E-Health: IoT and CPS in Healthcare

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***Abstract*— The internet-of-things paradigm is an increasingly powerful innovation in computing that may change the world as we know it. Certain industries can greatly benefit from IoT and cyber-physical systems, particularly the struggling healthcare system. Utilizing the strengths of IoT systems in the proper manner can help mitigate the rising costs of healthcare services while also helping streamline previously intricate and bloated architectures. In this paper, three IoT projects are presented and discussed in order to bring healthcare IoT or "E-Health" to the forefront of the CPS discussion and present its usability in the field.**

Keywords—e-health, internet of things, cyber-physical systems, healthcare

I. Introduction

The Internet of Things paradigm and cyber-physical systems are taking the world by storm, almost reinventing previous thought processes about system development. The potential impact and benefits of these systems implemented into everyday use is starting to show itself, however we have only scratched the surface of what IoT and CPS can bring to the table. Introducing these systems to different forms of industry comes naturally, and the healthcare field is becoming a shining example of what IoT systems can do.

Commonly referred to as 'E-Health', IoT healthcare systems are being introduced in a wide spectrum of use cases due to the unique problems of the field and IoT's abilities to solve them. Healthcare systems can be extremely intricate in the number of variables and operations in use, while also involving the most sensitive data of all; human health. The overall output of these systems can literally determine life or death, and that's something almost entirely unique to healthcare systems (similar to autonomous vehicles). The intricacy of the healthcare field is what make IoT systems and CPS so exciting for the industry; their potential to simplify issues we face with our health systems can not only improve overall quality-of-life but also allow for healthcare professionals to focus on moving the industry forward, rather than worry about technical tasks.

In this paper I wanted to present three different healthcare IoT systems in order to bring forward a conversation on why E-Health and CPS in healthcare is so important. In light of recent healthcare issues, I've seen personally how poorly our modern systems are working (specifically in the United States). For a long time, our healthcare was taken for granted, and thanks to hard working professionals it provided incredible service. However, we are beginning to see the consequences of the lack of progress in the industry, and common issues need to be addressed in order to further develop our healthcare systems. After introducing the three systems and explaining how they work, I will then analyze the systems in overall success and potential viability in real-world work and add in any potential suggestions of my own to improve the systems.

II. IoT Examples

A. Automated Bed Assignments

A large, yet not often thought of, part of healthcare is basic management practice. Healthcare facilities are large-scale operations with multiple variables and moving parts constantly changing. Properly managing a facility is critical in assuring overall success with patient's health. So, taking common managerial tasks and streamlining them in an IoT system would greatly benefit a facility and its patients. That is exactly what the General Electric team set out to do with their complex and dynamic Automated Bed Assignment system. According to the American Advisory Board, optimizing a hospital's patient flow by 27% could add $10 million to their margins, money that could go to more important uses rather than inefficient management issues [4]. In addition to lowering costs, you would also improve quality-of-life for patients by reducing wait times.

The goal of the Bed-Assignment model is to assign beds to patients ensuring that their care requirements are met, patient flow is managed, and the utilization of beds is maximized. The authors accomplish this in a clever manner by using a mixed-integer goal program that takes in weighted sums of benefits and penalties in order to determine the best-fit for the patient. Each benefit and penalty can be defined by the user, or hospital in this case, along with different constraints; either hard or soft. Beds are grouped into service lines which are broad categories encompassing clinical specialties, such as heart, medical, surgical, ect. Within each service line unit, a tier level is assigned to treat patients of a particular specialty. A tier is a multilevel ranking unit that decreases in order of preference (lower the number the higher the preference).

The type of bed a patient is assigned also has attached attributes; clinical and non-clinical. Clinical attributes are assigned by a physician based on a patient's condition for their own benefit and safety; telemetry, isolation orders, epileptic. Non-clinical attributes are decided by the patient's preferences in order to improve convenience and improve comfort; such as a room with certain amenities. Each constraint that is defined is also given the option of hard or soft [3]. This user-defined flexibility allows for staff to prioritize certain constraints based on current situations in the facility. Depending on the constraint chosen, a learn or constant penalty is applied to the slack variables in the function. An alert system is also added to the system, to alert staff about beds with recently discharged patients to be cleaned, as well as a system-wide alert if a patient has been waiting too long for bed assignment.

The system was implemented at Mount Sinai Medical Center in New York apart of a four-week pilot program and focused on bed requests for patients in the Emergency Department [5]. The results speak for themselves, as the average wait time from bed request to be assignment was down 23%. The number of dirty beds accidently assigned to patients was also reduced by 20%, thanks to the alert system for discharged patients. Overall, around 90% of all requests met respective facility requirements as well, meaning as low as 10% of all patients seen needed to be manually assigned to a bed or wait longer than usual [3].

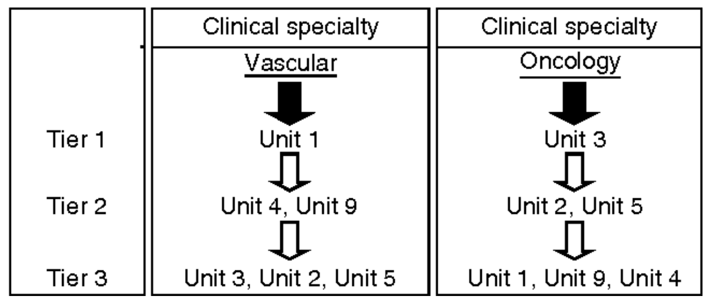

Figure 1 - Tier Levels for Bed Placement

B. *We-Care*

Another aspect of the healthcare field that would benefit from IoT systems is continuous monitoring patient's vitals. IoT systems can allow for a more personalized and preventative type of care for patients, while providing collaborative systems for patients and caretakers. This type of system is particularly useful for elderly care, as their health requires continuous monitoring for preventative measures, usually in a remote location like their own home. Many designs have already been implemented in this area of healthcare monitoring, however these designs lack robustness as well as a 'peace-of-mind' aspect for the patient, whereas they don't need to worry about the system. That's where the team from the University of Minho, Portugal come in; their We-Care architecture aims to contribute for a better elderly living assistance system by providing a wireless IoT solution that monitor vital data and making it available to necessary medical professionals and triggering necessary alerts in case of emergencies [7]. With a focus on low-cost as well as low-power requirements, We-Care is a cyber-physical system suitable for at-home use with network as well as independent capabilities.

We-Care utilizes a wristband for sensing vital data, aptly named We-Watch. The wristband contains sensors able to collect multiple forms of data including environment and body temperature, pressure, humidity, light, an accelerometer, Received Signal Strength Indicator (RSSI), as well as a panic button. The wristband also has an on-board MCU that supports Bluetooth and 6LoWPAN over the IEEE 802.15.4 standard, as well as the Contiki-OS embedded OS that provides the IoT stack support for the protocols of the MCU [7]. The wristband is small in size and utilized low-power features which makes it great for patient comfort and accessibility.

The We-Watch's data is sent securely through the We-Care board which runs the web services as well as acts as an interface to the cloud. It can act as either an Access Point for local network use or as a Station for over the internet use. We-Care utilizes the cloud for the base of their application for the caretaker's use; as well as a way of storing data in a database. The application is web-based, being a stream-lined GUI that provides information for up to 8 patients at the same time [7]. The sensor data is constantly updating the database, which is being sent directly to the web application for continuous monitoring of vital data.

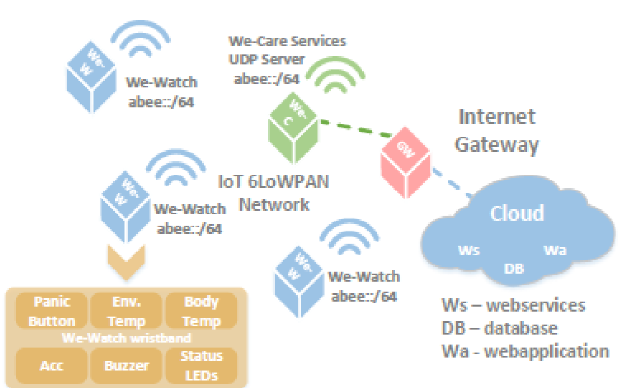

Figure 2 - WeCare Architecture

Low-power and low-cost were key focuses with this development, to allow for a broad range of uses for different people. Through power consumption tests, the expected battery lifetime was found to be around 306 hours, about 12 days without being charged. This allows for plenty of time for the healthcare provider to change batteries to continue monitoring services. The authors also developed a charging station for the We-Watch, in order to reduce the amount of needed caretaker interaction. The RSSI was also tested to improve usability for patients, and a maximum range was determined to be around 60 meters from the access point for optimal monitoring. An alarm will sound for both patient and caretaker if the access point is out of range for longer than 60 seconds [7].

C. *Philips E-Alert*

Not only is continuous monitoring valuable for patient data, but also for monitoring the complex machines used in healthcare facilities. In order to provide the best possible care for your patients, 24/7 upkeep of your facility and its equipment are crucial. With the costs for some of these machines astronomically high, as well as access to them being limited, preventative measures need to be taken in order to diagnose and solve equipment issues in a timely manner to keep your patient-flow maximized. IoT and cyber-physical systems are proving to be valuable in these areas as well, providing the same concise, continuous monitoring services for medical equipment as well as preventative alert capabilities when abnormalities are detected.

A prominent example currently being used in the field is Philip's E-Alert system for monitoring MRI machines, a collaborative project between Philips and OpenMarket [1]. E-Alert combines remote sensor technology at a medical facility with global networking reach of mobile messaging to rapidly respond to issues of a MRI machine, as well as proactively identify issues that could cause downtime of the machine. Since this is a corporate project, most of the technical details are under wraps. However, the overview of the project is available, and helps get across the key components of the system. E-Alert operates on a three-parameter schema; Inform, Act, and Resolve. Inform proactively monitors the MRI system with needed information specified the users. Act handles the alert system, whether that is a downtime alert or a potential sensor alert. Resolve try to regulate the system if it is possible without a technician, that is if a sensor detects something out of the ordinary, E-Alert will attempt to resolve the issue itself first. If it cannot, it issues the proper Act alert to technicians [1].

The monitoring system is very complex, as MRI machines themselves are incredibly complicated. This is what makes the system so valuable, as without a diagnosed problem from the system directly, downtime could be incredibly high when searching for the issue. This means less access to an important piece in healthcare diagnostics, and less overall healthcare for patients. Just some of the parameters E-Alert monitors includes the helium compressor function, chiller function, helium level, magnetic field, magnetic pressure, power supply, humidity, temperature, and the cold head function. Each monitor follows a certain threshold specified by technicians, and alerts are issued specifically for each monitored value if the threshold is surpassed. The system also boasts the ability to be used independently of region, system, age, internet access, or phone network coverage; allowing for further reach in healthcare improvement.

The alert system also provides valuable information in order to act proactively to issues or emergencies. Each alert is sent with three attributes; the impact, criticality, and required response time. The impact of an alert just details what monitor detected the issue, whether or not the senor is above or below the threshold, as well as a detailed action report describing what the facility should do in response to the issue. The criticality is a gradient scale from low to high that specifies how important the alert is and how it should be handled. This allows for a facility to judge, based on their current situation, what alert is most necessary to handle. Required response time is just the recommended response to the issue. If action isn't taken by the recommended time, another alert will be sent to the facility with an increased criticality of alert [1]. The alerts can be customized on who they are sent to, as well as what method they are sent; via text message or e-mail.

III. Analysis

These three systems were chosen because they address some of the most pressing issues facing the healthcare field today; lowering costs, maximizing efficiency, and providing the best care possible. They also are methods which work best for IoT systems currently; monitoring, alerts, and data processing via cloud/fog computing.

For analysis purposes, it's hard to directly compare each system due to differences in funding/man-power of the teams (corporate research teams vs. university group) as well as the purpose for each system. However, we can take each system independently and discuss the potential advantages as well as any issues that may be problematic (or already have).

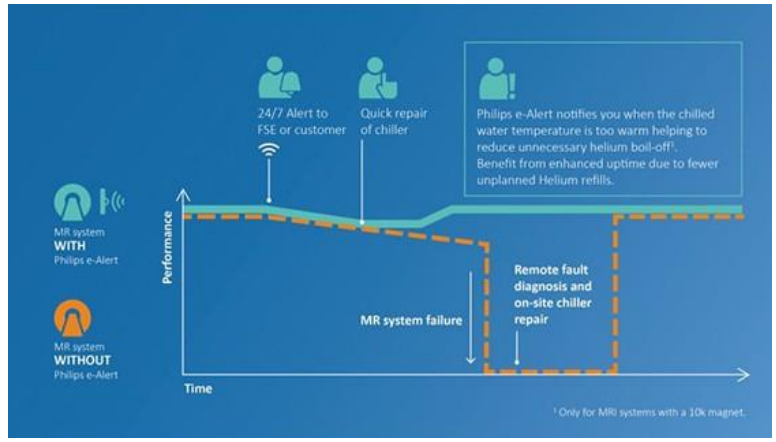

Figure 3 - E-Alert's effect on downtime

A. *Automated Bed Assignment*

Besides continuous monitoring systems, optimizing management techniques is crucial in minimizing costs and maximizing patient throughput. This method of IoT implementation has the most potential for not just healthcare services, but almost all systems that rely on variable management. The brilliance yet simplicity of this system makes it applicable for almost any type of variable system; replace bed assignment with any needed optimization feature needed for your system, and then alter the needed weights and constraints for defined requirements. Also, the flexibility of the system stems from user-defined constraints being changed from hard or soft, allowing for more modular design systems.

However, the main limiting factor of the current system is the lack of communication between multiple systems. The current system is only applicable to one hospital with its own set of attributes; number of beds, specific departments, their own tier of beds. In larger cities there are multiple hospitals that need to communicate with each other when deciding where emergency vehicles deliver patients. It would seem possible to implement, with the biggest hurdle being the communication between dynamic systems (which is no easy tasks). But once that is accomplished, everything else can be added to the current system; different weights for hospital specialization, and emergency vehicle integration. Some of the dynamic properties are suggested as future work by the research team, but overall that's just the goal of IoT systems; to have all dynamic systems communicating continuously so it is just a matter of time.

B. *We-Care*

Though it is the simplest system of the three, We-Care brings an important healthcare IoT method. Continuous monitoring and data processing are crucial to healthcare services all around, with scalability going to be a key function in the future. In this specific context, We-Care is a great solution for remote-monitoring services. Elderly-health services are in dire need across the world and assisted-living homes are becoming more and more tabooed. Remote health monitoring would allow for elderly patients to still enjoy the quality and comfort of living at home without putting potential health burdens on the family. The servers could also be expanded to handle more clients at a time, and a larger-scaled medical service could handle a similar client load as assisted-living homes at the same time.

The biggest issue with this system is scalability. With it being an IoT system, a focus on scalability and a modular nature is important. The future work of the project focuses on adding more sensor capabilities. However, taking the current system and making it work with a larger client maximum seems more valuable to a current healthcare service. An assisted-living home could completely change their offered service, to a large-scale remote monitoring system. Also, the sensor device should probably be an invasive device rather than non-invasive, especially when dealing with the elderly. Though the team thought of issues with the device, adding alerts for if it is removed for too long or too far away from the reception, the potential for the device being damaged or lost is very high.

C. *Philips E-Alert*

Besides the monitoring of patients, making sure equipment uptime is optimal is another crucial function of a healthcare system. This may be an under-appreciated method of IoT's potential, however a key benefit of IoT and cyber-physical systems is their predictive nature. Being able to predict potential downtime of equipment can significantly improve a facility's ability to care for their patients in the proper manner, adapting to needed changes based on the equipment available. Simplifying the debugging process is also a huge benefit to this system, as anyone who has experience trying to find a problem can attest to. E-Alert is a prime example of what an industry-backed CPS would look like. Besides a complex sensing system and a professionally-backed alert system, E-Alert has the industry polish you would expect from a company like Philips; scalable, flexible, and ease-of-access around the world. The IoT community apparently agrees with this sentiment, as Philip's E-Alert system won "Most Innovative IoT Solution" at the World Communication Awards this past year [6]. Monitoring maintenance of equipment is just another seemingly tedious task that if streamlined, allows for a greater focus on improving the healthcare itself.

Philips is currently working to transition the E-Alert system to work with other machine types, eventually leading to the universal IoT system we've been imagining. However, this is a limiting factor of the system, as it is only accessible to facilities that have MRI machines (specifically Philips MRI machines!) and there is no general use case for monitoring equipment maintenance. Recently discovered, there is also a great security risk with the E-Alert system. Nine cybersecurity vulnerabilities were found according to ICS-CERT that, if attacked, could compromise user details, the MRI's integrity and potentially the available uptime of the MRI. Philips is currently working out an update before the end of 2018 to close the vulnerabilities and recommend limited network access to facilities using the E-Alert system [2].

Cybersecurity is a huge issue not just in IoT or CPS devices but in all modern technology. However the threat is much greater, as is the potential cost of an attack, when IoT systems are compromised. When dealing with the sensitive data of patient health records, Philips should have implemented better security systems and the vulnerabilities are inexcusable. But if systems that are designed just to keep machines running properly are at risk of a cyberattack, you can only imagine the potential consequences of mass IoT systems becoming compromised. This is a big issue the entire tech industry will have to answer for soon or else the progress and potential of IoT and CPS will do more harm than good.

IV. Conclusion

The world is experiencing a true digital age, with exciting new innovations that are transforming previously dormant objects into complex-thinking machines. Soon all of these machines will be sharing information between one another in ways we'd never have imagined. The excitement of the IoT and CPS paradigm stems from the current architectures being created that continue to push the boundary on what we thought was possible. The potential benefits and impact of these systems are starting to be realized in a multitude of different industries, including healthcare services. The current healthcare climate around the world, and specifically in the United States, is one with inflated prices and long wait times for what should be a basic human right. In order to tackle these ever-complicated problems, E-health and IoT systems need to be implemented to maximize our healthcare's efficiency and minimize costs overall. As we have seen with the Automated Bed Assignment project, We-Care, and Philip's E-Alert system, complex and intelligent solutions have already been developed to tackle these issues. But these systems are just the first step in the right direction; each project set out to improve a specific aspect of the healthcare field. Whether it is optimizing patient-flow of a medical facility, continuous-remote monitoring, or predicting equipment failure before it happens, healthcare IoT systems are working towards a better future for healthcare services for all.

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