The project assignment was to utilize the Internet of Things to create a product that was economically sustainable and beneficial in daily life. We narrowed the scope of our project to wearable health monitors that could be used to improve patient care in nursing homes. The final system monitors health signs through a wearable, watch-like device, relays information to a computer that analyzes the data and provides care-givers with alerts, health information, and the location of patients through an interface that allows them to respond quickly and efficiently to patient needs. This streamlining system will allow for more efficient, higher quality patient care while decreasing care costs in nursing homes.
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1.0 Introduction

As wireless technology and communication has become more accessible and affordable, it has become applicable in more situations than ever imagined. The ability for devices to relay information to computers and other devices, and the ability for those devices to automatically interpret that information has made it possible to create a vast network of communication between any devices in the world. This Internet of Things (IoT) connects a sensor on a “thing,” whether it’s a pencil or a jumbo-jet, to computers that analyze and relay this information to other things which can automatically take action based on the status of other things.

This network could be used in limitless applications. Cars could relay their location to a system that would recognize if there was traffic ahead and automatically adjust the route of each car that would be affected. A college student could know exactly when their roommate opened the door of their refrigerator and what was removed. Using the vast wireless network AT&T already has in place, the IoT could change the way people interact with the world around them.

2.0 Project Background

2.1 Background

Our team did research on dozens of possible fields of application, and recognized an opportunity for a company such as AT&T to revolutionize the care of nursing home residents. Statistics from the Center for Medicare and Medicaid Services (Appendix A) show that close to 1.4 million people are currently living nursing homes in the US alone. Studies from the CDC (Appendix B) report that of these 1.4 million, 8% have had an emergency room visit in the past three months and that 40% of those visits could have been prevented with improved care. A network of sensors monitoring the health and location of residents in nursing homes could potentially improve patient care, decrease...
the frequency of emergency room visits, and provide At&T with a marketable line of sensors and monitoring software.

2.2 Problem Definition
According to a CDC study, most of the preventable health emergencies of nursing home residents were related to cardiac health or falls (Appendix B). These emergencies account for around 10,000 emergency room visits and millions of dollars in health care costs every month. Any system that could prevent a portion of these emergencies would appeal to the patients whose care could be improved, the care facilities (nursing homes and hospitals) which could provide better care more efficiently, and to the provider of this care system, At&T. This system would have to be designed to optimize care for patients and nursing homes, and be profitable for At&T.

As shown by the CDC study, the majority of health emergencies for nursing home patients are related to falls and cardiac issues. Wearable sensors would then have to be able to monitor and relay information related to these emergencies to nurses, who would be able to find and treat patients in distress, preventing or at least decreasing response time to emergencies. Although the system would be beneficial to the patients in a variety of ways, the sensors must be comfortable, unobtrusive, and easy to interact with so that elderly patients do not resent wearing them. In addition to emergency care, the system should allow nurses to give more attention to patients in everyday settings, as many falls occur when patients grow frustrated with caregivers and attempt to get up without assistance.3

The more active users in this system are the nurses and staff in nursing homes. Research shows that the biggest obstacle in nursing home care is understaffing. Federal regulations require that only two nurses be on duty to care for up to 60 patients and as 69% of nursing homes are profit driven, payroll is often minimized. These circumstances force nurses to constantly be on the move, trying to locate and check on patients. Our system would have to allow nurses to check patient status remotely and track patient movements to allow for faster and more frequent check-ups. As we can’t force nursing homes to increase staffing, we must create a system that allows caregivers to provide better care more efficiently.

In addition to benefitting patients and caregivers, the system would have to be marketable and profitable for At&T. This means that the system should rely on existing technologies, particularly technologies that At&T specializes in. First of all, the sensors worn by patients would have to communicate wirelessly with computers used by nurses. Although other means of wireless connection, like ZigBee, can provide service to more devices, At&T already provides WiFi networks that would allow widespread, reliable, fast wireless communication anywhere in the facility. At&T also provides wireless, mobile tablets that would be perfect for nurses to monitor patient health and location through an “app” that analyzed information from the patient-sensors. These sensors would be the only “new” technology that would require development, and even that would just be a combination of existing technologies as wearable sensors that monitor a variety of data are already being produced. Thus, At&T is creating revenue
through the one-time sale of WiFi routers and wearable sensors, and recurring fees for the internet service and subscription to the monitoring app.

2.3 Customer Needs
Now that the confines of the project were more clearly defined, the needs of the customer had to be assessed. The stakeholders in this design project were AT&T, the nurses/nursing homes and the patients who would be wearing the sensors. The needs of each party were considered through research and prior experience. One group member is an EMT in Centre County and has come into contact with many nursing homes and patients, gathering nursing and patient background. All group members have visited and volunteered in nursing homes in the past as well. This background experience has provided valuable contact with patients and nurses. In addition, research was conducted online to determine the biggest problems in nursing home care, the most common calls for an ambulance, and the greatest challenges that nurses face. The team also contacted several local nursing homes through email and phone calls, but the staff was too busy to be interviewed. AT&T’s interests were divulged from the project description given. The wants of these three parties were summarized in the following figure and translated into specifications for the project:

Table 1: Stakeholder Input Converted to Preliminary Specifications

<table>
<thead>
<tr>
<th>AT&amp;T</th>
<th>Preliminary Specs</th>
</tr>
</thead>
<tbody>
<tr>
<td>real time connectivity</td>
<td>continuous stream of info</td>
</tr>
<tr>
<td>must collect info</td>
<td>improves efficiency</td>
</tr>
<tr>
<td>benefit our lives</td>
<td>marketable and appealing</td>
</tr>
<tr>
<td>integrated</td>
<td>profitable</td>
</tr>
<tr>
<td>Nursing Homes</td>
<td></td>
</tr>
<tr>
<td>understaffed</td>
<td>improves efficiency</td>
</tr>
<tr>
<td>falls are an issue (frequent patient visits are current method)</td>
<td>alerts nurses sooner</td>
</tr>
<tr>
<td>most ambulance calls for cardiac issues</td>
<td>decreases response time</td>
</tr>
<tr>
<td>outdated</td>
<td>delivers stats to hospital</td>
</tr>
<tr>
<td>inter-nurse communication</td>
<td>can be used in conj. with existing technology or upgradable nurses communicate between each other</td>
</tr>
<tr>
<td>Patients</td>
<td></td>
</tr>
<tr>
<td>more attention</td>
<td>accurate location info</td>
</tr>
<tr>
<td>faster response</td>
<td>real-time alerts</td>
</tr>
<tr>
<td>nothing cumbersome</td>
<td>statistics monitoring (more personalized)</td>
</tr>
<tr>
<td>easier access to health (history)</td>
<td>secure records accesible to ambulance, nursing and hospital</td>
</tr>
<tr>
<td>security issues</td>
<td></td>
</tr>
</tbody>
</table>

2.4 Technological Research
As stated, this system is appealing to AT&T particularly because nearly all of the technology to be used in the system is already existing and being applied. First off, this network of sensors and computers will require wireless communication. This means every wearable device and every computer used will need a unique IP address and
wireless capability, technologies that At&T has been expertly applying in the scope of smart-phones. In addition, the entirety of the nursing home facility would have to have a reliable, fast wireless connection. As stated before, this is best accomplished by installing WiFi routers throughout the facility. Especially when equipped with range extenders, these routers would provide reliable service to hundreds of devices for relatively low cost. At&T is already applying this aspect of the system in schools and office buildings; the application in a nursing home would be no different.

This wireless network would allow the patient monitors to relay vast amounts of information to computers that process and respond to the data. The type of information streamed by these devices would only be limited by the capabilities of the wearable sensors. The idea of monitoring health signs with wearable sensors is not new, and many devices that accomplish this task already exist.

A company called Basis\(^6\) is already selling a watch that measures and displays heart-rate, skin temperature, perspiration, and movement; the watch is marketed to improve athletic performance, but these measurements could be used to track and detect early signs of cardiac emergencies, fevers, and possibly dangerous movements. Although they are not yet widely available, wearable devices are also being developed by EMPA\(^7\) to take blood pressure for patients at high risk for cardiac episodes.

Technology from Ekahau\(^8\) is being tested in hospitals to allow staff to locate patients through RFID tracking, a system that uses a sort of localized GPS to triangulate patient locations within a meter of accuracy using radio receivers in wristbands and WiFi routers fixed to walls. This Ekahau system also includes an alert button on the patient wristband that sends a signal to a monitoring system. Pulse Oximeters measure the amount of oxygen present in blood, an indicator of respiratory issues, and are already available in easy to use finger-cuffs. In addition to these wearable systems, wireless electrodes and mobile EKG machines could monitor cardiac rhythms and immediately report a cardiac emergency. There are also many types of pressure sensors that can be used in nursing homes to cause an alert when a patient leaves their bed. All of these technologies exist and could provide valuable information to monitor and improve healthcare. A wearable, watch-like sensor that combined any or all of these technologies could be given wireless capabilities to relay this information to a computer program that analyzed the data.

This computer program would need a powerful algorithm that recorded a constant stream of inputs from each patient monitor and calculated average and threshold values for each vital sign. This data analysis would be the most complicated aspect of the system, but still fairly simple for a company like At&T.
3.0 Conceptual Designs

3.1 Descriptions

Within the confines of a patient monitoring system, there were still many unknown variables that included how the patients would be monitored, what sensors would be used, who the information would be relayed to, and how the system would be integrated into a nursing home. To answer some of these questions, research was conducted on the current methods of the above stated questions and ideas were also brainstormed of new and innovative ways to tackle those problems. The research found that there are patient monitoring systems on the market, but they are limited in their breadth and not widely in use. We wanted to design a product that could monitor many things and actively communicate back and forth, an objective of the Internet of Things.

To accomplish this, we came up with a possible list of many of the types of biological markers that a sensor could measure for our system. These are listed in Table 2 along with the specifications they were measured against to determine their worth to the device. Each of these sensors would provide valuable information to a nurse, doctor or emergency personnel. These included:

<table>
<thead>
<tr>
<th>A) Heart Rate</th>
<th>D) Temperature</th>
<th>H) Heart Rhythms</th>
</tr>
</thead>
<tbody>
<tr>
<td>B) Location</td>
<td>E) Activity Levels</td>
<td>I) Blood Pressure</td>
</tr>
<tr>
<td>C) Perspiration</td>
<td>F) Oxygen Saturation</td>
<td>J) Pressure Sensors</td>
</tr>
</tbody>
</table>

A) Measuring heart rate is an easy thing to do and is a significant marker for heart attacks, and other bodily failures. When organs fail, or there is a blockage in a blood vessel, the heart compensates by speeding up the beats per minute to pump more blood to the body. A significant and sustained increase in heart rate would be a marker of a cardiac event or other dangerous bodily failure.

B) The location of a patient is of specific concern as patients in nursing homes often wander out of where they are supposed to be and can get lost or are simply unaccounted for. A tracking program for each patient would allow the nurses to remotely monitor their patient and immediately find out their location if they were needed for an activity or shower or the like. However, this component would be the most difficult to integrate because the location system would have to be precise enough to know the location of a patient within a distance of a meter or so.

C) Perspiration may seem an insignificant marker of health, however perspiration can indicate a fever being broken and is also an indication of a heart attack. A small sensor imbedded in a watch can measure the amount of sweat on the skin.

D) Temperature is an important sensor for infection and can also be measured with ease. When the body goes into a diseased state, it internally increases the temperature to try and kill some of the potential bacteria or viruses that are attacking it. Therefore increased temperature would be a sign of an infection.

E) Activity levels could be measured by a small, cheap accelerometer and would be useful as a quality control measure. The nursing system would then have
records of how active a patient had been and could correlate activity levels to health and help improve patient therapy and recovery.

F) **Oxygen saturation** is a measure of the percent of oxygen in the blood. This is a key factor for determining when a patient should be placed on oxygen and if so how much. Patients who have allergic reactions or respiratory diseases are at a risk for low oxygen levels and may even be on permanent oxygen. A pulse oximeter would measure the oxygen levels in the blood and thus monitor the respiratory health of a patient. However, pulse oximeters must be placed on a finger of the patient and limit the use of the hand because it must remain relatively still.

H) **Heart rhythms** are monitored by placing either four or twelve electrodes on the body and then analyzing the electrical impulses sent by the heart to cause it to beat. Patients generally find these electrodes uncomfortable and all the wires obtrusive. However, the results from this are printed out and a doctor can understand them. Heart rhythms are the main factor in determining whether someone is undergoing a heart attack or other stress on the heart, so they are very important. It also can determine the type of rhythm, but is especially useful when there is a baseline printout of the heart rhythms to compare to. That would be the benefit of this component of our system to health care professionals.

I) **Blood pressure** is one of the most important biological markers for a stroke, because when there is a blockage, the blood pressure increases to dangerous levels. It also is an indicator of shock or blood loss because when someone loses blood, the blood pressure falls. However the most reliable way to measure blood pressure is through a fairly obtrusive cuff, which cuts off circulation in the arm and then measures the pressure when blood begins to flow back through the vessel.

J) The last sensor that could be employed in our system, which is currently in use in some nursing homes, would be a **pressure sensor** in the bed, which would alert the nurses if the patient were getting out of bed. This sensor would reduce the number of falls, a significant issue in nursing homes, by alerting nurses so they can come and assist patients before they fall. However, it would not be advised for all patients as not all patients in a nursing home are at a high risk for falling. This would force our device to be split and not standardized for all patients.

After the types of sensors were explored, we had to decide who the information would be relayed to. The possible ideas were:

1. Nursing homes
2. Families
3. Patients
4. **Emergency Medical Services**
5. Hospital

The concerns for each of these people are patient privacy. We wanted only the people who were necessary to patient care to have this information to protect the privacy of the patient yet at the same time provide the prudent information to caregivers. We also thought it would be a good idea to allow the nurses to communicate with each other and the patients remotely. Another thought was to allow patients to communicate remotely to nurses, however in a nursing home setting that could present
problems with patients abusing the system. At first it was thought that nurses could send a written message to patients telling them to wait for help or stay where they are. Expounding from that idea, was another idea that a light could change colors on the wearable device to alert the patient that nurse had received his call and was coming to help.

3.2 Concept Selection

After brainstorming many sensor technologies, we proceeded with the evaluation process in order to determine which ones would be cost effective, provide a valuable service, be comfortable for patients, and increase nurses’ convenience. In the concept screening chart below (Table 1), the columns highlighted in green represent the ideas that we would continue. Those highlighted in yellow were considered further or combined with another idea. Those in red were eliminated. Table 2 shows each sensor’s weighted score.

Table 2: Concept Screening

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Patient Comfort</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Provides Valuable Service</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>+</td>
<td>-</td>
<td>0</td>
<td>+</td>
<td>++</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Nurses' Convenience</td>
<td>-</td>
<td>+</td>
<td>0</td>
<td>+</td>
<td>0</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Green: Continue

Yellow: Consider

Red: Discontinue

Heart rate, location, perspiration, temperature, and the alert button were decided to be continued to the detailed design process. Activity levels were cost effective and comfortable for the patient but the service provided by them is of little value and they would no affect nurses’ convenience. The pulse oximeter would provide valuable information and increase nurses’ convenience however it is cumbersome to the patient and only valuable in certain situations. The pressure sensors in bed were not cost effective but valuable in the other three selection criteria. For these reasons, E, F, and J were considered further in a concept scoring matrix to determine their worth by weighted selection criteria. Heart rhythms provided very valuable information, however they were too expensive and the current methods of implemented them too invasive for the patient. Heart rhythms could be an area of future improvement should the technology
become cheaper and less invasive. Blood pressure was similar to heart rhythms in that it was valuable but too invasive to patients with the current methods of measurement.

Table 3: Concept Scoring

<table>
<thead>
<tr>
<th>Selection Criteria</th>
<th>Weight</th>
<th>Rating</th>
<th>Weighted Score</th>
<th>Rating</th>
<th>Weighted Score</th>
<th>Rating</th>
<th>Weighted Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>24%</td>
<td>5</td>
<td>1.20</td>
<td>2</td>
<td>0.48</td>
<td>3</td>
<td>0.72</td>
</tr>
<tr>
<td>Patient Comfort</td>
<td>27%</td>
<td>5</td>
<td>1.35</td>
<td>5</td>
<td>1.35</td>
<td>5</td>
<td>1.35</td>
</tr>
<tr>
<td>Valuable Service</td>
<td>26%</td>
<td>5</td>
<td>1.30</td>
<td>5</td>
<td>1.30</td>
<td>3</td>
<td>0.78</td>
</tr>
<tr>
<td>Nurse Convenience</td>
<td>23%</td>
<td>3</td>
<td>0.69</td>
<td>4</td>
<td>0.92</td>
<td>4</td>
<td>0.92</td>
</tr>
<tr>
<td>Total Score</td>
<td></td>
<td></td>
<td>4.54</td>
<td></td>
<td>4.05</td>
<td></td>
<td>3.77</td>
</tr>
<tr>
<td>Rank</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td>2</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Continue?</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.3 Concept Review

Sensors:

A) Heart Rate: Heart Rate was kept as a sensor because of its significance to indicating many body failures or stressors and its ease of measurement.

B) Location: Location was kept as a sensor because it will improve nurses’ convenience by allowing them to remotely monitor the movements of their patients and immediately find them.

C) Perspiration: Perspiration was kept as a sensor based on its ease of measurement and the potential for helping diagnose heart attacks.

D) Temperature: Temperature was kept as a sensor because of its importance in determining infections or assessing a fever.

E) Activity Levels: Activity levels were kept as a sensor because of their ease of measurement and the potential for quality control in the nursing home.

F) Oxygen Saturation: Oxygen saturation was kept as a sensor but modified to be a detachable pulse oximeter because it can be cumbersome to patients.

H) Heart Rhythms: Heart Rhythms were discontinued as a sensor because of the cost and invasiveness to the patient. However, the sensor was considered for future upgrades.

I) Blood Pressure: Blood Pressure sensors were discontinued because the patient would be required to wear a cuff which would be uncomfortable and invasive.

J) Pressure Sensors: Pressure sensors were discontinued because they would not be advised for all patients and could send false positives to the nurses.
One of the major concerns for accessibility of patient information will be patient privacy. Keeping this in mind, only the people directly responsible for the care of the patient will have access to their information. Additionally, the information needs to be accessible early enough to accelerate and improve patient care. We considered these three factors when evaluating the people with access to patient information: acceleration of patient care, improvement of patient care, and respecting patient privacy. We considered nursing homes, families, patients, EMS and the hospital.

1. **Nursing homes**: The nurses were definitely included in our system to have access to the patient information because they are the primary care givers.
2. **Families**: While families might want to know the condition of their loved ones, we decided against this access to families as it might interfere with patient care.
3. **Patients**: Patients were not included in the immediate and continual access to their information because it might alarm them and cause them to deteriorate. However, at any time, they can always ask a nurse about their condition, or alert a nurse with a call button.
4. **Emergency Medical Services**: EMS will provided access in our system because if they can already have reviewed patient information and have accurate vitals by the time they reach the patient, then they will faster be able to diagnose the severity of the condition and administer treatment. However, that patient’s information will only become available to them once on ambulance has been called on their behalf.
5. **Hospital**: The hospital will also be provided access to the patient information but only in the case that the patient will be coming to the hospital since it will help the hospital know where to send the patient and the severity of their case.

### 4.0 Detailed Design

**System Description**

Once we selected the types of sensors that will go into our final design, we implemented an integrated wireless smart sensor network for monitoring patients in nursing homes. Our design approach relies on the Internet of Things (IoT) to connect all necessary parties to our system in order to provide superior patient care. As seen on Figure 1, the overall system includes the following:

1. An integrated patient monitoring system for the nursing home
2. Servers provided by AT&T for patient data storage
3. A Virtual Private Network (VPN) for displaying patient information in case of emergency
4. Emergency Services (EMS) access to the VPN for retrieving patient data in case of an emergency

**Figure 2: System diagram**

**Patient Data Collection**
Our system consists of a patient monitoring “watch” that integrates all the sensors we selected (Table 1). It will be worn by every patient in the nursing home. The sensors are the first components of our system. They essentially collect data from the nursing home patients and send those information to a computer acting as our central processing unit. They perform their tasks based on the commands specified by a command utility that is installed on the computer.

**Table 4: Sensors in watch**

<table>
<thead>
<tr>
<th>A) Heart Rate</th>
<th>B) Perspiration</th>
<th>C) Activity levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>D) Location Tracker</td>
<td>E) Skin Temperature</td>
<td>F) Oxygen Saturation</td>
</tr>
</tbody>
</table>
Data Analysis and Storage
The computer in our system plays the role of our central processing unit (CPU). It is equipped with software containing an advanced data processing algorithm that receives and processes data with a high level of accuracy. Upon processing data, the CPU encrypts it in a secure SSL packet and sends it to multiple servers, provided by AT&T, for storage. In addition, as seen on the diagram, there will be a firewall for added security. That being said, AT&T will not have access to private patient data. They are just providing the necessary infrastructure for storing data. They will benefit, not only from the Wi-Fi connectivity service, but for storage space allotted on their data centers.

Data Retrieval and Patient Monitoring
Data is retrieved from the servers by the computer, averages are computed and patients’ data are displayed, through a mobile app, on tablet computers carried by the nursing home staff. Every nurse will be in possession of one tablet computer (iPad, Galaxy Tab, etc…) from which they will be able to monitor patients. Patients’ location information, heart rates, skin temperature, etc… will be accessible on the tablets’ screen. If nurses notice anything abnormal in any patients, they will be able to quickly respond and assist the patients. Also, with the alert buttons, patients at high risk of fall will be able to call nurses for assistance. Nurses will also communicate with each other to better assist patients. In order words, there won’t be in confusions or discrepancies.

Emergency and Medical Response
From their tablets, nurses can trigger a red button for a 911 call in case of an emergency. That also prompts the CPU to post the patient data to the Virtual Private Network at Cisco. Once the 911 dispatcher contacts EMS with the issues, an operator will be able to securely access the patient information by logging on the VPN of that specific nursing home. That will permit the emergency team to prepare for fast and efficient aid. It should be noted that, because of HIPAA laws, the information available on the VPN will be limited to the necessary. That is to say, the patient’s entire medical history will never be published; only the basic information needed by EMS to efficiently prepare for better assistance.

5.0 Conclusion
With the aging population continuing to grow, nursing homes will become flooded with more patients who they cannot effectively care for. Nurses cite understaffing as the number one problem at nursing homes, and this increase in the number of people over age 65 will only exacerbate those problems. A new solution for patient monitoring needs to be developed to efficiently monitor the status of patients. Our Integrated Patient Monitoring System for Nursing Homes will improve patient care, decrease frequency of visits to nursing homes and provide a marketable line of sensors and technology for AT&T.
6.0 References


6. https://store.mybasis.com/


Appendix A

Trends in nursing home occupancy

Appendix B

Statistics for Emergency Department visits for nursing home patients