38

EMOTIONAL INSIGHTS VIA WEARABLES

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38.1 INTRODUCTION

Technology can read our emotions—a subject matter that stirs deep questions about ourselves, our societies, our methods of communication, our future civilization.

There are many science fiction books and films that vary from harmonious to dystopian futures depending on how paranoid the author or the characters are. Who is to know what way the future will play out, but we have the opportunity to shape that direction by grabbing hold of the devices, the data, and the opportunities to do better for humanity right now.

And this handbook will provide a comprehensive view of the array of hardware and software technologies being created to record data of our place in space, the parameters of the world and universe around us, and what is biometrically happening in our bodies. And that's a lot of data!

While we are right to be cautious of how the data may be used and by whom, we should take this opportunity to open up the discussions for this new age of data capture and transmission—we call it the Age of the Digital Self. If we treat the digital form of ourselves with the same rights as we would treat the human form of ourselves, we have a bright future in achieving harmony with emotional technology, machines, industries, medicine, and beyond.

This chapter will give you an introduction to how you can look at the measurement of emotions with these technological advances and why anyone would bother.

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Companion website: www.wiley.com/go/Geng/iot_data_analytics_handbook/

This will be largely in the domain of market research, branding, and entertainment, but the same principles could be applied to any use.

38.2 MEASURING EMOTIONS: WHAT ARE THEY?

Emotions are complex. Obviously.

But it's largely understood that they're a naturally occurring response to a situation or stimulus. They are a response to changes in environment or self. They are different to moods that can last for hours, days, or weeks. They are really to evoke a reaction. A survival reaction. Anger is to make you fight back. Disgust is to make you get it out of your system or stay away from it. Fear is to make you run. Laughing or crying is to make you empathize with your fellow "flock."

Emotions research from the mid-1800s to now has shaped today's understanding of the measurement of human emotions, and even after that time theorists disagree when we get beyond the core emotions.

Most psychologists agree that our core emotions are evolutionary survival tools that most species have.

And then as humans have evolved with morals and self awareness, these have expanded.

There are largely two schools of thought to emotions—one is that your body generates the physiological change and that we then feel it, and the other is that we judge the emotion, and then the physiology changes accordingly.

But the main thing to note is that there are physiological changes that are aligned with your emotions, and these can be measured.

Some statistics would have us believe that up to 95% of decisions are made instinctively and emotionally before we even know it. The nonconscious.

But traditional market research, and therefore the decision making based on those insights, only looks at the deliberative and logical processes, which are carried out via surveys and focus groups which are open to massive bias. The conscious.

Companies then spend millions of dollars based on this one-sided consciously expressed emotional information.

It's important that we look at both conscious and nonconscious processes to gain a holistic view of emotional response.

Even more importantly is to be able to contextualize what the triggers of that emotional response and expression are.

38.3 MEASURING EMOTIONS: HOW DOES IT WORK?

We express emotional responses in one of three ways:

1. *Externally* through our face, body, and voice:
    - How we sit, carry ourselves, or express ourselves can be both conscious and nonconscious across our face, through our voice, and through our body movements. By analyzing the muscle movements in our face, the tones of our voice, and the way we sit toward or away from someone, we can express a lot about the emotions we feel.

  - Paul Ekman's Facial Action Coding System (FACS) basic emotions model has allowed us to measure basic emotions, panculturally, and since you can do this kind of measurement via any camera, it is unintrusive, while some argue it impacts on nonanonymity, although this is down to how the images are captured, processed, and used.
  - The main benefit of voice and face analysis, using microphones and cameras that are inbuilt to most mobile and computing devices, is that they don't interfere with the test stimulus response, since they are nonintrusive.
  - Sometimes both voice and facial responses can be consciously controlled by a respondent, so not indicating their true emotion.
  - Additionally mild emotions and mixed emotions, beyond the basic emotions, can be difficult to assess.
  - Some expertise is still required to be able to interpret what the signals mean.
2. *Internally* with physiological changes in "arousal," which can be measured via changes in heart rate, skin conductance, skin temperature, breathing among others:
  - These operate at the nonconscious level and cannot be controlled by a person thus providing an objective point of view on how that person emotionally responds to the stimulus or experience. These responses are also outside of cultural and social variables so they can be measured across cultures and groups.
  - While these signals are great for identifying when a stimulus has occurred, it is still not possible to associate an emotion to that stimulus without secondary data to assist. Also it is important to gather as much contextual data as possible to qualify whether the response is an emotional stimulus or driven by an alternative physical response, for example, exercise.
  - Some expertise is still required to be able to interpret what the signals mean.
3. *Consciously* expressing how we think we feel:
  - Through self-reporting how we feel, be that a survey, a focus group, or a conversation, we can offer up a wide range of emotions describing how we feel, from positive to negative.
  - A wide number of tools exist for asking questions to express how we feel and also in displaying them, requiring little expertise in designing or interpreting them.
  - The problem with conscious measurement of emotions is that they can be biased based on what people think you want to hear, or people can find it difficult to provide the precise emotion.

38.4 LEADERS IN EMOTIONAL UNDERSTANDING

There are a wide and varied number of models and theories when you look into this space of emotions, with thought leaders specializing in psychology, medicine, biometrics, neuroscience, and behavioral economics, among the disciplines.

I'll lightly touch on three individuals here: Paul Ekman, Dr. Daniel Kahneman, and Robert Plutchik, but there are many in the space of emotions research, and specifically as the interest in understanding emotions and behaviors grows, this list grows.

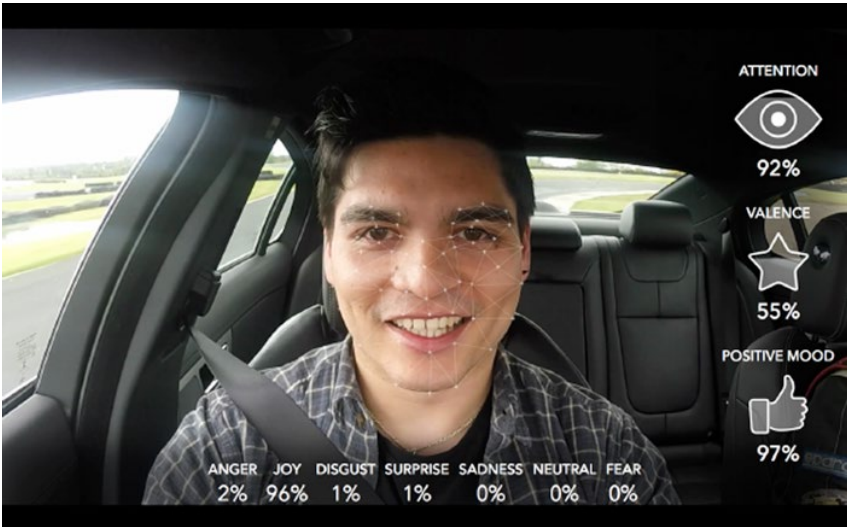

FIGURE 38.1 Use of FACS within a PR campaign. Courtesy of Sensum.

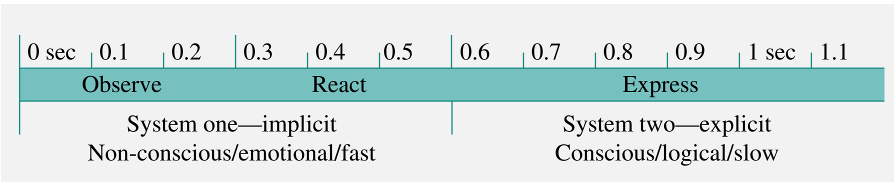

FIGURE 38.2 System 1 and System 2. Courtesy of Sensum.

Paul Ekman has been one of the main proponents of understanding emotional responses using facial coding analysis.

His research has been used to look at nonverbal emotional detection and pancultural emotional understanding and to develop the FACS (Figure 38.1) with the aim of generating a taxonomy for every human facial expression.

In 2011 Economics Nobel winner *Dr. Daniel Kahneman* released a book, *Thinking, Fast and Slow*, where he coined these terms for our two modes of thought (Figure 38.2):

"System 1" is fast, instinctive, and emotional:

- The nonconscious. The under-the-surface gut responses
- Biometric, Neurometric, Psychometric types of research

"System 2" is slower, more deliberative, and more logical:

- The conscious. The calculated processed response
- Surveys, Focus Groups, Ethnography research

Robert Plutchik was professor emeritus at the Albert Einstein College of Medicine, and his theories were based on psychoevolutionary classification of emotions that basic emotions were evolutionary.

His was an integrative approach taking a number of overlapping theories on evolutionary principles resulting in the development of the “Plutchik Wheel,” illustrating in 2D and 3D a wheel of polar emotions.

Created to illustrate variations in human affect and the relationship among emotions, he looked at how emotions pair, and this kind of model is being used in quite a lot of robotics work and sentiment analysis.

38.5 THE PHYSIOLOGY OF EMOTION

Let’s start with facial analysis—our body’s outward facing tool to express emotion.

Paul Ekman is largely seen as the godfather of emotions research. While not the first person to research emotions, he pioneered the study of emotions in facial expressions.

His research in the 1970s identified basic emotions across cultures including anger, disgust, fear, happiness, and sadness and that the only real differentiator was in the “display rules,” where a culture may conceal certain effects of the expression.

As his research has progressed, he has added a range of positive and negative emotions.

Since then there have been moves to bring that down to four since anger and disgust have similar facial muscle movement and so do fear and surprise.

Alongside this research an array of biometric and neurometric research has grown, with an ever-expanding set of tools to research with, and the area of emotions research has dramatically increased in psychology circles and beyond.

While the face expresses your emotion to your fellow humans, your body is going through continuous fluxes and changes in physiology as your emotions change, from heart rate, to sweat response, to pupil dilation, to breathing, to blood pressure.

And as such there are many ways to be able to measure those emotional changes. And this has far reaching implications for understanding emotions, from health and well-being through customer behavior to behavioral economics.

With the increasing number of wearables and sensors coming onto the market, produced from a number of sources from university spinouts, to crowdsourced prototypes, to high-end medical grade products, there is a wide disparity in the quality of the data capture.

This causes some concerns when applied to the world of medicine. Clinicians must make decisions based on the quality of the data they have access to, and if they are to integrate consumer grade data into this process, they need reliability in what they’re seeing. On the flip side if it’s to act as a controller for entertainment or an additional data feed into a nonmedical app or game, then the reliability of the data is nowhere near as important—you just need to know if it’s going up or down and assign the parameters as necessary.

38.6 WHY BOTHER MEASURING EMOTIONS?

You can consciously describe the emotion when you've had an argument, fallen in love, or lost a family member, but it's very challenging when it comes to a glass of orange juice or packaging concept or latest commercial, and you can certainly forget about being able to quantify that emotion. Until now. With these new methods of data capture and analysis, we are getting close to being able to do that.

That's all well and good, but why bother? How does this apply to brands and customers?

In the case of advertising, it has been proven that emotive advertising campaigns perform better on *every* business metric:

A *30% increase in sales* when your ads engage emotionally with your customers

As much as a *three-fold increase in brand loyalty* and motivation to purchase

These metrics were researched and published by Les Binet, Head of Effectiveness at the London-based agency Adam&EveDDB who runs DDB Matrix, the network's econometrics consultancy. Adam&EveDDB is the producer of commercials for UK department store John Lewis, widely recognized as being some of the most emotional commercials created.

And understanding emotions isn't just important for making better advertising but for better products, services, communications, media, and experiences.

Depending on the experimental design for your research, whether it's a large quantitative study or a deep qualitative study and whether it's in lab or in the field, there are a selection of methodologies for capturing emotions, behaviors, and system 1 and 2 responses. This could be eye tracking, ethnography, biometric responses, or implicit response testing.

The key is to establish the most appropriate tools for the study, from wearables to mobile devices to webcams, and then upload the aggregated data for analysis and reporting.

Every emotion has a physiological and psychometric response, increased heart rate, muscle movement, or response time, and once consolidated deep insight is the result. And it's all about the insights.

38.7 USE CASE 1

38.7.1 "Unsound": The World's First Emotional Response Horror Film

"Unsound" was a collaborative project that brought together the disciplines of film production, music composition, environmental art, technology, and engineering to research "future cinema" and the ever-increasing demand for audience interactivity and immersion in the audiovisual experience.

Beginning as a conversation about creating films that helped the audience feel more involved and more immersed in the experience, Gawain Morrison (Sensum CEO and cofounder) and Dr. Miguel Ortiz Pérez (Sonic Arts Research Centre, Queen's

FIGURE 38.3 Image from "Unsound" screened in SXSW 2011. Courtesy of Sensum.

University, Belfast) discussed a number of techniques before deciding that tapping into emotions of a film audience could be really interesting. The aim was to create a film that was unique for every audience that watched it based on their emotional response.

Horror feature-film writer Spencer Wright scripted the film, and film director Nigel (N.G.) Bristow directed it. The film was 15 minutes in length, and a number of permutations could be viewed or heard depending on how the audience felt as they moved from scene to scene.

Small attachments to the audience member's hands pick up electrocardiogram (ECG) signals, measuring and recording the electrical activity of the heart, and electrodermal activity (EDA) which measured the change in conductance of a person's skin, which is highly sensitive to emotion arousal in people.

The world premiere of the film was screened in SXSW 2011 (Figure 38.3) and attracted interest from Disney Research to Coca-Cola, resulting in an article in the New Scientist and the creation of the Sensum platform for measuring emotional insights (Figure 38.4).

38.8 USE CASE 2

38.8.1 Thrill-Seeking Seniors? Identifying the Pension Personal

In a first-of-its-kind experiment, Skipton Building Society, the United Kingdom's fourth largest building society, was keen to gain a true understanding of people's retirement wishes, hooking up the nation's preretirees to scientific probes, revealing their conscious and subconscious reactions to images of life after work (Figure 38.5).

FIGURE 38.4 Sensum platform for measuring emotional insights. Courtesy of Sensum.

FIGURE 38.5 Conscious (dotted line) and nonconscious (solid line) reactions to images of life after work. Courtesy of Sensum.

The starkest finding was their dramatic physical and emotional rejection of traditional views of retirement. This included increased perspiration and goose bumps when shown key words and images associated with it, ranging from it being "the end of a chapter" to the start of their "golden years." The study also found that today's preretirees are bored by traditional "pipe and slippers" images of life beyond work.

Dr. Jack Lewis, a published neuroscience consultant and author of Sort Your Brain Out, said "Skipton has broken new ground by using physiological and sensory research, together with traditional methods. By applying this cutting edge new technology, the Society has been able to dig deep into its respondents' true feelings and combine this with qualitative and quantitative findings, to give the most comprehensive insight yet into what really makes individual people tick when it comes to retirement."

The key to these findings was combining conventional qualitative and quantitative fact-finding techniques with a scientific twist. Portable skin sensors provided by

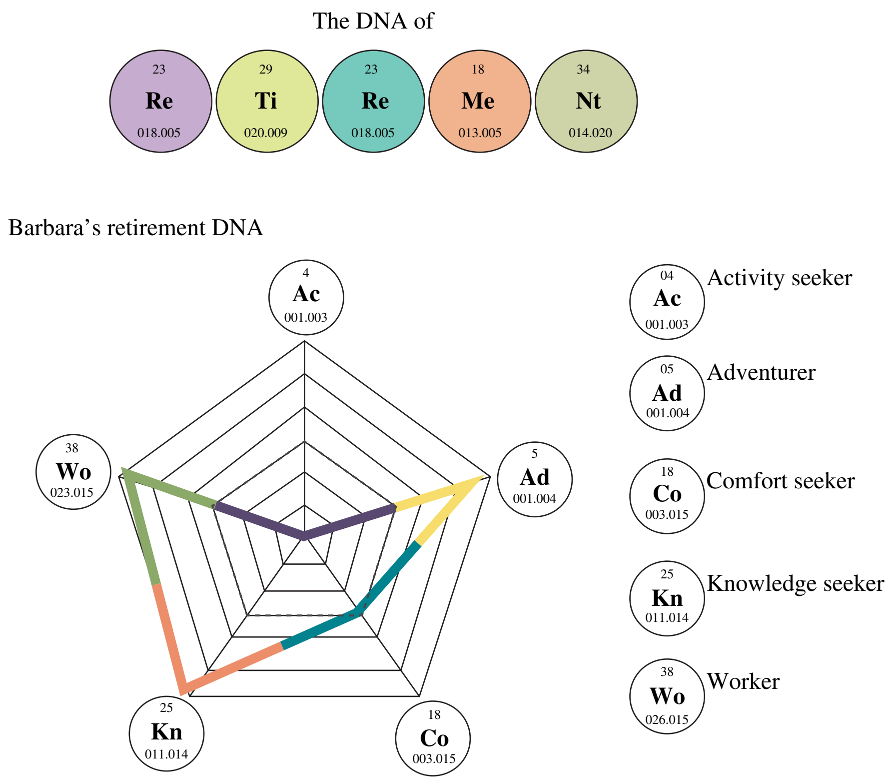

FIGURE 38.6 Retirement DNA. Courtesy of Sensum.

research technology firm Sensum were used in focus group and interview settings to help their agency Jaywing to track latent responses alongside people’s mindful, verbal reactions.

- Five retirement personas discovered—research pinpoints individuals’ most and least dominant traits to give profound individual fingerprint.
- People physically rejected stereotypical ideas of retirement, while welcoming suggestions of exciting new beginnings.
- In 64% of participants there was, however, a telling difference between their conscious and subconscious visions of their retired selves.
- Encouragingly, most people are aspirational about their retirement, and 51% are looking forward to it.

Armed with this research, Skipton and its customers are now better placed to understand their specific individual preferences and retirement ambitions, as well as creating a mobile app for their staff to use whenever identifying these key personas, the retirement DNA (Figure 38.6).

38.9 USE CASE 3

38.9.1 Measuring the Excitement of Driving a Jaguar

Sensum was approached by agency Spark 44 to record the emotion of excitement while drivers raced Jaguar's new car, the XE, and generate visualizations to overlay video footage captured of each driver (Figure 38.7).

Since excitement is a high arousal emotion, we were able to establish the increases in excitement easily using ECG signals for heart rate and EDA for skin conductance. This was cross-referenced with the video and geolocation data for their place on the track that contextualized what was driving those excitement responses; that ranged from high-speed straights, to fast corners, to the professional driver pushing the limits of what the car could do on track.

The data gathered was presented graphically, showing not only the changes in the raw EDA and ECG but also in the moments of highest excitement, and all cut into a series of promotional videos for sharing online, via key influencers, demonstrating the emotions that could be felt, captured, and visualized due to an exciting driving experience (Figure 38.8).

38.10 CONCLUSION

If we were to use gaming analogy here, our level of understanding of how to capture, measure, and deliver on emotional insights is at the time of "Pong," the simple bat and ball game, NOT Halo. As a result we should understand that any tools providing

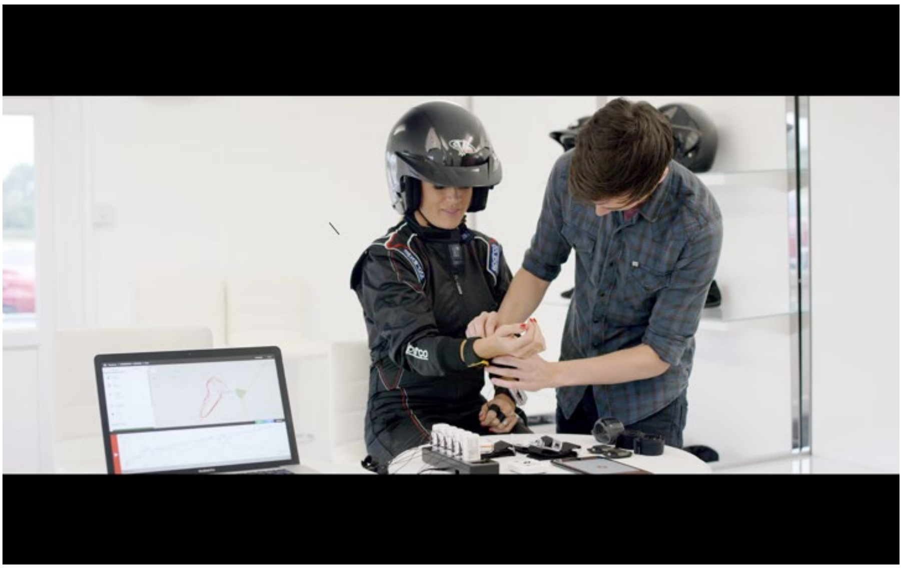

FIGURE 38.7 Measuring the excitement of driving a Jaguar. Courtesy of Sensum.

FIGURE 38.8 Captured and visualized due to an exciting driving experience. Courtesy of Sensum.

insight into emotions are presently at the foundation stage, but very quickly the data will grow, both in terms of scale and in terms of context, and before we know it we will be at the level of Halo, so the conversations on how it should be used need to be had now, and we'll create an amazing world for all people—human and digital.

The Internet of Things. Wearable technology. Smart devices. Quantified self.

A world where everything around you, including yourselves, can be measured, visualized, and reacted to, providing a hyperpersonalized understanding of the self. From health to education to entertainment.

It's all happening around us, through the devices that we see, we carry on our being, we work on, we have in our homes, and that's just the devices that we will notice. And before we are aware enough of what kind of data can be captured and used for decision making, at a personal, corporate, or governmental level, it may be too late to be able to take control of that data. But it's important to talk about it now and have an opinion.

Trust and transparency in this age will be the making of those who succeed.

FURTHER READING

Averill, J. R. (1980). A constructivist view of emotion. In R. Plutchik & H. Kellerman (Eds.), *Emotion: Theory, research, and experience* (pp. 305–339). New York: Academic Press.

Bridger, D. (2015). *Decoding the irrational consumer*. London: Kogan Page.

Damasio, A. R. (1994). *Descartes' error: Emotion, reason, and the human brain*. New York: G. P. Putnam.

Ekman, P. (1977). Biological and cultural contributions to body and facial movement. In J. Blacking (Ed.), *The anthropology of the body* (pp. 39–84). London: Academic Press.

Ekman, P. (1992). An argument for basic emotions. In *Cognition and emotion*, Vol. 6 (pp. 169–200). London: Routledge. https://www.paulekman.com/wp-content/uploads/2013/07/An-Argument-For-Basic-Emotions.pdf (accessed September 10, 2016).

Lewis, M., Haviland-Jones, J. M., & Barrett, L. F. (Eds.). (2008). *Handbook of emotions* (3rd ed.). New York: Guilford Press.

Roseman, I. J. & Smith, C. A. (2001). Appraisal theory: Overview, assumptions, varieties, controversies. In K. R. Scherer, A. Schorr, & T. Johnstone (Eds.), *Appraisal processes in emotion: Theory, methods, research* (pp. 3–19). New York: Oxford University Press.

40

STRUCTURAL HEALTH MONITORING

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40.1 INTRODUCTION

Structures are all around us. Structures are ubiquitous in the physical world we live in. The structures we live or work in need to shield us from the weather elements, withstand some degree of degradation over time, and stay strong over a time scale that is comparatively longer than one's lifetime. The vehicles we travel in need to offer comfort and safety through the modes of transportation and be able to protect us through collisions. We expect likewise of the transportation infrastructure we travel on: the railroads, bridges, ramps, etc.

Structures don't last forever; to build and operate structures within a reasonable budget, they are designed to support a specific load over a limited lifetime and withstand environmental changes to a limited degree. Structural health degrades over time as intended. It is important to make sure that a structure continues to offer the required level of service as it ages. Structural failures are very expensive and often cost lives. Structural health monitoring (SHM) is essential to inspect a structure's health over time to ensure it continues to meet operational requirement. SHM is essential to ensure public safety and efficiency.

SHM has been done mostly manually and periodically. The interval between inspections varies, depending on the operating organizations' practice. It is not rare to hear of annual or even biannual inspections. Modern SHM systems take advantage of the rapid advance in low-power processors, sensors, wireless communication, and data storage to automate the inspection process. Such SHM systems started to deploy

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within the past decade [1]. With the rapid decline in the cost of enabling technologies, it is becoming practical to consider real-time continuous monitoring broadly.

This chapter presents the authors' firsthand experience at designing and implementing a SHM solution for bridges. It is intended as a case of practicing the engineering approach described in the earlier chapter on IoT and smart infrastructure.

40.2 REQUIREMENT

The SHM system was designed based on requirement from a team at National Taiwan University of Science and Technology, led by Prof. Chung-I Yen and Prof. Wei F. Lee, that has expertise in applying modern SHM for bridge monitoring [2, 3]. From here onward we will refer to each edge sensor device as a Bridge Monitoring Unit (BMU).

40.2.1 Operating Environment

The BMU will be deployed directly on bridges. The system needs to be able to withstand direct exposure to all sorts of weather conditions.

40.2.2 Power Supply

At some target sites there could already be grid power available from prior installation of environmental monitoring equipment. In most cases there is not prior power supply installation. It is strongly preferred if the BMU could operate without the expensive installation of grid power. Whether solar or grid power is used, it is required to have backup battery that could keep the system operating for 5 days after losing primary power source.

40.2.3 Monitoring Only

The BMU is only required to perform passive monitoring. No supervisory control is required.

40.2.4 Connectivity

The BMU is required to support both wired and wireless connectivity. Occasionally, some sites already have wired connectivity from prior monitoring equipment installation. Nevertheless, wireless connectivity should be the norm in most cases.

The BMU is expected to utilize local wireless service provider's 3G service for uplink to server. On structures where multiple monitoring units are deployed, it would be cost efficient to share uplink.

Connectivity, wired or wireless, could be unreliable. Connectivity could be lost during critical event when the data is most important. This would be the case during an intense typhoon or earthquake that damages a local cell tower. It is therefore required for the BMU to retain up to 20 days of data. When data could not reach the server, it could be retrieved from the BMU eventually. In the event of major structural failure, such data could be extremely valuable for forensic analysis.

40.2.5 Data Acquisition

The BMU is required to monitor both dynamic and static parameters. Dynamic parameters include acceleration in three axes and inclination in two axes. Static parameters include water level, water velocity, and structure temperature. Sampling rate of dynamic parameters should be configurable, from 50 to 200 Hz.

As specific choice of sensors may change over time, it would be ideal if the BMU could accommodate different sensor interfaces.

The data samples should be grouped into a file every 30 seconds and timestamped.

Notably, all sampled data needs to be transmitted to server for analysis and long-term archive.

40.2.6 Robustness

The BMU should be able to tolerate intermittent wireless connectivity to server, as 3G connections are known to drop often. In the case of unreliable connectivity, data transmission to server should resume when connectivity is restored.

The BMU should be able to operate in the absence of GPS reception and still meet all previous requirements over short duration.

40.3 ENGINEERING DECISIONS

40.3.1 Power Supply

We understand that grid power may not be available in most sites. Even when grid power is available, its constant availability could not be counted on. We decided to utilize a rechargeable battery as the primary power source, which is recharged by grid power or solar panels as applicable.

We chose lithium iron phosphate ($LiFePO_4$) chemistry over the more common lithium ion or lithium polymer because it better retains capacity over longer cycles, ensuring adequate capacity over years of deployment. Lithium iron phosphate has lower energy density, resulting in larger and heavier battery. This is less of a concern for SHM application since it would be static once deployed at a site. Capacity retention over large number of cycles is more important.

Due to obstruction by the structure and foliage, it is possible that the site could afford direct sunlight on the solar panel only during certain time each day. For such sites one should choose solar panel of higher power rating so that it could adequately recharge the battery in the limited hours of direct sunlight.

40.3.2 Connectivity

The requirement that all sampled data needs to be transmitted to server for analysis and long-term archive is a tall one. It rules out low-power mesh networking options like 802.15.4 which could not support the needed bandwidth.

Wi-Fi could provide the needed bandwidth. Wi-Fi is common enough that we could easily get parts that support the long-distance transmission. Typical bridges span hundreds of meters. Some bridges could span kilometers. This one-dimensional topology is not a good fit for the typical Wi-Fi installation where one Access Point serves edge devices over a circular area. We decided that Wi-Fi mesh would be a practical way to link multiple systems deployed on one bridge to an edge router, using intermediate BMUs to relay the traffic from BMUs further away. An edge router would act as the gateway to remote server. For sites with only a single system, it could be simpler to support 3G uplink directly in a BMU.

With either 3G or Wi-Fi, to reduce bandwidth and power consumption, we would compress data before transmission. Each 30 seconds window of data is saved into a file, whose name includes the current date–time and unique ID of the BMU. The file is then compressed and saved to flash storage before queueing it for transmission. The compression effectively reduces size of data to be stored and transmitted by 70%.

There are many Wi-Fi modules designed for IoT-type application. These modules typically could interface to a microcontroller (MCU) via UART or SPI. These Wi-Fi modules tend to have their own MCU to run their protocol stack. We are not aware of any such modules that could support mesh protocol. They also tend to have limited RF power (under 20 dBm) that is not suitable for the kind of long-range outdoor application we have in mind. We found success with Wi-Fi USB dongles that support 27–30 dBm output power, with Linux kernel drivers that support mesh networking. Even with omnidirectional antenna, we were able to achieve close to 400 m range between adjacent BMUs.

For 3G connectivity we found many 3G USB dongles designed for consumer or industrial uses.

These connectivity device choices would necessitate use of a Linux single-board computer (SBC) due to the driver and network protocol stack that is required for operation.

40.3.3 Protocol Considerations

While not part of the requirement from customer, we wanted to be able to *ssh* over Virtual Private Network (VPN) into the BMU for miscellaneous services, mainly to update application and MCU firmware as needed. This is not mere convenience as the deployment sites are thousands of miles away from us physically. Requiring on-site work by field engineer that is familiar with embedded computer is inefficient and costly. This meant we would want the field devices to support TCP/IP networking on Linux. Linux would also afford us ample choice of open-source tools for application development and deployment.

We had planned simple Web server on each BMU so that we could directly monitor status of BMU's operation during development and deployment. It could also evolve to support a RESTful API.

We used an asynchronous message queue to transmit compressed data files from BMUs in the field to server. The asynchronous message queue provides us the required robustness against connectivity disruptions.

40.3.4 Architectural Choice

We wanted a SBC-based on ARM microprocessor. ARM-based SBCs are known to have low power consumption. They are available from several suppliers, with Linux OS. Most importantly, growing number of open-source SBC was starting to be available at low prices. When we were making the SBC decision, BeagleBoard had already been introduced for a few years and BeagleBone was just released. We liked the active developer community and were very attracted by the large number of peripherals exposed on the 92-pin headers.

Linux is not a real-time operating system and is not an ideal platform for low-latency tasks such as data acquisition. We said “not an ideal platform” because there existed patched versions of the Linux kernel that could make it more suited for real-time applications. Nevertheless, we needed many ADC ports that are usually available in MCUs but not in Linux SBCs. While we could use external ADC IC that interfaces to Linux SBC via SPI or I2C, MCU could offer far more flexibility in addition to cost and performance advantages. We decided it would be easier to use a combination of MPU and MCU.

To accommodate large variety of possible sensor interfaces, we decided to use two ARM Cortex M3 class MCUs as dedicated data acquisition processors, DAQ1 and DAQ2. Their function could be implemented in firmware. MCU firmware could be updated in the field from the Linux SBC, offering us a convenient way to fix bugs or add new functionality after field deployment. Two UART channels could be utilized to interface with these two DAQ processors.

40.3.5 Data Acquisition

The critical aspect of data acquisition is the timing for sampling dynamic parameters. The sensor interfaces to be utilized and sampling rate, set by customer for the particular site, would be transmitted from a software application on Linux SBC to DAQ processors. Our MCU firmware would set a hardware timer based on the specified sampling rate. On timer overflow, data would be sampled from the specified interfaces and passed to SBC.

To ensure correct timestamping of sampled data, we use ntpd and GPS to set time on each BMU [4, 5].

40.4 IMPLEMENTATION

We designed and assembled a printed circuit board for our BMU design. It contains:

1. Two ARM Cortex M3 MCUs (with the necessary passive parts and clock sources)

2. GPS module
3. Terminal blocks to connect:
   a. Temperature sensor
   b. 3D accelerometer
   c. Two inclinometers
   d. Power supply
   e. SDI-12 bus for water velocity and water level sensors
4. Headers to mount the BeagleBone SBC
5. Many extra signal pins for future expansion

The USB host port on SBC provides the wireless interface, either 3G or Wi-Fi.

The BeagleBone SBC was mounted on the PCB and loaded with Debian Distribution, ntpd, VPN client, openSSH server, and application software that

FIGURE 40.1 BMU mounted on a pilot site in Taiwan.

FIGURE 40.2 Yuan Shan Bridge in Taipei where two BMUs have been operating since 2014.

manages the DAQ processors as well as data file compression–storage transmissions.

The PCB is mounted on a rigid stainless steel plate inside an IP67 enclosure, with flanges to facilitate mounting to the target structure. Field deployment usually takes only a couple of hours (Figures 40.1, 40.2, 40.3, and 40.4).

Although the requirement is to transmit sampled data to server for analysis and archive, we have demonstrated doing FFT on the data immediately after sampling. We could identify frequency peaks corresponding to vibration nodes and track their deviation over time.

40.5 CONCLUSION

The underlying technology for SHM is still evolving rapidly. New protocols are still being proposed to help achieve standardization and accelerate wider adoption. We recommend developing your SHM system with loosely coupled functional modules, using open standards as much as possible, so that individual modules could be upgraded without reengineering the whole solution.

We believe it makes sense to utilize computation on the edge to analyze data for anomaly before transmitting it to servers. Vast majority of the sampled data in SHM applications will not indicate a significant event and thus is not worth transmitting and archiving. Long-term analysis using snippets of periodical data is sufficient to monitor a structure's health over time. Event detection on the edge sensor could

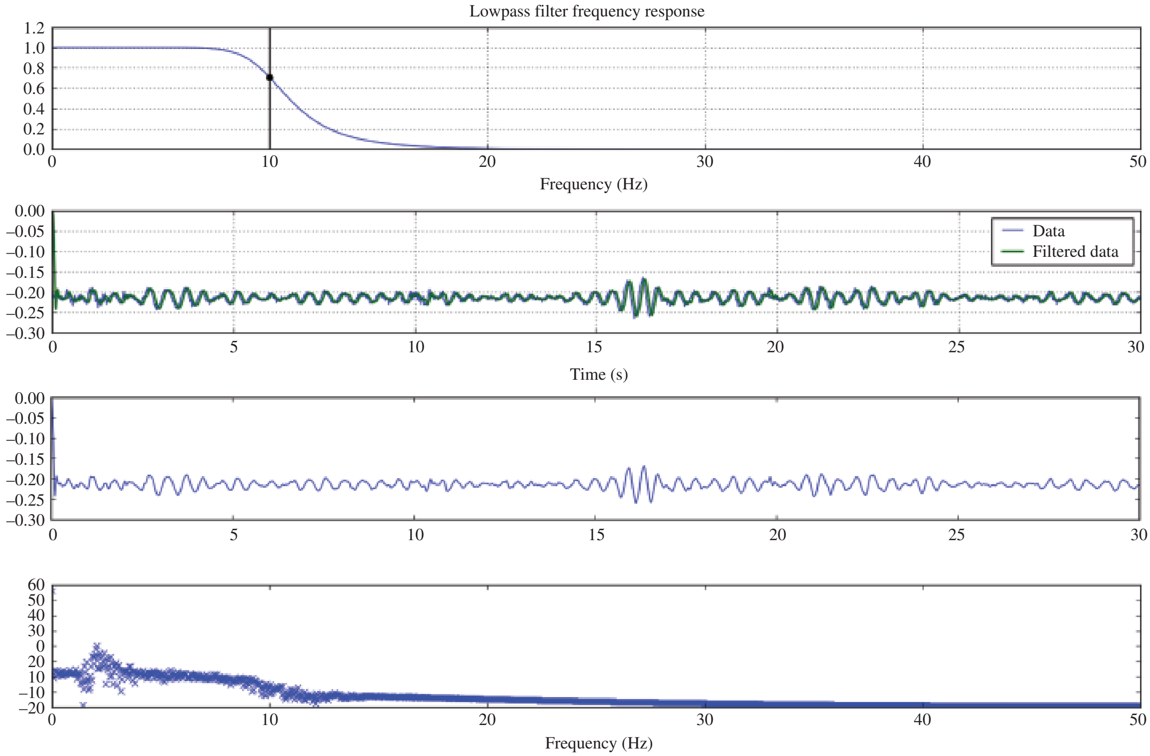

FIGURE 40.3 Data from a dynamic inclinometer processed to show clearly identifiable peak on the frequency spectrum. Shifts of frequency peaks are important indicators in SHM.

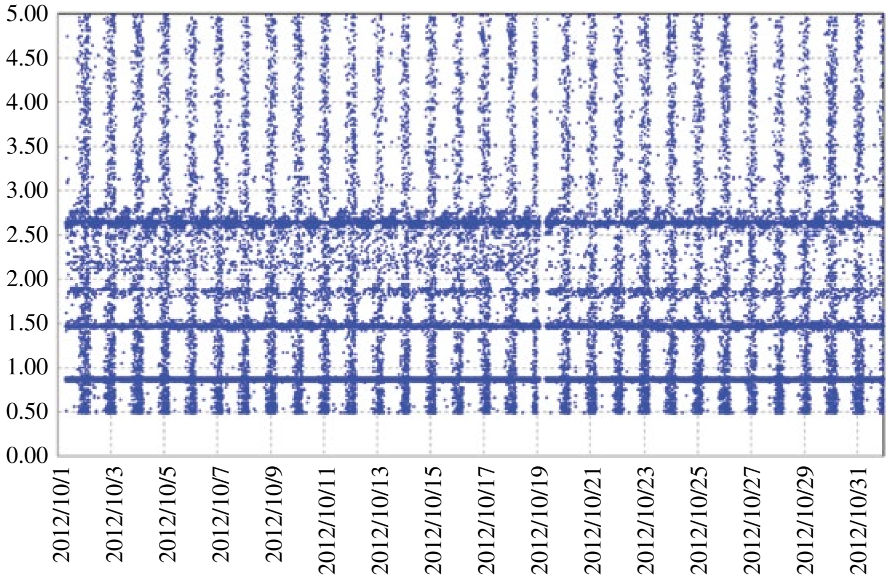

FIGURE 40.4 Spectrum of one of the dynamic inclinometers over time. The darker bands indicate the vibration nodes of the structure.

significantly reduce latency to event detection and reduce the bandwidth to transmit data indicating routine conditions. Such bandwidth reduction could make it practical to take advantage of nascent low-power wide-area networking technologies, such as LoRaWAN, for efficient connectivity for SHM applications.

REFERENCES

[1] Health Monitoring of Civil Infrastructures Using Wireless Sensor Networks, Sukun Kim, Shamim Pakzad, David Culler, James Demmel, Gregory Fenves, Steven Glaser, and Martin Turon. In *the Proceedings of the 6th International Conference on Information Processing in Sensor Networks (IPSN'07), Cambridge, MA*, April 2007, ACM Press, New York, pp. 254–263.

[2] Performance of a Highway Bridge under Extreme Natural Hazards: Case Study on Bridge Performance during the 2009 Typhoon Morakot, W. F. Lee, T. T. Cheng, C. K. Huang, C. I. Yen, and H. T. Mei. *Journal of Performance of Constructed Facilities*, Vol. 28, No. 1, February 1, 2014, pp. 49–60 (ASCE, Reston, VA).

[3] Application of a High-Tech Bridge Safety System in Monitoring the Performance of Xibin Bridge, C.-I. Yen, C.-K. Huang, W. F. Lee, C. H. Chen, M. C. Chen, and Y. C. Lin. *Proceedings of the Institution of Civil Engineers—Forensic Engineering*, Vol. 167, No. FE1, 2014, pp. 38–52 (ASCE, Reston, VA).

[4] https://en.wikipedia.org/wiki/Network_Time_Protocol (accessed August 13, 2016).

[5] https://en.wikipedia.org/wiki/Synchronization_in_telecommunications (accessed August 13, 2016).

FURTHER READING

http://www.goodxense.com/structuralhealthmonitoring (accessed September 7, 2016).

Health Monitoring of Civil Infrastructures Using Wireless Sensor Networks: https://www2.eecs.berkeley.edu/Pubs/TechRpts/2006/EECS-2006-121.pdf (accessed September 13, 2016).

Structural Health Monitoring of Long-Span Suspension Bridges, by You-Lin Xu and Yong Xia, CRC Press, Boca Raton, FL (October 7, 2011).

41

HOME HEALTHCARE AND REMOTE PATIENT MONITORING

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41.1 INTRODUCTION

The *Internet of Healthcare Things* is the theme for Connected Health Symposium 2015 for *Internet of Things (IoT) in Healthcare*. As we are all in the evolution phase for the devices that communicate through wireless technology, there are a lot of lessons to be learned with real-world Healthcare usage scenarios.

The application of IoT in the Healthcare (Figure 41.1) can be classified as follows:

- Critical care
- Follow-up care
- Preemptive care
- Monitoring
- Diagnosing
- Treating

At the time of writing this chapter, we were still evaluating the reliability of IoT in Healthcare, and still Healthcare industry is evaluating the use of IoT Device to treating patient in real world. The Clinical usability sometimes does not fulfill the Healthcare services outcome, for example, why would I need a wireless device that is not reliable in the hospital? I can use an existing wired Medical device that is reliable. Assumption is that it is dangerous to put an IoT device to treat Critical care

Internet of Things and Data Analytics Handbook, First Edition. Edited by Hwaiyu Geng.

Companion website: www.wiley.com/go/Geng/iot_data_analytics_handbook/

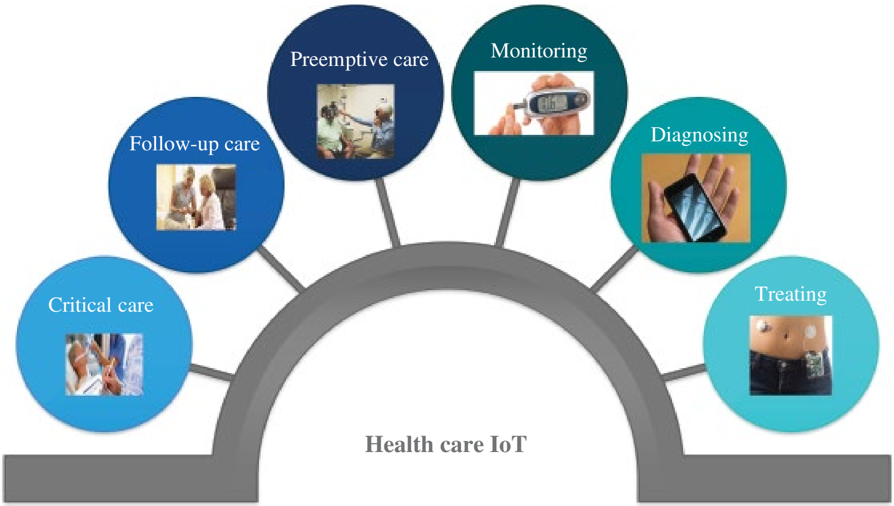

FIGURE 41.1 Application of IoT in healthcare. © University of Utah TeleHealth Services.

patients. We can send home IoT devices for follow-up care for patients by getting their biometric Data. Using IoT medical device, getting biometric data can be used as Preemptive Care approach for and create change in patient's Life Style. We have to identify the class of IoT application and prove the use case. Certain usability can be only performed through wireless IoT Devices for tracking a moving person or object. In this case we cannot tether device with a wire attached to a person or an object to monitor. The application of IoT for different class has to be based on the Use Case. The Use Case has to have a basic need or critical need. Technical possibilities and hurdles can be evaluated. When setting up an IoT device in a Hospital environment, it has a lot of challenges. The Hospital may have some or all of the ambulatory division, inpatient, Emergency, specialty, pharmacy, rehabilitation, Laboratory, and so on. The IoT application varies from monitoring patient, to biotest sample tracking, to nurse practitioner spending time with patients.

41.2 WHAT THE CASE STUDY IS ABOUT

CASE STUDY 1

Out of these classifications we chose to start with simple and less intrusive case study like tracking patient's movement in University of Utah Hospital physical medicine and rehabilitation (PM&R) (Figure 41.2). There are different kinds of patients who come to PM&R facility for treatment such as patients who are mentally not capable but physically strong enough to walk within the hospital premises, and there are some occurrences that patients wander off to the street and even to freeway. It is not viable to lock the patients undergoing therapeutic treatment

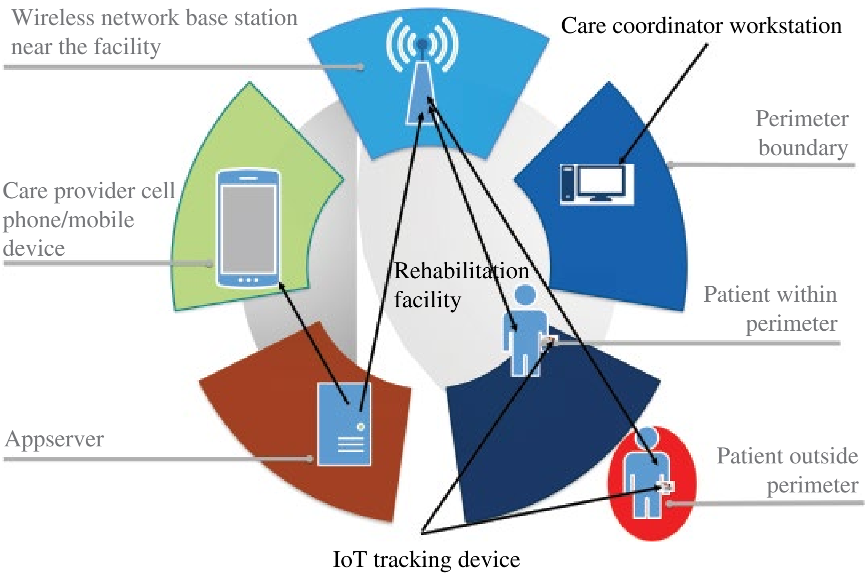

FIGURE 41.2 IoT patient tracking system diagram. © University of Utah TeleHealth Services.

into a confined room or area. So we need to track a patient with a lightweight device, and network should be capable to pick up the device chirps (emitting message) to care provider and alert them through their phone or other devices. Using this approach patients can move around freely within the facility but with constantly monitored performance.

41.3 WHO ARE THE PARTIES IN THE CASE STUDY

The following are members who participate in the case study. An organizational chart is shown in the succeeding table with their responsibilities.

Role	Specific Role Name	Responsibilities
Care Provider	Physician	Diagnosing and treating patient
Care Provider	Nurse practitioner	Patient care
Technical strategist	IT person	Coordinating, implementing, and assisting in planning
Project manager	Program manager	Manages overall project development
Care coordinator	Nurse manager	Oversee any patient notification
Network engineer		Set up perimeter and security with network
Network vendor		Provides networking hardware tools
Device vendors		Any vendor provides I/O device

- Physician, Nurse Practitioner, and so on
- Network Engineer
- Technical Strategist
- Project Manager
- Care Coordinator
- Network Vendor
- Device vendor

A road map with timeline is also shown in the succeeding table.

Solution	Implementation Timeline
Patient tracking	2016–2017 University of Utah fiscal year
Nursing time spent on tracking	2016–2017 University of Utah fiscal year

41.4 LIMITATION, BUSINESS CASE, AND TECHNOLOGY APPROACH

Currently, there is no mechanism to track a patient; moreover, there is limitation in Ethernet Wi-Fi and Bluetooth in the Hospital perimeter. The device cannot emit its presence after certain distance due to limitation in network capability or some dead Spots. So the simple tracking device sends tiny packets of data. So we need Ultra Narrow bandwidth and dedicated network for IoT devices. A very lightweight IoT device wearable in patient's Wrist.

41.5 SETUP AND WORKFLOW PLAN

Equipment

1. Base station which transmits and receives IoT device Messages should be installed on the Roof of the nearby facility so that it has better coverage.
2. IoT device is put on the Patient's wrist (Figure 41.3).

The IoT sensor devices are worn on patient's wrist during the therapy period. The devices will constantly emit message to base station about the location of patients. The Network operator-provided Base station will establish an Ultra Narrow Bandwidth that is dedicated for IoT devices. So the patient wearing IoT devices on boot-up will communicate with network (Ultra Narrow Bandwidth base station) pre-programmed frequency and message. This is publish/subscribe model, so the devices registered to the network, and only it can send a message by communication token established by Business Support System.

All the Device to Antenna are Radio Links. There are very few network operators in this unlicensed Bandwidth. Assume the security (tampering, resending messages,

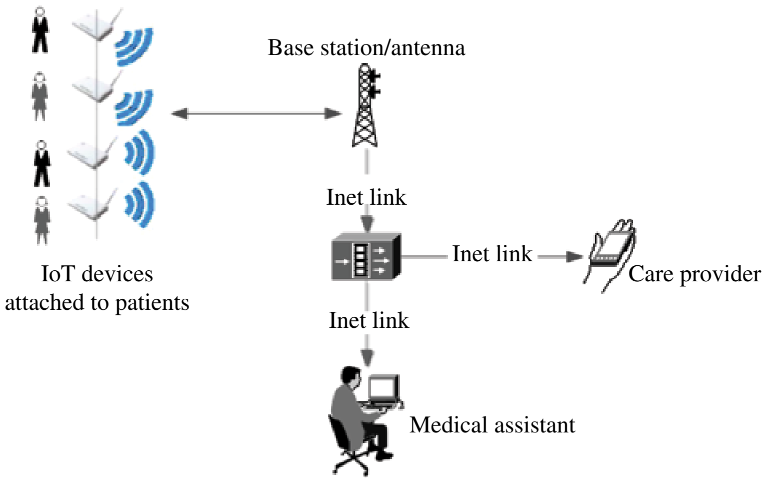

FIGURE 41.3 Patient tracking system using IoT sensor devices. © University of Utah TeleHealth Services.

integrity of messages, no open-inbound port listening, authentication, authorization) of the IoT devices is taken care of.

Classification is crucial to manage the ecosystem of Healthcare IoT devices (Figure 41.4). For example:

- Device Type = Tracker, Temperature, and so on
- Device Group = Medical
- Device Type Related to Business Support System = To track Patient movement
- Device taking a communication token in Business Support System Order = Communication Token for Device Group and Device Type

41.6 WHAT ARE THE SUCCESS STORIES IN THE CASE STUDY

1. The prepilot exercise points out the person's movement from room to room or location to location, and we can see that the status is Web portal dashboard. This feature can help the care coordinator to actively locate the patient movement.
2. There is no issue in network proxy settings for the Bluetooth listeners.
3. Using commercially available consumer-friendly wearable devices will be welcomed by Healthcare community.

Note: Due to Hospital-wide Network Wi-Fi is enabled. This project is reevaluated to use Wi-Fi 5G bandwidth replacing all Bluetooth frequencies.

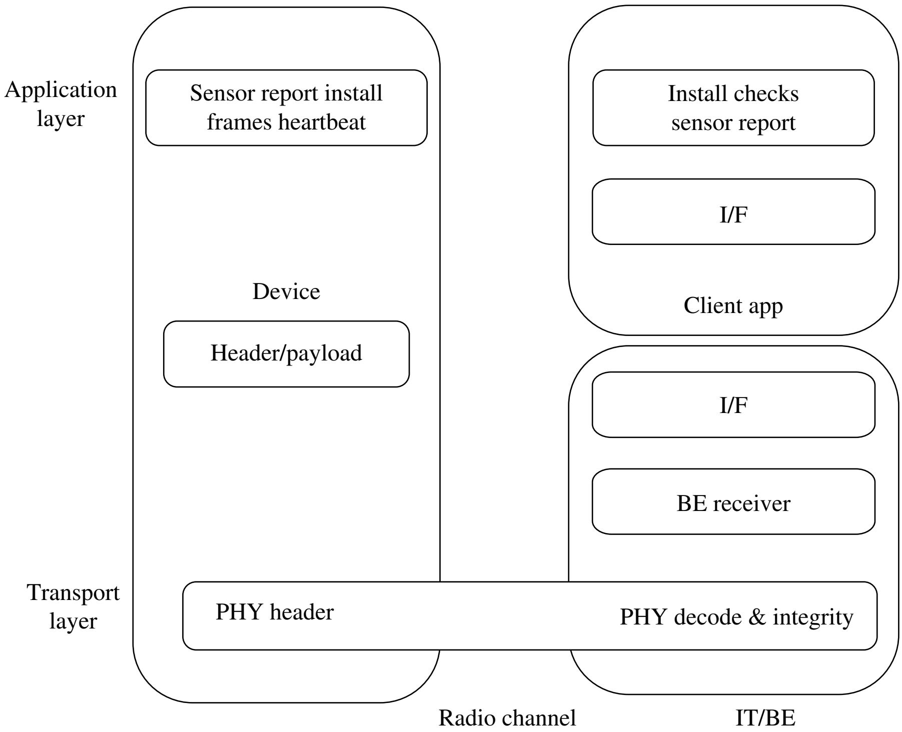

FIGURE 41.4 Healthcare IoT devices and classification. © University of Utah TeleHealth Services.

Serendipity Finding 1

When this demo of the solutions caught the attention of our orthopedics clinic operations director, we found that this can be applied to operational efficiency. He mentioned the typical current workflow of the department.

1. Patient checks in the front desk.
2. Patient is given a tablet for survey.
3. Patient is taken to X-ray by technician.
4. Nurse practitioner takes vitals.
5. Doctor checks the patient details.
6. Doctor meets the patient face to face.

The current workflow process has delays between the next steps. This is due to lack of patient location awareness. They perform action only when they see the patient, and it involves actual person monitoring and notifying. Alert and notification is missing in real time. So this patient tracking solution can be used to alert the care coordinator to move the patient to the next step and avoid waiting time. So the patient will be able to see the physician ASAP. This is a good candidate for patient satisfaction. So this is another potential pilot with IoT.

Serendipity Finding 2

Second doctors want to find how much time the MA/Nurse spends with Spinal cord-injured patients and Quadriplegic patients. This information helps the department to better allocate resource and capacity management.

Currently, IoT devices have potential opportunities for the following:

1. Send home Bluetooth-enabled medical devices with Gateway. This gets instant biometric readings from patients and update in the patient and nurse portal.
2. In patient setup will also benefit from continuous reading of vitals using IoT devices without any wire tangled.
3. IoT Compression suite having electromyography sensors (EMG) will provide real-time and recorded-time muscular activities, heart rate, and respiration.
4. IoT Shoe Insole provides real-time Gait, Symmetry, Jump details of Rehabilitation patient. These details give care providers information to adjust the physical therapy exercise for patients.
5. Ingestible pills through IoT technologies provide medical adherence, tracking, and so on.

41.7 WHAT LESSONS LEARNED TO BE IMPROVED

- The latest IoT devices in Healthcare and evolution are ongoing. Currently, Skin patch biometric devices which are also noninvasive are going to be the future within couple of years (current year 2015). So adoption of these devices is essential, and interface with the mainstream Healthcare application is crucial.
- When IoT Healthcare devices come to the market (like consumer-related step monitor, sleep monitor, and heart rate monitor), it is necessary to communicate with the provider (Physician, Nurse, etc.) for multifactor diagnosis. They are the sole authority on the decision-making process. Since the patient empowerment is necessary from home perspective, physician empowerment on clinical setup is crucial. Data generated with IoT medical devices/sensors fed to the smart applications can provide rapid preliminary diagnosis and provide prescription conjunction with provider.
- With this explosion of IoT devices, there should be very effective implementation governance for secure and solid integrity of data delivery to be taken care of for successful Healthcare.

Figure 41.5 shows IoT components in a Digital Health Ecosystem. The Digital health ecosystem starts with IoT Devices at the bottom. Those devices provide a wide range of information on biometrics, laboratory sample tracking system, health and

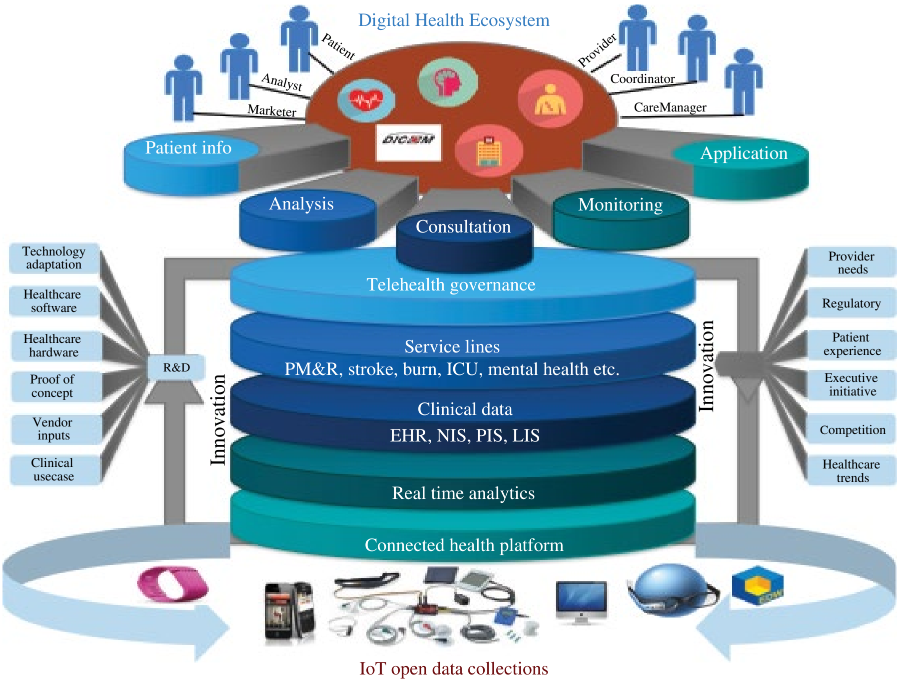

FIGURE 41.5 Digital health ecosystem with IoT components. © University of Utah TeleHealth Services.

wellness devices (wearables), and so on. They are connected to a health platform and move upward by applying analytics and workflow. The information that reaches to clinical data EHR, NIS, and so on will be more actionable data or decision-making data. This actionable data can be available to different service lines like PM&R, Stroke, and so on. The whole deployment will be notified and tracked by Telehealth team to facilitate Telehealth calls. The whole Telehealth system's goal is to automate the process and notify the critical actions to take place. This process will be constantly influenced by R&D on the one hand and innovation on the other hand. The top figures consist of care provider, patient, and other actors. These actors use the appropriate action tools (DICOM for seeing patient's MRI) to provide care. For example, the action tools and IoT data at the bottom can provide shared decision making on certain ailments. The patient's insole sensors provide data on patient rehabilitation exercise adherence, and the MRI provides patient improvement after the surgical procedure.

FURTHER READING

http://mobihealthnews.com/ (Accessed January 19, 2016).
http://www.telehealth.com/ (Accessed January 19, 2016).
https://digitalhealthsummit.com/ (Accessed January 19, 2016).
https://www.wearable-technologies.com/ (Accessed January 19, 2016).