CPR Connect: Integrated Health System to Notify and Assist First Responders
Department of CIS – Senior Design, 2015-2016

Richard Kitain, rkitain@seas.upenn.edu
Kevin Lei, kevinlei@seas.upenn.edu
Vivek Panyam, vpanyam@seas.upenn.edu
Shichao Wang, wshichao@seas.upenn.edu
ABSTRACT
When a cardiac arrest incident occurs, every minute counts. The average national response time for cardiac arrest incidents outside of the hospital is 9 minutes, but according to the American Heart Association, brain death starts to occur in 4 to 6 minutes. As a result, only 8% cardiac arrest victims outside of the hospital survive. However, if bystanders give CPR and use an AED, survival rates can increase to 38%.

Our team created a mobile application that alerts CPR certified volunteers to nearby cardiac arrest incidents. The application leverages nearby bystanders to reduce the wait time until help arrives, thus improving patient outcomes. It allows two types of users to sign up: (1) users who are at risk of cardiac arrest; (2) CPR-certified responders. If a patient undergoes cardiac arrest, the application notifies nearby responders. Once a responder agrees to help, the application guides that responder to the patient’s location. Finally, the application also informs any emergency contacts that the patient has listed.

SECTION 1: BACKGROUND
Cardiac arrest is the abrupt loss of heart function in a person. Unlike heart attacks, which are caused by blockages in the arteries that stop blood flow to the heart, cardiac arrest occurs due to malfunctions in the electrical system of the heart that cause arrhythmias or irregularities in heart beats. As a result, emergency treatment with cardiopulmonary resuscitation (CPR), can be very effective.¹²

CPR is an emergency technique that is useful when someone’s breathing or heartbeat has stopped. There are two basic parts to performing CPR, chest compressions and mouth-to-mouth ventilation. Chest compressions require responders to push hard and fast on the chest of cardiac arrest victim. These compressions push blood throughout the body and help delay the onset of brain and organ damage. A rate of 100 chest compressions each minute is recommended. The second part of CPR is mouth-to-mouth ventilation, or rescue breathing. In this part, the cardiac arrest victim’s airways are opened by tilting the head back and lifting the chin. The nostrils are pinched shut to create a seal and breaths are forced into the victim’s airway through mouth-to-mouth contact. The recommended ratio is two rescue breaths for every 30 chest compressions.³⁴

¹ http://www.mayoclinic.org/diseases-conditions/sudden-cardiac-arrest/symptoms-causes/dxc-20164872
² http://www.heart.org/HEARTORG/Conditions/More/CardiacArrest/About-Cardiac-Arrest_UCM_307905_Article.jsp
However, a study in swine models has shown that chest compressions alone can be very effective in responding to cardiac arrest. In these studies, cardiac arrest was induced in swine for 5 minutes. Then CPR was administered to the swine for 8 minutes. No significant difference in survival rates was detected between the group given CPR with ventilation and CPR without ventilation. Thus, this study showed that only in prolonged arrest intervals does assisted ventilation make a difference in survival rates. The immediate damage done by cardiac arrest is mainly due to lack of blood circulation, not lack of blood oxygenation. This is an important fact because even if bystanders are uncomfortable with mouth-to-mouth contact, chest compressions alone could help sustain victims of cardiac arrest until emergency medical technicians arrive on the scene.  

In a lot of cases, CPR alone is insufficient to stop cardiac arrest. This is particularly true in cases of cardiac arrest that result from ventricular fibrillation. Automated external defibrillators (AED) are needed to actually restore the heart to normal sinus rhythm. These devices work by sending electrical current into the victim’s cardiac muscles. They are completely automated and can be used by bystanders without any prior training; they only need to be connected to the victim’s chest. The device will then automatically detect whether the victim has the types of arrhythmia that can be treated by an AED and automatically sends the necessary electrical current to the heart muscles. Nevertheless, CPR is still an important part of mitigating the damage of cardiac arrest until medical technicians arrive on the scene or until an AED can be found and brought to the victim.  

Cardiac arrest is one of the leading causes of death in the United States. Over 320,000 out-of-hospital cardiac arrests occur each year. In only 10.6% of these cases does the cardiac arrest victim survive, and in only 8.3% does the victim survive with good neurological function. This is mainly because permanent brain damage can set in 4 minutes after the circulation of blood stops, and death can occur after another 4 to 6 minutes, whereas the average national

---

5 https://upload.wikimedia.org/wikipedia/commons/5/54/2002_CPR_Technique.jpg
6 http://circ.ahajournals.org/content/96/6/2102.full
7 http://www.mayoclinic.org/automated-external-defibrillators/art-20043909
response time to a cardiac arrest incident is 9 minutes.\textsuperscript{9,10} For every minute without CPR, survival from ventricular fibrillation cardiac arrest decreases by 7–10\%, and immediate CPR can double or triple the victim's chance of survival from cardiac arrest.\textsuperscript{11}

SECTION 2: GOALS
Our goal was to create an integrated system that would allow for CPR certified bystanders to be alerted of cardiac arrest incidences that occur near them, so that they can reach the victims quickly and give CPR. We initially thought that this could be achieved by having the at-risk population wear a heart-rate monitoring device on their wrists which would be able to alert bystanders of an incident as long as bystanders had our companion application. Some examples of risk factors for cardiac arrest are a family history of coronary artery disease, smoking, high blood pressure, high blood cholesterol, obesity, diabetes, and family history of cardiac arrest or previous cardiac arrest incidents.\textsuperscript{12}

As we progressed throughout the year, we learned that creating both the wearable and the mobile application would be quite hard to do in just a year’s time. We therefore chose to focus solely on the software platform since this was where our team had the most expertise. In addition, the mobile application can still be useful on its own without the wearable whereas the reverse is not true. Finally, our platform is agnostic to the choice of wearable device, and in the future, our platform could integrate with any number of off-the-shelf wearable devices, so long as they have the necessary features such as low-energy Bluetooth and constant monitoring of heart rate. We hope that the software platform that we have created, combined with integration with future wearable devices, will help to greatly increase the levels of bystander CPR response. This will greatly increase the overall survival rate of cardiac arrest instances in the United States.

\textsuperscript{9} \url{https://www.nlm.nih.gov/medlineplus/ency/article/000013.htm}
\textsuperscript{10} \url{http://www.cprtrainingsource.com/blog/georgia-cpr-statistics.html}
\textsuperscript{11} \url{http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2600120/}
\textsuperscript{12} \url{http://www.mayoclinic.org/diseases-conditions/sudden-cardiac-arrest/symptoms-causes/dxc-20164872}
As far as system architecture, we used React Native to develop the mobile portion of the application. We developed the backend using Node.js and hosted this on Heroku. From this, we accessed various services: MongoDB for a database to store our accounts and locations, Google Cloud Messaging to send push notifications, Twilio to send SMS, and SendGrid to deliver e-mails. As Figure 2 depicts, both at-risk users and responders make requests from the mobile application to the same backend server.

Upon creation, each account has the following data stored in MongoDB:

- Name
- Phone
- Email address
- Whether this account is a responder
- Password

The passwords are hashed before being stored to add an additional layer of security. Furthermore, we authenticate by providing the client with a login token. This token only lasts for a fixed time (an hour) and needs to be updated when it expires. This security measure ensures that passwords are not constantly sent to the back-end. We also store tokens for Google Cloud Messaging and IDs for emergency contacts to ensure that we can use the correct services for each account.

Our application can be used by two types of users: (1) at-risk individuals; (2) CPR certified responders. The at-risk individuals can create accounts where they can input their contact information as well as the contact information of emergency contacts. Once this setup process is complete, these users will be taken to a home screen where they can change their settings or trigger an alert of a cardiac event. A persistent push notification from the application will allow these users to quickly access the application, ensuring that the button to trigger an alert is never far away. When an alert is triggered, the emergency contacts set by the user will receive an e-mail and text message. This ensures that first responders as well as close family and friends will receive notifications.
CPR certified responders follow a different workflow. After they signup, there must be a verification step to ensure that these users are CPR certified. Although there is no formal mechanism yet for us to check, we could use institutional channels (e.g. MERT, American Red Cross) in the future to ensure that only valid users signed up as responders. When responders are within 0.5 miles of an alert, they will receive a push notification from the application. If the responder chooses to accept, he or she will be redirected to a map and can see the location of the alert. This map updates every 5 seconds to provide a responsive interface and facilitates the responder reaching the correct location to administer CPR.

SECTION 3.1: MOBILE APPLICATION
The mobile application is built in React Native, which is a framework for building native applications for iOS and Android using React. React, in turn, is a JavaScript library from Facebook and Instagram for creating user interfaces. This framework is extremely powerful because it lets developers create performant native applications in JavaScript. Furthermore, it allows us to declaratively define our user interface, removing much of the complexity of building an imperative UI system. React also lets us define components so we can heavily reuse parts of our UI.

In our application, every "screen" is a component. For example, the login screen is one component and the sign up screen is another component. These components contain subcomponents. For example, we have a button component, which can be pink or blue and can have arbitrary text. By building our application in this way, we were able to quickly iterate.

In addition, since all the logic is in JavaScript, we were able to build a JavaScript library to communicate with our backend and develop it all in a desktop environment. Once this library passed all our tests, we included it in the React Native project and were able to quickly integrate it with the rest of the application.

SECTION 3.2: NOTIFICATIONS
When an alert is triggered by an at-risk user, the application finds all responders within a half mile radius of the at-risk user and sends out alerts to them, prompting them to respond to the emergency. Multiple responders can respond to the same event, which will be shown as various blue markers on the at-risk user's map. Users can choose how they wish to be notified in the
application. There is a choice of text message notifications, push notifications, and emails for all users. These modes of communication were chosen after various interviews were conducted with MERT volunteers. About 60% of responders we interviewed wished to receive text messages, while 40% wanted push notifications. Additionally, half of the responders wanted emails, but the other half did not. Therefore, allowing responders to choose which means of notification they wished to receive was the obvious solution. Text messages are sent through Twilio, push notifications through Google Cloud Messaging, and emails through SendGrid.

![Figure 4: Example of SMS and push notification](image)

SECTION 3.3: LOCATION
We need to keep track of the locations of each responder so that when a cardiac arrest incident occurs, we can immediately find out which responders are nearby that are able to respond. To minimize the battery impact of our application and avoid unnecessary calls to our backend, we used Android’s geofencing feature. This sets up a virtual perimeter and the responder’s location is only updated once they move out of this perimeter.

---

13 [https://developer.android.com/training/location/geofencing.html](https://developer.android.com/training/location/geofencing.html)
On the backend, we use MongoDB to store the last location update from each responder. MongoDB can create geospatial indices that allow for the efficient retrieval of all responders within some radius of a cardiac response incident. Under the hood, MongoDB takes all the locations in our database and generates a geohash for each location. It projects the 2d sphere representing earth onto a 6 sided cube. Then, it recursively splits each square face into quadrants and appends two bits to each geohash depending on which quadrant the point falls into. Points that are close by would tend to have a shared prefix.\textsuperscript{14}

\[ \text{Figure 5: Map that at-risk individuals (left) and responders (right) will see} \]

\[ \text{Figure 6: Visualization of how Geohashing works}^{15} \]

\textsuperscript{14} \url{https://docs.mongodb.org/manual/core/geospatial-indexes/#calculation-of-geohash-values-for-2d-indexes}

\textsuperscript{15} \url{http://image.slidesharecdn.com/mongosp-geoindexes-110723080139-phpapp01/95/mongo-sp-geoindexes-16-728.jpg?cb=1311408162}
SECTION 4: EVALUATION AND RESULTS

Although we were not able to deploy this system with an emergency medical response team to help perform end-to-end real life tests of our system, we were able to mathematically estimate response times using data from the US Census. Looking at the data for Philadelphia and assuming a uniform distribution of CPR certified responders, we were able to create a graph that mapped adoption of our application (in %) to average response time to cardiac arrest instances (in minutes).

To give an overview of our thinking, we first looked at the population of Philadelphia (1,567,442 people) and the total area of the city (134.10 square miles). This gave us a population density of 11,689 people per square mile. In addition, between 4% and 15% of the population is estimated to know CPR in Philadelphia. For our simulation, in order to come up with a conservative estimate, we assumed that 4% of the population knew CPR. Looking at different rates of adoption, we calculated an estimate of the number of responders available. From this, we calculated the average amount of time required to respond to any cardiac arrest incident within this distribution of responders.\(^\text{16}\)

![Response Time vs. Adoption](http://www.census.gov/quickfacts/table/PST040214/42101)

We quickly realized that even if less than 5% of all CPR certified individuals had our application downloaded and responded to events, average response time was drastically reduced to 3.5 minutes, already below the brain death threshold of 4 minutes. If adoption increases to just 10%, average response time is even more dramatically reduced to just 1 minute.

These calculations assume an average travel speed of only 3 miles per hour which is the average speed at which people walk. Chances are quite high that CPR certified bystanders would run to the cardiac arrest victim to provide assistance, so response time estimates are in fact a ceiling on what they could possibly be.

\(^{16}\) http://www.census.gov/quickfacts/table/PST040214/42101
SECTION 5: ETHICAL CONSIDERATIONS

One ethical problem with our software platform is that we are tracking the real-time locations of anybody that signs up to be a responder. This sort of information can be extremely sensitive and can easily be abused. The two places that a person is at most often are their home and their workplace. Thus, location data can reveal where they work and where they live. In the hands of thieves, such information can reveal when a person is away from their home and reveal opportune times to burglarize them. Location data can also increase the risk of stalking and be used to predict where a person will be at some day and some time. The locations of private homes that a person calls upon can be used to figure out who is part of their social circle. Location information can also reveal visits to potentially sensitive places such as medical clinics, courts, political rallies, and so on.\(^\text{17}\) Thus, securing this location data is of paramount importance. We do mitigate some of the potential problems of storing as little of it as possible, by only keeping the last location update. In addition, an at-risk individual’s location is only available to responders when a cardiac arrest incident occurs and vice versa. We can mitigate this problem further by adding a location toggle to our application. When the toggle is on, the responder will be “on call” and their location will be tracked. When the toggle is off, we stop tracking their location.

Another ethical problem with our project is the psychological toll that our application may impose on responders since they will be notified about all cardiac arrest incidents within 0.5 miles. Even with bystander CPR and AED defibrillation, the survival rate is still only 38%.\(^\text{18}\) Even if everything goes right and the responder arrives on the scene of the cardiac arrest incident immediately, it is more likely than not that the cardiac arrest victim will die. Dealing with such deaths, especially a quick succession of such events, can be deeply traumatizing. Responders might blame themselves for such failures even when it isn’t their fault. One way of mitigating this is to spread out the responders that are notified, so that it’s not always the same responders being notified. However, this may not always be possible depending on the geographical distribution of responders. It can also be traumatizing to responders if we notify them about a cardiac arrest incident but they are unable to arrive on the scene in time, either due to distance or physical barriers such as locked doors and so on. We can mitigate some of these problems by only notifying responders if the cardiac arrest victim is in a public place. In addition, we currently only notify responders within half a mile, and this can be adjusted further as well.

Finally, there is also the possibility that the application that we created may be abused. For example, thieves could abuse our application by triggering fake cardiac arrest incidents to draw responders to an opportune location. Once responders arrive there, they could be mugged. There is also the problem of fake incidents in general. If responders are constantly spammed with fake incidents, it is likely that they would stop responding to our application entirely. One possibility to mitigate such abuse is to verify the identity of our at-risk users before giving them an account. For example, we could change our application so that at-risk users can only sign up with the permission of their doctor. We could also require submission of documents verifying their identity before giving an at-risk user an account.

SECTION 6: CHALLENGES

We faced several challenges as we progressed through our implementation, beginning with general problems with the end to end process. As we thought about it, we realized that it would be challenging for CPR certified bystanders to enter at-risk people’s homes, mainly because of locked doors and obtaining consent. However, the application will work well for other cases, and

---

\(^{17}\) https://www.cdt.org/files/pdfs/CDT-MorrisLocationTestimony.pdf

in some cases, bystanders will be able to alert neighbors who may have a key to the victim’s house.

The main issue we faced was integrating various hardware components to build a wearable to detect cardiac arrest. Firstly, the pieces were quite bulky and would likely be uncomfortable on a user’s hand. Secondly, the heart rate monitor was not very accurate and would only detect heart rate sporadically, often outputting that our heartbeats were 0 beats per minute (bpm) and thus declaring the user dead. The reason for this was that when one moved his or her hands too much, the heart rate monitor would lose contact with the wrists. To create the wearable, we would need a better way of holding the heart rate monitor in place and also would need to acquire less bulky parts. Furthermore, off-the-shelf devices were also similarly inaccurate. In addition, most of them even prevented real time access to data. Finally, a wearable used with this system may be classified as a medical device and thus be subjected to FDA approval. Therefore, we chose to focus on the mobile application and used that as the main method of triggering an alert.

SECTION 7: FUTURE WORK
The main goal of future work for this project is to complete implementation of the wearable device. New parts need to be purchased and tested to ensure that they are not as bulky as the original ones and that they are far more accurate at displaying heart rate. When it comes to medical emergencies such as cardiac arrest, where mistakes can cost lives, the data needs to be extremely accurate. Once the wearable is complete, we will be able to run end-to-end tests to see how viable this product truly is for people who are at-risk for cardiac arrest. Additionally, we hope to further optimize the speed and simplicity of the application and may work with various responder groups (e.g. MERT, American Red Cross) to obtain feedback and see what further features we can develop. An example of such a feature is a metronome which produces ticks at regular intervals, making it easier to perform CPR. CPR needs to be performed at the same rate at which the heart beats. The optimal rate of compression is 100 beats per minute, which can be maintained by listening to a metronome and compressing when a tick is heard.

Our final objective for the future is to finish porting the application to iOS, which should be relatively easy because React Native allows you to share codebases across platforms.

SECTION 8: CONCLUSION
Our application sets a strong foundation for an integrated system that will help decrease the mortality rate associated with cardiac arrest. With the help of our application, victims of cardiac arrest will be able to receive help from CPR certified bystanders more than twice as quickly as they do now. At-risk users can trigger an alert when they go into cardiac arrest, which notifies nearby CPR certified responders of their location. In the future, we will develop a wearable that can be synced with our application so that the alert is triggered automatically when heart rate falls below a specific threshold. The responders can then rush to the victims and perform CPR, preventing brain death and fatality. Partnering with various nonprofit organizations such as MERT and eventually the American Red Cross will allow us to raise awareness of our application and grow our userbase.