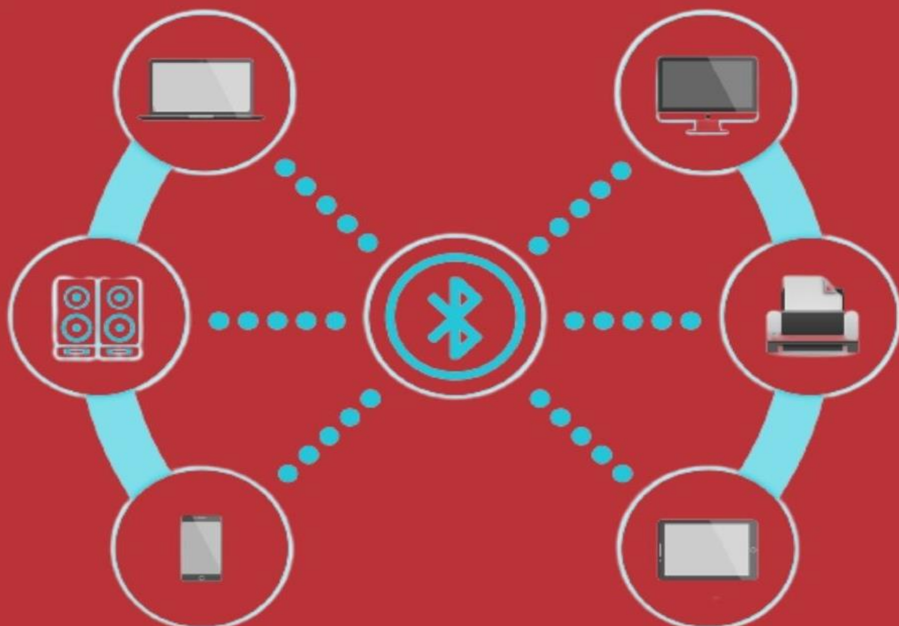

ASSESSING POTENTIAL APPLICATIONS OF THE INTERNET OF THINGS IN HEARING RESEARCH AND CLINICAL OTOLOGY

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Assessing Potential Applications of the Internet of Things in Hearing Research and Clinical Otology

An Interactive Qualifying Project

Submitted To:

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Abstract

The emerging "Internet of Things" has been used to greatly advance data collection in various medical and technological fields. Our sponsor, the Universitätsspital Zurich, wanted to find different applications of IoT devices that could benefit the field of otology. To accomplish this, research on the current state of IoT within medical fields was done through a literature review as well as interviews with researchers, clinicians, and industry experts. We found that IoT technologies are currently used to monitor patients' health and acoustic environment remotely and can also communicate findings to patients and their doctors. Additionally, IoT systems can improve direct audio streaming to hearing devices in a given area, allowing for enhanced patient quality of life and data collection.

Acknowledgements

We would like to express our gratitude to everyone who has been a part of the project and given us guidance. We would first like to thank all the researchers in the Department of Otolaryngology at the Universitätsspital Zürich, who despite their busy schedules offered us their insight and answered all our interview questions. To Dr. Christof Röösli, Dr. Alexander Huber, Dr. Flurin Pfiffner, Dr. Adrian Dalbert, and Dr. Jae Hoon Sim, thank you so much. Thank you to Professor Adam Lammert, who generously gave us time for a lengthy interview.

We would also like to thank the experts we interviewed from the hearing care industry, Dr. Patrick Boyle and Mr. Craig Sharp, for their expertise and the many inspiring ideas they shared with us.

For their dedication and support in helping us craft our project's proposal and methodology, we sincerely thank WPI professors Carol L. Stimmel and Guillermo Salazar.

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To our sponsor Dr. Ivo Dobrev, we sincerely thank you for making this project possible, trusting us, and giving us the resources and time to complete it.

Lastly, we would like to thank the WPI Global Experience Office, Ms. Candace Ruta, and WorldStrides for arranging our on-site travel. We really enjoyed our time in Switzerland, and we hope we can return to Zürich in the future.

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All sections were reviewed and edited by each of the four group members.

Executive Summary

Founded in 1208 A.D., the Universitätsspital Zürich (USZ) is a leading research and teaching hospital in Zürich, Switzerland, that is home to a variety of clinical and scientific divisions that include our sponsor organization, the USZ Department of Otolaryngology (ear, nose, and throat studies). Affiliated with the University of Zürich, the hospital produces projects in collaboration with the students, researchers, and doctors of the nation's other universities and medical establishments. The Otolaryngology Department is technologically advanced and consists of researchers from around the globe. Through our primary contact in the department, Dr. Ivo Dobrev, our project assessed awareness of the "Internet of Things" (IoT) in hearing research and otology (the study of the ear) and researched its potential applications in that field.

The term "IoT" refers to any Internet-connected device that has the capacity to store or process data and communicate with other devices that have similar data-transferring capabilities. The concept itself is still relatively new and unfamiliar to many, including hearing researchers and clinicians. However, despite the limited use of IoT in past medical activities, an upward trend of IoT usage in other technological fields has inspired this project to investigate the possibility of applying IoT to hearing research and clinical otology.

The goal of this project was to research the current awareness of IoT among hearing researchers and clinicians, propose several potential applications benefiting otology, and relay the findings back to researchers to help improve future research. To adequately complete this goal, we identified four objectives that were accomplished through a series of literature reviews and expert interviews:

1. Research the current state of IoT in medical and hearing research and assess awareness of IoT in healthcare.
2. Explore ethical and regulatory challenges that IoT may face in hearing research.
3. Assess how IoT could benefit otology and future hearing research and relay the findings to clinicians and researchers.
4. Identify new applications of IoT technologies and provide resources for successful implementation.

We reviewed and analyzed about two dozen studies from the healthcare and medical field that involved IoT technologies to see what technologies are being used and how they are being used. From this analysis we learned that most IoT-enabled devices currently rely on Bluetooth technology, usually in the form of Bluetooth Low Energy (BLE), to communicate with other sensors and devices placed around the environment or on an individual's body.

IoT is currently somewhat used in hearing research and otology, as three out of six of the interviewed researchers had some knowledge of it and used it for low-level applications. In our literature review, which spanned about a dozen scientific review articles and independent studies, it was common that IoT-linked wearable devices were used to monitor a patient's health and environmental conditions. In one study, researchers created an IoT network that would allow independent gas detection and vital signs monitors to communicate with each other, potentially improving doctors' diagnostic abilities and reducing workplace and environmental harm (Haghi et al., 2017). In a direct manner, devices like cochlear implants can accurately distinguish and classify the spaces and noise level of a user and then send the data to both a smartphone and database, improving sound knowledge for researchers and users alike and leading to better communication experiences for the future. Additionally, due to technological and surgical advancements, cochlear implants are now worn by both younger and older patients, allowing for a more complete body of hearing data over the lifespan. Overall, IoT has been more prevalent over the past couple of years as using IoT can solve issues such as noise analysis, that was not possible before. The analysis of data trains the program of the devices to be able to recognize the environment of the users, and function differently depending on the setting. Researchers view this as a tool for devices to do the work on their own, as seen from the studies in Section 4.1.2.

Most of the interviewed experts were able to recognize what IoT meant, yet there was a range when it came to identifying how much it was applied. Some hearing researchers had little to no knowledge of IoT, while others have employed IoT centrally in past research projects; one example is a robotics-driven microscope that used IoT to communicate with sensors, controls, and databases. In another example where IoT was used to a lesser extent, researchers extracted and studied medical data to observe different hearing conditions and determine the sources of hearing issues and loss. Out of the entire field of interviewees, experts of the commercial hearing care industry were more knowledgeable of IoT than hearing researchers, and their perspectives provided insight into how privacy concerns and the slow pace of the regulatory process surrounding IoT is causing the technology's underutilization in hearing research.

When researching IoT, we realized that security is currently the greatest concern, and many papers have been published addressing these concerns and their solutions. Thus, it was not a surprise that most of the interviewees were wary of IoT; the devices' connection must be almost perfectly reliable to be accepted in medical research and clinical care. This concern is well-justified; a device's connection could fail even if it's only connected to one other device. Nevertheless, since an attempted cyberattack must go through many layers to reach the core of a connection, recognizing and reinforcing vulnerable layers can ensure the safety and confidentiality of shared data. Simple methods for deterring varying levels of cybersecurity threats include using signature-based authentication, rejecting the creation of weak passwords, and avoiding software access to USB inputs. Because a drop in connection could cause the loss of personal medical information, maintaining system privacy is paramount in successful IoT implementation. Most of the interviewees agreed that this is the main obstacle in the application of IoT, followed by a lack of knowledge and discussion on the topic in the medical field. Some even suggested that a new or updated regulatory policy would be required for IoT to be widely used in a secure way. However, the slow pace of the regulatory process described by the interviewees makes the legal and ethical implications of IoT a long-term, dynamic obstacle to its implementation.

The findings from our literature review and analyses of past studies showed us what IoT has made possible in other medical fields. Using this knowledge, paired with the knowledge gained from industry professionals, we were able to visualize new potential applications in hearing research and relay these findings to our sponsor and other researchers during meetings and interviews. The applications described in the literature proved consistent with what our expert interviews revealed: although IoT technology has limited uses in both research and clinical settings, the experts we interviewed agree that its future capabilities could very well improve hearing in both younger and older demographics. IoT could particularly facilitate data collection and hearing care for lifelong cochlear implant patients, whose ever-changing abilities require close monitoring and prompt clinical attention. Because IoT is underutilized in otology, it would be beneficial to the clinicians, researchers, and patients who would potentially use it to have succinct, informative resources on its implementation.

The goal of this project was to determine how IoT technologies could improve their research abilities and create educational resources for hearing researchers and clinicians. Through our literature review, analyses of past studies, and interviews, we developed a poster and a pamphlet defining IoT and its uses, determined new and improved applications of IoT technologies in hearing research, and presented them in a meaningful way to our sponsor and readers. Being an overarching introduction to IoT, our poster defines IoT, shares some of its common uses, and summarizes its potential benefits to hearing research. One of the poster's featured topics is data flow in the context of a research hospital:

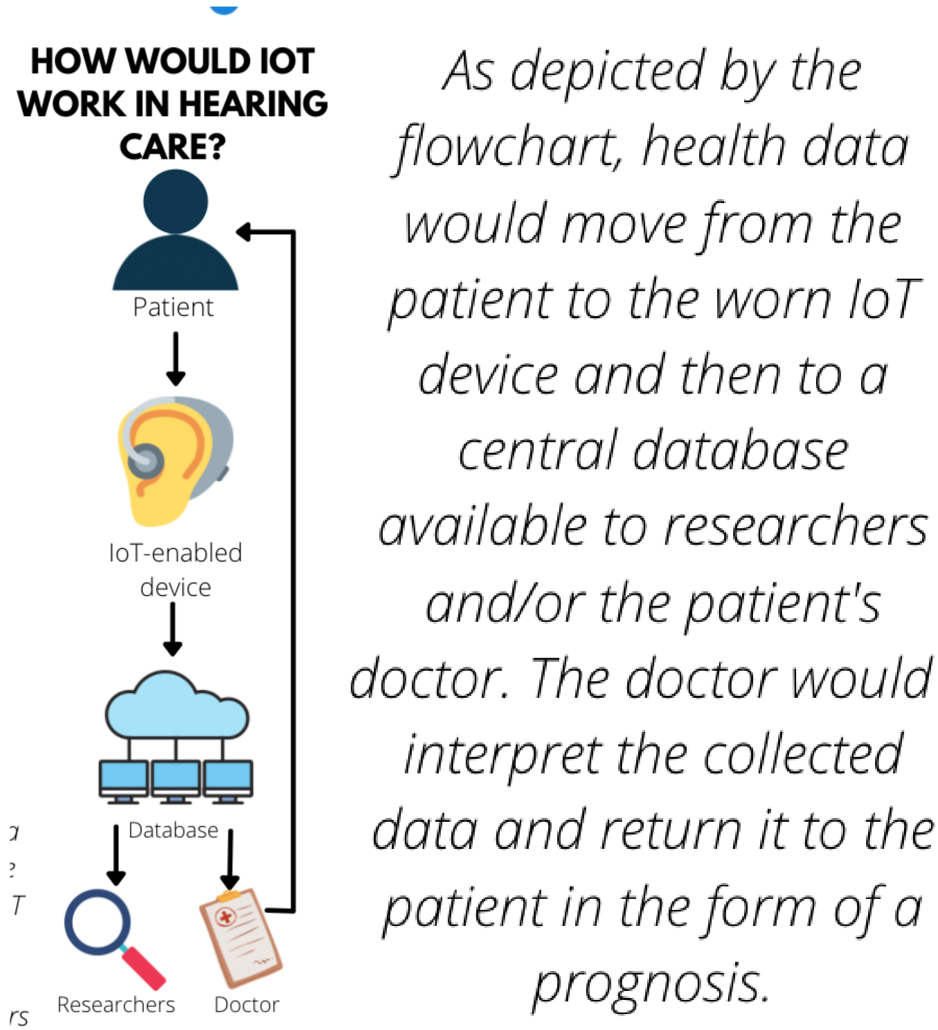

Figure ES1: A simplified illustration of IoT data flow in a research hospital, accompanied by the caption found on the poster.

The pamphlet we created expands on the topics of our poster, discussing the methods and some of the details behind the fundamental concept of IoT as well as what it is used for. Applications of IoT included in the pamphlet range from an improved telecoil to noise-cancelling microphones and wearable fitness trackers. Additionally, highlighted by the pamphlet are the wireless communication systems and devices such as Bluetooth that make IoT possible. Through our project work, an awareness of the potential benefits of IoT can inspire its adoption in hearing research, clinical otology, and other fields of medicine as well. Perhaps more importantly, our educational poster and pamphlet can help the researchers, clinicians, and patients who would use IoT better understand its purpose and implementation, helping ensure that transparency and informed consent continue to be the standard in the digital age of the Swiss healthcare system.

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1. Introduction

The use of the “Internet of Things” (IoT), networks of embedded electronic systems constantly communicating with each other to allow for more efficient data collection and transfer, is accelerating many fields of research and industry. In the field of medicine, IoT technologies are changing the way research is conducted, providing groundbreaking new methods for data collection and analysis. One area that could particularly benefit from enhanced data collection is otology, the study of hearing, which relies heavily on quantifying the interactions between a patient’s acoustic environment and their sense of sound.

When connected to an IoT network, individual hearing devices can collect data for the development of future sound processing software and hardware that would improve the auditory environment in numerous settings. Further applications of IoT in hearing research can accelerate the development of technological innovations in hearing protection, clinical diagnosis, and noise abatement, and improve the working conditions and/or standard of living of people in noisy surroundings and urban areas. However, otology researchers have yet to realize the benefits IoT devices could provide and are behind other medical fields in implementing them into their work.

The mission to improve hearing devices and diagnostic technologies for patients is a worldwide effort, but Switzerland in particular is at the forefront of innovation and technological advancement within the field (Organization for Economic Development and Cooperation, 2019). However, some otology researchers argue that advancements in the field can be made much more rapidly and efficiently by utilizing IoT technologies to improve their research and data collection methods. Although the Universitätspital Zürich (USZ) is an active leader in global otology research, according to our team’s sponsor, Dr. Ivo Dobrev, their methods for collection and analysis of hearing data are limited in comparison to other medical fields and would be greatly improved by the implementation of IoT technologies. USZ’s researchers are particularly interested in better understanding IoT technologies and how they can be applied or adapted to aid their otology research.

New implementations of IoT technologies are beginning to change the way medical data are collected and analyzed, allowing researchers to tackle problems from completely new perspectives and develop more accessible, user-friendly solutions. As it stands, IoT device integration in hearing research is lagging compared to other fields and USZ’s researchers are looking to change that. Hearing researchers have only scratched the surface of what could be accomplished with these devices, and new applications and developments of IoT technologies could allow USZ’s otologists to pioneer new data collection and real-time analysis methods. These new advancements could not only make their existing devices more cost-effective and accessible, but they could also create entirely new solutions and diagnostic methods.

Working with the Universitätspital’s department of otolaryngology (ear, nose, and throat), our aim was to determine how IoT technologies could improve current otological devices and data collection methods while also raising awareness of the potential these technologies have within the field of otology. First, we determined the current state of otology research, and the level of familiarity researchers have with IoT technologies. Next, we assessed current IoT technologies and provided examples of how they have transformed research in other medical fields. Then, we investigated applications of IoT in otology to inspire new data collection ideas among hearing researchers. Finally, we documented our ideas for IoT device integration and addressed the legal/regulatory challenges of patient data security associated with these wireless technologies in our final report. Following this general plan, we were able to research the current usages of IoT devices used in other fields as well as the medical field.

2. Background

This chapter introduces the "Internet of Things" (IoT) as a recently developed technology that is accelerating innovation in many fields of research and industry. Shifting focus to IoT applications in healthcare, we then summarize how IoT systems operate in the context of patient monitoring and include a discussion of IoT's potential to advance data collection in otology. In considering the risks of IoT, concerns surrounding data privacy and security are outlined in their own section. Because we are working with USZ's researchers, Swiss IoT development and research is investigated, with special attention given to interdisciplinary collaboration between IoT companies and medical researchers. Finally, we conclude by identifying potential applications of IoT in hearing research and otology.

2.1 The increasing prevalence of IoT

Although many of us may not realize it, "Internet of Things" (IoT) technology is now used regularly in everyday devices such as cell phones, electronic appliances, and personal computers. The use of IoT has revolutionized the way data are collected and interpreted from these devices. As a result, IoT in data collection has accelerated many areas of research and industry for decades. First invented in the 1980s as a way for companies to assess inventory and transform data, IoT has been more recently applied in consumer electronics and their "smart" capabilities (Teicher, 2018). The abilities of IoT to improve performance of automated tasks are most popularly known for their use in the concept of the "smart home." a residence that operates lighting, indoor temperature, and appliance activity based on a schedule or other features. Additionally, the "smart" electronic components of a smart home can be programmed to collect and share usage and performance data with other devices, enabling home technology to collect information for other purposes, such as performance improvements and home security. As more IoT-enabled devices are installed, data collection continues to grow exponentially and can strengthen the predictive power of these "smart" machines (Merenda et al., 2020).

Outside of the home, IoT is applied to many kinds of devices with a variety of functions, including automobiles and other transportation systems (*Insider*, 2020). Today, virtually all new automobiles have embedded systems that transmit data to external devices to process the automobiles' performance. Based on the given data, hardware and software modifications can be made to current and subsequent models and system updates are delivered directly over the air (OTA) to the vehicle. Additionally, IoT allows vehicles' cloud-based systems, such as navigation, to respond to real-time changes in things like traffic and route calculation. Meanwhile, sensors of a vehicle's operational components (i.e., the engine and electronics) monitor condition and functionality, triggering maintenance alerts that can help an owner keep their vehicle running at optimal performance. In terms of other vehicle-to-network connections, IoT has safety and security applications; the accuracy of external sensors in back-up cameras, proximity beepers, lane recognition systems, and collision avoidance technology relies on data collected by a network of IoT devices. Also, vehicle tracking via the Global Positioning System in conjunction with a variety of sensors makes it possible for owners, dealers, and trucking companies to locate their vehicle, better understand consumer trends, and manage their fleets. In the automotive industry, there are countless other ways that IoT increases efficiency and enhances the consumer experience.

The use of IoT in consumer products is increasingly taking on novel forms, such as with wearable technology developed in just the last decade (Haghi et al., 2017). Sometimes called "smartwear", modern wearable technology includes electronic devices worn as accessories, as parts of clothing, or as implants inside the body. These devices are typically powered by miniature microprocessors that transmit data via the Internet, and together they form a vast network of data-sharing machines. Since the early 2000s, smartwear products have been popular with consumers looking for more convenient ways to access Wi-fi networks. For example, Bluetooth-enabled cell phones, headsets, and smartwatches have become popular commodities in virtually every country on Earth (The World Bank, 2019). Furthermore, although its consumer applications have proved to be a success, IoT-enabled smartwear is even more valuable in industrial applications. Similar to the automotive industry, IoT in smartwear has enabled safer surroundings for its users (Campero-Jurado et al., 2020). For instance, microchip-embedded safety vests alert construction workers when they approach a designated hazard, and first responders are testing the uses of wearable technology in emergency situations. In firefighting, such technology can protect the health of firefighters and paramedics by detecting location, levels of air quality, radiation, and chemical exposure. For policing, IoT-based smartwear gathers information from body cameras and transmits it to a database for later reference. With the IoT market predicted to grow three-fold over the next decade, IoT is quickly transforming many industries (Transforma Insights, 2019). In the healthcare industry in particular, current applications of IoT have already proven valuable in applications like health monitoring and medical data collection.

2.1.1 IoT in Healthcare

Using IoT devices in healthcare has created many options and opportunities previously unavailable to researchers and clinicians. Currently, IoT-enabled devices like Apple and Galaxy watches are capable of remotely monitoring patient parameters such as blood pressure and heart rate, no matter if the patient is in or out of a clinical setting. In this way, clinicians cannot only monitor their patients' health but also collect data on specific conditions and measurables for future diagnoses. For example, IoT-enabled cardiac pacemakers can be remotely monitored and set by a physician based on the data they transmit. On a macro level, sensors can monitor populations in places like senior living facilities, where healthcare must be especially accessible. Across the healthcare spectrum, researchers benefit from the databases comprised of information transmitted by patients' IoT-enabled sensors, accelerating research through data analysis of patients' chronic and/or life-threatening conditions.

Despite these benefits, since IoT systems are a new and growing field, many medical researchers are unfamiliar with what an IoT system is and how it works (Kelly et al., 2020). Otology is a field where IoT systems can have many benefits. IoT has been used to greatly advance data collection capabilities in other medical fields and could do the same for the field of otology. Switzerland, like many other countries, has the foundation for the infrastructure needed to run IoTs smoothly and integrate them broadly over a relatively short period of time. For example, Zurich was ranked second in the Institute for Management Development (IMD) Smart City Index in 2019 and third in 2020 (IMD, 2019-2020). The IMD Smart City Index is based on economic and technological data from the city in question. There have also been community efforts to help nurture the growing IoT data network in Zurich. For example, The Things Network Zurich is a community dedicated to creating a community owned IoT data network for Zurich. As of 2020 they have over 200 community-run LoRaWAN gateways (which link source data to people) in and around the Zurich metropolitan area (The Things Network, 2020). There is already infrastructure in place to help support IoT systems and this infrastructure can be used to apply IoT devices into otology.

One demonstrative case study presents an IoT-based smart rehabilitation system which alleviates a lack of resources due to an increasing elderly population (Yuehong, 2016). The goal of this system is to connect the available resources of a healthcare provider to the home and to extend the range of accessible services. This system would also give other hospitals, doctors, and assistive devices in the surrounding area a way to communicate with each other and to the patients. Most of the incoming data will be from IoT systems and other wireless devices in the patient's home or devices directly on their person (i.e., a cellular device or a smart watch). Before the information is presented to healthcare workers, it will go into a centralized database, which will consolidate and analyze the incoming data to detect events that warrant the need for a medical professional (Yuehong, 2016). Figure 1 is a generic description of how the data are collected and then used within a medical field. “Things” are all the devices that collect and send the data to the central database or server; “masters” is the technical name for the people who have access to the system by being a healthcare worker or a patient who is receiving relevant medical information.

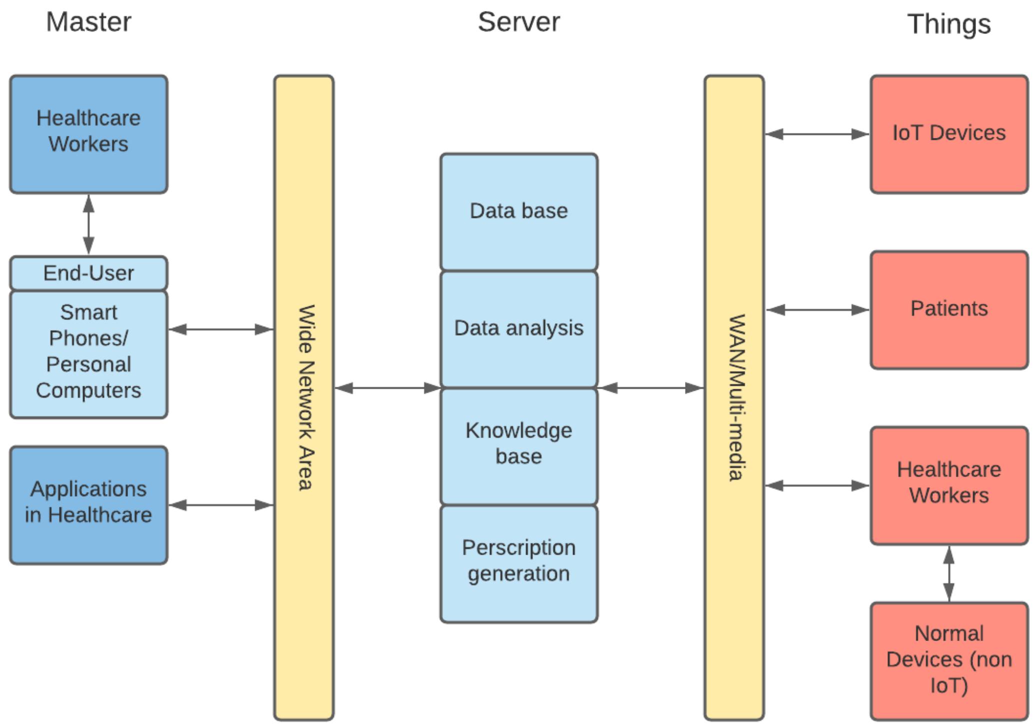

Figure 1: How data moves in a generic IoT rehabilitation system, based on the flowchart of Yuehong (2016).

2.1.2 The application of IoT in advancing data collection.

Applications of IoT have massively advanced the data collection and, therefore, research abilities of many industrial and scientific fields. In a 2016 study, world-leading IT research company Gartner estimated that about 6.5 billion devices utilized IoT to transfer data in sectors from manufacturing to healthcare (Gartner, 2016). Using IoT in otology would make possible more rapid and extensive collection of data from patients, allowing healthcare workers to make more informed diagnoses when addressing complications outside of the medical clinic. According to the Gartner report, IoT is most effective if there is a steady stream of data collected and analyzed to be presented for action; this is accomplished by having the devices transmit frequently with a centralized server and with each other (Gartner, 2016).

A main benefit of IoT is that the devices can always transmit data to the central database as well as to other IoT devices. The different IoT nodes can piggyback off each other which creates a mesh network that better facilitates transfer of data. Piggybacking is a technical term referring to when there is two-way transmission between two or more nodes; when node A sends a data packet to node B, node B waits to send an acknowledgement to node A until it receives data to send to node A. This helps reduce the amount of bandwidth needed for a system. A mesh network is capable of transferring data between each IoT node as well as send its own data to the target endpoint. In the mesh system, nodes can piggyback off each other so that the mesh can be extended over a large region. This redundancy is especially useful because it allows researchers to have reliable access to real-time data from an entire geographical region. However, the main problem with this is power: energy efficiency of individual IoT devices as well as the energy required to transmit data to a central server on a continual basis. If the system is not energy efficient, the device batteries will need to be charged or replaced often, which is expensive and difficult in many cases.

A mesh system could incorporate cluster heads into the array to create a more battery-efficient method of data transfer. This solution mitigates the challenges with a mesh by including a "head" IoT device in the network that collects all the data from a cluster of devices and then sends the data to the central server. The clusters are placed close together and require only a low transmission power, which improves energy efficiency. The "head" of the cluster does require a more powerful transmitter that can reach the central server. The "head" device could also be put into specific places around a region or household, that way IoT cluster devices would be able to communicate only using short distances (Orsino, 2016). Figure 2 shows how the cluster system would ideally operate and could be expanded to the specific requirements of the IoT device in question. This would help with the data collection process due to its ability to rapidly transmit data to and from different IoT devices and to the central server. Different hospitals and other healthcare servers would be able to share the data they collect with each other, which would help all facilities improve care based on a broad representation of information.

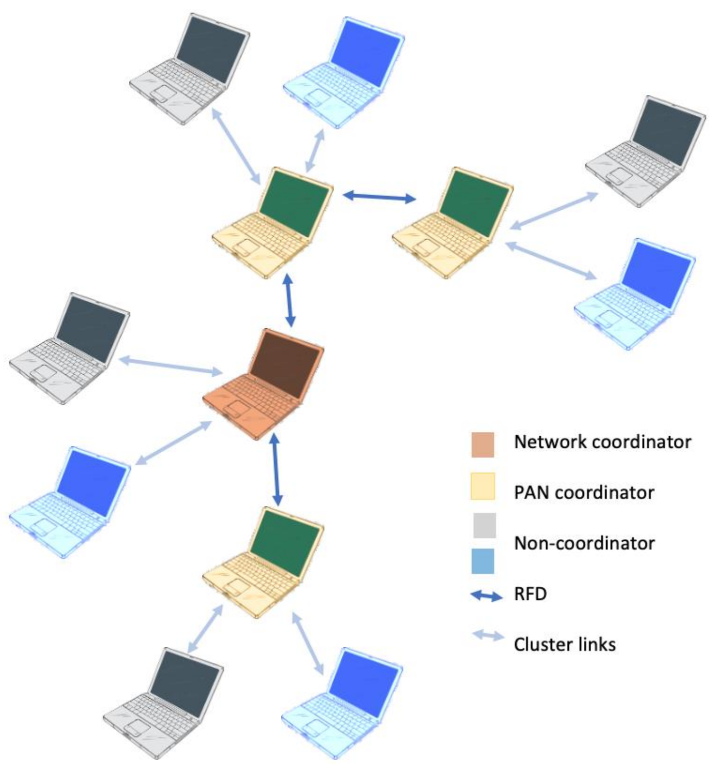

Figure 2: Diagram of how a cluster-based IoT system would upload data (PAN: Personal Area Network, FFD: Full Function Device, RFD: Route Flap Damping). These kinds of systems could send data directly to a central server, improving energy efficiency and creating the possibility for short-length communication. Based on work by Rob Blanco, via Wikimedia.

2.1.3 Cybersecurity and Data Privacy

IoT in hearing research will have to meet local privacy regulations and protections if it is to be integrated and developed as a mean to collect personal information. In the United States, for example, the Health Insurance Portability and Accountability Act (HIPAA) has been updated to protect individuals' medical data from being shared without individual consent (U.S. Department of Health & Human Services, 2020). Meanwhile, the European Union's General Data Protection Regulation (GDPR) aims to protect any personal data related to an E.U. member in any circumstance (Wolford, 2019). Although they provide a good baseline for medical data security, HIPAA and other privacy laws are not airtight security measures when it comes to IoT and Internet data. Many U.S. data laws do not apply to data shared over the Internet, and an increased amount of data, including medical data, is becoming available to Internet service providers (Harrod 2019). Switzerland generally has stricter privacy laws than the U.S., and the Swiss Constitution explicitly guarantees that "[e]veryone has the right to be protected against the misuse of their personal data," medical data clearly falling under that guarantee (Federal Constitution of the Swiss Confederation, 1999). Additionally, to collect and use medical data in Switzerland, it is necessary either to have a legal basis, to demonstrate a public interest, to have informed consent, or to ensure the use of anonymous or encrypted data (Federal Act on Data Protection, 1992). Thus, to be viable, any organization applying IoT in Switzerland must meet these high standards of privacy and security. Cybersecurity concerns related to new IoT implementation are a subject of wide attention, even with progress in existing policy responses and technical safeguards.

In the modern age of digital information, it is more challenging than ever to protect personal data from cyberattacks and malfeasance by third parties. One survey conducted by Fortinet highlighted the concerns of users with IoT adaptation; around 1,801 homeowners from all parts of the world, including Switzerland, answered the survey. The results concluded that around 67% of respondents were worried about privacy in IoT, and around 57% considered it very crucial (Fortinet, 2014). There are many strategies to prevent user mistrust of IoT, but a few mentionable ones are User Consent Acquisition (which allows users to accept or deny certain information sharing), stakeholders (such as device manufacturers) taking responsibility to prevent concerns in their services, and the use of anonymous network addresses (Perera, 2015). Given security concerns about IoT, privacy and security research will be an ongoing—and very important—endeavor.

2.2 IoT development and research in Switzerland

As one of the world's most technologically advanced countries, Switzerland is a strong leader in IoT research and corporate integration (World Intellectual Property Organization, 2019). Many well-established Swiss and foreign companies have allocated significant assets toward the advancement of IoT technologies and new, secure implementation methods. DataArt, a global IT consultancy company, has recently expanded its focus to include innovative IoT solutions in improving corporate device communication, data collection, and data management. DataArt works with companies in a wide range of industries, including health and life sciences, to not only improve data collection and processing but also to ensure the security of these technologies and the data collected. With one of their main facilities located in Zug, Switzerland, DataArt is a large contributor to Swiss IoT development and provides extensive opportunities for Swiss researchers and companies to collaborate with them and reap the benefits of their IoT expertise.

In the past, DataArt has worked with healthcare organizations to determine new ways to secure their patients' data by analyzing the effectiveness of current methods and removing any vulnerabilities (Kobelev, 2020). Much of this research was carried out through their embedded systems program. This program was designed to aid researchers and corporations working to integrate IoT technologies into their devices by facilitating the prototyping, evaluation, and development of their connected systems (*Embedded Systems,* n.d.).

Also, several IoT-oriented startups have recently formed throughout Switzerland and surrounding European countries. These new companies focus solely on IoT technologies and IoT-related issues, especially cyber and data security. For example, DAC Digital is a recently founded Swiss software and hardware development company focused on custom IoT implementations. DAC's main objective is to work with companies or research teams to discover more efficient ways to collect and process data as well as automate tasks by integrating IoT devices into their existing infrastructure. DAC employs a variety of methods to ensure data security and is well-known and trusted among very security-oriented industries, including the financial and healthcare sectors. DAC has worked on many important projects to develop unique solutions for efficient and secure data collection and processing (DataArt, *Hardware*, 2021).

Another indication of Swiss interest in the field are the focused conferences held in Switzerland and its surrounding nations that discuss various topics related to IoT devices, and their secure implementation. For example, the International Conference on The Internet of Things Privacy, Trust, and Security (ICIOTPTS) will be held in Zurich on January 14, 2022, and will facilitate discussions, lectures, and moderated panels. This conference aims to educate attendees and serves as a springboard for collaboration between IoT experts and researchers across various industries. The focus of ICIOTPTS specifically is data and information security and innovative new methods for encryption and secure data transfer among IoT devices (World Academy, 2021). However, with other annual Swiss-held conferences like the International Conference on Internet of Things based on Blockchain (ICIOTBB) and the International Conference on Internet of Nano Things and Nanotechnology (ICINTN), all topics of interest will be covered, allowing researchers extensive opportunities for collaboration with experts in the field.

2.2.1 Swiss hospitals and hearing research-based companies

Switzerland flourishes with technological advances and medical development; collaboration with many of these companies and hospitals will further support the research for this project. Even though IoT is still a relatively new technology to the field, it does not change the fact that researchers are seriously pursuing IoT for many applications (Laplante 2016). The University hospital Zurich has done award-winning research to improve the technology of hearing research (University of Zurich, 2021). Throughout Switzerland, hospitals and companies have had their input in the development of IoT and otology. DataArt has implemented IoT and has advanced previous technologies to improve healthcare. Currently, they are trying to create wearable medical devices with the addition of IoT, and they work alongside other medical companies in their research, frequently collaborating with Zesty (a European digital health company) (DataArt, *IoT services,* n.d.). One collaboration includes improving patient's experience with their technology, which includes easier bookings as well as navigation through their media's services (DataArt, *IoT services,* n.d.). There are also companies like Sonova, whose main mission is to develop hearing care solutions; their brands Phonak, Unitron, and Hansaton provide a variety of hearing instruments for patients (*Home*, Sonova, n.d.). Phonak creates hearing aid products and accessories that are easy to use and are branded to deliver high quality sounds. For example, their product the Phonak Naída™ Paradise can connect to TV, smartphones and the myPhonak app that customizes users' experience. It also has a speech enhancer, tap controls, motion sensor hearing, and noise cancellation features. Thus, it is an incredible product that could be made even better via a connection with an IoT-enabled smartphone (Phonak, *Life is on*, n.d.). Collaboration with Swiss groups and companies who focus on hearing research will give this project insight on product productions and the technologies that are needed to provide hearing loss solutions and prevention. Understanding the exciting field of hearing devices helps show opportunities for improvement with IoT.

With similar missions in hearing loss research, Bern University Hospital (Department of Otolaryngology, Inselspital, n.d.) collaborates with the ARTORG Center for Biomedical Engineering Research in their Hearing Research Laboratory. Their research includes psychoacoustic experiments, anatomical and electrophysiological studies, the design and implementation of clinically applicable software and devices, and the conduct of observational studies and clinical trials (ARTORG, *Hearing Research Laboratory*, n.d.). Some of their case studies include a system for combined hearing and balance tests for a hearing-impaired person, and the use of a cochlear implant processor as a contralateral routing of a signals device (ARTORG, *Publications*, n.d.). From the hospital to the research center, Bern University Hospital develops hearing analysis and innovative research methods.

2.3 Our Project

As other medical and industrial fields see the benefits of their IoT applications, our project aimed to explore how IoT devices could aid researchers at University Hospital Zurich's Otolaryngology department and more broadly benefit hearing researchers across the globe by improving their data collection methods. Additionally, we worked with researchers from USZ's Otolaryngology department as well as researchers from other sites across Switzerland to analyze the feasibility of IoT device applications within hearing research. We determined the feasibility of implementation strategies by first determining regulatory challenges as well as the health and safety challenges associated with each strategy, and then by determining if these challenges can be managed. Finally, through our work with researchers across Switzerland, we raised awareness for the opportunities of IoT technologies in hearing research as well as other medical fields. These focus points helped our group create a methodology to effectively complete our project's objectives.

3. Methodology

Our research approach for our work with the Universitätspital Zürich (USZ) was a goal-oriented, multi-step process with several objectives:

- Research the current state of IoT in medical and hearing research
- Assess awareness of IoT in healthcare
- Explore ethical and regulatory challenges IoT may face in hearing research
- Assess how IoT could benefit otology and hearing research
- Identify new applications of IoT, provide resources for successful implementation, and relay our findings to clinicians and researchers

This chapter highlights each objective and gives details of the steps took to achieve them. It also describes the methods that were used to meet each objective, criteria for assessing when each goal is accomplished, and how each goal ties into the overall project goal.

Our objectives and their accompanying research strategies were developed to target a specific aspect of our project's focus: "The role of the 'Internet of Things' in hearing research and clinical otology". Figure 3 summarizes the methodology of the project, from the main goal to the final synthesis of the results. It was our intention that all interviews described in this chapter be conducted in-person, however local and international health restrictions did not always allow this during the ongoing COVID-19 pandemic. If in-person interviewing was prohibited or an interviewee did not feel comfortable with an in-person meeting, their interview was conducted on a digital meeting platform, like Zoom.

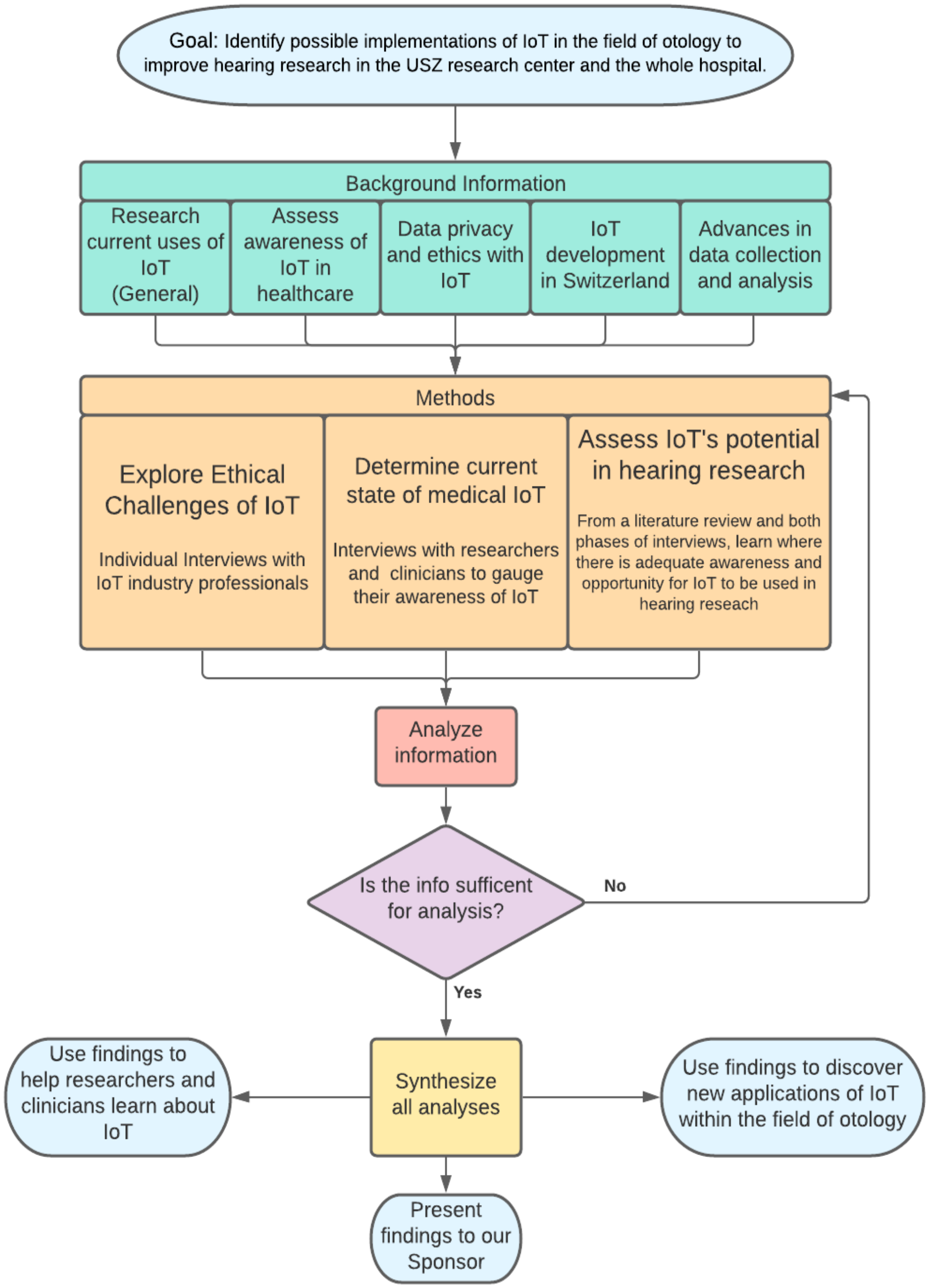

Figure 3: Graphical representation of the project's step-by-step methodology

3.1 Objective 1: Research the current state of Internet of Things (IoT) in medical and hearing research and assess awareness of IoT in healthcare.

To set a baseline for our project, we first researched how IoT technologies have already been used within the field of otology, revealing hearing researchers' current level of awareness of IoT technologies. To gather this information, we conducted an in-depth literature review of case studies, peer-reviewed papers, expert discussions with the authors when possible, and transcripts of past interviews with experts. We also conducted expert interviews with hearing researchers when permitted by project conditions. The outcome of this objective's research provided a survey of current IoT technologies in hearing research, while also revealing the extent of inquiry of researchers and medical professionals in the field.

3.1.1 Data Collection of IoT Usage in Medical and Hearing Research

Using secondary research, we surveyed both otology and IoT information to understand current IoT usage in hearing research. In addition, using science-based search engines and case study materials from university/hospital repositories, we assessed the role IoT currently plays in the medical field at large. Worcester Polytechnic Institute (WPI) provided us with access to many online databases, books, papers, and other university resources that we accessed as needed. Also, collaboration with USZ's researchers as well as WPI engineering professors and librarians helped set the foundation of our research.

3.1.2 Literature Review of IoT usage in Medical and Hearing Research

First, we conducted a literature review using scientific search engines such as Google Scholar, ScienceDirect, and PubMed for medical-based data. Using broad search terms such as "IoT in otology" and "wireless otology," we gained a high-level understanding of how IoT technologies have been implemented in hearing research. We also sought to learn the extent to which Swiss medical institutions, including our sponsor, have come in their research of IoT technologies by including their names in our search terms and analyzing publications posted to their websites. We analyzed these readings and stored the extracted notes and data in group documents for simplified collaboration and further analysis. These documents were categorized by institutions to give us a streamlined way of referencing relative familiarities with IoT technologies for our analysis. This process helped us focus our efforts and provided a solid base for the next steps of our project.

3.1.3 Expert Interviews

The approach to the second part of this objective was to interview hearing researchers, doctors, students, and other academic experts to assess the current state of IoT technology and awareness. Thanks to our project's location at USZ, we had access to numerous potential interview candidates to aid us in our work, such as otology clinicians and hearing researchers. We also met with researchers and academics from other institutions. We began our recruitment process for expert candidates early in the project schedule (see Appendix E) to determine their availability and conduct as many interviews as possible. Due to the pandemic, we took into consideration interviewees' methods of meeting; whether it was in-person or on Zoom, we respected their decisions. We kept our interviews under an hour and ensured they contained questions covering a variety of topics. While we included questions both opened and closed, they were tuned based on the individual's area of expertise. A common group of generalized questions such as: "to what extent are you familiar with IoT?", "how do you see IoT playing a role in otology?", and "what kind of difficulties in hearing research do you think IoT could resolve?", were asked to all interviewees (see Appendix E for our interview schedule).

We strived to apply ethical interviewing techniques that helped ensure clear, unbiased, and respectful communication. These techniques included making the interviewee feel comfortable, encouraging elaboration when needed, and avoiding leading questions that force a certain response or acknowledgment. Each team member was assigned a role for each interview: one or two members asked questions, one was the designated note-taker, and one recorded/transcribed the interview (given the interviewee's consent). For each interview, the gathered data were sorted into a document where it could be easily accessed and referenced.

3.1.4 Analysis

The interviews verified our literature review findings and filled in blanks with respect to clinician awareness of IoT and its current uses. We aimed to obtain as much information as possible about IoT in medicine and otology, and we synthesized what we found about the challenges, current trends, and medical potential of IoT in Section 4. This outline revealed where to start in fulfilling the project's other objectives and provided IoT applications for consideration later in the project. One major limiting factor for this objective was that it depended on researchers having at least some basic knowledge of IoT and how an IoT device functions. If a researcher did not know anything about IoT in hearing research, the interviewers would provide a brief explanation of the concept as well as some examples of potential IoT applications in otology and other medical fields.

3.2 Objective 2: Explore ethical and regulatory challenges IoT may face in hearing research.

To assess the implementation of new, unfamiliar technology to medical data collection, it was crucial to understand the ethical standards and regulatory policy regarding privacy in Swiss society and the healthcare industry. In determining these potential barriers, we were better prepared to address them and suggest IoT applications that satisfy the privacy expectations of patients, hearing researchers, and clinicians. In combination with our own literature review on the topic, we consulted local industry professionals and examined their own experience-driven perspectives to introduce ourselves to IoT's ethical and regulatory challenges. Once we had sufficient background knowledge, individual interviews allowed us to collect valuable primary information from unbiased sources. As we gathered more information, we created an "ethics checklist" that outlined the qualities of ethically valid IoT use. Based on our checklist, written sources, and live interviews, we determined the ethical and regulatory limits of IoT implementation.

3.2.1 Literature Review of Ethical and Regulatory Challenges of IoT

Similar to the first objective, a careful literature review was accomplished by utilizing, among other resources, the many scientific databases available to us through the George C. Gordon Library at WPI. The databases, which provide a wealth of information on topics as far-ranging as engineering, literature, and social studies, were instrumental in the proposal's background research and continued to have an impact on our understanding of IoT implementation. In our searches, we used key phrases such as "IoT and privacy", "healthcare data ethics in Switzerland", and "Swiss IoT regulation" to find multiple sources on the topic. In addition, because data privacy is often discussed as a public issue, many legal and ethical challenges of IoT are written about openly and are accessible to anyone. By collecting and analyzing this type of information from public resources and databases, we acquired a broad understanding of the IoT regulatory environment before we met with experienced individuals.

3.2.2 Interviews

Our interview phase included semi-structured interviews with industry professionals. This phase of interviews took place early in the project and depended on our ability to recruit and schedule interviews. The interviewees were informed of the purpose of the interview before it took place. We recruited individuals who had first-hand experience with the regulatory challenges of IoT. These individuals were affiliated with organizations like IoT companies, government regulatory agencies, and care-providing institutions that have worked with USZ in the past. While working with our sponsor at USZ, we compiled a list of about two dozen interview candidates. Depending on who responded to our requests, we created a final roster of interviewees and then, based on our database research, assembled a series of interview questions relevant to the individuals' areas of expertise. As described in Appendix B, to capture the distinct perspectives on IoT regulation and ethics from our respondents, we used the same series of interview questions for each interviewee, with one or two deviations per question set. The questions aimed to identify specific obstacles IoT may face in otology, as well as any potential courses of action to overcome them.

3.2.3 Analysis

To analyze the interviews and confirm the ethical challenges of IoT in hearing research, we reviewed notes taken during the interviews, using qualitative coding techniques to systematically categorize the data, documenting the important issues discussed by the interviewees. When we finished this round of interviews, we had a clearer picture of the relative significance of obstacles IoT would face. This information advised our assessment of IoT's benefits and limitations in otology and hearing research, directly contributing to the fulfillment of this project's goal.

When we completed this stage of interviews, we had developed an informed "ethics checklist" that we could reference while determining the potential applications of IoT. To be declared a potential application of IoT, a proposed application and its implementers must first meet the requirements outlined by the ethics checklist. Our analysis of the literature review and interviews together allowed us to include points such as: the application being standards-based and secure (as defined by the interviewees), the application conforming to institutional, local, and national regulatory policies, the application's use being disclosed to the individuals whose data it collects, the application only collecting data that has individuals' consent to be collected, and not collecting any data that is extraneous, not consented to, or planned to be unused.

For this objective, our literature review of IoT ethical challenges was somewhat limited by the lack of available resources on IoT implementation in otology. While many written sources discussed the ethical/regulatory aspects of IoT in other fields of medicine and healthcare, there was a clear absence of the topic as it related to hearing research. However, through our literature review we still gained an important base of knowledge of the laws and ethics surrounding the sharing of medical data and other private information in Switzerland.

3.3 Objective 3: Assess how IoT could benefit otology and future hearing research and relay the findings to clinicians and researchers.

IoT is used in other medical fields with varying degrees of success depending on how IoT was integrated into the field and how well the researchers and clinicians understood the uses of IoT devices. Thus, it was essential to our project that clinicians and researchers at USZ understand how IoT can improve their daily research and diagnoses. Once we determined various uses of IoT devices that could benefit the field of otology, we relayed those uses and how to implement them to hearing researchers and clinicians at USZ using an educational medium. Because each use was unique, it was important that we understood how IoT systems work so that we could apply the most applicable one to an individual researcher or clinician.

3.3.1 Data Collection of IoT's Potential Benefits

Data collection regarding the potential benefits of IoT in hearing research was accomplished by looking at past literature of IoT systems in otology as well as the implementation of IoT in other medical fields and technology. We examined successes and challenges of IoT systems to see what the differences between them are; even the failures may have been using a good IoT system but had worse integration into the field, or vice versa. The literature review gave us a general sense of how IoT technology was being used around the world and how it could be applied to specific cases that a researcher may need. As we looked through the literature, we noted how past researchers had done their work and used what we found to create our own guide on how to integrate IoT systems into otology.

Our team interviewed five researchers and clinicians to get a better understanding of how to teach others to use IoT technologies as well as aid researchers looking to implement IoT technologies into their own research. The questions focused on their firsthand experience with IoT systems and how they integrated the systems into their research. The interviews were scheduled in advance based on our proposed timeline (Appendix E), although they were ultimately scheduled at the convenience of the interviewees. The interviews were recorded if consent was given, and notes were taken in real time by the team's designated scribe.

3.3.2 Analysis

After the interviews, our notes were analyzed as described in prior objectives through qualitative coding (systematic categorization), which allowed us to discover recurring themes that arose across multiple interviews. These themes helped us address any recurring problems in implementing IoT in otology and allowed us to develop stronger feedback and recommendations for the researchers and clinicians we interviewed.

Once all the interviews were conducted and analyzed, they served as input into the development of a written guide and recorded presentation intended for researchers and clinicians who want to use IoT in the field. Using this guide, our team gave otological hospitals, researchers, and medical professionals the information we had learned so they could begin to use IoT in their research as they see fit.

Although we obtained multiple perspectives during our project, conducting individual interviews as opposed to other means of data collection (i.e. via mass survey or questionnaire) somewhat hindered our ability to gain a broad consensus of how hearing researchers and clinicians integrated IoT in their research. Additionally, the team only interviewed medical professionals from one department of one hospital system, further increasing the possibility of narrow results that do not completely reflect the state of IoT in healthcare and otology. Interviews with industry professionals were similarly limited, as only two such individuals were interviewed. A third limitation to this objective's methodology was the inherent possibility of interviewer bias in forms such as implicit bias and inconsistent phrasing between interviews. Despite its limitations, the employed methodology helped us gather valuable firsthand insight into IoT's current and potential applications in hearing research and ultimately fulfilled the project's objectives.

3.4 Objective 4: Identifying new applications of IoT technologies and providing resources for successful implementation.

Our objective was to identify new applications of IoT technologies and provide hearing researchers with resources for IoT education. This was accomplished in many stages over the course of this project. This objective had a long-term focus, and it was accomplished following the completion of previous objectives as well as various subtasks outlined as follows.

3.4.1 Data Collection of new Applications of IoT Technologies

First, we made considerable progress in our previous objective assessing the current awareness of IoT technologies in hearing research. This was a necessity as it revealed the level of education and collaboration needed by researchers to implement the technologies we suggested. It also gave us a much better understanding of how intricate and advanced our suggestions could be. For this reason, components of this objective have been at play throughout the project.

Once we decided to hear researchers' current understanding of IoT technologies and how they can benefit their research, we began to assemble relevant educational resources. These resources included descriptions and analyses of current IoT technologies, explanations of current uses of IoT in medical research and devices, and expert documentation of IoT devices. We also provided information about various IoT teams looking to collaborate with researchers from the medical industry as well as information and analysis of their past work.

To assemble the educational resources and background information regarding IoT technologies and their relevance to healthcare, we conducted an in-depth literature review of IoT-focused scientific documentation and compiled relevant industrial IoT applications. The scientific documents were sourced from the various well-respected scientific databases that this chapter has already mentioned. We also sourced information about basic industrial IoT applications from company websites and documentation as well as unbiased, third-party reviews and analyses of these devices.

3.4.2 Forward-Looking Analysis

We summarized our findings into a concise section of our paper as a brief description and background of basic IoT devices and their common uses. This section sets the stage for an in-depth analysis of current medical IoT applications to give the reader a better understanding of the intricacies of these devices and what is required to implement them in their research.

Next, as a point of contrast, we briefly highlighted some of the ways IoT devices have revolutionized research in other medical fields and presented examples of technologies that could not have been created without IoT. Based upon our prior research and analysis with experts in the field of IoT, we discussed the most relevant applications of IoT, with a specific focus on data collection, and presented summaries of these technologies. We also provided in-depth technical details of how these IoT devices work to improve data collection and analysis so they can be more easily implemented in hearing devices and applications.

Finally, expanding on the ways IoT devices have revolutionized research in other medical fields, we presented innovative ideas for its integration into the field of otology by reviewing the case studies identified previously from other medical fields. In many of these examples, the IoT technologies used could be directly adapted to current hearing devices, making them far more efficient and accessible. We concluded by presenting new ideas for IoT device integration into hearing devices. These were presented mainly as aspirational but helped to reveal the extensive possibilities allowed by IoT devices. By presenting a few ambitious ideas, we succinctly encouraged creativity and collaboration among researchers and IoT experts.

By following the described methodology, we obtained and analyzed qualitative information that helped us reach meaningful conclusions relating to IoT in hearing research and otology. The following chapter is a detailed discussion of the results we obtained as well as what they told us in relation to each objective. In different ways, each interview contributed to our understanding and achievement of each project objective, fundamentally helping to accomplish the main goal of assessing potential roles of IoT in hearing research and otology.

4. Findings

The goal of this project was to assess the current level of understanding otology researchers have for Internet of Things devices and how they can benefit their research, then determine the best way to educate the researchers on the topic. The objectives we identified to reach our goal were:

1. Research the current state of Internet of Things (IoT) in medical and hearing research and assess awareness of IoT in healthcare.
2. Explore ethical and regulatory challenges IoT may face in hearing research.
3. Assess how IoT could benefit otology and future hearing research and relay the findings to clinicians and researchers.
4. Identify new applications of IoT technologies and provide resources for successful implementation.

In this chapter, we describe and analyze the resulting information that we collected to achieve these objectives and our goal.

4.1 Research IoT usage in medical research and assess awareness of it in healthcare

Following the methodology, an analysis of past medical studies that used IoT was conducted to gain a better understanding of how the technology is currently being used in medical fields. Next, a literature review covering future and potential uses of IoT was performed to gain a higher-level understanding of how IoT devices have been implemented in hearing research as well as the benefits they bring. Finally, we held interviews with experts from the field of otology to assess their current level of understanding of IoT. The results are shown and analyzed in the following sections.

4.1.1 Analysis of Past Studies

We reviewed and analyzed almost two dozen studies from the healthcare and medical field that involved IoT technologies to see what technologies are being used and how they are being used. From this analysis we learned that most IoT-enabled devices currently rely on Bluetooth technology, usually in the form of Bluetooth Low Energy (BLE), to communicate with other sensors and devices placed around the environment or on an individual's body. A few examples of studies incorporating IoT devices and a breakdown of how they use IoT are highlighted in the following paragraphs.

In one past study, a series of smart devices that monitor or manage various aspects of diabetic foot ulcers (DFUs) were linked together using IoT (Basatneh et al., 2018). The seamless communication provided by the Internet of Things network allows these devices to collaborate with each other to provide doctors, as well as patients, with an in-depth analysis of past and real-time data without the patient having to leave their home. When compared to current methods of monitoring and treating DFUs, this IoT-based solution proved to not only be far cheaper than regularly scheduled in-person testing, but also allowed for a much more personalized and timely diagnosis. Also, since these devices are able to collect and analyze an abundance of data and instantly notify doctors of any alarming changes, this IoT-based solution has the potential to greatly reduce the number of DFU-associated injuries and amputations (Basatneh et al., 2018).

Another study used IoT to link wearable devices that monitor various aspects of the wearer's health and environmental conditions. (Haghi et al., 2017). This study determined that the use of motion trackers, gas detectors, and vital sign monitors would provide the best overall indications of a person's health and environmental dangers. However, the researchers of the reviewed literature were unable to efficiently integrate both a gas detector and a vital sign monitor into one device. To combat this problem, an IoT network was created that would allow all these independent devices to communicate with each other. It is believed that these technologies and the abundance of data they provide could greatly improve doctors' diagnostic abilities and reduce workplace and environmental harm. Using this network, individuals and their physicians can gain a much timelier and holistic insight into their physical health and activity trends when compared to the current standard of yearly and/or sickly check-ups (Haghi et al., 2017).

4.1.2 Literature Review

Throughout our research many applications of IoT have come up in the current years, as projects and case studies with IoT have been more prevalent. Examples of uses and projects are described in this section to give a better idea of how far the technology has come.

A team from Sri Sivasubramaniya Nadar (SSN) College of Engineering, India has successfully developed a home security system that integrated IoT into its system to assist the hearing impaired (Sneha et al., 2021). This system can become a preventative tool for any user, and it can help people with hearing problems to immediately recognize a dangerous situation. How the system works is that it has various safety sensors and features; it immediately sends an SMS when it is triggered, and the user can press the panic button when there is an emergency. Just like smart devices from past studies, it can monitor levels of danger such as fire, water, and carbon monoxide.

One of the issues with a cochlear implant is the user's adaptation to the environment, which forces users to be overly conscious of their surroundings. One team from the University of Texas at Dallas tested IoT in a cochlear implant to accurately distinguish and classify the surroundings and noise level of the user's location (Ghosh et al., 2020). The team's Auris interface, an experimental cochlear implant outfitted with environmental sensors, collects, processes, and sends acoustic data to the CCi-MOBILE Android app, where data can be sent to the implant and a signal can be sent to the users. The experiments were able to produce 96.67% accuracy in location identification and 91.67% distinguishing of sound. This could improve sound knowledge as well as background noise extraction, making better communication experiences with devices and the users (Ghosh et al., 2020).

IoT has been more prevalent in the late 2010's as it can solve issues in subjects such as noise analysis that were not before possible. The analysis of data trains the program of the devices to be able to recognize the environment of the users, and function differently depending on the setting. Eventually, IoT will become a key part of collaboration between machines as it has already established its place in this field.

4.1.3 Expert Interviews

Table 1: The names, roles, and institutions of each of the project's expert interviewees.

Name of Interviewee	Role and Institution
Dr. med. Christoff Röösli	Surgeon & researcher, Dept. of Otolaryngology, USZ

Dr. Flurin Pfiffner	Engineer/researcher, Dept. of Otolaryngology, USZ
Prof. Dr. Alexander Huber	Director, researcher, professor, Dept. Of Otolaryngology, USZ
Dr. Jae Hoon Sim	Team lead engineer/researcher, Dept. Of Otolaryngology, USZ
Dr. med. Adrian Dalbert	Doctor/researcher, Dept. Of Otolaryngology, USZ
Dr. Adam Lammert, PhD	Neuroengineering researcher, assistant professor of biomedical engineering, WPI
Dr. Patrick Boyle, PhD	Senior Director of External Communications, Advanced Bionics. Dr. Boyle provided us with his own opinions and did not speak on behalf of Advanced Bionics' parent company, Sonova.
Craig Sharp	Vice President, Connected Care. Mr. Sharp also provided us with his own opinions and not those of Connected Care or Cochlear.

Interviews with IoT hearing researchers gave a perspective of where IoT is in their field (a summary of all interviews can be found in Appendix F). Most of the experts were able to recognize what IoT meant, yet there were some with little to no knowledge of IoT. Out of the project's eight interviews, six interviewees had heard the term "IoT" before while four out of eight have previously used IoT technology in some capacity. Some of the hearing researchers have employed IoT centrally in past research projects, one example being that of a robotics-driven microscope that used IoT to communicate with sensors, controls, and databases. WPI assistant professor and researcher Adam Lammert was somewhat knowledgeable of IoT (he extracted and studied medical data without being intrusive to the patient) but has not directly used it. In his work, he observed conditions and made connections to determine the sources of hearing issues. These observations also included speech patterns and how these can change with emotions, which can allow doctors to have a better understanding of how the patients are feeling.

Another type of data looked at, which came up in an interview with Professor Lammert, is otoacoustic emissions, which are sounds produced by the mechanisms of the inner ear. These emissions are normal for people without hearing loss and tend to dissipate for people with hearing loss. Hearing aids could have sensors imbedded in them to look for these emissions, and if emissions appear to be lessening the doctor could be notified. The patient then could relay what their surroundings were, or the device could be sophisticated enough to know its own surroundings, to see the causes of the decreased emissions. Collecting this data will allow researchers to better understand why the emissions decrease and how to treat it in patients.

Out of the entire field of interviewees, industry experts who have used IoT understand it the most. Dr. Patrick Boyle of Advanced Bionics (a subsidiary of the Swiss hearing care company Sonova) has IoT part of his company's functions. Their new product, the Marvel Cochlear Implant, has built-in wireless capacities that can use Bluetooth to communicate with other Bluetooth-activated devices. Similar to Dr. Boyle, Craig Sharp, the Vice President of Connected Care, was very knowledgeable in the uses of IoT and its potential in hearing care. During our interview, we discussed the integration of IoT in hearing aids and household products as well as the limitations of IoT (which were mainly privacy and Bluetooth security). According to the experts interviewed, IoT is a promising, albeit nascent technology in hearing care.
Based on what we gathered, the main reasons IoT is still underutilized in hearing research and clinical otology are due to privacy concerns and the slow pace of the regulatory process governing IoT integration into medicine. This topic will be discussed further in Section 4.2 of this chapter.

IoT can be difficult to define and relay to someone who has not studied or ever heard about it. To have a conversation about IoT, one must understand what it is, what it is used for, why it is used, and how it could affect people. Although our interviewees understood some of the complexities and potential applications of IoT, we realized that some of them use IoT-enabled devices daily but simply do not recognize them as such. Thus, current, and potential applications of IoT can be overlooked due to the concept being too new. Further details relating to this phenomenon can be found in the interview responses and analyses in Appendix F.

4.2 Explore ethical and regulatory challenges IoT may face in hearing research

Discussions of privacy are prevalent when it comes to IoT because the applied technological systems can be complex and involve communication between devices with their own unique systems and services. When the reliability of an IoT system is in question, a thorough look at the types of cyber challenges and security issues faced by the system can help determine the best solutions to secure the shared data. In this way, we can inform not only medical professionals but also anyone who encounters IoT, ensuring that they are comfortable with this technology. In this section, we will discuss the challenges at hand for IoT as well as their potential solutions based on our independent research as well as expert advice.

4.2.1 Literature Review

When web searching IoT, one of the most common result topics was privacy. When the device must connect to many other types of services and go through diverse communication there is the possibility of an attack. Even connections between only two devices are vulnerable to attack from each other as well as a third party. For example, one publication categorized three levels of security threat regarding IoT deployment architecture (Khan et al., 2017). First, low-level security was defined as an insecure physical interface that uses various physical compounds to harm the functions of IoT systems. On the intermediate/second level of security threat, an attacker may exploit compromised nodes already existing in the network, an example being a Routing Protocol for Low-Energy and Lossy Networks (RPL) routing attack. A low-energy and lossy network is defined as a network of embedded devices with limited power, memory, and processing resources. On the third and final tier of security threats, a high-level security threat is caused by insecure, Internet-connected interfaces vulnerable to attack. According to the reviewed literature (Khan et al., 2017), suggested solutions for deterring low- to high- security threats include:

- Avoiding software/firmware access to USB inputs,
- A technique known as "hashing" to defend against RPL routing attacks,
    - Hashing is the process of converting a key into another value which cannot be changed back.
- Signature-based authentication,
- Not accepting the creation of weak passwords.

Since an attempted cyberattack must go through many layers to reach the core of a connection, recognizing and reinforcing the layers that may be vulnerable is a preventative method that can be used to ensure the safety and confidentiality of data in the future.

4.2.2 Expert Interview Findings

Most of the interviewees were wary of IoT due to the difficulties in keeping data private during inter-device communication. For a summary of the privacy issues surrounding digitized medical data, see the referenced review article *Big Data in Public Health: Terminology, Machine Learning, and Privacy* (Mooney & Pejaver, 2018). Since the patients and potential users (i.e., clinicians and researchers) of IoT are the main user groups, their permissions and concerns will be viewed as most important. Based on the feedback received during the interviews, the technology must be virtually perfect and without data leaks for medical professionals to trust it. The devices must be almost perfectly reliable when it comes to connection between devices because a drop in connection could cause the loss of important data. Most of the interviewees agreed that this is the main obstacle in the application of IoT, followed by a lack of knowledge and discussion on the topic in the medical field. Some also say that if this system should be widely used, a new policy must be implemented in response to the innovative way that patients' medical and personal information will be shared and used. Another aspect that must be considered is to have the patients be in control of their data, or to have the data be reported to them. It is mentioned as feedback, the patients can feel safer because they are in control of the types and amounts of data they can give out.

4.3 Assess how IoT could benefit otology and future hearing research and relay findings to clinicians and researchers.

The analyses of past studies, the extensive literature review we conducted for the previous objectives, and our expert interviews from varying sectors of the medical and Internet of Things industries provided us with ample insight into the benefits IoT could bring to hearing research. These findings are discussed in the following sections of the results chapter and summarized into two educational materials—a poster and a pamphlet—designed to aid hearing researchers and accelerate the integration of IoT into otology. See Appendices G-I to view the educational materials.

4.3.1 Data Collection

The findings from our literature review and analyses of past studies showed us what IoT has made possible in other medical fields. Using this knowledge, paired with the knowledge gained from industry professionals, we were able to visualize new potential applications in hearing research and relay these findings to our sponsor and other researchers during meetings and interviews.

From our research into newly developed hearing aid and cochlear implant technologies as well as our interview with Mr. Boyle we learned how IoT is currently being used in hearing research. At the time of writing, Advanced Bionics was releasing their new cochlear implant, the Naìda CI M. The Naìda CI M is a revolutionary product within the hearing industry and one of the first products to integrate IoT technology by including Bluetooth Low Energy (BLE) technology. The BLE capabilities of the Naìda CI M allow it to connect to any Bluetooth-enabled device and stream audio directly to the user’s implant (Advanced Bionics, 2020). At the moment Bluetooth is used to connect the implant with the users' phone, radio, and television. The introduction of Bluetooth capabilities allows for the device to be used as a medical IoT device, the implants could be used to collect data from the user, and the data could be transmitted to a database to be looked at by a doctor.

4.3.2 Analysis

With more knowledge about IoT technologies and their capabilities, researchers would have the ability to not only develop new technologies, but also expand on existing technologies like the Naìda CI M. From our research and interviews, we have concluded that the sensors currently included and new sensors that could be included in implants such as the Naìda CI M could be connected to other devices. This connection would function in a similar manner to the wearable devices discussed in Section 4.1.1 and allow not only for improvements to the hearing devices themselves, but also provide the wearer and their doctors with useful health data.

Another potential application of IoT, which we discovered during a meeting with Dr. Ivo Dobrev, is on the diagnostics side of the hearing industry. With current diagnostic methods, hearing tests are a very costly process that must be performed by a professional audiologist in a soundproof room. Due to the costs and inconveniences associated with the process, these tests are generally only performed once an individual has noticed a significant decline in hearing ability. However, since most individuals have access to high quality headphones and/or many mobile devices, a new software could be developed to perform a more basic hearing test from home. This software could easily mimic many of the tests performed during a professional hearing assessment. High quality headphones could be used to test the individual's ability to hear different tones and volumes by pressing a button on a mobile device. Another test that could be performed is placing calibrated speakers at key locations around a room and assessing the individual's ability to discriminate the direction a sound is coming from. While this test would be a less accurate measure of hearing, it would provide a simple and potentially free assessment that could be performed at the first sign of hearing loss (Mayfield Brain & Spine, 2018). Having an easy and rapid test allows people to be more likely to complete the test and could help detect early cases of hearing loss.

4.3.3 Educational Materials

To best explain to researchers what IoT is and how it could benefit their work, we created visual displays that can be shown at any relevant events or in any relevant areas. By looking at past projects' educational materials and verbally asking researchers their preferred display form, we determined that a poster and a pamphlet (Appendices G-I) would most efficiently relay the information.

In these educational materials, we have included a simplified definition of IoT and some projects that were made possible by IoT technologies. In fact, while many researchers will be aware of the projects showcased by our posters, they likely did not realize that IoT technologies played a crucial role in the project and therefore they are unable to imagine further improvements to these devices. In the pamphlet, we also included some examples of potential applications of IoT technologies in hearing research. By presenting these potential applications and past applications, we aimed to not only provide research ideas for our readers, but also inspire creativity and collaboration among researchers and industry experts.

4.4 Identifying new IoT applications and creating implementation resources

After gathering hearing researchers' current understanding of IoT technologies, we were prepared to begin the educational component of the project and provide researchers with the relevant resources. As stated in the methodology, this objective had a long-term focus and was accomplished through the subtasks outlined below.

4.4.1 Data Collection

To prepare for this objective, we first assessed the current awareness of IoT technologies in hearing research using a literature review and a series of expert interviews. Building off background research conducted before the project, our literature review found several interesting applications of IoT in medicine, mentioned in Section 4.1.1 of this chapter. The applications described in the literature proved consistent with what our expert interviews revealed: although IoT technology has limited uses in both research and clinical settings, the experts we interviewed agree that its future capabilities could very well improve hearing in both younger and older demographics.

One particularly insightful discussion came from our interview with Dr. Patrick Boyle, Senior Director of External Cooperation at Advanced Bionics. Speaking from the perspective of the commercial hearing care industry, Dr. Boyle explained to us how advancements in surgical techniques and medical technology have made younger patients (less than five years old) with hearing impairments more likely to receive a cochlear implant than an older patient. Technological and surgical advancements have reduced the risks associated with implanting a cochlear device into a young patient. Coupled with the importance of hearing ability to childhood cognitive development, these advancements have driven the shift in cochlear implant reception to the younger demographic. Once a cochlear implant is received, Dr. Boyle emphasized, its sensors can investigate the interface between a patient's brain and the environment, a key area of interest for hearing researchers at USZ. Additionally, in explaining Advanced Bionics' newly released devices, Dr. Boyle stressed that the ear is more an intermediary rather than a focus of data collection. For example, wireless capabilities built into the new Marvel Cochlear Implant allow the patient to make and receive calls using the implant, and the implant's Bluetooth capabilities can isolate dialogue from connected television and film audio by modifying what sounds ultimately are converted into electrical signals.

Although these applications are intriguing, the Marvel CI's true value lies in research; it is currently being used to gather electrical data to improve balance and focusing abilities for patients with reduced bilateral vestibular function, a condition resulting from damage to the inner ear's central cavity or semicircular canals that manifests itself in dizziness and difficulty maintaining balance. Electrical impedances are not the only data Advanced Bionics devices can collect; the technology used in the Marvel CI can also monitor changes in a patient's audiological environment or their voice intonation and adjust its settings accordingly.

4.4.2 Forward-Looking Analysis

Based on the results of this objective, we believe that IoT is a realistic, possible solution to collecting both environmental and patient-oriented data. Coupled with our literature review findings, specific applications of IoT shared by interviewees show that the technology is already capable of collecting information that would be useful to clinicians, researchers, and patients. Despite the limited current use of IoT in medical settings, IoT could particularly facilitate data collection and hearing care for lifelong cochlear implant patients, whose ever-changing abilities require close monitoring and prompt clinical attention. Furthermore, convenient features of IoT-enabled devices such as Bluetooth audio connection would directly improve hearing-impaired patients' quality of life, providing benefits beyond scientific and clinical efforts.

Because IoT is underutilized in otology, it would be beneficial to the clinicians, researchers, and patients who would potentially use it to have succinct, informative resources on its implementation. Our project provides such materials in the form of three media: a pamphlet or "user guide", an infographic poster, and the final presentation (Appendices G-I). As previously stated, each of these resources will be shared with our sponsor,
the Department of Otolaryngology at USZ, and ultimately any other interested institution upon publication of this report. By having a few different, accessible options for potential users, this objective will inspire IoT implementation in a way that all stakeholders can understand, encouraging future usage and advancing the field of hearing care.

4.5 Summary

The goal of this project was to determine how IoT technologies could improve their research abilities and create educational resources for hearing researchers and clinicians. In addition to this, we aimed to discover new applications of IoT, improve on current applications, and present our findings to our sponsor, Dr. Ivo Dobrev, as well as in this paper. Through our literature review, analyses of past studies, and interviews, we were able to develop a poster and a pamphlet defining IoT and its uses, determine new and improved applications of IoT technologies in hearing research, and present them in a meaningful way to our sponsor and readers. In the following chapter, we discuss the best ways to quickly expand researchers' knowledge and usage of IoT technologies, ways to incorporate our suggestions and potential applications, and how more applications of IoT in hearing research can be discovered and incorporated in the future.

Conclusions and Recommendations

After an exhaustive literature review and several interviews with hearing care industry experts, the team had enough information to address each of the project's objectives. Based on the evidence gathered, we made the following conclusions:

1. Among other things, the reviewed literature revealed that IoT can be used to share medical and environmental data collected by motion, gas, and vital sign sensors.
2. The cybersecurity measures mentioned in Section 4.2.1 are ways to protect the privacy and anonymity of patients using IoT devices. However, there is no Internet-connected system that is 100% secure, and most of the interviewees agreed that this is the main obstacle in the use of IoT in medical applications.
3. With more knowledge about IoT technologies and their capabilities, hearing researchers and clinicians would have the ability to develop new technologies while also expanding on existing ones. Visually engaging, educational materials that include examples of potential IoT applications in healthcare could succinctly and effectively explain the technology's benefits to researchers and clinicians.
4. IoT is a realistic, possible solution to collecting both environmental and patient-oriented data; IoT-enabled devices recently introduced to the commercial hearing care market already collect anonymized patient data to better understand generalized patient conditions.
5. By having a few different and accessible educational media for potential users, IoT implementation can progress in a way that all stakeholders can understand, encouraging future usage and advancing the field of hearing care.

From the listed conclusions, this chapter offers recommendations to hearing researchers and clinicians considering IoT implementation as well as ways to make IoT most impactful in their work. The recommendations are intended in a general sense, and IoT solutions and implementation strategies may vary based on the needs and resources of individual research institutions and clinical organizations. Identifying a way to tailor IoT solutions to different types and sizes of scientific groups could be a subject of a future research project. Nevertheless, for a large research and teaching hospital such as USZ, we recommend implementing an IoT system that has proven successful in a similar role in the past. If there is no current IoT system that fulfills the hospital's research and clinical needs, then a prototypical system can be created and brought to use in a more forgiving regulatory environment. As far as the needs of the USZ Department of Otolaryngology are concerned, applications in environmental data collection, patient monitoring, and improved hearing device capabilities would benefit patient care as well as future otological research, and we recommend the Department considers implementing IoT for those purposes. Furthermore, we encourage the researchers at USZ to circulate this project's educational poster and pamphlet among hearing researchers and institutions outside of USZ to further share IoT's potential benefits to the rest of the field of otology.

In addressing the legal requirements of data sharing in IoT, one possible implementation strategy is to create a system that meets the standards of European privacy law and test it in the United States, where data sharing is a more acceptable societal practice and there is more legislative leniency regarding it. After resolving any potential issues with data privacy, the implementers of an IoT system can then introduce the procedures to European systems. One example of an effective, secure means of data sharing is single direction Bluetooth, which has safeguards and a user protocol that protects data from being stolen. Nonetheless, as a precursor to the implementation process, an IoT system would need the consent and opt-in of patients to use their data. To incentivize patient opt-in, it would be ideal to provide patients an immediate benefit regarding their hearing condition to create both short- and long-term value for them. For instance, if an IoT system could immediately enable a patient to hear in a large lecture hall or eliminate the need to use the maximum volume of a television, patients would likely be more inclined to participate in data sharing. Having short-term benefits would allow more data to be collected, helping both each single user and other patients with the same condition in the long run.

Per interviews with experts in the commercial hearing care industry, IoT has sparked innovation in data collection using Bluetooth technology. The Marvel CI, a cochlear implant designed by Advanced Bionics, uses Bluetooth to gather electrical data to better understand reduced bilateral vestibular function, a condition resulting from damage to the inner ear's central cavity that causes patients dizziness and difficulty maintaining balance. Bluetooth-enabled implants and hearing devices can also monitor changes in a patient's audiological environment, their voice intonation, and adjust its settings accordingly. In a more individualized application, IoT could facilitate data collection and hearing care for lifelong cochlear implant patients, whose ever-changing abilities require close monitoring and prompt clinical attention. Additional applications shared by interviewees show that the technology is already capable of collecting clinically relevant information for patients, doctors, and researchers. Therefore, we conclude that IoT has current and potential applications that would be both feasible and practical in hearing research and otology. Regarding implementation of such systems, we recommend that an otology and/or research department consult their organization's patients as to what they are comfortable with as well as what their individual health monitoring needs are.

Although our project only reviewed a handful of scientific writings and individual perspectives, our findings were consistent and almost unanimously supported that IoT is currently and effectively used in medical research. In addition, the possibilities for new applications of IoT to collect environmental and patient-oriented data while solving some of patients' everyday problems were made clear through our discussions with hearing care industry experts, whose knowledge of upcoming innovations within the field proved highly valuable to achieving our project's goal. To convey all our findings succinctly, we created educational materials designed to summarize and introduce the project's topic and goals to all the stakeholders of hearing research (Appendices G-I). In relaying the information this project has gathered, IoT implementation can progress with limited confusion, most importantly among patients and their doctors, and future IoT usage may continue to advance hearing care in Switzerland and globally. As a final recommendation, we urge hearing researchers, clinicians, and patients at USZ and any other otological institution to review and share our project's poster and pamphlet so that the potential benefits of IoT can be made known to the widest audience possible.

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Appendices

Appendix A: Objective 1 Sample Interview Questions/Script

Questions for all interviewees
What do you think of when hearing "Internet of Things"?
To what extent are you familiar with IoT?
Have you ever knowingly used IoT directly for academic or professional purposes?
Do you see IoT playing a role in otology or in your research?
What kind of difficulties in hearing research do you think IoT could resolve?
Professor/student participants
Have you ever taught IoT in your classroom?
What have you learned about IoT?
Focus Areas: IoT awareness, comfort level, and current uses

Appendix B: Objective 2 Sample Interview Questions/Script

How do you use IoT in your daily professional activities?
Do you ever encounter limits on how you can use IoT or what data you can collect? If so, what are they?
From a regulatory perspective, what are you permitted to do with IoT in your role at _________ (I.e. company, hospital, laboratory, etc.)?
Would you say data privacy is a conscious subject for people in Switzerland? Do you feel medical patients or other people would trust IoT to collect personal data?
On a personal or professional level, do you feel any ethical problems with the implementation of IoT to collect medical data?
In your opinion, do current regulations you're familiar with ensure the protection of personal data as best as possible?
Focus Areas: Daily IoT usage, IoT ethical challenges, IoT regulation, Data Privacy

Appendix C: Objective 3 Sample Interview Questions/Script

Are you familiar with IoT and how it works?

- If yes, what do you know about it? What do you want to learn about it?

How has the introduction of IoT impacted your research? How do you implement IoT systems in your field of research?
What challenges have you faced with IoT? What worked well?
Do you think IoT will play an important role in advancing your field/research?
Is there anything you wish you knew when you were first starting to implement IoT devices/systems into your research?
Focus Areas: IoT familiarity, IoT impact on research, Future of IoT in research

Appendix D: Informed Consent Agreement for Participation in a Research Study

Investigators: Marino Bertone, Jack Ciroli, Jason White, Thanh Trac
Contact Information: mbertone@wpi.edu, jvciroli@wpi.edu, jwhite2@wpi.edu, ttrac@wpi.edu
Title of Research Study: Assessing potential applications of IoT in clinical otology
Sponsor: University Hospital Zurich (USZ)

Introduction:

You are being asked to participate in a research study. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks, or discomfort that you may experience as a result of your participation. This form presents information about the study so that you may make a fully informed decision regarding your participation.

Purpose of the study: The purpose of this study is to assess potential applications of the "Internet of Things" (IoT) in hearing research and otology. Interviews with industry professionals and hearing researchers in Switzerland will provide insight into current IoT awareness, usage, and suggestions for its practical integration. This study will help investigators recommend potential applications of IoT in hearing research and otology to clinicians and other hearing researchers.

Procedures to be followed: Within an estimated thirty minutes, research participants will be asked a series of questions pertaining to their experiences with IoT in their professional field. Participants can take as much time as they want to answer each question, while the investigators may have follow-up questions and/or comments for a response.

Covid-19 procedure: Participants meeting preferences will be respected and Covid-19 protocols will be strictly followed. All parties will be asked to wear a mask and remain 6 feet apart from other whenever possible. Options: online meeting (zoom links will be provided or participator own meeting links and preferences in communications), in-person, emails, phone calls. All preferences in communication will be followed.

Risks to study participants: There is minimal risk of injury and harm to study participants.

Benefits to research participants and others: There are no benefits to research participants involved in this study.

Record keeping and confidentiality: Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or it's designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

Compensation or treatment in the event of injury: This research study poses minimal risk of injury or harm to its participants. You do not give up any of your legal rights by signing this statement.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact any of the study's four investigators by email (see beginning of form). Additionally, you may contact the IRB Manager at WPI, Ruth McKeogh, by telephone (508 831-6699) or email (irb@wpi.edu). Also, you may contact the Human Protection Administrator Gabriel Johnson (tel. 508-831-4989, email: gjohnson@wpi.edu).

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The

project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.
By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

Study Participant Signature: ______________________________ Date: ___________
Participant Name (printed): ______________________________ Date: ___________
Signature of Person who explained this study:______________________________

Appendix E: Tentative Project Schedule

Task	At least one month before beginning of project	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
Schedule Project's Interviews									
Literature Review									
Interviews to assess IoT awareness									
Literature Review of IoT regulatory challenges									
Interviews with IoT industry experts (reg. and ethical challenges									
Literature Review of Medical Applications of IoT									
Interviews with clinicians and researchers who have used IoT									
Assemble Educational Resources									
Final Presentation									
		8/26 - 8/28	8/29 - 9/4	9/5 - 9/11	9/12 - 9/18	9/19 - 9/25	9/26 - 10/2	10/3 - 10/9	10/10 - 10/15

Table 22: Gantt Chart Displaying Our Tentative Project Schedule

Appendix F: Interview Summaries

F.a: Interview Questions

The set of interview questions that were used to interview several clinicians from USZ, numbered for referencing:

1. To what extent are you familiar with IoT?
2. How do others in your field use IoT technology?
3. In the future, do you see IoT playing a role in advancing hearing research and otology?
4. How has the introduction of IoT impacted your own research? / Do you think you can use IoT technologies in the future for your research?
5. On a professional or personal level, do you have any ethical concerns with the implementation of IoT technology to collect medical data in Switzerland?

F.b: Summary of Interview Responses

<u>Responses - Dr. Christof Röösli:</u>

1. Knows of the term IoT and has thought of using it for his research but not in a large capacity. Uses real bones from cadavers and needs to keep them in a freezer and gets a message on his phone when the freezer is not at the correct temperature. The experiments that are conducted to not utilize IoT.

2. It has a strong implication for hearing research since you are able to have many connections between hearing devices and other hearing aids. A main reason that IoT is not used commonly is due to privacy and patient data being transmitted. The laws for data privacy vary from country to country making it difficult to make a device that is compliant with all the laws in place.

3. IoT devices could be used to help with remote fittings of devices and remote feedback of data to and from hearing/medical devices. If there is a technical difficulty with a machine or computer a technician gets notified of the problem and can go and fix it. IoT devices could be used to monitor surrounding noise and can be used to make noise cancellation/suppression software, these could differentiate between background noise and language, or the different devices could communicate with each other to determine noise levels and whereabouts. Health diagnostics could be added to hearing aids, such as blood pressure sensors, which Sonova is currently adding to hearing aids. A small Bluetooth computer could be placed within hearing aids to help facilitate the transfer into IoT devices to help the transfer of data. Another function of IoT devices could be to monitor the storage of various supplies and either notify someone to order more or order more automatically.

4. Not used actively in his research yet, more of a background technology in this field. IoT has not been put into a clinical environment yet.

5. It will be critical to see what data is being collected and how it will be transferred and stored. The data will need to be secure because if insurance companies get the data, they would be able to deny people coverage of health or life insurance. The state could be interested in its people's location data, but could be useful for looking at COVID-19 outbreaks and tracking of spreading of diseases.

Responses - Dr. Alexander Huber:

1. Is familiar with the concept of IoT and has used an exceptionally low level of it. Connects the hospital network imaging to the operation navigation system to help facilitate easier surgery operations. Hearing tests are automatically uploaded to the hospital system.

2. Has heard of a robotically driven microscope that uses IoT to communicate with the controls, sensors, and database and uses a similar display as "Google Glasses." The robot would move using motion controls, for example: if you moved your head to the left the robot moves to the left.

3. Computers could be used to filter out certain background noises or listen to something specific. IoT devices could be used to recognize speech and could reconstruct speech to be understandable. He thinks that IoT advancement is the next logical step in the advancement of science and medicine. Having a centralized database of data will help ease and facilitate medical care.

4. Regulations can cause problems when implementing IoT devices in a clinical aspect. When a software tries to access a patient database, regulation will delay or stop implementation. There are also concerns for patient data security and network security, this will cause a need for new paperwork and rules to be implemented for consent and accountability. The more people are using the system, the stronger the system must be, and if there are outages it can cause problems with medical services.

5. The more we rely on systems the worse it becomes if the system fails for some reason, meaning the IoT network needs to be exceptionally reliable. The devices also need to have good connectivity between one another so that no lapses in connection occur.

Responses - Dr. Flurin Pfiffner:

1. Has heard of the term before but is not super familiar with the topic.

2. Has application in patient monitoring, could track patient hearing without them being on site, making it easier during the pandemic or if they are far away. Already have a hearing aid with an implanted microphone but it is picking up other noises

such as heartbeat and blood pressure, IoT could be used to filter out what is not needed for the specific noises being looked at. Could implant a device on the mastoid bone in the ear which is close to the middle and inner ear allowing for optimal data collection. Talked about the company Cochlear Americas

3. If the data were transferred to a hub where clinicians could analyze, it could be easier to produce a diagnosis. This could also allow for more collaboration from different clinicians within the same field to get a more accurate diagnosis to better care for the patients. The hearing aids could function differently based on where you are, restaurant vs church vs library, could have lower or higher noise detection thresholds. The user could also communicate sounds like are abrasive and should be lowered. Could assist with balance and the vestibular system within the ear.

4. It could be used to connect hearing aids to phones and other hearing aids as well as connect cochlear implants directly to the phone of the wearer. The hearing aids could record voices and noises to auto translate languages without hearing the original spoken language, for example: person A is speaking German to a person B who only knows French, person B would only hear French. Noise cancellation is also a proposed use for IoT enabled hearing implements because it can filter out unwanted voices and sounds, as well as adjusting the frequency of the sounds.

5. Many people are scared of uploading medical data to the cloud because of potential data breaches. The reliability of the devices needs to be very high.

<u>Responses - Dr. Adrian Dalbert:</u>

1. Does not have a very deep knowledge of IoT and does use it in his own research. But can think of applications within his own research and in general. Can be used to help with hearing thresholds and baselines for better diagnostic tests.

2. Has heard of some people using very limited versions of IoT withing their research.

3. With a huge collection of data there will be a large pot of information that can be used by different clinicians. Diagnoses can also be based off a large pool of data to get a more accurate result.

4. Could use recorded electrocortical signals from cochlear implant patients, didn’t have a specific direction but knew that would be an important step to take. The data could be collected in the cloud or a central database to facilitate easier diagnosis. Worked with Sonova and Advanced Bionics, a cochlear implant company, said they were thinking of adding Bluetooth and sensors to implants. Big companies have a large amount of data that would benefit from the usage of IoT devices as well as the clinical field that the data pertains to.

5. Did not have much to say about data privacy. Thought it was important to keep the data secure and confidential.

Responses - Dr. Jae Hoon Sim:

1. Was not familiar with the term IoT, asked us to explain what IoT was. Knew some about the topic after it was explained.

2. Could use devices to look at the middle ear bones and see how the ossicles vibrate/move to capture the movement to see how it translates to sound.

3. If you are able to collect a large amount of data from the middle ear mechanisms from people around the world and in the same city could lead to better diagnoses. With all of the collected data on hand, the baseline would be much more accurate representation. This would also help figure out which treatments are more effective with a larger sample size.

4. Not much of an impact but will look for it more in his research. Could also help with ordering temporal bones for more experiments.

5. There are many privacy laws and restrictions in Switzerland. You need approval from the cadavers' family if you want to publish the results from the study. Ethics approval has to be mandatory for data usage to make sure the data is not being misused. Patients will also have to consent to their data being used in studies as well as consenting to using an IoT device. Researchers should go through a safety and ethics training course regarding IoT devices and how they should be used, suggested a one-week course format.

Responses - Professor Adam Lammert:

What is your specific research at WPI?

Works on trying to gather relevant health data without being intrusive on the patient being studied or looked at. Try to use readily available data that has been or is already being collected to help diagnose mental illnesses. The illnesses can range from fatigue to depression and minor and serious brain injury.

Also works to look at how our brain is able to choreograph complex movements relatively quickly. Based off of that research, advances can be made in helping people who have movement and muscle problems after suffering a traumatic brain injury. This would include mitigating dizziness and helping speech patterns return to normal.

Many devices exist currently that have sensors that are capable of detecting how we move and speak, which can be used to help predict movement and speech. Speech and the movement of the face are predictive of underlying problems that can be diagnosed if the correct data is collected. Also looks for preexisting devices that can be used to collect new data for better diagnoses.

Works with a Deep Neural Network (DNN) which is used because they outperform most other machine learning algorithms. Talked about how there are large barriers between BME and using a DNN. This is because DNN's are seen as a black box, where something is input, and an output is given. Many scientists want to know the science behind what happens to the data to see if it is sound science before they use it for patients or for their own research.

How important is the reliability of the devices?

Accuracy and reliability can and are different values for different people in different fields. For example, a person creating the neural network may be ok with a 95% accuracy/reliability rate, but this would not be acceptable if you are working with patients and especially if it was lifesaving treatment. As said before clinicians would like to know how the output is reached so that they can be sure that the output is trustworthy and accurate.

What hearing research have you been involved with?

Collaborated with UMass Medical on a project looking at tinnitus. They were mainly looking at how to categorize different types of tinnitus and to find better ways to treat it for all patients. Tinnitus is associated with hearing loss, meaning that people often have hearing aids. Some of these hearing aids are relatively sophisticated and can have some of the needed sensors to be involved with IoT.
Worked with otoacoustic emissions, noise produced by the mechanical section of hearing within the inner ear, it has been shown to disappear with hearing loss. Devices used for checking the emissions can be used to see if the inner ear mechanisms are working well, this will help diagnose earlier stages in hearing loss as well as confirm the hearing loss in a patient. Using this technology, otoacoustic emissions sensors could be added to hearing aids to monitor the patients' inner ear health. This could also work if people without hearing loss wore otacoustic emission sensors to see if their inner ear health declines through their daily activities.
Audiograms are created based off a patients' hearing test and can be used to see where someone's hearing is going wrong, which can be used for diagnosis.

How would you teach someone about IoT devices?

Being able to effectively teach depends on the audience you are presenting/teaching to. If you know how they want to use and see data, it will be much easier to get the message across to them. When trying to get people to use an IoT device you need to know in what format they want the output to be in, or at least in a useful format for them to use. This is important for diagnoses, if the doctor does not know how to read the results or the results can be interpreted differently it can cause problems. Make sure you know how the end user is going to want to read the final output from the devices. Another thing to think about is how long do the clinicians want or need to wait before getting the results, I.e., real-time, or longer integrated results?
Need to think about who the end user is going to be and to tailor the presentation towards them. Must think about the How, Who, Why, and What they need from the device.

The following set of interviews were with an industry expert in the field of hearing care and cochlear implants:

<u>Responses – Dr. Patrick Boyle, Senior Director for External Operations, Advanced Bionics</u>

To what extent are you familiar with IoT technologies?

Was very familiar with the topic but said there was not much IoT involvement in the hearing field. This was because a majority of people with hearing loss are of the older generation, meaning that they do not know as much about current technologies and do not see a need or benefit for added sensors in cochlear implants or hearing aids.

Connectivity is a huge market around the world, not just for devices, being connected to people around you is much better for your mental and physical health.

Low-energy Bluetooth can be used to transfer many kinds of data, currently being used in cochlear implants for streaming music and radio directly to the patient's implant. Younger patients are prioritized because the younger you are able to hear the easier it will be to grow up in the world.

Are there any extra sensors embedded in the cochlear implants currently?

Advanced Bionics currently measures electro impedances within a patient with the current models of cochlear implants. Electro impedance spikes have been correlated with hearing loss, tinnitus, and vertigo. They are easy to monitor with cochlear implants. This will lead to a huge amount of data being stored from the devices, which can help lead researchers in the direction to learn more about the impedances.

The cochlear implants are able to listen to the speech of the wearer, this can be used to help researchers understand how the person communicated and what their surrounding is like given the different speech variations. Along with this the devices can be used to monitor your surroundings and how you adapt to that surrounding, either by lowering the volume or how you change your speech. If this data is available to doctors it could help explain a person's reaction to certain events and see how their voice intonation changes with emotion, which could help doctors understand their patients better. Having this data could help quantify how people are living and coping with life events.

An important distinction to make is that cochlear implants are medically led by ear, nose, and throat research and not made for collecting data, even though now that is becoming more and more common.

For the Marvel CI release, what types of devices are the implants able to connect to and could data be transmitted?

The Marvel CI has built in wireless capabilities, which allows them to "talk" to any type of smartphone, which is the most common, and essentially all other Bluetooth capable devices. This allows the wearer to connect and answer a phone call directly to their cochlear implant as well as block out background noise to better hear the call. Advanced Bionics listens to what the recipients want to be added to the cochlear implants for ease of use.

Once Bluetooth has been added you can connect to basically everything, which will help facilitate the use of IoT technology. The implants will be able to isolate dialogue and somewhat ignore the background noise in a specific environment, for example: watching a movie.
New sensors are being added to detect cortical waveforms which could allow the user to choose specific sides of their body to focus their hearing on. This will help researchers find a brain perspective of a specific user. This is because the sensors can see what you are interested in and how you act when you are interested in something.
A bug that became a feature in cochlear implants, was that the implant would accidentally stimulate the vestibular system in the ear, which is the system your body uses for balance. Using the electro feedback that cochlear implants use you can help people who have Bilater vestibular system malfunctions, which will help with balance and focus.

On a professional or personal level, do you have any ethical concerns with the implementation of IoT technology to collect medical data in Switzerland/the world?

Some aspects of IoT data collection would need to have security measures to help protect the collected data and patients' privacy. Confidential information must be safeguarded.

What collaborations have been done with hospitals and researchers?

There is a KTI grant (Kommission für Technologie und Innovation) with Dr. Huber and the USZ. The grant is being used to collect data from sensors in cochlear implants to measure electro impedances which can be used to determine if damage is being done to the ear or surrounding area during the surgery/implant process. This is important data to be collecting because we as humans cannot regenerate/heal parts of our ears, birds on the other hand, can. People are looking to make a small silicon chip that can be implanted in birds to see how they are able to regenerate parts of their ears, and maybe use that to better treat people with hearing loss.

Responses - Craig Sharp, Vice President, Connected Care

To what extent are you familiar with IoT technologies?

Was very familiar with the topic of IoT and talked about a competitor Phonak who has invested in the usage of IoT technologies. A main thing that companies are trying to fix is that many household devices are still hard to hear with hearing devices. In the future washing machines, dryers, and doorbells could be connected to the hearing devices so that the user is aware when they make a sound. This is also being used to just make the sounds easier to hear for people with hearing devices and does not necessarily have to stream directly to it.
The market has not quite absorbed the idea of IoT technologies and marketing them as such does not give a noticeable uptick in sales for the product. One way to help with this is to be able to collect data about the sound environment to learn more about the users' surroundings to help optimize the device for hearing. For this the devices will need to be able to capture enough information about the sound environment as well as contacting the user to see what their preferences are. This could be done by being in contact with the user and tweaking the hearing device to see if it has a good or bad effect. This can be accomplished in a similar way that Apple uses other iPhones to help find a missing device, where hearing devices in proximity to each other are able to communicate to create a better experience for the wearer.

In home audio tests are currently being used at Connected Care. We worked with Apple and Google to create calibrated audio streams that can be played from a phone. With the precise calibration it could be used as a hearing diagnostic and allow for accurate hearing data to be easily obtained.

Are there current limitations to IoT as it is currently, if yes what are they?

A main reason that IoT has not taken off yet is because of the limitations that devices have with Bluetooth connections, where only one device can be connected, and they constantly switch their connections. In 2022 Bluetooth is coming out with a new standard (Bluetooth 5.2) which will allow for connection and streaming from multiple devices. Another limitation is that different companies use different file types for data transfer meaning that different hearing devices would not be able to talk to on anther. This could be fixed if one company made the devices or if the multiple companies came together to make a universal file for sharing data.

Does Connected Care have any IoT/IoT related devices currently in use?

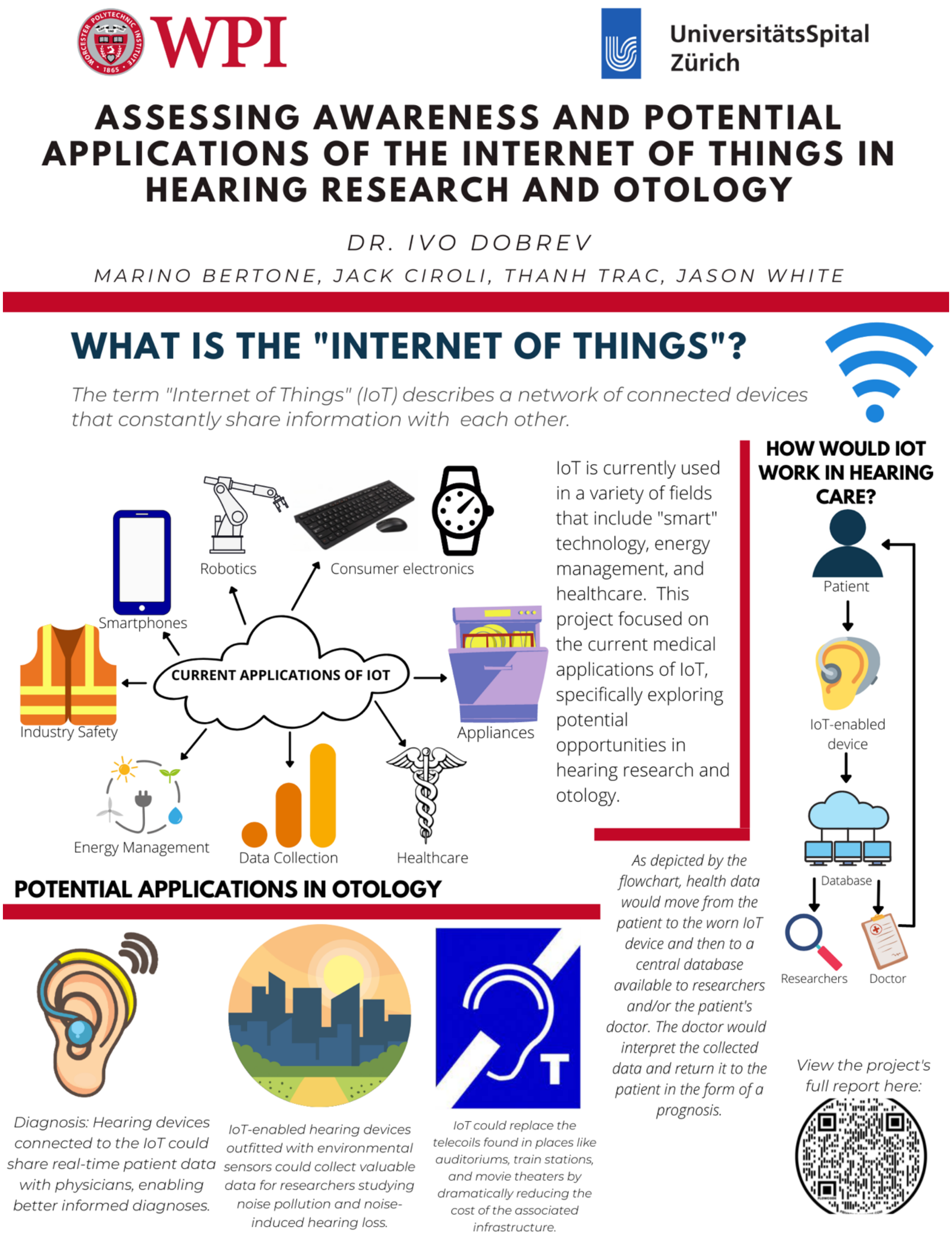
A main problem for people with cochlear implants is that they need to be taken off to charge, meaning they are charged overnight. This causes the user to be functionally deaf when they are sleeping, which can cause safety issues because they will be unable to hear a fire alarm or a regular alarm. Some people with hearing impairment need to get a bed shaker to wake them up because they are unable to hear the alarm. An IoT system could be used to create a network that would allow them to receive important notifications.
Many train stations have telecoils that broadcast at a specific frequency to alert people with hearing devices of the train schedule and alerts, this type of technology is also being used for lectures and conferences to help people with hearing impairment. The problem with the telecoil system is that the infrastructure is very expensive to set up, an IoT system could be set up instead to reduce the cost of the telecoil system. If these systems can be put into place, then it could help with accessibility for hearing impaired people. There could be “hotspot” areas that give a prompt on the user's phone if they would want to connect to the broadcast that is being used at that specific place that could stream directly to the device. There could also be a survey that is given out online after you leave the area as a diagnostic for the quality of the system and if there were any changes to make. Another application of these systems is to be able to collect longitudinal data from a single user across many scenarios and public places to better understand them.
A patient needs to be motivated to participate in the studies that will collect the data. The problem is that right now the data cannot be obtained passively, and many people are not willing to be in a study if they themselves are not going to receive the benefits, even in the relatively short term. Incentives should be added to help users give feedback to help improve the performance and value of the devices.
There is currently a device called the TV streamer which is a device that is plugged into the audio jack of the TV and streams the audio directly to the hearing device, the audio is independent from the audio that is played from the speakers of the TV itself, making it possible for people with hearing devices to watch with people who are not hearing impaired. New generations of TV’s will have this built into the Bluetooth in the TV meaning an external device would not be needed. As of now most hearing devices have microphones in them to help identify

the sound algorithm that best fits the environment the person is in. These microphones could be used to create/develop a standard to capture and share background noise between devices.

On a professional or personal level, do you have any ethical concerns with the implementation of IoT technology to collect medical data in Switzerland/the world?

If a single company manufactured all of the hearing devices, then it would be much easier for people to consent to have their data used for research and medical care. The data would be anonymous or deidentified to a certain point, where your name is not attached but your age, gender, height, activity would be known. This would be needed so that when global data is collected you are able to help specific people better based on who they are and what they do. For this to happen an Opt-in with informed consent about data usage would have to be signed, this is much easier to obtain in the U.S.A. but more difficult in the E.U. A way to increase Opt-in participants is to have immediate rewards/value given to the user when operating the hearing device. Try to make it worth their while in the short term and long term. Since trials are harder to run in the EU, many times they happen in the U.S.A first. This allows for value to be proved in collecting the data and makes it easier to implement in Europe.
As of now, if a user is directly using the protocol, then safeguards have been put into place to protect the data. These safeguards stop the ability to hack a device through the Bluetooth connection which stops them from getting to the data itself. The devices will also only use one way Bluetooth which is safer than two-way Bluetooth pairing, which would not be necessary. This is important because the devices have some personal information on them.

Appendix G: Poster



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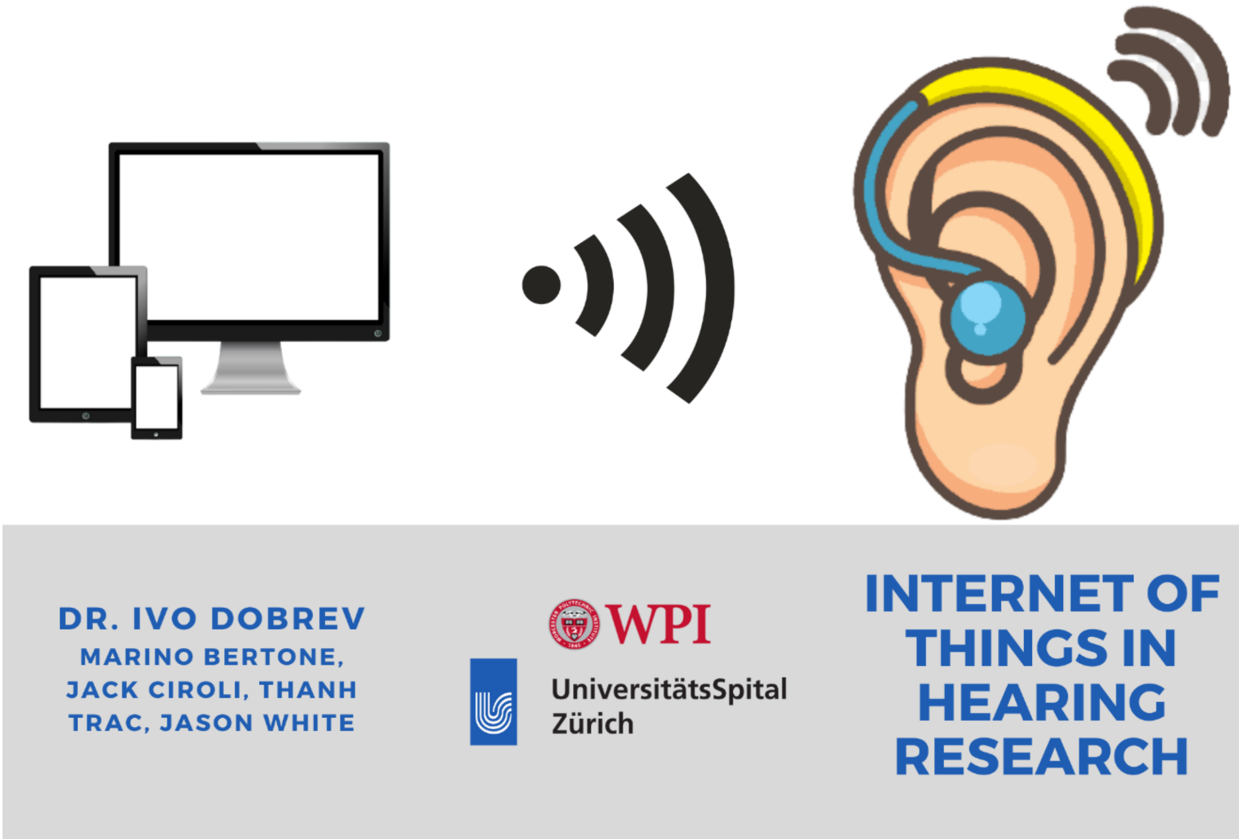
Appendix H: Pamphlet Cover



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Appendix I: Inside of Pamphlet

THE FUTURE OF IOT

HOW IOT COULD BE USED IN THE FUTURE

- At-home hearing tests using IoT-enabled calibrated speakers or headphones
- Using an IoT protocol to create a cheaper and more advanced telecoil
- Using multiple microphones to improve noise canceling

LEARN MORE ABOUT IOT AND ITS BENEFITS

To learn more about IoT and what it can do for hearing research, scan the QR code below and read our paper.

WHERE IS IOT USED?

IN HEARING RESEARCH

- Hearing aids and cochlear implants use Bluetooth to connect to and stream audio from other devices
- The telecoil uses IoT technology to stream audio and assist hearing devices with noise cancelation

IN EVERYDAY LIFE

- Wireless mice and keyboards use radio frequencies or Bluetooth to connect to and send data to your computer
- Wearable fitness trackers use IoT technologies to connect to other devices

Smart watches use IoT to communicate with smart phones

This symbol indicates an IoT-enabled device using Bluetooth technology

WHAT IS IOT?

The term Internet of Things (IoT) describes a network of physical devices (sensors, computers, appliances, wearables, etc.) that are connected to each other using Bluetooth or any other communications protocol. These devices can seamlessly share any information, processing ability, software, or data. This network allows for many tasks to be completed simultaneously or complete tasks that are not possible without the wireless transmission of data.

Bluetooth allows all types of devices to communicate with each other