Internet of Things for Social Impact

A design framework by design that matters

design that matters™

A Design Framework for the Internet of Things (IoT)

What Is This and Who Is It For?

This report is to provide a product strategy framework for organizations and individuals who want to incorporate Internet of Things technology in products designed for social impact.

To better focus this research and our recommendations, we will walk you through the concrete example of how we designed Project Echo, a remote-monitoring technology for medical devices in developing countries. Echo will prolong the lifespan of medical devices so that we can save more lives, make our products more cost-effective for stakeholders, and protect the environment.

While the example come primarily from our work in the social sector, the observations and recommendations that follow are broadly applicable to designing an IoT solution in any field.

Design That Matters is an award winning non-profit that solves problems for and with the poor in developing countries using design.

This framework is made possible with support from The Lemelson Foundation in celebration of their 20-year history of improving lives through invention.

Table of Contents

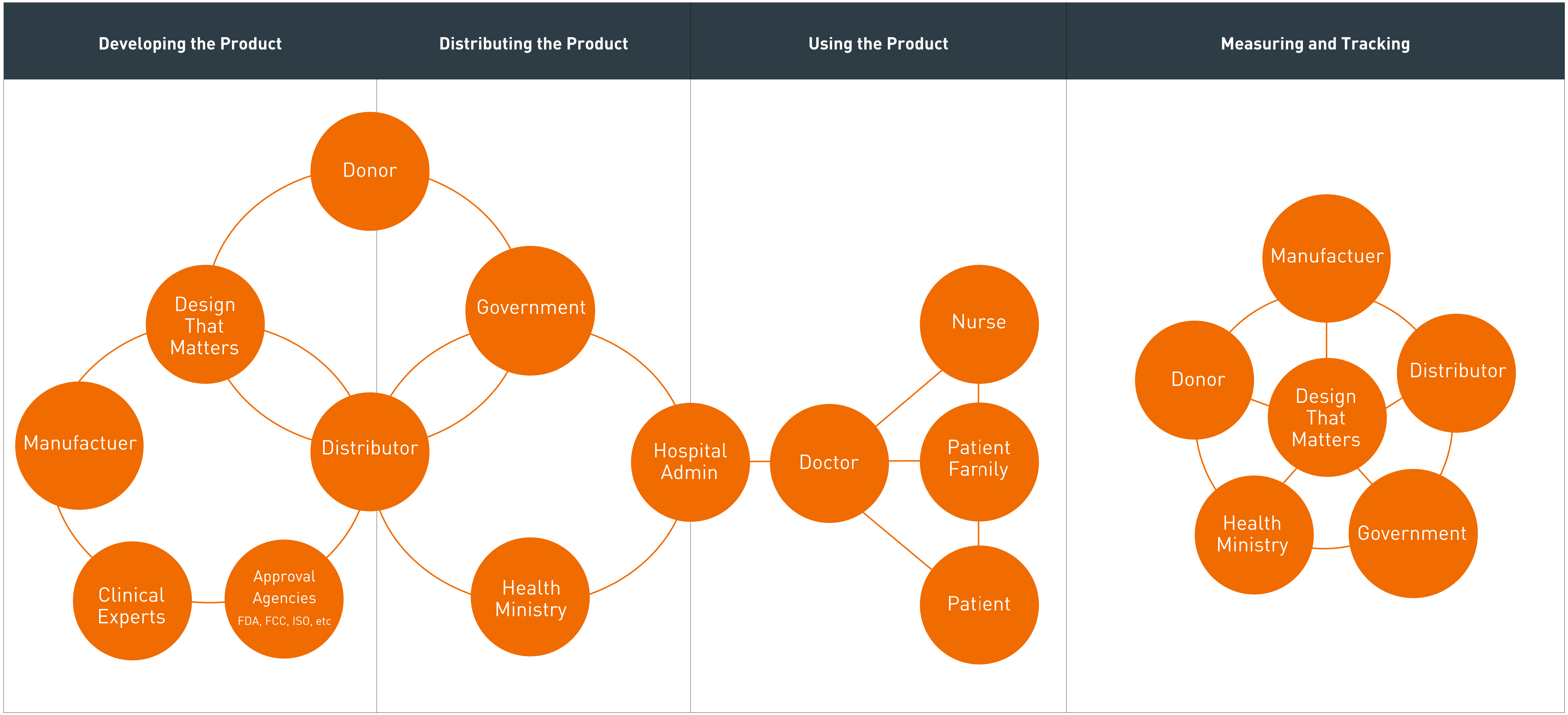
Design Framework

Design Principles	System Design Questions	Hardware and Software Design Questions	Example - Echo	Read More
1. Outcome Your device supports and is aligned with the outcome of the organization	• What is the outcome you (your company) want to achieve? • How do you align your IoT device to achieve that outcome? • What matters most to your design and what are the trade-offs?		Echo will support DtM's mission of saving newborn lives by prolonging the lifespan of medical devices and making DtM's products more cost-effective for stakeholders.	Section IV Step Ia. From Outputs to Inputs Defining Design Constraints to Optimize outcomes
2. Integration Your device can be integrated into existing product lines, activities and workflows of the stakeholders	• If you have multiple products, would you want to add remote monitoring to just one or all of them? • Do you want the remote-monitoring device to be visible to the user? • Do you want to give them the ability to turn it on or off?	**Collect Data** • Who are you designing this for? • What data points benefit your stakeholders? • What are you measuring? • What are your stakeholders' normal workflows?	Echo will be built as an internal component of Otter, the warming bassinet. Otter is made to complement the Firefly Phototherapy device that has been widely distributed across the world. Therefore, Echo will be able to measure both Otter and Firefly performance in the longrun.	Section IV Step Ib. How Project Echo Fit in the Existing Product Line Section IV Step Ic. Internal vs. external device?
3. Adaptivity Your device is flexible and can be easily adjusted to work in various environments and countries		**Transmit Data** • What is the technical environment like? • How does the environment impact the device? • Do we want to transmit data in aggregate or in real time? • How do you want to access the data?	Echo is designed to work in low-resource hospitals in developing countries where wifi is unstable. We will use GPRS whenever possible and use SMS only when GPRS network is unavailable to lower the cost of transmission.	Section IV Step IIa. Analyze Current State of Firefly Section IV Step IIb. Assess Communication Environment Section IV Step III. Transmit Data
4. Service Your device provides a service to and benefits all stakeholders involved	• Would adding remote-monitoring feature influence stakeholders' behaviors in some way? • What benefits does your device provide for your stakeholders?	**Share Data** • What is the user environment like? • What data do they want to see? How often do they need to see it? Do they use computers or phones? • Do they need real time alerts?	Echo provides benefits to donors, technology developers, manufacturers, distributors, hospital staff, and health ministries.	Section IV Step IV. Share Data
5. Security Your device protects the data it gathers and makes sure sensitive information is private	• Have you reviewed regulation requirements in the corresponding countries? • Are you being transparent about what data you are collecting and what the benefits are to the stakeholders? • Is the device secure?		DtM is partnering with Dimagi, who specializes in mobile technology company in developing countries to ensure our data is secure and protect user information. We also studied extensively on relevant regulations for remote monitoring.	Section V. User Rights and Privacy Section VI. Regulations

Echo Stakeholders Map

What Is A Stakeholder Map?

We define **stakeholders** as a person or a group who can affect or be affected by the Product. The stakeholders map for an IoT product can be complex, especially in the healthcare industry. Below graph helps us understand the relationship between different stakeholders in the entire design process.



I: Introduction

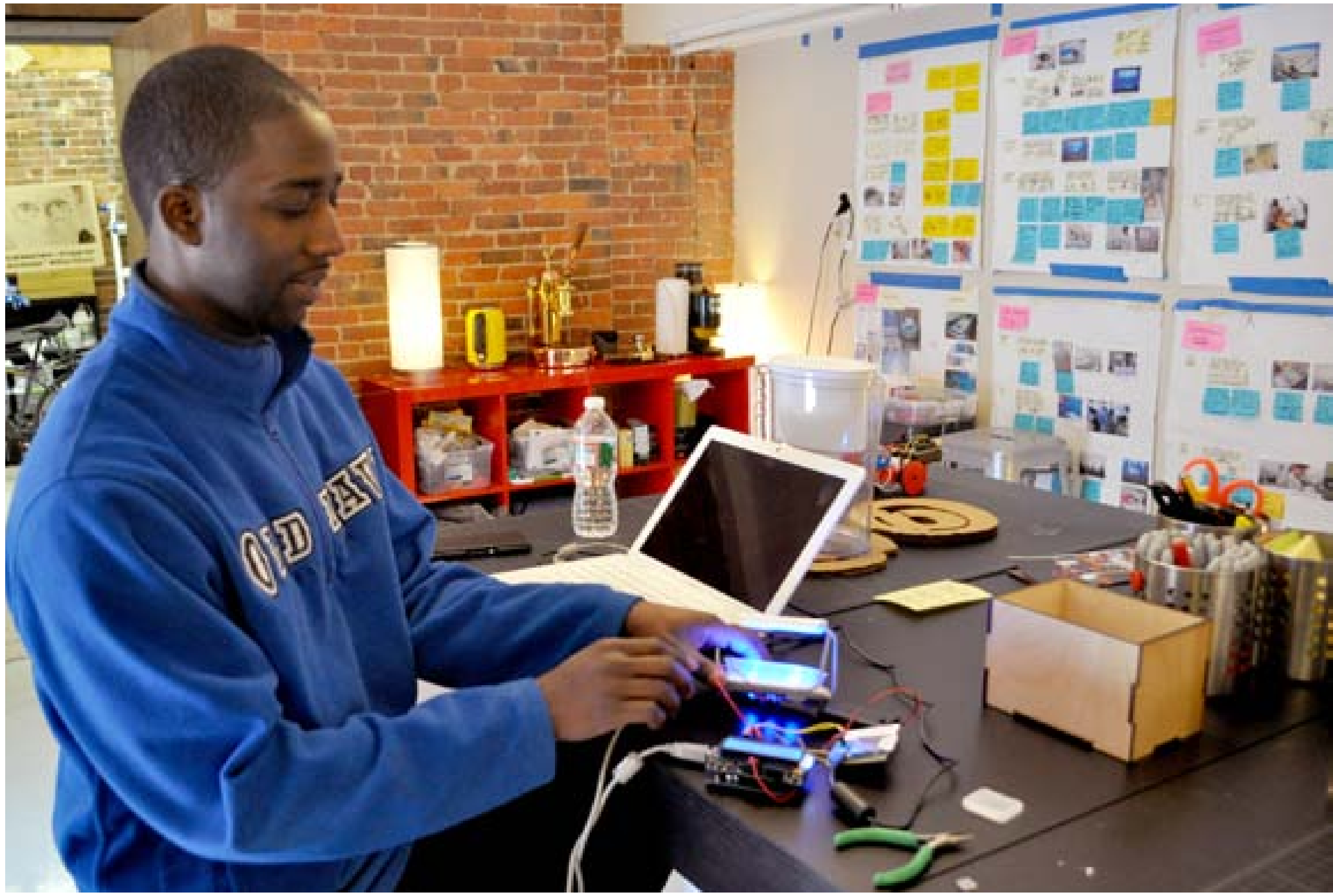
A World of Connectivity and the Internet of Things

"Internet of Things (IoT)" is all around us. Our smartphones, smart TV and smart coffee makers are all IoT objects. Even though they are just "things", they can communicate with people and with each other through the Internet. For example, you can tell your coffee maker to brew a fresh cup of coffee every morning at 7AM except on lazy Sundays through your smartphone.

The term "Internet of Things" became a buzzword in recent years. However, the concept has been around for a long time. It was coined in 1999 by Kevin Ashton, then executive director of the MIT Auto-ID Center. It helped explain the concept of putting a low-cost RFID transponder to track product from manufacture through sale.

Today, "Internet of Things" has broadened over time to include sensors inside medical equipment or photocopiers that can report on a machine's condition through an connection to the Internet, from John Romkey's TCP/IP toaster in 1990 to Peter Semmelhack's networked office chair for Herman Miller. We could also use IoT sensors to help grow crickets faster and make sweeter wine.

In the near future, even a rural village in Africa could have wireless data access. Estimates predict there will be 20+ billion connected devices online by 2020, representing a market size of $200+ billion. Not only that, 90% of the world's population will be covered by mobile broadband networks. Bluetooth Low Energy (BLE) would be a key enabler, making it easy for devices all around us to become connected. How might we apply "the internet of things" to move beyond concepts like mHealth and



mobile money to improve tools like medical devices designed specifically for low-resource rural hospitals? If we are envisioning a world where sensors can prevent the collapse of a bridge, if we could warn drivers about ice on the bridge, we should be able to do the same in medical devices distributed across the world.

IoT Framework for Social Impact

Given the potential impact IoT can have in our society, our goal in this report is to provide a framework for organizations that seek options for incorporating the Internet of Things (IoT) and real-time remote-monitoring in products designed for developing countries.

Apply IoT to Social Impact at Design That Matters (DtM)

The two other DtM products relevant for this report are:

Firefly - a newborn phototherapy device designed specifically to allow rural hospitals with limited resources and inexperienced staff to successfully treat otherwise healthy newborns for jaundice. Already implemented in Vietnam, Myanmar, Thailand, Malaysia, DtM partners plan to expand to at least 1,000 Firefly devices next year, reaching at least 500,000 newborns.

Otter - a newborn conductive warmer designed specifically to allow rural hospitals with limited resources and inexperienced staff to successfully treat premature newborns who are especially vulnerable to hypothermia.

Right now, we have no way to follow up on Firefly implementations. short of visiting each clinical facility. How might we assist clinicians to better track patient treatment schedules in the crowded wards of a poor hospital? How might we empower hospital administrators and national ministries of health with more information about the use and benefits of specific medical technologies? How might we help the international aid community stay engaged with equipment they've already donated, and make better choices in the future based on data received about the effectiveness of equipments in the field?

To address this problem, **Echo** is DtM's effort to add remote-monitoring to the Firefly Phototherapy device. The biggest challenge we face is: it is very difficult to add tracking to a device that is already distributed around the world. The good news is Project Echo, Otter and Firefly support and complement each other. The better idea would be to build Echo as an internal component of Otter. Otter is designed to fit with and complement Firefly or function as a stand-alone device. Phototherapy and warming are usually used together, if we are able to track usage from the warming bassinet, it should provide us a reasonable idea on Firefly usage as well.

Firefly Phototherapy Device

Otter Warming Bassinet

II: Why Echo?

If we could implement Echo successfully to Otter and be able to scale the model to other medical equipments, the impact would be tremendous. The World Health Organization (WHO) estimates that as much as 80 percent of medical equipment in developing countries is donated or funded through foreign sources, but only 10 percent to 30 percent of the donations are ever put into operation. We found three major reasons for donated medical equipment to be unused in developing countries, as shown in the figure below, as (1) broken equipment, (2) under-trained healthcare workforce and (3) unreliable infrastructure.

For global health organizations who are dissatisfied with the inefficiency and lack of transparency associated with medical equipment donations, Echo is a remote-monitoring technology designed specifically to provide equipment-use data that identifies when and which rural hospitals need additional devices, additional training or product maintenance. Unlike follow-up site visits and phone calls, Echo provides continuous, real-time data on the status and social impact of donated medical equipment.

Three major reasons for donated medical equipment to be unused in developing countries

Real-time diagnostics and troubleshooting of devices ultimately ensures better optimized field service operations. It enables us to identify recipient facilities in need of additional capacity, additional training or product maintenance. Specifically:

- It could respond to the customers faster and decrease time-to-repair.
- It could save on operational costs by knowing exactly what to fix and eliminating redundant service trips.
- It could extend the useful life of equipment and increase average-time-between failures by identifying and repairing small problems before they become big ones.

III: What Exists?

IoT is an established technology that has proven utility, and in fact has already found applications in various industries, including the social impact sector. Without re-inventing the wheel, let us look at some examples of how other companies have applied remote-monitoring across industries. The examples are grouped into three different categories, we begin with the healthcare sector because it is probably the most different sector to navigate. Then we discuss other non-healthcare commercial applications and finish with examples in the non-for profit sector. The broad range would remind us what *has been* and *can be* done.

A. For-profit healthcare sector

Qualcomm Life 2net Platform is one of the biggest and most successful IoT platform in the healthcare industry. It helps hospitals connect medical devices wirelessly and capture data to aid hospital operations. The technology was initially developed by Capsule Tech, which then got acquired by Qualcomm in 2015.

The 2net Platform supports secure socket layer (SSL) communication of data and is FDA listed as a Class I Medical Device Data System (MDDS) in the U.S., Class I MDD and CE registered in Europe, and Class I in Canada. As an MDDS, the 2net Platform is designed, developed and manufactured in accordance with a quality system compliant with ISO 13485 standards, meaning it aligns with the quality requirements of U.S. and international regulatory agencies in the healthcare industry.

This is very important to note if you are developing IoT products in the healthcare industry, on a platform similar to that of Qualcomm 2net, you will likely have to obtain the above certifications. Healthcare related products have strict regulatory requirements.

There are four gateways onto the 2net Platform's data center:

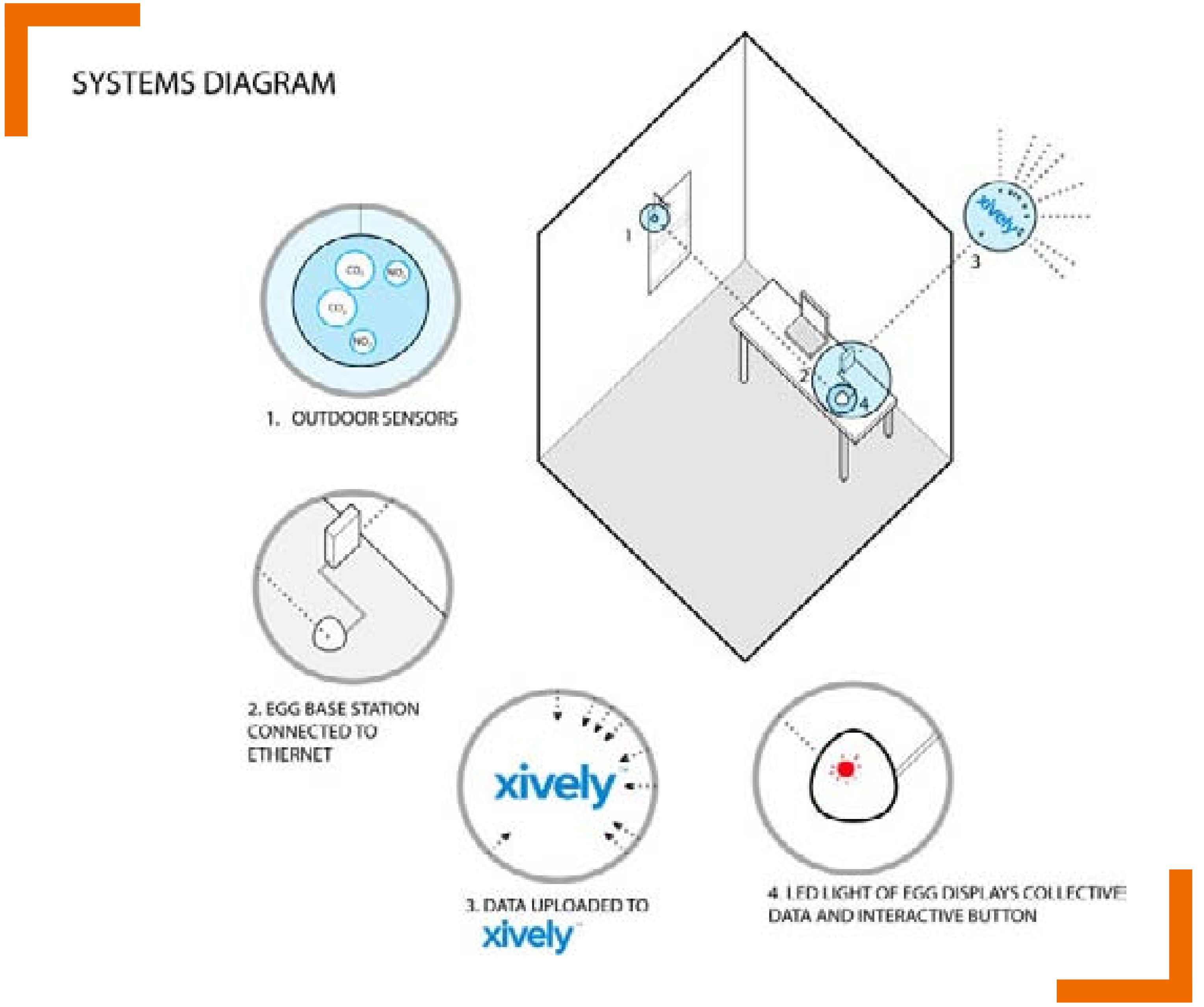
- A standalone FDA listed external device – the 2net Hub
- An FDA listed software module that connects mobile computing devices – 2net Mobile Core
- Medical devices with an embedded cellular component
- Service platform integration between the FDA listed 2net Platform to customer and technology partner service platforms using application programming interfaces (APIs)

A complete overview of the Qualcomm Life 2net Platform Bill of Materials can be found here. Other IoT examples in the healthcare industry:

- Mainspring Healthcare Solutions and Lynx Systems (platforms)
- GlowCaps (product) - The prescription bottle cap reminds you when to take your medication through sound and light. When it's time for a refill, simply push the button at the base of the GlowCap, and a refill request will be sent to your pharmacy through AT&T Mobile Broadband Network.

B. For-profit non-healthcare sector

- Mesh Systems has an IoT system called MESHvista to remotely monitor, manage, and predict machine maintenance across industries, not just in healthcare. This white paper explains how the beverage industry embedded cellular technology within the dispensing machine to get a direct view into each machine's performance, maintenance needs and vital statistics.
- Exosite One Platform is similar to Mesh Systems. Here is their technology overview. They specialize in designing BLE solutions for enterprises.
- BiKN - BiKN is a sensory tag that you can add to your keys to locate them up to 50 feet away inside and up to 200 feet away outside. It uses RFID technology which we would explain below.
- AirQualityEgg - The Air Quality Egg is a sensor system designed to allow anyone to collect very high resolution readings of NO2 and CO concentrations outside of their home by using inexpensive sensors. How it works: A small electronic sensing system plugs into a USB 'wall wart', and sends the data over Wi-Fi. The data is sent to the cloud at Opensensors.io, an open data service, which both stores and provides free access to the data. From there, it is sent to Xively, where you can see graphs and other visualizations of the data. The service includes embeddable graphs and the ability to generate triggers for tweets and SMS alerts (it looks something like this), as well as a robust API which allows for developers in the community to unlock the potential of this new dataset by building mashups, maps, and applications.



Air Quality Egg System Diagram. Source: airqualityegg.com

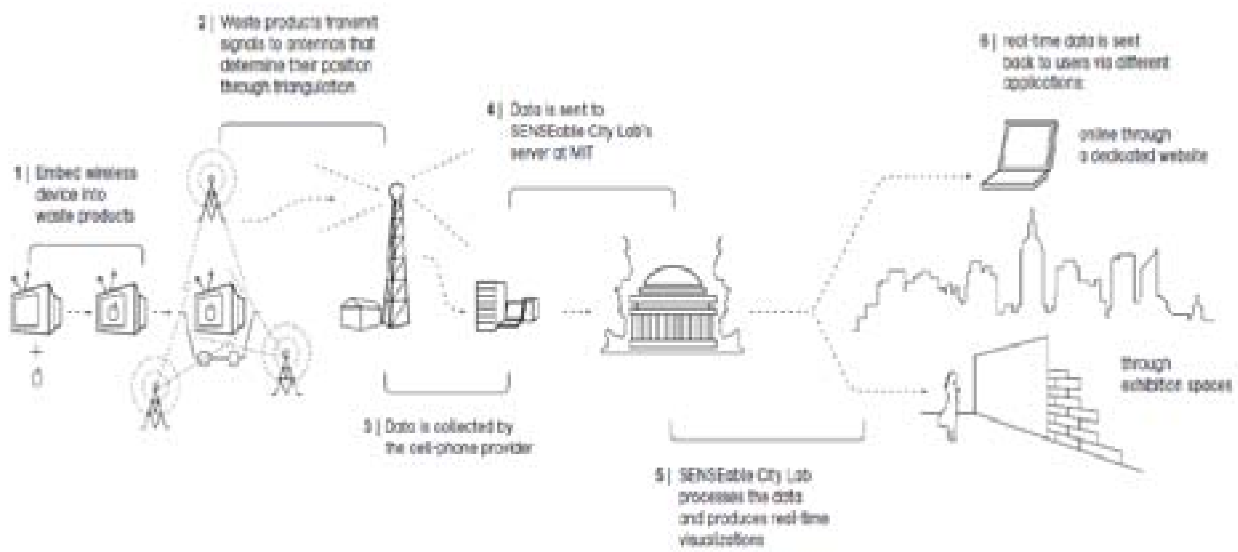
C. Non-for-profit sector

Trash Track

The MIT SENSEable City Lab used IoT technology to track where our trash went in order to study the "removal chain". Trash was given a tag that periodically measures its location and reports that data to the server via the cellular network. The first generation of trash tags was based on GSM cellular phone technology that estimates the tag position by measuring signal strength from each cell tower in sight of the device and comparing it to a map of cell phone towers – a technique known as CellID triangulation. The location accuracy is not as good as GPS but tends to be more robust, as cellular signals can be picked up inside buildings and from within piles of trash, not requiring an unobstructed sky view. Our second generation of tracking tags use the best of both worlds – GPS and CDMA cell-tower trilateration based on the Qualcomm inGeo™ platform (device shown in photo 2) in combination with Sprint's cellphone network, utilizing Qualcomm's gpsOne® technology to provide both accuracy and availability for position tracking applications. Future generations of devices will work seamlessly across CDMA/GSM/UMTS networks, a feature that will allow tracking items across international borders.

All of the components used in the tags are RoHS compliant, which means that toxic material levels are below both U.S. and European Union standards for electronics products for which the Trash Track tags can be legally introduced into waste streams. The triangulation / tower location service is provided by navizon.com.

How the system works:



Source: senseable.mit.edu/trashtrack

Charity: Water, remote-monitored water pumps

Charity: Water launched a $5 million pilot project with Google to develop remote sensor technology that will tell us whether water is flowing at any of our projects, at any given time, anywhere in the world. In order for a sensor to withstand natural elements, it has to be durable. In order for a sensor to monitor water flow, it has to be food-grade quality. It can't impede the flow of water. It has to be secure. It needs to be accepted by the community. It has to transmit data. The power needs to last a really long time. And it must be affordable. Here are the design references for Charity: Water:

Open source bill of materials

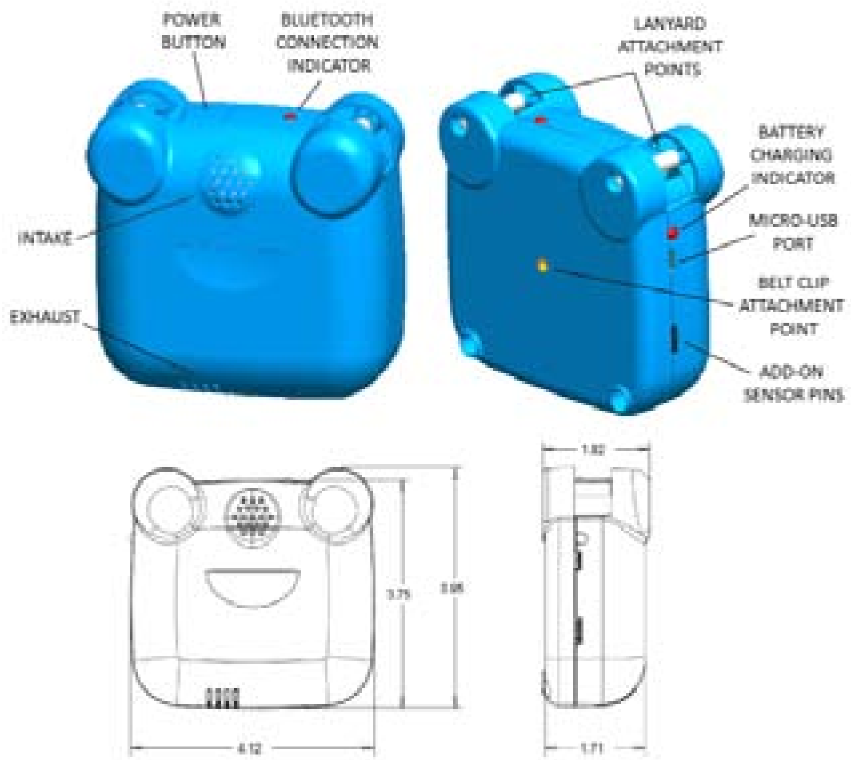
- Afridev Sensor Firmware Specification
- Afridev Sensor EE Drawings
- Afridev Sensor ME Drawings

Github archive

- https://github.com/charitywater/dispatch-monitor

AirBeam

Similar to the Air Quality Egg, the AirBeam helps detect changes in your environment and physiology. It uses a light scattering method to measure fine particulate matter or PM2.5. The measurements are communicated via bluetooth once a second to the AirCasting Android app, which maps and graphs the data in real time on your smartphone. At the end of each AirCasting session, the collected data is sent to the AirCasting website, where the data is crowdsourced with data from other AirCasters to generate heat maps indicating where PM2.5 concentrations are highest and lowest. You can see how AirBeam is built here.

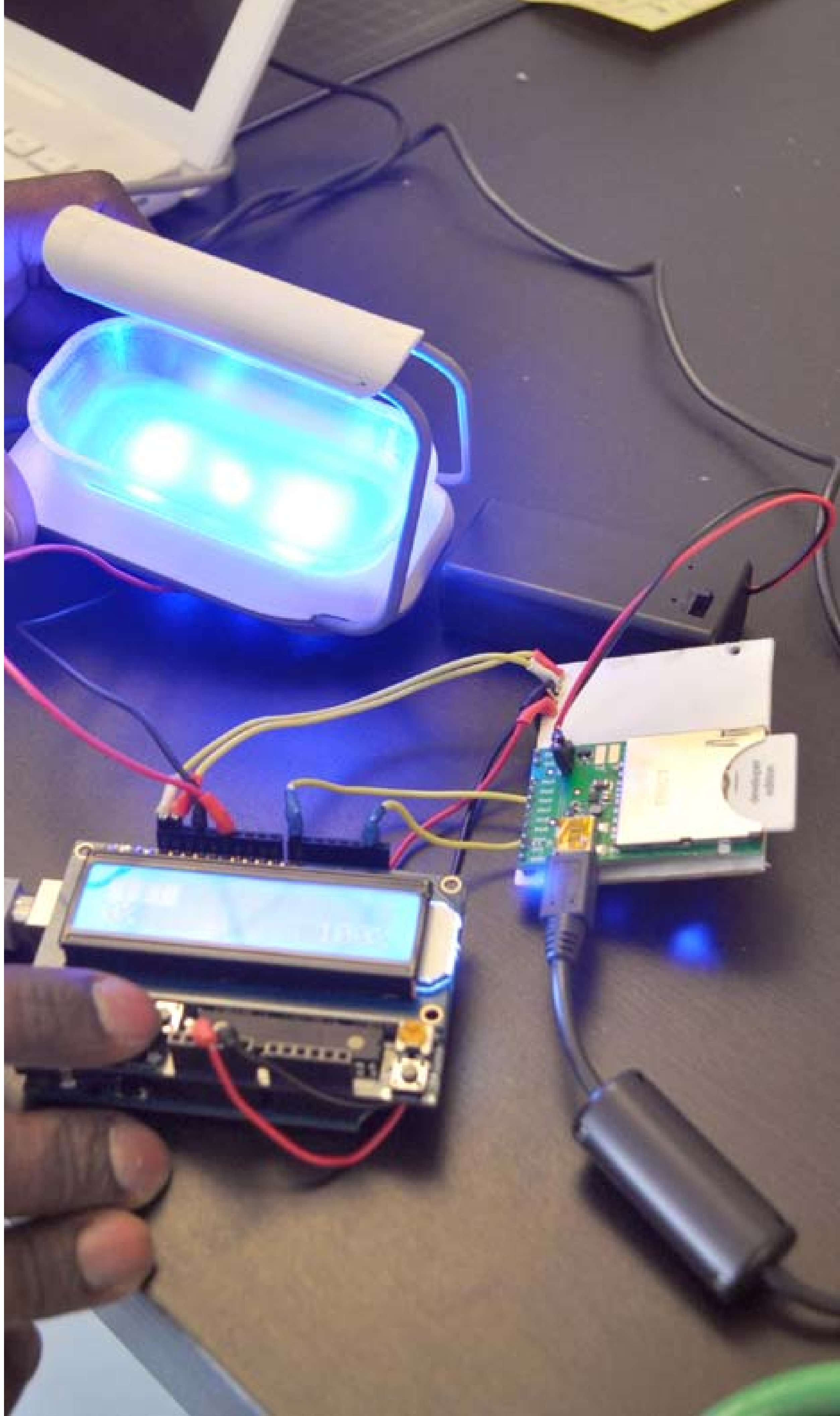


AirBeam System Diagram [Source: takingspace.org]

Safecast

Safecast is an IoT tool that helps people monitor, collect, and openly share information on environmental radiation and other pollutants that are growing quickly in size, scope, and geographical reach. You can find resouces on how Safecast was built below:

- GeigieNano firmware on Github
- Bill of materials
- Other useful resources



IV: Project Echo Development Process

In Section IV, we will walk you through the steps we took to develop Project Echo. Project Echo is specifically a IoT solution for social impact in poor countries, however, the design process we used can be applied to projects across indudstries. To better help you apply this design framework to your own IoT projects, we have proposed some questions you should think about in the development process. These questions can be found in the summary paragraph after each step.

Step 1 - System Design Considerations

Systems design is the process of defining the architecture, components, modules, interfaces, and data for a system to satisfy specified requirements.

(a) From Outputs to Inputs - Defining Design Constraints to Optimize Outcome

Design That Matters' mission is to save newborn lives. The ultimate goal of Echo is to align with this goal. Since Echo itself does not treat newborns, the first question we need to ask is what can Echo do to have the most direct impact on saving lives? We know that if the machine runs longer, it will treat more newborns; if Echo provides accurate information on how the machine is performing and relevant usage data, it would provide us insights to improve the next generation of devices. In other words, in order for the whole project to make sense and be worthwhile, we need to make sure Echo's design will optimize our outcome. The first two criteria we came up for Echo are: **reliable** and **affordable**. Specifically, Echo needs to have:

- No moving parts and consumable (replacement parts)
- Low maintenance need: Cannot cause the failure of the medical device
- Real time alerts
- Continuous signal
- Low cost (during both implementation and operation phase)
- Long lifetime

Are there any non-technical things that would influence saving newborn lives? For example, are there any user related benefits and constraints we need to be aware of? Would people be more or less likely to abandon the device if they feel that they are being tracked? Would the stakeholders overuse or underuse the devices if they know that usage data impacts how soon they will receive the next device? Would stakeholders feel that we don't trust them to do their jobs well when in fact we want to help them? There are various user incentives and psychology factors we need to consider in designing a product. Given the above, the two additional criteria for Echo are:

Accurate

- Ensure time resolution of data, accuracy of measurement, and also the measurement capability of different variables (whether we can measure certain variables or not)
- Ensure that Echo cannot be removed or disconnected
- Ensure that Echo does not have a separate on/off switch

User Friendly

- Design as simple as possible
- Avoid any possible paperwork
- Social aspect (we're helping the front-line healthcare provider, not monitoring their work performance)

Summary:

Here are some good questions to ask ourselves as we define the design criteria for the project. How might we...

- Achieve our organization's mission?
- Align the IoT device to achieve that outcome?
- Determine the most important criterias for the design?
- Access trade-offs between reliability and cost? (Note, this is important because it might impact the sensors you choose to use for your design later on.)
- Consider the non-technical elements that would impact the design?
- Benefit all stakeholders?
- Control or influence stakeholders' behaviors? (In other words, would adding the remote-monitoring feature influence stakeholders' behaviors in some way?)

(b) - How Project Echo Fit in the Existing Product Line

We discussed this briefly earlier in the report, Project Echo's initial goal was to track Firefly's performance. However, since a significant number of products are already in the field, adding a remote-tracking device to Firefly presents many challenges. First, there is little to no incentive for a user to add monitoring to a device they already use. Second, Firefly is all over the world, it will be resource and labor intensive to add monitoring to an existing device. Therefore, DtM is planning to incorporate Echo into the Otter Warmer. Otter is intended to solve the most urgent Firefly user request of providing some means to protect newborns receiving phototherapy from hyperthermia. Since Otter is not out in the field yet, we can incorporate Echo to Otter much more efficiently. Our goal is that we will be able to distribute Otter to countries where Firefly already exist and renew the bassinets. This way, we can track Firefly usage through Otter.

Summary:

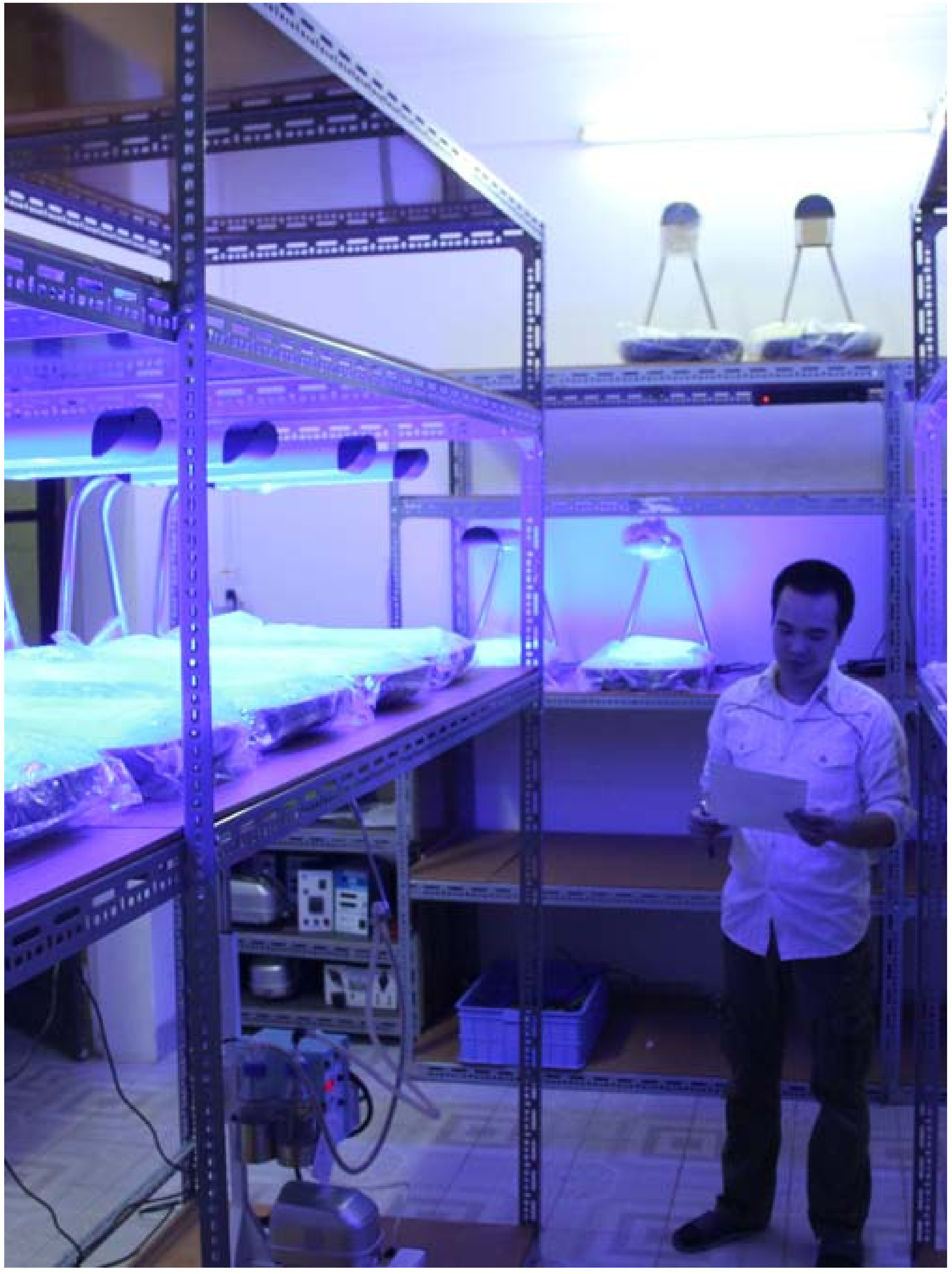
- Do you have one product or multiple products?
- If you have multiple products, would you want to add remote monitoring to just one or all of them?
- What is the relationship between this device and other devices?
- What percent of products are already out in the field? (5% vs.85% would influence your design strategy dramatically)

(c) - Internal vs. external device?

Another important aspect to consider is whether Echo should be an external or internal device. There are a few tradeoffs between the two. An external monitoring device would go through FDA or CE approval separately, without slowing down the production timeline of Otter. It would also be more scalable long term since you can use this device with other products down the road. The downside is that there is a chance of the device being removed from Otter either by accident or by intent. If Echo was built as an internal component of Otter, this could potentially slow down production because additional quality assurance and product certifications are required. However, this will position Otter as a holistic product that complements phototherapy and provides remote monitoring as an additional benefit. This also prevents people from removing Echo from Otter (i.e. If Echo was an external device, it could be plugged into power, but detached from Otter, thus potentially transmitting inaccurate data). To conclude, we believe Echo should be made as an internal device.

Summary:

- Do you want the remote-monitoring device to be visible to the user?
- Do you want to give them the ability to turn it on or off?
- Do you want them to be able to remove it from the device easily?
- How small does your device have to be?



Step II - Collect Data

In order to scope the project, we need to understand who our stakeholders are and what data should be collected. In the context of Echo, we considered the needs of the measurers and the measured: how might we design this system to benefit all stakeholders? Below are stakeholders for Echo and potential questions they may ask about Firefly:

- Donor - how is that Firefly I bought doing?
- Technology developer (DtM) - how is our product doing?
- Manufacturer - are the devices in good shape?
- Distributor - do hospitals need more devices? When do we need to replace them?
- Hospital (doctors and nurses) - are patients getting proper care? Are the devices working correctly?
- Governments and health ministries - are we addressing the needs of the citizens? Are we allocating enough resources?
- Parents/family of patients - are the machine new and in good condition? Can we watch our baby as he/she is being treated?

(a) - Analyze Current State of Firefly

The Otter device is not yet out in the field, so we analyzed the contexts in which Firefly is currently operating to estimate the environment in which Otter will be used. For example, Firefly is currently being used at St. Boniface hospital in Haiti. Here is what we learned about St. Boniface:

There are 200 staffs and 70 community workers in the St. Boniface hospital. Among these healthcare workers, there are 6 permanent physicians and 30-40 nurses who can be the end user of the Firefly device. The one Firefly they have is placed in the emergency room alongside 2 other phototherapy devices. Due to its benefit of ease-to-use and high reliability, the firefly is the primary machine to use for blue light therapy for newborns and it is actively used. There are 25-30 deliveries per month in the hospital—2-6 of the infants require the treatment with Firefly. To the interviewee's knowledge, the machine is in capacity. With the new Maternal and Neonatal Health Center open, there will be one more Firefly in place; however, it is also expected that there will be more intense use of the device due to the much higher number of deliveries will be performed in the center.

Similar case is observed in Hanoi, Vietnam. Each hospital has usually one Firefly device which is usually under heavy use. The nursery room is crowded and the staff-patient ratio is low. The Firefly device is purchased either through NGO such as the Breath of Life program or directly via hospitals. Maintenance is provided by local service people.

Summary:

- What is the user environment like?
- What is the technical environment like?
- How does the environment impact the device?
- Who are you designing this for?
- Can this device benefit multiple stakeholders?
- If it can't benefit all stakeholders, who are your most important stakeholders?

Step II (b) - Assess Communication Environment

Internet access is available in the hospital for simple data transmission such as emails. However, the signal stability is questionable. Cellular coverage is excellent in the hospital. The network providers are Digicel and Meckcom.

Summary

- Is Internet access available? How good is the signal?
- Do people use cell phones? What about cellular coverage? Who are the providers?

Step II (c) - Study Machine Details

Firefly is connected by an external power supply (220V AC--→12V DC). No moving parts or replacement parts are used in the machine thus minimum maintenance is required. Current issues are:

- E 05' hour meter error (early production run software issue, later one case due to manufacturing issue, bad solder joint).
- Failed external power supply/converter (appears to have gotten wet, worked after drying out at MTTS).

To translate above context and apply it to Otter, here are the data points we should collect:

- Device usage data (this will also serve as a good proxy for how long Firefly is being used, assuming warming is used in conjunction with phototherapy)
- Device power state
- Room temperature
- Light using Photocell sensor (to see if Firefly is on)
- Air quality
- Device error codes

It's important to study the user environment in order to pinpoint the key design features for Echo. The next step is to determine how to collect data outlined above.

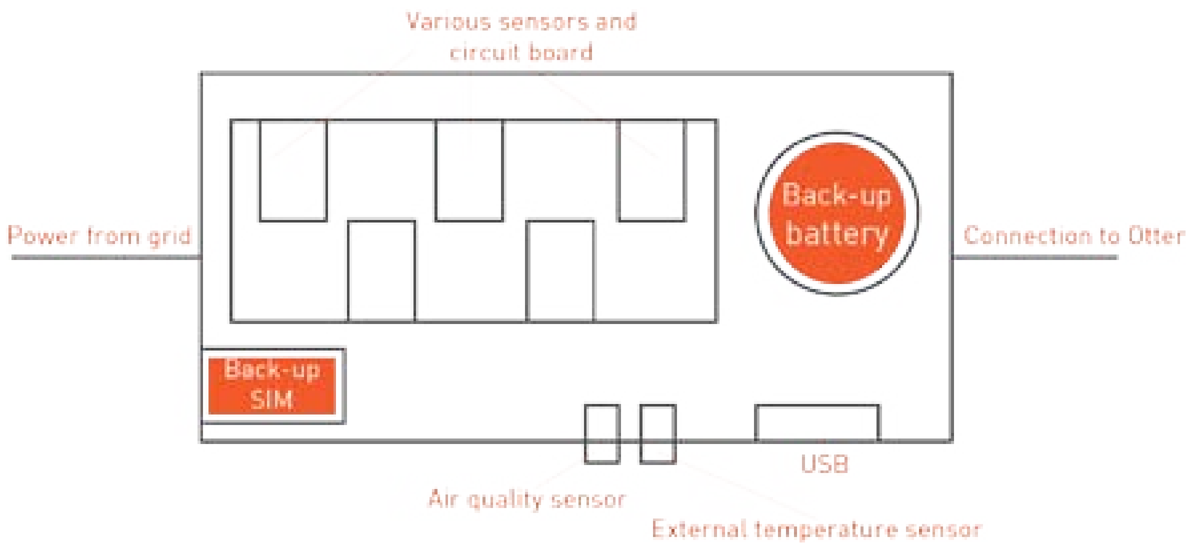
(d) - Gather hardware design requirements

Echo hardware is consists of a micro-computer, sensors, a data transmission board, an external battery, and an enclosure. An Arduino-UNO is used as a micro-computer because it is compatible with sensors and a data transmission shield; however, it could be replaced by a smaller, cheaper and more energy efficient micro-computer in the future. Sensors include a CT sensor, a temperature sensor, a communication button, and LED lights. Data transmission will be supported by an Arduino GSM/GPRS shield that could be also replaced by a simpler data transmission device in the future. Echo needs a battery to power it for as much as a year.

Echo could be place inside the electric board. Ideally, the dimension of Echo should be less than 10cm.

Summary:

- How much space do you have to fit all the sensors?
- What kind of power source does it require?



Echo works-like model

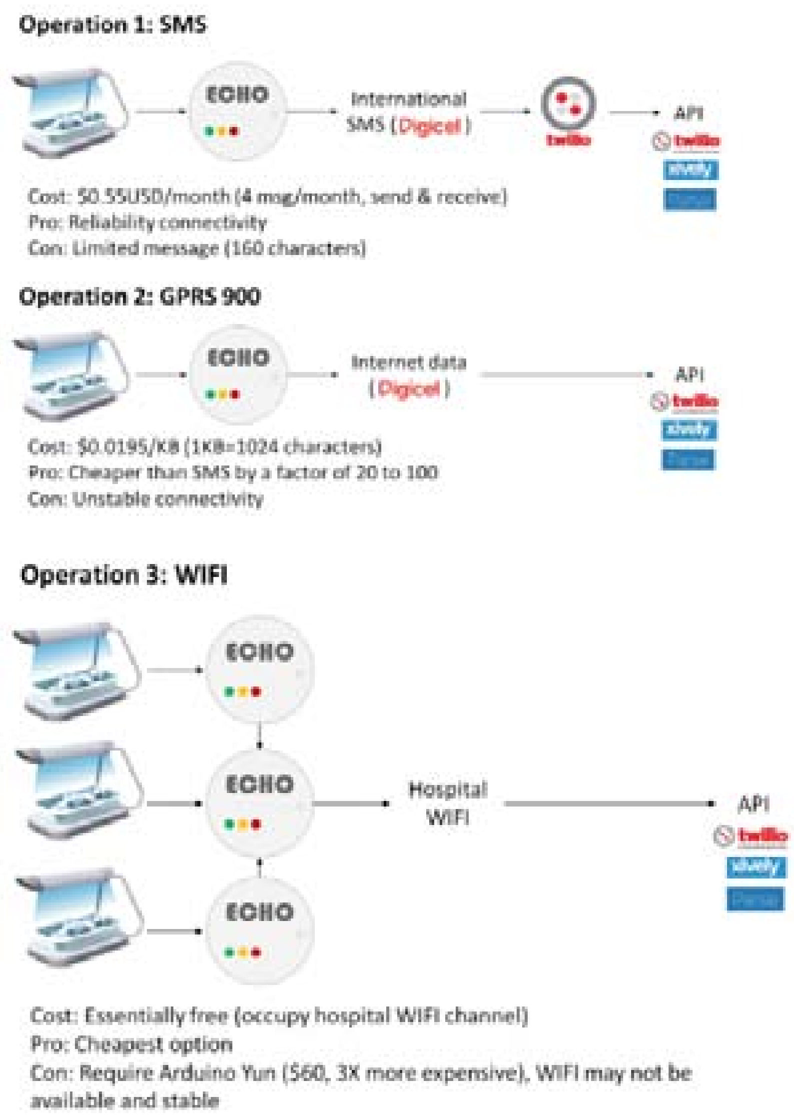
Step III: Transmit Data

There are multiple ways data can be transmitted, such as WIFI, Bluetooth, ANT+, USB and Cellular to name a few. Before we decide on the technology itself, it's important to to answer two questions first:

- Do we want to transmit data in aggregate or in real time?
- Do we want to access the data from our phones (through SMS) or web pages or both?

For Otter, we want to transmit data in real time and we want stakeholders to be able to access data through web pages primarily.

There are three channels to transmit data from Echo to the cloud, as shown below:



Options to transmit data (Credit: MIT HST Course 936)

Herein, we found that the cheapest option being transmitting data through WIFI. The cost of operation would be nearly zero in this case. Nevertheless, WIFI stability is reportedly poor in low resource settings, e.g. St. Boniface hospital. Even when WIFI connection is available, it is debatable whether we should occupy the valuable WIFI channel with Echo.

On the other hand, GPRS (aka 2.5G cellular network) has the benefit of low operational cost—the cost for sending data is 50 times cheaper than that of SMS. However, it also has problem with unstable connectivity. Fortunately, the GPRS network comes with most international SIM card. Thus, our design decision is to send data via GPRS whenever possible and use SMS only when GPRS network is unavailable.

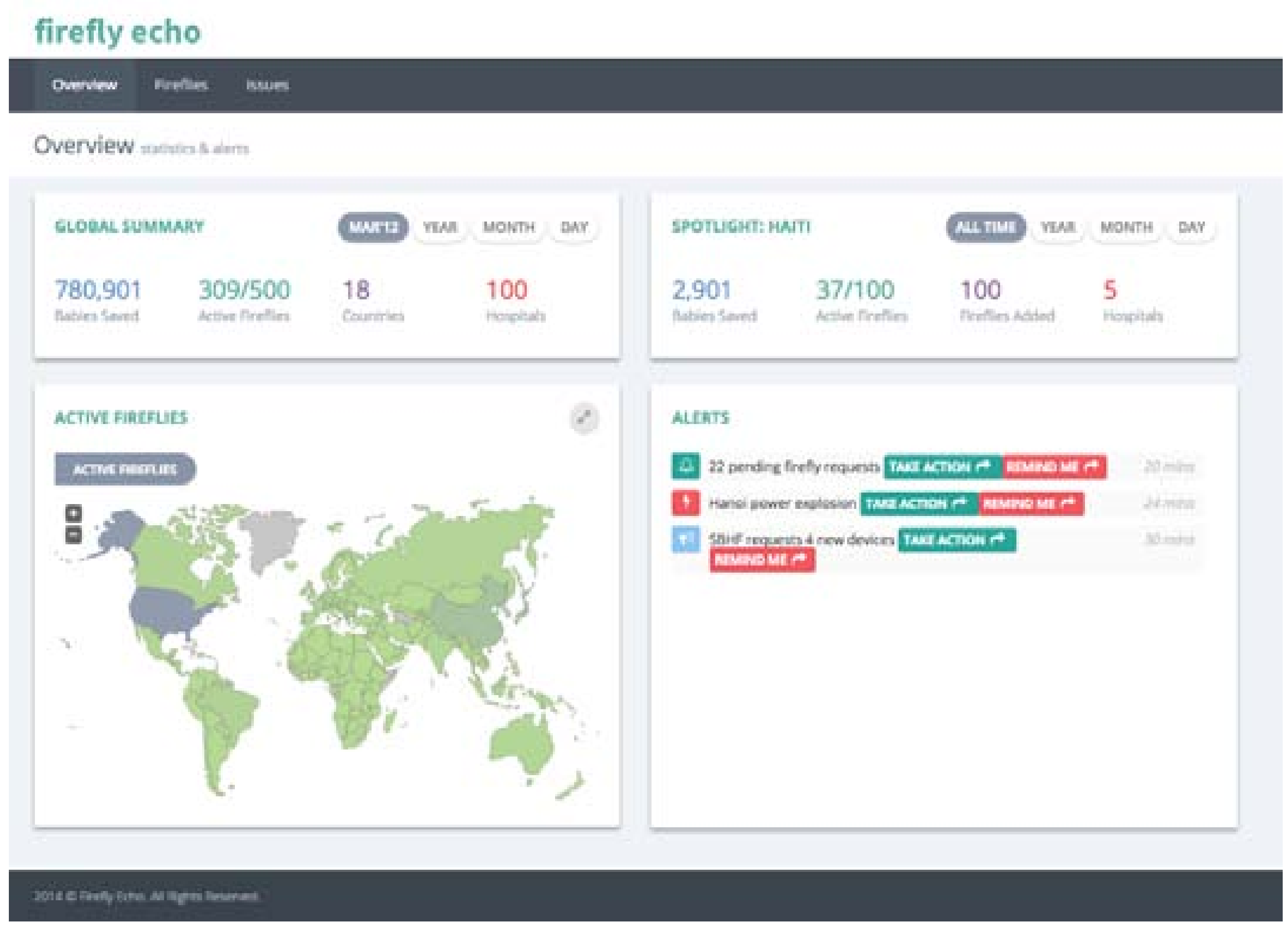
In the case of St. Boniface hospital in Haiti, we recommend collaborate with local carrier such as Digicel for SIM card procurement. The company is the most reliable mobile plan carrier in Haiti and allows international SMS with a reasonable price. The data transmission monthly cost for SMS is estimated to be $0.55/month and $0.01/month for GPRS. The measured data is sent to a Twilio virtual number. With a small receiving fee of $0.0075/msg, the virtual mobile account can store and process the received data. Working essentially as a cloud number, stakeholders can incorporate pre-developed API to process the data (with specified format) and obtain key insights for later decision making. In addition, Echo allows alert messaging, for example, the overheating of Otter, to the designated health care providers, creating convenience for the health care workers.

Summary:

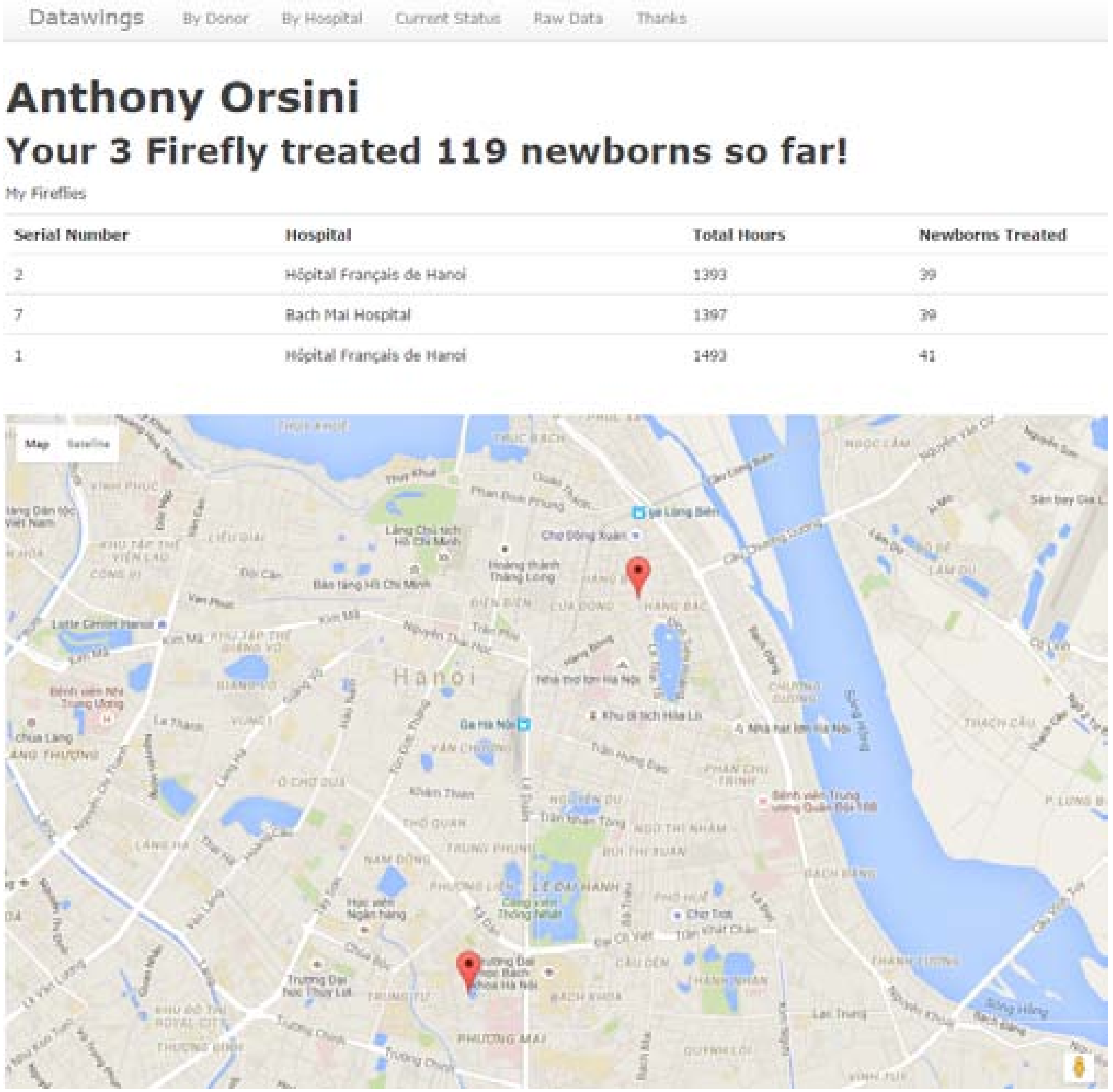
- Is wifi stable and easily accessible? Is there enough bandwidth?
- Do you need to transmit data in real time?
- What is the most sustainable option?

Step IV - Share Data

We recommend push alerts for urgent matters, for example if Otter is overheating, the device would automatically shut down and sent an SMS to the doctor and to the manufacturer to send service repair crew. All other alerts would be passive and communicated via the website. There are three ways to publish and share the data with our stakeholders. One, custom build it. Two, partner with someone with the data and IT expertise. Three, use existing platforms like dweet.io. As long as we could connect Otter to the Internet, it can use dweet.io to easily publish and subscribe to data. Dweet.io also comes with a dashboard where you can add relevant data points. By default, any(thing) can dweet or read dweets simply by knowing the object's name, but you can keep it provide by purchasing a lock for $0.99/month.



Graph 1 - Dashboard prototype for Project Echo (Credit: Harvard Course CS179)



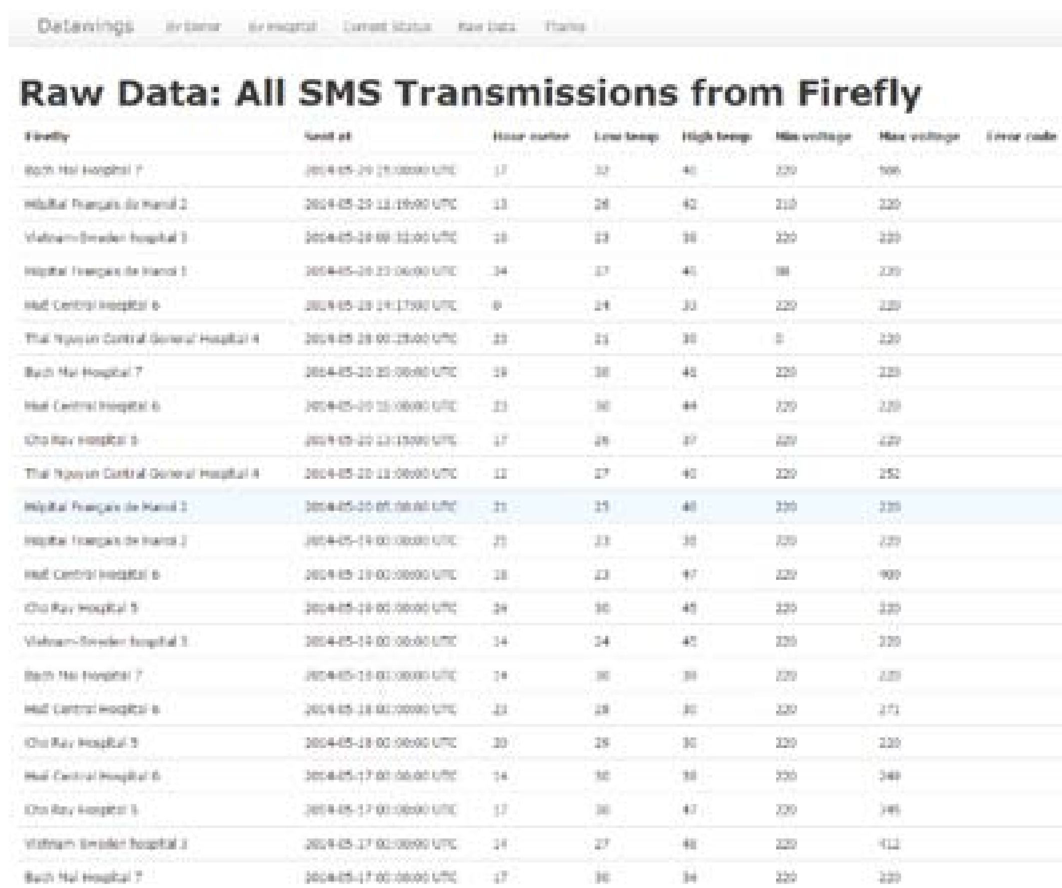
Graph 2 - Donor view of Firefly dashboard dummy data (Credit: Galia Traub and the Healthcare's Grand H@ckfest Team)

For the case of Otter, since we are working with private, sensitive medical data, we are partnering with Dimagi who specializes in customizable, open source mobile platform that supports frontline workers in low-resource settings.

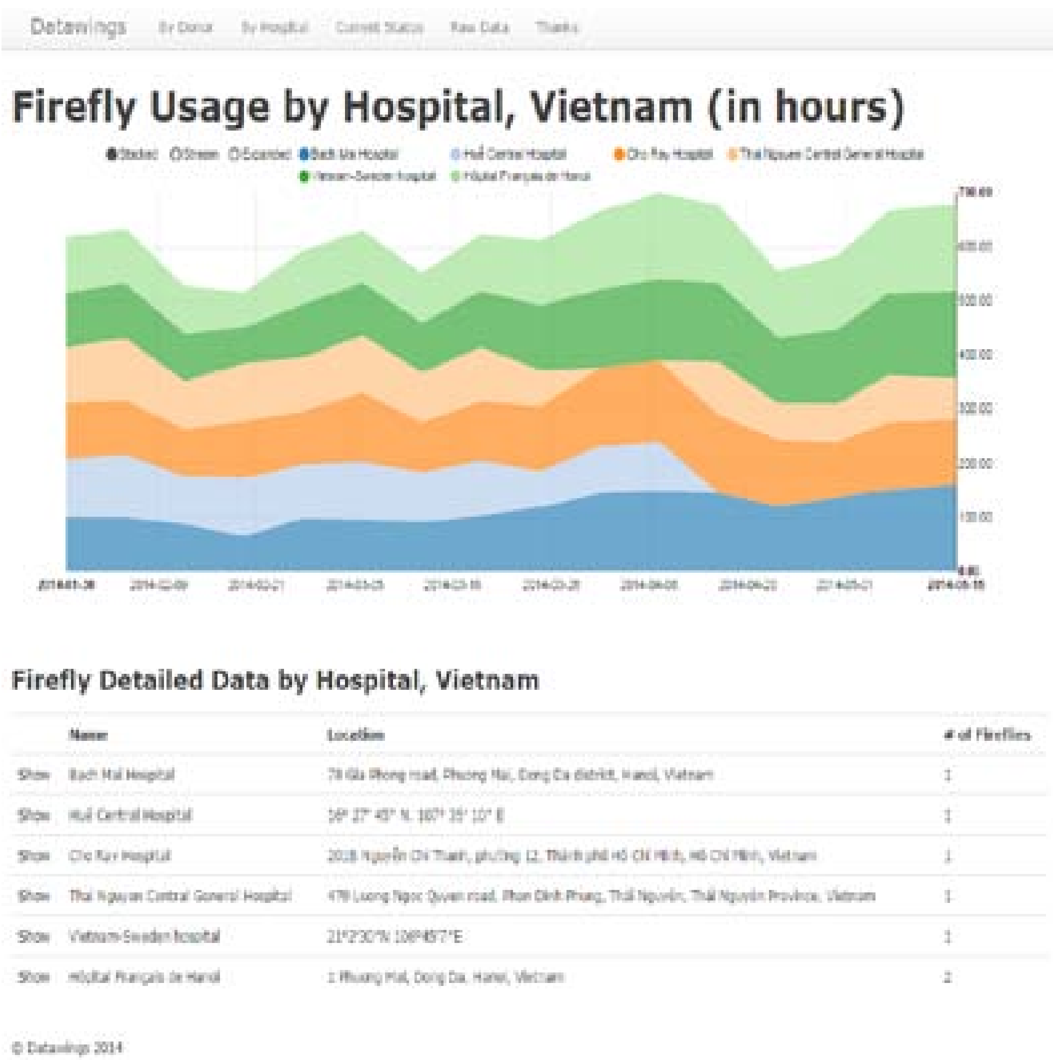
An important note on data security: depending on your project scope and data you are interested in collecting, you need to select secure API endpoints. TLS or Datagram Transport Layer Security (DTLS) should be used for the standard best-of-class Internet security. It is used in banking applications and most other online financial and health platforms. Similarly to TLS, DTLS allows applications to communicate in a way that is designed to prevent eavesdropping, tampering, or message forgery, but does so over datagram protocols.

You also need secure data storage and necessary device/user authentication to further protect the data. Check out the recommended reading section below to learn more. Graph 1-4 provides some visual examples of what that interface could look like. For example, Graph 3 shows the overall status of Firefly deployment. Graph 2 tells a specific donor how a particular Firefly device is performing and Graph 4 provides DtM and the manufacture an overview of the technical status.

Graph 3 - Current status of Firefly devices dummy data (Credit: Galia Traub and the Healthcare's Grand H@ckfest Team)



Graph 4 - Raw data view of Firefly dashboard dummy data (Credit: Galia Traub and the Healthcare's Grand H@ckfest Team)



	Name	Location	# of Fireflies
Show	Bach Mai Hospital	78 Giải Phóng road, Phương Mai, Đống Đa district, Hanoi, Vietnam	1
Show	Huế Central Hospital	16° 27' 45" N, 107° 35' 10" E	1
Show	Chợ Rẫy Hospital	201B Nguyễn Chí Thanh, phường 12, Thành phố Hồ Chí Minh, Hồ Chí Minh, Vietnam	1
Show	Thai Nguyen Central General Hospital	479 Lương Ngọc Quyến road, Phan Đình Phùng, Thái Nguyên, Thái Nguyên Province, Vietnam	1
Show	Vietnam-Sweden hospital	21°2'30"N 106°45'7"E	1
Show	Hôpital Français de Hanoi	1 Phuong Mai, Dong Da, Hanoi, Vietnam	2

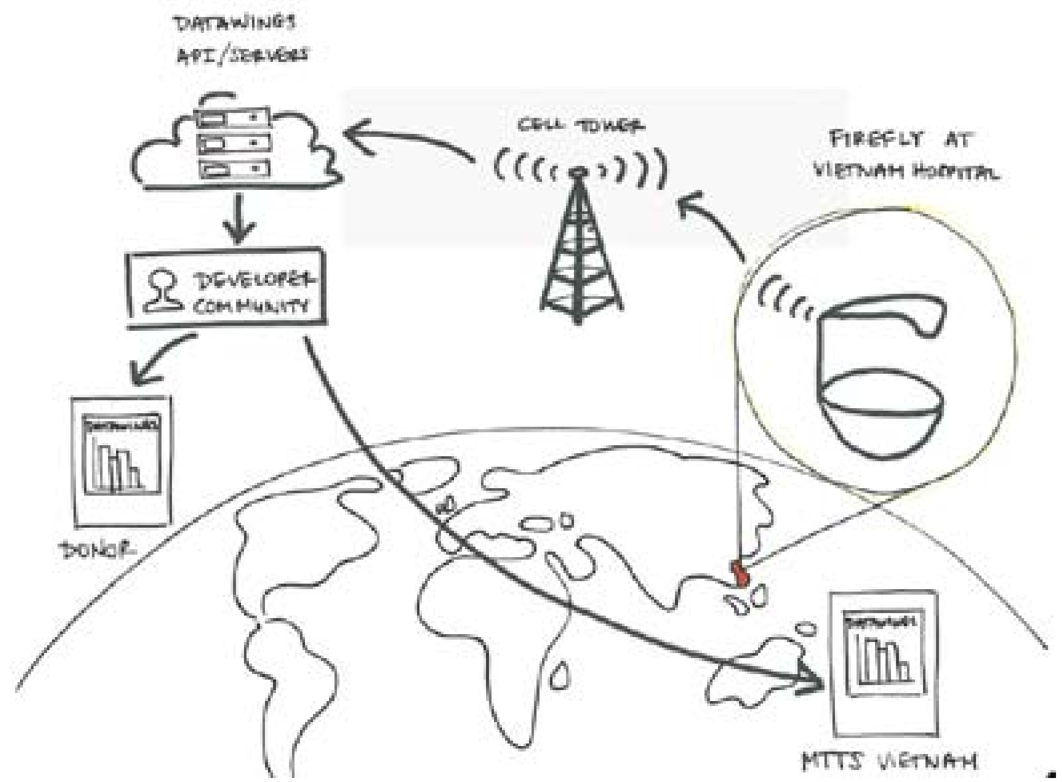
Graph 5 - Donor view of Firefly dashboard (Credit: Galia Traub and the Healthcare's Grand H@ckfest Team)

Summary:

- Are there friends or organizations you could partner with to help you process and manage the data you collected securely?
- How much does it cost to transmit and store data?
- Do existing platforms provide you the level of security you need?

Step V: Putting it Together

The device would have built-in online sensors, measuring the DC or AC current flowing into Otter as well as the temperature near the machine. These data are stored in an Arduino microprocessor and pre-processed into the desired format (as detailed in later section). With in-built GSM functionality, the data is transmitted via SMS or GPRS (with the use of local SIM card) weekly to a Twilio virtual number which stores the information in the cloud. The stakeholders can subsequently use the pre-developed API to process the data and obtain crucial insights of the usage and user environment of the medical equipment.



Overview of how Echo works (Credit: MIT HST Course 936)

Summary:

- Have you considered everything you want to measure and how you would measure it?
- Have you considered the cheapest, fastest and safest way for data storage and transmission for your device?
- Have you considered how you would tell the stakeholders what is being monitored and what is the benefits or risks associated with it?

V. User Rights and Privacy

There have been rising security issues with IoT devices. As a good IoT device designer, privacy and security issues are not to be ignored. Always remember that stakeholders have the right to control the data collected about them, and you should be transparent about the data you are collecting and how it will be used and benefit the users.

VI. Regulations and Resources

As you are developing the IoT device, there are a few different type of regulatory standards you need to be aware of and oblige to, particularly if you are working on a medical device. Unfortunately, there is no global certification body in place with universal standards you can test your product against. In the United States, the FCC is the certifying body; in Canada, it's Industry Canada (IC); in the European Union, testing is performed against the European Telecommunications Standards Institute (ETSI) requirements for CE approval. Each country you wish to sell into will have similar, but also very different, certification and testing requirements. Identifying all the vital certifications that are needed is critical for your commercial teams to successfully launch your product.

If this is your first wireless development project, the best advice is to seek out an accredited EMC testing laboratory that is willing to partner with you and provide guidance throughout your development process, such as LSR, a manufacturer of certified RF products, as well as an ISO 17025 accredited EMC and RF testing laboratory. There are many regulatory organizations and associated standards for medical devices, depending on the technology and application. Some of the common ones for IoT devices are below, for simplicity of this paper, we will discuss FCC, FDA and ISO standards in more detail. [Source, Author: Neil Miller]

REGULATORY ORGANIZATION	STANDARD	DESCRIPTION
EN/UL	60601-1	The general standard for medical devices
EN	60601-1-2	The EMC portion of the general standard
EN/UL	60601-1-1	Requirements for medical eletrical equipment and systems used in home healthcare environment
ISO	ISO 14971	The mandatory risk assessment for medical devices, required under 60601-1
GISPR/EN	CISPR11 EN55011	Emissions-only standards for Europe covering radiated and conducted emissions
FCC/ICES	FCC Part 15C ICES-003	Emissions standards for North America
FCC/ETSI	FCC Part 15BRSS210 North America ETSI 300-32 for Europe	Required for non-approved intentional radiators
FCC/CS/ETSI	FCC Part 68 CS-03 TBR21	For medical devices connected to the Public Switched Telephone Network (PSTN)

Source: nuvation.com

FCC

The IoT space may soon find themselves inviting regulation from the Federal Communications Commission ("FCC"). Depending on your product design there are different levels of requirements for FCC certification. FCC plans to hold the first incentive auction of broadcast television spectrum in the first quarter of 2016. Spectrum is the radio frequency over which all wireless communications signals travel. As of now, most IoT systems operate in unlicensed radio frequencies, namely in the ISM (industrial, scientific, and medical) bands: The sub-125 kilohertz (kHz) for video surveillance and access control systems; 13.56 megahertz (MHz) for near-field communications (NFC) to support mobile payments; and 900 MHz for Electronic Product Code (EPC), one of the industrial standards for global Radio Frequency Identification (RFID) usage, just to name a few. And they make their critical connections using a range of different (and sometimes competing) wireless connectivity standards, such as Bluetooth, ZigBee, Z-Wave, and Wi-Fi, all of which were designed to work in unlicensed spectrum. FCC Part 15 regulates unlicensed radio frequency transmissions, both intentional (like a Bluetooth Smart data transmission) and unintentional (like the EM noise that a motor emits).

FCC testing for Product Certification can be broken into two parts: General Emissions testing and Intentional Radiation testing. Virtually every electronic product needs to undergo General Emissions testing. These tests typically can be completed at a cost of $1,000 to $5,000 when performed by an accredited laboratory. For Intentional Radiation testing there are additional tests required to specifically evaluate a product's wireless technology, and as a result it is generally more involved and complex than General Emissions testing. Depending on the technology and the frequency or frequencies the product operates at (2.4 GHz, e.g.), this testing typically costs on the order of $9,000 to $15,000.

The good news is that there's a way to minimize not only the cost of these Product Certification requirements, but also to minimize both your total design time and the risk of designing a product that fails FCC testing. A product that utilizes a certified RF module, such as the SaBLE-x Bluetooth Smart module from LSR, as opposed to a discrete circuit design can leverage the certification of the off-the-shelf module and avoid the Intentional Radiation testing portion of the FCC certification process. For many companies, the time to market, risk mitigation, and lower non-recurring engineering (NRE) costs of their product development efforts makes the use of a certified RF module the optimal strategy.

(Source)

Off-the-shelf wireless platforms such as the SaBLE-x Bluetooth Smart module can be leveraged in connected systems to circumvent the costs associated with Intentional Radiation testing. Source: nuvation.com

FDA

The FDA is responsible for protecting and promoting public health through the regulation and supervision of medical devices and electromagnetic radiation emitting devices (ERED), etc. The FDA recently released guidelines pertaining to wireless medical device design, development, testing and use. A few important points to note:

- Prior to selecting a wireless technology, the FDA recommends choosing an appropriate wireless technology (e.g., WMTS, IEEE 802.11) and RF frequency of operation for the intended application.
- Consider risks such as data data corruption or loss and interference from simultaneous transmitters in a given location, which can increase latency and transmitted signal error rates

If multiple devices will be used in close proximity, such as in a hospital, wireless coexistence issue need to be addressed. Bluetooth, for example, uses Adaptive Frequency Hopping (AFH) to facilitate coexistence with Wi-Fi devices.

The FDA also recommends EMC to be an integral part of the development, design, testing and performance, as well as conformance to the IEC 60601-1-2 standard or other appropriate standards.

ISO

The International Organization for Standardization, is the world's largest developer of voluntary international standards and facilitates world trade by providing common standards between nations. Nearly twenty thousand standards have been set covering everything from manufactured products and technology to food safety, agriculture and healthcare.["About ISO". ISO. Archived from the original on 4 October 2007.] The regulation most relevant to your IoT project would be ISO/IEC 27002 - an information security standard published by the International Organization for Standardization (ISO) and by the International Electrotechnical Commission (IEC), titled Information technology – Security techniques – Code of practice for information security management.

The relationship between ISO, FDA and CE standards

Many customers (hospitals, clinics, doctors, etc.) want their medical device suppliers to be ISO 9001 certified. Customers perceive some level of security in knowing they are buying from a manufacturer that has an ISO 9001 certified quality system.

The European Union does not require device manufacturers to comply with ISO 9001 in order to obtain a CE mark. Manufacturers have several options including having their devices tested OR having a quality system. If they have a quality system they can design it to comply with the quality system standard of their choice. In theory, they could use FDA's Part 820. However, since many of their customers want them to have ISO 9001 certification, most medical device manufacturers choose to use ISO 13485 or EN 46001 to obtain a CE mark. These standards, which are currently being revised, reference the quality system requirements in ISO 9001:1994 and contain additional requirements for medical device manufacturers who are establishing or maintaining a quality system.

For Project Echo, since it is to be implemented within Otter, we studied the types of regulations other incubator/infant warmers have passed to guide our directions. These devices are also compatible with the Qualcomm 2net platform which means they have remote monitoring capabilities.

Computer/Network	RS232
Manufacturer's MDD compliance	ISO900, ISO13485, EN46001, Class IIb
Supplier's Quality System	ISO9001, ISO46001, ISO13485
Device Compliance	EN60601-1, EN60601-2, EN60601-2-19, EN60601-1-2 (EMC)

VII: Sensors and Prices

The table to the right provides a list of prototyping sensors you could use for your design if you know what you need to measure. Prices for production sensors vary.

For example: If you want to detect or measure distance, an active infrared distance sensor is on the expensive side and are less commonly used for prototyping. For prototyping, the ultrasonic sound sensors listed to the right would work well.

Distance Sensors		
Ping by Parallax	Ping works by listening to the echo of sound	$30
HC-SR04	Works similar to Ping	$5
Smoke and Gas Sensors		
MQ-2	Flammable gas and smoke	$4
MQ-3, MQ-303A	Alcohol (ethanol)	$100
MQ-4	Methane (CH4)	$3-4
MQ-7	Carbon monoxide	$5-7
MQ-8	Hydrogen	$7-9
MQ-9	Carbon monoxide, methane, LPG (propane or butane)	$9
Touch Sensors		
Capacitive Touch Sensor QT113	When properly adjusted, a capacitive touch sensor can detect a hand through solid objects.	$12-15
Light Sensors		
KY-026 Flame sensor	The KY-026 flame sensor reports the level of infrared light with a change of resistance	$2-4
Photocell	Sensors that allow you to detect light. They are small, inexpensive, low-power, easy to use and don't wear out.	$3
Acceleration and Angular Momentum Sensors		
MX2125	MX2125 is a simple two-axis acceleration sensor, it reports acceleration as a pulse length, making the interface and code simple.	$23
MPU 6050	Inertia Measurement Unit used in self balancing robots, UAVs, smartphones	$6
Identity Sensors		
ELB149C5M sensor	Radio frequency identification (RFID) offers cheap, unique object identification from a distance.	$17
GT-511C3 fingerprint scanner	Scan a fingerprint and tell if it's one of the stored fingerprints	$50
Sound Sensors		
Electret Microphone (BOB-09964)	A small electret microphone with a 100x opamp to amplify the sounds of voice, door knocks, etc loud enough to be picked up by a microcontroller's Analog to Digital converter.	$8
Weather and Climate Sensors		
GY65 atmospheric pressure sensor	Barometric pressure sensor that measures range of anywhere between 30,000 and 110,000 Pa.	$9
DHT11 humidity sensor	Basic, ultra low-cost digital temperature and humidity sensor. It uses a capacitive humidity sensor and a thermistor to measure the surrounding air, and spits out a digital signal on the data pin (no analog input pins needed).	$2-5
LM35	Reports temperature with varying voltage.	$2

Source: *Getting Started with Sensors*

VIII: Glossary

Familiarize yourself with IoT and electrical engineering vocabulary.

General	
Internet of Things (IoT)	Broad concept used to describe the creation of a "Smart" product or system where "Things" are interconnected via wireless and/or wired networks. The "Things" are physical devices, equipment, machines, computers or screens – of any size – that are embedded with software applications, sensors and electronics. The embedded components enable "Things" to connect and exchange data that monitors, analyzes and controls the Smart product or community of products. The goal of an Internet of Things system is to streamline activities and processes to make the "Thing" more valuable so that users can do their jobs or live their lives more easily. It can also be called Machine-to-Machine (M2M).
Wireless	The ability of one wireless system to perform a task in a given shared environment where other systems (in that environment) have an ability to perform their tasks and might or might not be using the same set of rules.
Data Types	
Archive Data	Also referred to as "Cold Data" by the industry. Archive (cold) data undergoes ongoing analysis by the IoT Smart system to identify trends, predictions and correlations across the entire "Thing" system.
Near Data	Also referred to as "Warm Data" in the industry. Near (warm) data is used by the IoT Smart system to create reports and identify problems across the entire "Thing" system or by each "Thing."
Now Data	Also referred to as "Hot Data" by the industry. Now (Hot) data must immediately be acted upon by the Smart system to trigger alerts, notifications and if/then/else commands.
Data Transmission	
AMQP	Advanced Messaging Queuing Protocol. It is used by IoT / M2M systems to connect devices and enable data transfer in a system that uses different devices and software applications. It is a standardized protocol which allows organizations and applications to pass information between systems. It allows systems to connect to support business processes to reliably transmit data.

Source:

- http://www.mesh-systems.com/resource-hub/iot-glossary
- Radio Frequency Wireless Technology in Medical Devices (FDA report)

MODBUS	It is used by IoT / M2M systems to connect devices and enable data transfer in a system that uses different devices and software applications. It is a standardized protocol which allows organizations and applications to pass information between systems. It allows systems to connect to support business processes to reliably transmit data. It was originally published by Modicon (now Schneider Electric).
MQTT	MQ Telemetry Transport. It is used by IoT / M2M systems to connect devices and enable data transfer in a system that uses different devices and software applications. It is a standardized protocol which allows organizations and applications to pass information between systems. It allows systems to connect to support business processes to reliably transmit data.
Data integrity	Assurance that transmitted files are not deleted, modified, duplicated, or forged without detection.
Latency	The time it takes for a unit of information to cross a wireless link or network connection from sender to receiver, which is also known as transfer delay.
QoS	Quality of service (QoS)— the necessary level of performance in a data communications system or other service, typically encompassing multiple performance parameters, such as reliability of data transmission, transfer rate, error rate, and mechanisms and priority levels for time-critical signals.
Electrical Engineering	
EMC	Electromagnetic compatibility — the ability of a device to function (a) properly in its intended electromagnetic environment, and (b) without introducing excessive electromagnetic disturbances that might interfere with other devices.
EMD	Electromagnetic disturbance — any electromagnetic phenomenon that might degrade the performance of an equipment, such as medical devices or any electronic equipment. Examples include power line voltage dips and interruptions, electrical fast transients (EFTs), electromagnetic fields (radio frequency radiated emissions), electrostatic discharges, and conducted emissions.
EMI	Electromagnetic interference (EMI)— degradation of the performance of a piece of equipment, transmission channel, or system (such as medical devices) caused by an electromagnetic disturbance. Note: Disturbance and interference are cause and effect, respectively.
ESD	Electrostatic discharge (ESD)—the rapid transfer of an electrostatic charge between bodies of different electrostatic potential, either in proximity in air (air discharge) or through direct contact (contact discharge).
Immunity	The ability of an electrical or electronic product to operate as intended without performance degradation in the presence of an electromagnetic disturbance.
RFI	Radio frequency interference (RFI)— one type of EMI resulting from radiated emissions at one or more radio frequencies, which causes degradation of the reception of a wanted signal by a radio-frequency electromagnetic disturbance.

IX: References and Recommended Reading

General IoT

1. Burrus, Daniel. "The Internet of Things Is Far Bigger Than Anyone Realizes." Wired.com. Conde Nast Digital, 1 Nov. 2014. Web. 22 Oct. 2015.
2. O'Connor, Mary. "Technical Machine: IoT Enabler." IOT Journal, 11 Mar. 2015. Web. 22 Oct. 2015.
3. Barker, Colin. "Using the Internet of Things to Make Wine Taste Sweeter." ZDnet, 21 Oct. 2015. Web. 22 Oct. 2015.
4. Lohr, Steve. "Looking to Industry for the Next Digital Disruption." The New York Times, 23 Nov. 2012. Web. 22 Oct. 2015.
5. Semmelhack, Peter. Social Machines: How to Develop Connected Products That Change Customers' Lives. Print.
6. Pfister, Cuno. Getting Started with the Internet of Things. Sebastapool, CA: O'Reilly Media, 2011. Print.

Data/Network

1. Pinboards Maciej Ceglowski on Internet tracking, data storage and a thoughtful proposal for user rights.
2. Faludi, Robert. Building Wireless Sensor Networks. Beijing: O'Reilly, 2011. Print.

Sensors

1. Karvinen, Kimmo, and Tero Karvinen. Getting Started with Sensors. Sebastopol, CA: Maker Media, 2014. Print.
2. Karvinen, Tero, Kimmo Karvinen, and Ville Valtokari. Make: Sensors. Sebastopol, CA: O'Reilly, 2014. Print.

Regulations

1. Barbagallo, Paul. "As 'Internet of Things' Evolves, FCC's Spectrum Strategy Will Be Put to the Test." Bloomberg, 19 Nov. 2014. Web. 13 Nov. 2015.
2. Radio Frequency Wireless Technology in Medical Devices (FDA report)
3. Chipara, Octav. "Electromagnetic Interferences (EMI) from Active RFId on Critical Care Equipment."
4. Standards Applicable to Wireless Medical Devices (source: Fish & Richardson)
5. Miller, Neil. "Medical Device Design for IoT: Meeting FDA Guidelines | Nuvation." Nuvation. 18 Feb. 2014. Web. 10 Dec. 2015. Medical Device Design for IoT: Meeting FDA Guidelines

IoT Security

1. Wind River published a white paper titled Searching For The Silver Bullet, it summarizes the IoT security challenges in three paragraphs.
2. White paper by Exosite and this article talk about why security is the key to IoT success. There are also established players like Symantec and Cisco that offer services to protect your IoT solutions.
3. Dhanjani, Nitesh. Abusing the Internet of Things: Blackouts, Freakouts, and Stakeouts. N.p.: O'Reilly, 2015. Print.

X: Credits

We extend a big **thank you** to our donors, partners and collaborators

Volunteers

Healthcare's Grand H@ckfest Team
Bryan Ranger
Emmanuel Mensah
Galia Traub
Hari Iyer
James Fox
Karthik Mukund
Katerina Mantzavinou
Katie Woodward
Paul Franzosa
MIT HST Course 936
Chris Lai
Noriko Endo

Harvard Course CS179
Melissa Chan
Karen Kennedy
Ibrahim Muhammad

MIT HST Course 936
Chris Lai
Noriko Endo

Advisors

MIT HST Course 936
Dr. Leo Anthony Celi
Dr. Kenneth Paik

Harvard Course CS179
Prof. Krzysztof Gajos
Winston Boucher
Ryley Reynolds

IDEO
Michelle Kwasny

Technical Advisors

Gregory Dajer, MTTS
Matthew Blyde, MTTS
John Anner, Thrive Networks
Luciano Moccia, Thrive Networks
Amber Gaumnitz, Partners in Health
Dr. Kristian Olson, CAMTech
Elizabeth Bailey CAMTech
Smitha Gudapakkam, CAMTech
Andrea Ippolito, MIT Hacking Medicine
Elliot Cohen, MIT Hacking Medicine
Lina Colucci, MIT Hacking Medicine
Allison Yost, MIT Hacking Medicine
Adrienne Cochrane, Hack/Reduce
Dr. Ryan Carroll, MGH Pediatrics
Alex Resnick, Sprout & Co.
Bakhtiar Mikhak, Media Modifications
Jeanne Zucker, Athenahealth
Lindsay Olin, Athenahealth

Donors

Design Visionaries
Anonymous
Autodesk Foundation

Leadership Circle
Suzanne and Michael Graves
Lemelson Foundation
Salama bint Hamdan al Nahyan Foundation
The Jeannie Tseng and Colin Rust Charitable Fund

Design Society
Jonathan and Melinda Moulton
Lauren Stewart and Benjamin Vigoda
Emily V. Wade

DtM Friends
Garon Family Fund
Jon Goldberg and Lisa Levy
Gould Family Foundation
Margaret Holen and David Coulson
Roman and Karen Lubynsky
Jack Oldham and Virginia Mulkern
Dr. Steven and Eleanor Ringer
Benjamin Spiess
Dr. Ralph and Christina Sweetland
Philippe and Kate Villers
Minhua Zhang and Beidi Gu
Samantha and Adam Zirkin