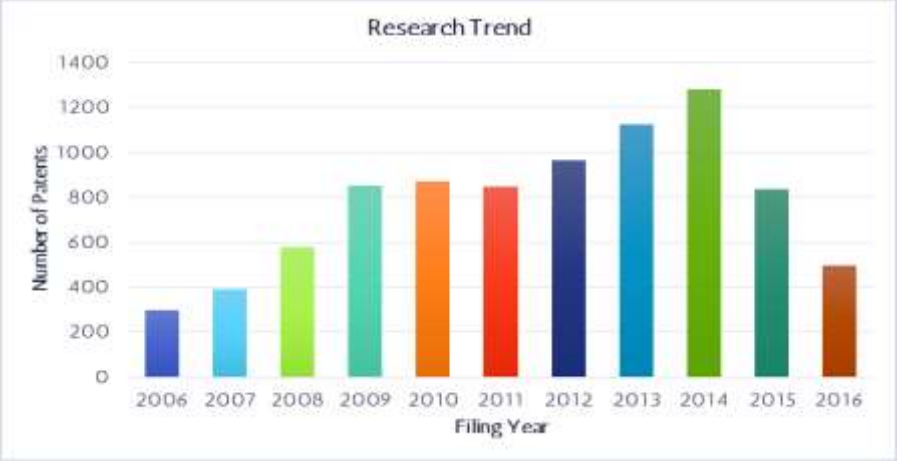

Figure 3: Ppatent filing activities in the field of IoT.

II. PROGRAM OBJECTIVES AND LEARNING OUTCOMES

A recent study by [8] from the International Data Corporation (IDC) indicates that more IoT applications are being introduced across Saudi companies. IoT Program Manager Krishna Chinta said, "The current scenario presents opportunities for local, regional, and global services providers and technology vendors to form mutually beneficial partnerships" [8]. According to the same study, this IoT application increase is driven by the rise in IoT offerings from system integrators and telecommunication companies in the region. The primary objective of our bachelor program is to bridge the gap between the industry and academic institutions, so knowledge of our students is updated to match local and global market needs. The goal of this program is to teach students all different steps involved in building an IoT application. These steps cover topics such as programming of embedded devices, making devices communicate, and data presentation. Other than the core subjects, students will learn about *security*, *ethics*, *standardization issues*, *integration*, and the *impact of IoT on society* & *business*. The core objectives of our proposed bachelor program are to teach the core IoT concepts. Students must understand and practice the following IoT core areas:

- *Hardware*: how IoT system is built.
- *Programming*: how to program embedded devices.
- *Communication*: how embedded devices communicate with the Internet and other devices.
- *Presentation*: how to present collected data in a meaningful and insightful format.

Specifically, students exiting this programs will be able to:

- Recognize the main components of IoT systems.
- Learn the needed skills of interfacing embedded systems with the outside world.
- Learn data communication and networking fundamentals as well as network protocols.
- Learn the basics of data presentation through the Web and Mobile technology.
- Learn the basics skills to build a simple IoT system from end to end.

III. IOT COMPONENTS

IoT is a multidisciplinary field that combines technical areas spanning from embedded devices and networking to cloud computing and data science. At times, the IoT field seems so complicated because it is a field comprised of different and diverse aspects of applications, vision, features, and descriptions. Hence, designing an undergraduate degree program that will encompass all these core subjects becomes a challenge. Many postsecondary programs teach courses in embedded systems, networking, data science and other IoT-related topics, few offer courses that tend to focus on a specific aspect of IoT. To design an IoT degree program that will equip students with a comprehensive IoT toolset, we started by examining the necessary IoT components. Several IoT architectures are proposed and depicted in the literature depending on the classification of IoT components [9] [10] [11] [12] [13] and [14]. Due to some overlapping between IoT layers, most of

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the proposed models consist of 3-5 layers. We chose to spread our model into a four-tier one, so we can relate which subject belongs to which layer. The model depicted in Figure 4, is divided into four segments; the Device Layer, The Processing Layer, The Gateway layer, and The Application Layer.

The "Thing" / Device Layer

We will start with the lowest layer where the actual device is located. The actual device should be equipped with an electronic component that collects data from the device and its surroundings and sends data to over the internet. The device in this layer communicates with the upper layer mainly through Radio Frequency Identification (RFID) and Wireless Sensor Network (WSN). Each device in this level has to be assigned a unique IP address so it can be uniquely identified over the internet. An excellent tool that can be used to teach a course at this level is a microcontroller by Arduino. The Arduino microcontroller is a small computer which gets connected to the "thing" and is the most suitable and capable of collecting data. In our suggested degree plan, courses directly related to this layer are: Electrical Circuits I, Embedded Systems, Digital Electronics and Wireless Sensor Technology. These courses should cover main topics in this level such as the working basics of sensors and actuators, circuit design skills, communication between microcontrollers and connected sensors & actuators, connecting the device to the internet.

The Processing / Control Layer

In some layering models, this layer is combined with the previous layer (The Device Layer). We chose to separate it in our layout to relate corresponding courses to this layer. This is the embedded computer layer which receives data from sensors then process data depending on it makes a decision or send data to the cloud to create a more complicated decision based on other global data. Single-board-computers like the Raspberry Pi is most suited to this layer since it has more capabilities in processing data than Arduino. Courses about this layer are Programming I, Programming II, and IoT Programming. These courses should cover the core most essential aspects of microcontroller programming. Python and JavaScript are becoming are currently used more often to prototype IoT devices.

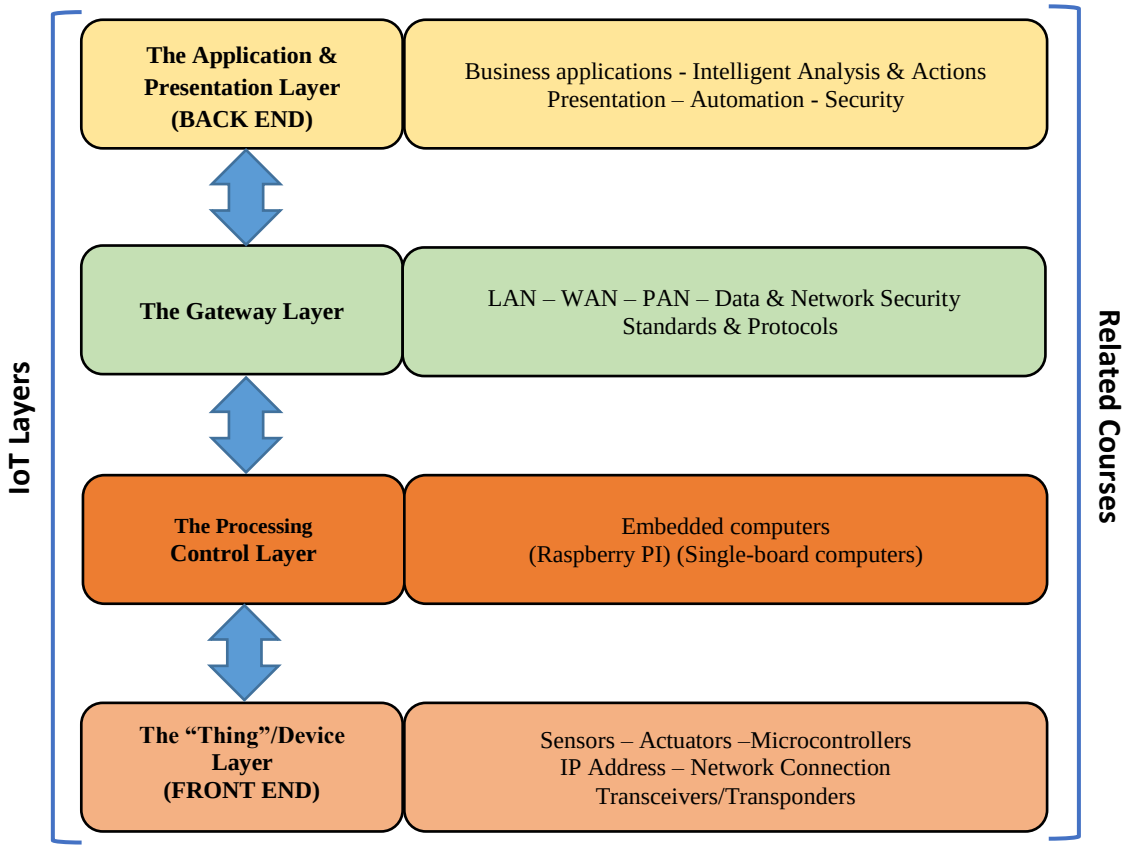

Figure 4: IoT Layers

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The Gateway Layer:

This is the guiding and routing layer where all means are applied to guarantee sending collected data and receiving instructions. Network connectivity is an essential part of any IoT application. Hence, this is a necessary and core topic which will be covered by several courses such as Data Communication & Networking, Wireless Sensor Technology, Distributed Systems, IoT Security, IoT Standard & Protocols, and Cybersecurity Management. These different courses will provide the basis of connectivity and related subjects such as network design, network standards & protocols, network technologies (Bluetooth, WiFi, RFID, Zigbee, and Low Power Wide-Area Networks (LPWAN)),

The Presentation Layer:

Informative and insightful meaning should be extracted from collected raw data. This is the backend of an IoT system with applications residing in a cloud or on dedicated servers. In this highest layer of any IoT system, several different applications exist that cover various markets such as home automation, transportation, E-government, industry, environment, etc. Several disciplines are involved in this area; Database Management, Data Presentation, Data Science. Subjects that should be taught in this layer are different and broad; essential courses are Web Development, Mobile Application Development, Artificial Intelligence, Data Mining, Distributed Systems and Cloud Computing.

IV. IOT DEGREE PLAN

This suggested Bachelor program in IoT starts at an Associate degree where students enter into a 2-year program to study basic IT courses. This Associate program named Computer & Information Technology (COIT) teaches the necessary prerequisite courses for the suggested IoT program. Relevant courses taught in COIT include Data Communication & Networking, Database Fundamentals, Programming Concepts, Computer Security, Multimedia & Web Design, Internet Service Management and Management Information Systems. In addition to other related and supporting courses. Our suggested IoT Bachelor degree is based on the so-called two-plus-two program. Students may complete their first two years and gain an Associate degree in computer and information technology, or they may choose to continue into a bachelor of IoT program. Table 1 shows the basic courses that will be taught in the IoT bachelor program:

Table 1: Core Courses of the IoT Bachelor Program

Semester I	Semester II
• Programming and Data Structures	• Advanced Programming
• Web Development I	• Web Development II
• Introduction to IoT	• Database Systems
• Discrete Mathematics	• Embedded Systems
• College Physics	• Digital Electronics
• Electrical Circuits I	• Wireless Sensor Technology

Semester III	Semester IV
• Distributed Systems and Cloud Computing	• Introduction to Data Mining
• IoT Security	• Cybersecurity Management
• IoT standards and protocols	• IoT System Administration
• Mobile Application Development	• IoT Project
• IoT Programming	
• Artificial Intelligence	

Electric Circuits, *Digital Electronics*, *Embedded Systems*, *Embedded Systems*, and *Wireless Sensor Technology* are fundamental courses in the bottom layer where they teach students how to connect the "thing" to the Internet and how to facilitate effective communication with the Internet and other devices.

Programming courses are essential to equip students with a broad range of programming and problem-solving skills. These courses should cover the basics of algorithm and data structure designs. The languages to be used in teaching these two courses will JavaScript and Python which are most suitable for programming embedded computers as well as for creating web applications.

Database Systems, *Data Mining*, and *Artificial Intelligence* are the data courses that will help students build their fundamental basis on how to extract useful information and create an integrate different components from collected data into a unified data-analytic solution and how to construct insightful plans based on collected data.

Web Development and *Mobile Programming* courses are also essential to create a means for interaction with IoT devices as well as presenting extracted data through web application such as dashboards and scoreboards. As most of the IoT devices will be managed by mobile devices since most of the market is controlled by Android and Apple IOS, the ability to develop apps that communicate with external hardware and sensors is a mandatory requirement in any IoT education. Visualization of acquired data and computed analytics are essential aspects of IoT.

Distributed Networks & Cloud Computing, *Cybersecurity Management and IoT System Administration* courses provide an understanding of the different Operating Systems involved in managing and troubleshooting the necessary structure required to support IoT systems. Students will understand the concepts and practical experience of building and maintain secure and scalable distributed computer systems. It's important to study the new and emerging cloud technology; the technology of Infrastructure-as-a-Service (IaaS) providers; the Platform-as-a-Service (PaaS) providers, and the Software-as-a-Service (SaaS) providers are now becoming cloud technology that is closely related to IoT and ought to be part of any IoT study.

In the capstone *IoT Project* course, students will apply all learned knowledge and skills in constructing a complete IoT system. This project should display how students would integrate all diverse subjects in creating an end-to-end IoT application. This project will not only build the student skills but also add to the student industry-related experience.

V. RELATED PROGRAMS

In this section, we list some existing IoT programs that we think are similar to our program but not identical. The online search we conducted has identified only a few IoT bachelor degree programs. We aim to focus on offerings of complete programs that lead to a full bachelor degree, not on single course offerings. Almost all of the programs that came up in our search offer a certificate in IoT, very few offer full postsecondary programs.

Waterford Institute of Technology [16]. This is the first hit in our search which revealed a pure and comprehensive 4-year Bachelor of Science (Honour) Program designed on six broad themes; Programming, Data Science, Mathematics, Device & Systems, Networks & Clouds, and finally the Project strand which delivers a substantial experience in integrating the aforementioned different strands. We consider this as an excellent program that provides students with a complete set of tools to build an IoT system. One noticeable remark about the project component is how the project is distributed over different semesters to cover most of all aspects of an IoT system.

Swinburne University of Technology [17]. This program titled "Bachelor of Computer Science (Professional) with a major in the Internet of Things" which is also a four-year full-time program that covers through the prescribed courses all the different components of an IoT system.

James Cook University [18]. Again another Australian institute offering a Bachelor program in IoT. The program title is "Electronic Systems and Internet of Things (IoT) Engineering," and we feel the program is inclined more towards electronic and digital systems design. The program offers only two courses that are directly related to IoT, namely "Embedded Systems Design" and "Sensor Technologies."

The Technology Incubation Center CIU [19]. Being part of *Cambridge Intercontinental University* is offering a bachelor program titled "BSc in Cyber Security & Internet of Things." The program puts more emphasis on cybersecurity as it only offers just a few IoT directly related courses such as "IoT with Raspberry Pi," "IoT in Industrial Deployment," and "Applied Internet of Things Projects." Although the program title carries IoT in it, we don't consider this program a strong one.

Staffordshire University [20] offers a BSc (Hons) Internet of Things where students start with basic computer science fundamentals then the program branches off into the IoT field. Although this program covers almost all IoT components, it lacks other core courses such as IoT security, data presentation, and data science.

Beijing-Dublin International College (BDIC) [21] is offering an inter-disciplinary bachelor program that combines the field of computer science and electronic engineering. The program puts some emphasis on IoT by providing courses in wireless communications, sensor devices, internet technologies, and cloud computing. The program provides a stable base for the device and communication layer but fails to include other core IoT courses such as data presentation and data analytics.

Florida International University (FIU) [22] is proposing an IoT bachelor's degree as the first university to offer such a program in the US. The proposed IoT degree curriculum is using some existing IoT courses such as Embedded Operating Systems and Programming Embedded Systems. Most of the new courses added to the program deal with topics from the Device Layer and the Processing Control Layer; courses such as Circuits & Electronics, Microcontrollers for IoT Device, Sensors for IoT Devices, Computer Design, and Wireless Communication. Some other courses offered as electives cover the areas of Network Forensic & Security, Cyber Security, Data System Software, and Entrepreneurship. The proposed program has some depth and breadth covering the first three layers of our IoT model. However, we didn't see any course assigned to data presentation, big data, and data analysis.

VI. SUMMAR, CHALLENGES, AND CONCLUSION

In this paper, we presented a proposal for an IoT bachelor's degree program to be added to the programs at Jubail Industrial College in KSA. This comprehensive 4-year program is uniquely designed as a 2-plus-2 - it's divided into two parts - students start in a two-year Associate degree program that covers basic general IT courses and then moves on to the second two-year program with a high emphasis on IoT related courses. We believe this program is first of its kind in KSA and should help current and future students enter into the digital world by acquiring the needed knowledge to grasp and implement the concepts of designing IoT devices. Computer curriculum specialists will always be challenged with obstacles when developing a new major, IoT is no exception. We believe this program was designed to the full format given background and time frame. Indeed, there is always a room of improvement, so here we will list some of the challenges and advances that can be resolved or added had this program been offered in a full four-year time frame.

Cybersecurity is a primary concern especially when millions of devices are connected and increasingly connected day by day. This increase in connected devices will increase the number of potential points of attack. If not properly secured, these devices will create entry points to launch Distributed Denial of Service (DDoS) attacks. We believe more security courses should be part of an IoT program; the kind of courses that deal with ethical hacking, threat assessment, securing network architectures, securing applications, encryption, and data integrity, as well as activity logging, event monitoring, and threat intelligence. There are more potential and future improvements to the program such as adding GPS programming. As more devices are now location-enabled, it's vital that any IoT bachelor program include teaching the development of IoT tracking applications.

Despite any difficulties, we believe the value of introducing this ambitious IoT program will outweigh any snag that might occur. With this presented proposed program, we hope another step has been taken to support the learning of practical knowledge and skills needed for our students to meet the fast-growing market of the Internet-of-Things.

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