DoseNet: Developing a Network of Remote Dosimeters

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INTRODUCTION

After the Fukushima Dai'ichi nuclear power plant accident of 2011, many people have been worried about radiation in the atmosphere, and its impact on the world around us. This project aims to demonstrate that radiation is a natural part of the universe and mostly, should not be of major concern to the public. In order to do this, the framework was set for the creation of a dosimeter network centered around the UC Berkeley campus. This dosimeter network (DoseNet) would measure radiation at various locations around the campus, and display this near real time information online (eventually https://radwatch.berkeley.edu/dosenet) in order to educate the public on background radiation in the world around us, while simultaneously serving as a means for genuine scientific data collection.

PROJECT SUMMARY

Humans have always felt the need to monitor and understand the world around us, and radiation should be no different. Many organizations and groups have attempted to raise public awareness of the radiation present in our world. One such group was the National Nuclear Security Administration (NNSA), which released information displaying monitoring radiation in the atmosphere following the Fukushima Daiichi Accident.

In March 2011, a 9.0 earthquake and resulting tsunami devastated Japan. Not only did the earthquake and tsunami cause considerable damage to Japan, but the events led to the nuclear disaster at the Fukushima Daiichi power plant. After power was lost at the plant site, and considerable core damage, large amounts of radioactive materials were released into the atmosphere.[1]

The public became concerned about what impact this radiation would have on the surrounding area and population. Therefore, many efforts began in hopes of quantifying the radiation that was released, as well as informing the public on the possible risks that could be associated with this radiation. An example of the monitoring information that the NNSA released can be seen on their website.

Other efforts focused on quantifying specific isotopes (such as ^{131}I and ^{137}Cs) that had been released into the atmosphere.[2] However, whether focusing on quantifying the released radiation as a whole, or specific isotopes, these studies aimed to achieve the same goal: addressing the public's concern with radiation, and granting the public means to gaining a better understanding of radiation.

Although this effort of raising public awareness was only implemented after a nuclear disaster struck, other efforts have focused on raising awareness on a more frequent basis. One such effort focused on monitoring solar radiation on multiple continents, and is known as the European light dosimeter network (ELDONET). This network comprised of more than 40 stations in 24 countries on 5 continents. It's efforts demonstrated to the public that natural radiation, including solar radiation, is all around us. The importance lies in quantifying the amount of radiation that is normal on a daily basis, as well as attempting to understand that it will always be a part of our environment.[3],[4]

Efforts such as these have provided a foundation that can be expanded on to allow the public to gain a better understanding of radiation, as well as means for monitoring the natural occurring radiation in the world. These efforts, along with the current existing goals of the UC Berkeley radiation watch (RadWatch) team, led by Professor Kai Vetter, has led to the desire to create a dosimeter network in UC Berkeley.

The aim of this project was the creation of the framework for a functional network of radiation dosimeters. These devices would be used for radiation monitoring and public outreach. Our project consists of the establishment of an initial network of dosimeters (1 or 2 devices) that can be easily expanded as more devices are constructed and deployed. These devices are to be placed throughout the UC Berkeley campus and Berkeley area more generally, with a special effort to get the devices into high schools for the purpose of educational outreach. These devices, networked over the internet, communicate to a central server on UC campus and display the collected information on the RadWatch website, which is accessible to the general public.

GOALS AND OBJECTIVES

The aim of this project was the creation of the framework for a functional network of radiation dosimeters deployed at remote locations. These devices would be used for radiation monitoring and public outreach. Our project consists of the establishment of an initial network of dosimeters (1-2 devices) that can be easily expanded as more devices are constructed, deployed and setup. These devices are to be placed in the UC Berkeley campus and Bay Area more generally, with a special effort to get the devices into high schools for the purpose of educational outreach. These devices, networked via the internet, communicate to a central server on UC campus and display the collected information in the RadWatch website (radwatch.berkeley.edu), which is publically accessible.

The first part of this project was the actual construction of the dosimeter units. This hardware included a Raspberry Pi 1 Model B+ and a Radiation Watch Type 5 'pocket Geiger' small silicon detector. After the dosimeter units were assembled, they were to be deployed at selected locations throughout campus. Following this, the dosimeter units had to be connected to the network and added to a database table in order for the data to be stored.

The next goal of this project was the presentation of the data via the website. This presentation was to include a map of the area with local readings associated with each dosimeter location, the ability to view radiation levels over time (including but not limited to, the past hour, day, month, and year), and an interactive interface with real-time updating.

Similarly with the presentation of data, another objective this project aimed to accomplish was public outreach regarding background radiation levels. In order to raise awareness to the public of this naturally occurring radiation, the website aimed to portray data in a public-friendly way, as well as compare the monitoring data to familiar units to the public, such as dental X-rays or hours on a flight. However, scientific units such as mRem/hr and μSv/hr, are displayed on the website also. In order for this information to be useful to the public, a description of these measurement units would be provided on the website.

Furthermore, another important feature of our project is the potential for schools to be involved with our network. This project attempts to involve high schools in our efforts, so that participating high school students can learn more about radiation in generaland get an understanding of how radiation detection works. This educational component will be handled in collaboration with Ali Hanks (Ph.D.) leading those efforts. Ideally, this framework could be expanded into dosimeter kits that local schools could assemble into dosimeters that tie into the system (DoseNet) we‘ve created.

All of these efforts combine to address the overlapping theme of the project, which is the development of a broader framework, that will allow the expansion of this network to various locations within the UC Berkeley community, as well as the surrounding bay area. In order to create this framework, this project aimed to first establish the ‘alpha‘ stage of one dosimeter, which could successfully connect and send data to the server. Along with this, would be step-by-step documentation of how this dosimeter network was created, which would allow for more dosimeters to easily be created and integrated into the network. Once one dosimeter is collecting data and sending it to the network, the idea is that more dosimeters can be created and added to the system with minimal effort using our project. The addition of an extra dosimeter will eventually be physically installing the device and running a BASH script and changing a configuration file. Ideally we could then develop dosimeter âĂIJkitsâĂİ that local schools could assemble into dosimeters that integrate our DoseNet system.

To summarize, the objectives of this project are:

- Develop software for a dosimeter network
  - Construction of dosimeter units
  - Deployment of dosimeters on campus
  - Connecting dosimeters to our database server
- Present radiation data through RadWatch site
  - Map of area and local readings
  - View radiation levels over time at a specific location
  - Have an interactive interface and real-time updating
- Public outreach about background radiation levels
  - Unit conversion of radiation levels to more familiar units (dental X-rays, hours on flight, etc)
  - Portray data in public-friendly and accurate way
  - Potential for high school student involvement
- Development of broader framework
  - Make instructions and scripts so that future dosimeters to be easily created and added to network
  - Make dosimeter data compatible with other radiation monitoring systems

TECHNICAL APPROACH

The dosimeter network consist of three layers: the physical devices that measure the dose at each location; the server backend where the data is stored and processed; and the frontend website interface that displays the information.

The physical devices (dosimeters) measure the radiation at the location in which they‘re deployed by measuring the number of detection events over a preset amount of integration time (2 minutes) produced by the semiconductor detector. This number in counts per minute, is then sent to the database server, along with the dosimeter ID, date-time and any error flags.

The server listens for packets from the dosimeters, parses the packets and injects the data into a MySQL database. This count rate is then converted into the various units that are displayed on the website, using a calibration specific to each dosimeter.

This database is queried, makes all plots, sends them to Plot.ly and generates an output file (GeoJSON formatted) that is securely copied to the website server. This file contains where the dosimeters are displayed, the most recent radiation levels and the URLs for the embedded plots. The Google Maps interface uses this file and updates the maps count rate along with any additional dosimeters and plot URLs.

By setting this system up in this modular fashion, each component could be developed somewhat independently from the others. Regular communication between the team members ensured that the output from one component would remain consistent with the inputs of the others. Similarly, regular testing and updating ensured that each component functioned as expected.

During this testing, the systems have been extensively stress tested. For example, during early database testing and development we showed the maximum rate of data injection to the database is many orders of magnitude above what we would ever handle.

Furthermore, this modularity allows flexibility in the number of dosimeters in the network, as each dosimeter acts independent of the others. This allows additional units to be added as needed, as well as allowing for removal of any units that encounter errors with almost no extra steps.

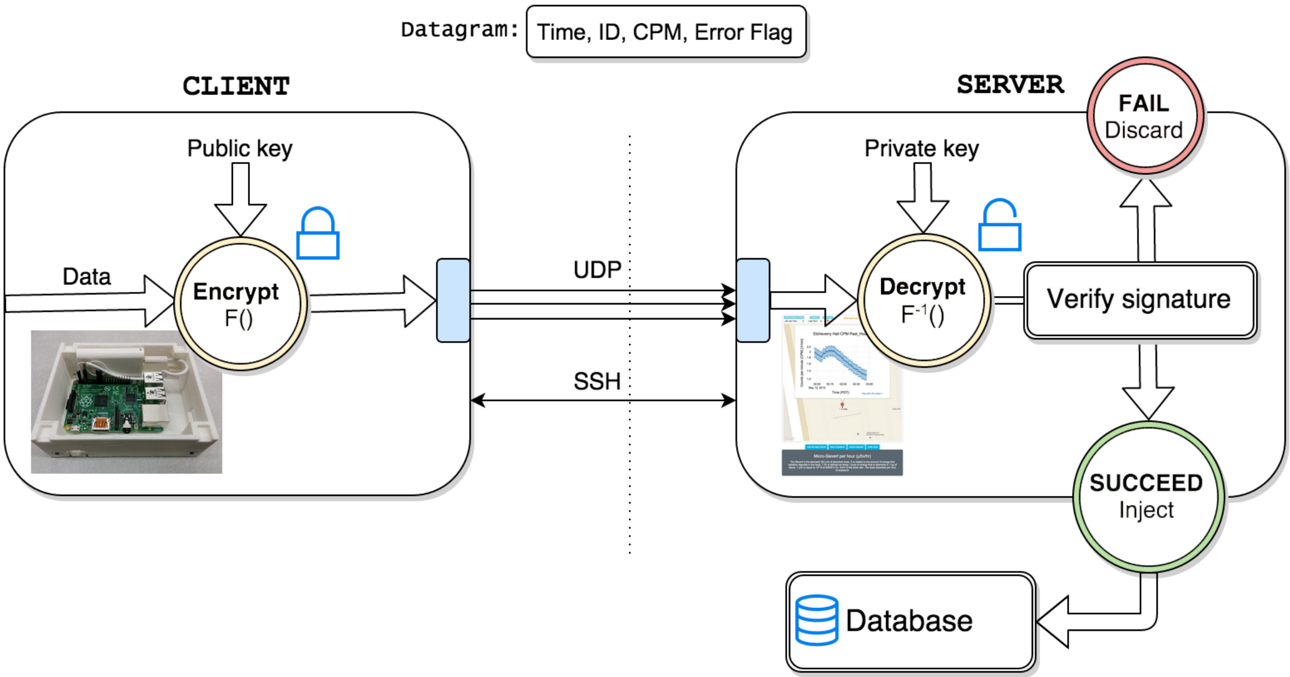

Fig. 1: A logical system overiew detailing the primary data flows.

We have constantly made steps to ensure that this system is highly scalable. One way in which we achieved that goal was by minimizing server load wherever possible. We have made sure to use CDNs (Content Delivery Network) for the JavaScript and CSS libraries so that less queries are sent to the web server. Also, we have no plots stored on the web server - all of them are stored and downloaded from the Plot.ly servers themselves. The only data that our web server actually sends is the HTML page itself - no images, libraries or other such resources are stored on or sent through the web server.

Physical Devices

The physical hardware consists of two main components: the radiation detector, and the computer. The radiation detector used is a $100mm^2$ 'RadiationWatch Type 5' silicon detector. These units were chosen due to their relative affordability and previous experience with the units. The computer, a Model B+ Raspberry Pi, was chosen for similar reasons, along with its python capabilities and built-in ethernet port. In addition to these components, each dosimeter unit has a power supply, and a custom case, with the option to include a touch screen display. The radiation detector connects to the computer using general purpose input and output (GPIO) pins on the Raspberry Pi.

We wanted the case to be able to securely hold the electrical components, while simultaneously remaining lightweight and sufficiently robust. Due to these considerations, and the flexibility in manufacturing, we decided to use a 3D printer to make a plastic (PLA) case courtesy of Applied Nuclear Physics, LBNL. By using this printer, we were able to make

Fig. 2: Interior of our dosimeter unit - containing the Raspberry Pi and the radiation detector.

the case relatively complex and very reliably similar, without requiring machining from us.

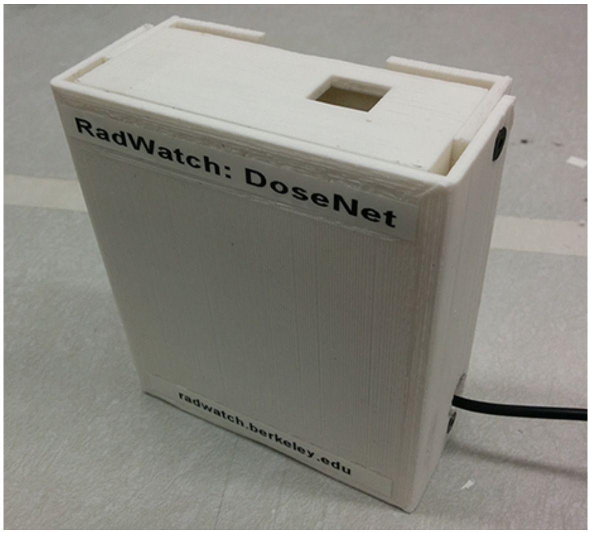

Fig. 3: Completed Model (exterior) - prototype first version.

The code that runs on the Raspberry Pi performs three main functions. First, it counts the number of pulses (events) that the Radiation Watch board produces and compares it to its interior clock. From this, a count rate over a specific amount of time is produced. Then, by checking the microphonics sensor on the radiation detection board, false measurements can be detected. Comparing the microphonics reading to that of the counts, and looking for coincidences, vibrational noise that triggers the semiconductor detector can be properly accounted for.

The second function of the Raspberry Pi is to package the count rate, time, and station ID into a UDP packet that is sent via ethernet to the database server. By using SSH key pairs and a separate server-side validation stage, we ensure that the dosimeters and servers communicate securely and reliably. Future work for security would include a security measure for DoS (Denial of Service) attacks, which could be implemented with a Fail2Ban type system [5].

Finally, the Raspberry Pi also runs error checking codes, and sends the proper error flag whenever a problem arises. This happens in a number of ways. First, if the count level goes beyond some arbitrary threshold value (set for each device) it will send out an error flag. This alerts the server that the device is encountering an error, a radiation source of some kind is close to the detector, or some other similar issue. Another possible error flag that the device can throw is a zero count rate. While low radiation levels are expected, if the detector finds 0 counts for a certain amount of time, then it will send a different error flag to the central server. By having different error flags corresponding to different errors, the nature of the problem can be (at least partially) remotely deduced before being implemented to the dosimeter site.

A major feature of these dosimeters is the **low cost**. The total cost for each unit, consisting of the Raspberry Pi, the silicon detector, the casing, and all relevant connectors, is around \$100. If the device were to contain a touch screen, the price would be approximately an additional \$35.

Fig. 4: Our dosimeter is based on this one, created by Ryan Pavlovsky - primarily the detector and computer combination being the same.

Networking & Server Communications

The entire networking system begins when data is collected by the Raspberry Pi, which then places the data into a UDP packet and encrypts it before sending it to a specific port on the GRIM server. The server then acts to decrypt and validate the data received from the Raspberry Pi, and inserts it into the database. From here, the data from the database is processed and URLs to the plots are stored into a GeoJSON file which is sent to the website. When the source file is updated, users of the website are able to access the updated information.

The main Python scripts we used are:

The udp_sender.py script is the main python script running on the Raspberry Pi. It sends an encrypted package containing all the relevant information from the dosimeter module: stationID, count rate, time of acquisition and any error flags to the server, where the python script udp_injector.py runs.

The udp_injector.py is a python script that runs on the GRIM server, and decrypts the incoming package from the Raspberry Pi. It then injects the data from this decryption into the mySQL database.

Finally, the makeGeoJSON file which as mentioned previously, updates the plots on plot.ly with the new data, produces a file containing references to the plots online, the latest reading and copies that file to our web server.

The Raspberry Pi - database server connection and the database server - radwatch.berkeley.edu connection were implemented through Secure Shell (SSH). SSH works using secure keys, which are generated during the initial setup process. Once the keys are shared between the nodes a authentication-free communication becomes possible.

A softer problem that we have encountered is having too many data points for plotting purposes. Since we have one measurement for each dosimeter for every 2 minutes, plotting this on a month long plot is simply not practical - the resulting plot is not useful. Therefore some data reduction algorithm is required to reduce the number of points - we envisage using an exponential moving average (EMA) or another type of NumPy (numerical extension to Python) based averaging technique.

Due to time constraints we have not implemented such a sophisticated method. Instead, a lossy reduction method of ignoring 3/4 of the measurements until the total number of points is less than 200 is in temporary use. This was used only because it was very rapid to implement. An implementation of a moving (rolling) statistics was tested at the end of development during this project and was not included in the 'final' development script.

Web Interface

One of the major considerations for the website was making sure that the page was user-friendly. This meant using Javascript to make the information that the webpage displays dynamically update as the user selects different units or clicks various links via a dropdown menu. This allows for a large amount of information to be available to the user without displaying it all at once. This gives the finished webpage a clean, elegant look while still having the information and descriptions that are needed.

Another consideration for our web interface was ensuring it would stylistically match with RadWatch. As DoseNet will eventually be displayed onto the RadWatch site, it is important that the page styles (colors, fonts, formatting, etc) match up between the two. This was done by using the page styles (CSS) of the RadWatch website, as well as manually determining the color pallette used and adjusting our page to match. The web developer who made the site several months ago provided a document which contains such information as the color palettes and the custom CSS styling elements.

This was useful as we had significant problems attempting to adapt our page to the Drupal web CMS (content management system). Initially, we developed the web page locally which meant that we had full control over every aspect of the page and all of it's associated files. We were then given access to the test RadWatch Drupal site. Many unique restrictions are placed on us with use of Drupal - these are restrictions affect styling, file handling, JavaScript implementation amongst other technical aspects. Many otherwise unexpected changes and manual overrides had to be made in order to port our original web page to make it work within Drupal. This resulted in a clean and cohesive overall look and feel to our page with the use of powerful and popular libraries.

Public Outreach

Another aspect of this project's outreach was the presentation to the Nuclear Engineering Advisory Board, which took place on April 22. From this, we were able to gain exposure of our project, as well as receive important feedback.

The final goal of having this network as a means for public outreach impacted several of our design choices. Firstly, we wanted to portray the data in ways that would be accessible and understandable to the general public, as well as convey the information in ways that are unalarming. To do this, we chose to make a weather map style display. By having points for each dosimeter location, it allows the general user to easily see the current readings across the mapped area. Furthermore, as weather maps are common, presenting radiation data in this familiar form is helpful in reducing any of the more negative

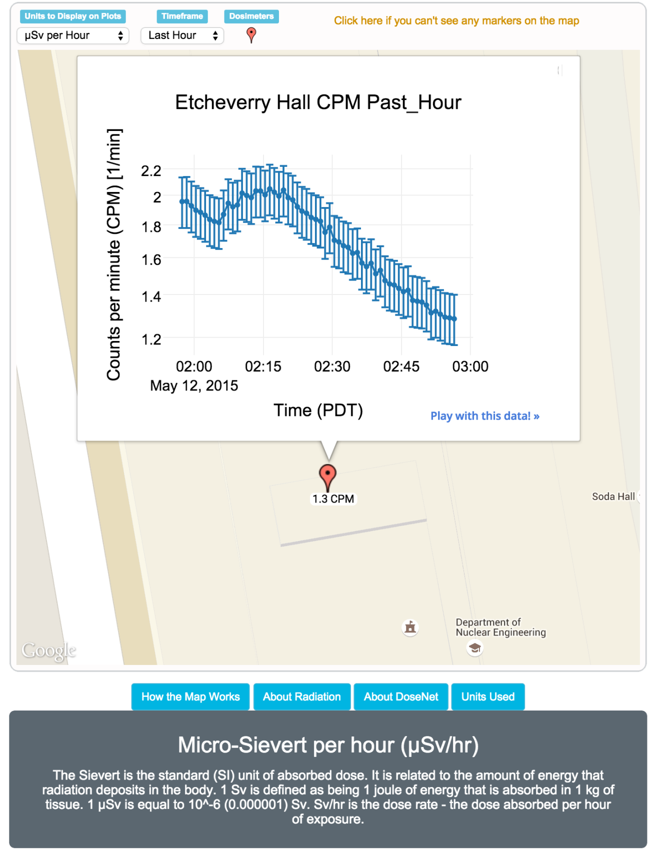

Fig. 5: Web interface as of May 2015

connotations of radiation.

On a similar vein, this meant choosing radiation units that would be meaningful to non-experts. This meant expressing dose in terms of common activities that the general public doesnt normally think of as exposure. Things like potassium-40 exposure in bananas, medical procedures, airplane flights, and comparison to different cities (Denver especially) made the initial list of these comparative units. We also wanted to include the technical dose units (μSv/hr and mREM/hr) so that the actual location dose could be directly read by those in the field.

Connected with the unit selection was creating explanations for the units we chose. These explanations would then be integrated on the website, making an interactive map where information about the currently selected unit would be displayed.

RESULTS

The current state of the project is that two dosimeter modules have been created , one for software testing located in 1110C Etcheverry Hall, and another for the use in creating the case. The website $https://radwatch.berkeley.edu/dosenet$, is not yet live since testing on the actual dosimeter modules is still being conducted. However, the current display features of the website include the changing of units, changing timescale, interaction with the plots, and description of the units. The current units can be changed between CPM (counts per minute), $mREM/hr$, $\mu Sv/hr$, time on an airplane, medical procedures, and number of cigarettes. The current timescale that is implemented on the website allows the user to view the radiation in the last hour, last day, or last month. Furthermore plots are generated using Plot.ly which the user can fully interact with and also download all the associated data for that plot in a variety of formats. Lastly, in order to allow for public outreach, descriptions of each of the units, how the dosimeters work, as well as a general description of radiation in general can be found on the website in dynamic updating boxes below the map.

Ultimately, the feedback we received from our sponsor was very positive, but it is important to note that this is not a finished product - Navrit worked on this project for 3 months over Summer 2015. While the framework for the larger network is in place, there still exists work to be done before the system is production ready.

Based on the initial goals that this project aimed to accomplish, the current state of the dosimeter network is where we expected it to be. Throughout the first half of the semester, most of the work done dealt with the software end of things, since the ordered hardware had not yet arrived. Nonetheless, the current state of the project demonstrates that the deployment of the network is nearly complete.

Throughout the semester, many people provided feedback on improvements that could be made to the website. For example, we had a teachers conference where we presented our work at the time. This feedback was taken into consideration and implemented where possible.

FUTURE WORK

Future work on the hardware includes improving the quality assurance and error checking on the devices themselves. This includes accurate calibration of the RadiationWatch silicon detectors, as well as further improvements and implementations of the microphonics of the devices. Furthermore, more dosimeters need to be built and installed across campus, and on-site tests need to be conducted to ensure they are working and connecting to the server. Lastly, a deployment plan for these devices at high schools still needs to be fully developed.

On the software side of things, future work includes final improvements to the website and its display. Firstly, the live update time of the information to the website can likely be improved, and so efforts to implementing this should be explored. Next, data accessibility and analytics can be improved, and discussed further. Lastly, data downsampling can be improved, so the plots are not filled with excessive data. As mentioned above, this work will be continued over the summer by Navrit, and beyond that by Joseph, Ali and Prof. Kai Vetter's RadWatch team.

CONCLUSIONS

In conclusion, the framework for a dosimeter network branching across UC Berkeley has been created. This network uses a Radiation Watch type 5 pocket Geiger silicon detector connected to a Raspberry Pi model B+ in order to collect counts of radiation. The Raspberry Pi then encrypts this data and sends it in a UDP package to the database server where the package is decrypted and the data is stored in the MySQL database. From here, the data is processed and a .GeoJSON file is created. This .GeoJSON file is processed by a Google Maps Javascript based API, and is made available on the RadWatch website.

This project allowed the team to not only acquire skills working with radiation detectors and 3D printers, but also allowed us as a team, to gain a better understanding of so many different open-source software tools. Furthermore, this project allowed each of us to gain knowledge of project management tools and techniques that can be used in the real world.

Although this project is in development (as of June 2015), the framework of a dosimeter network has been created in the UC Berkeley campus. This network allows for near real-time monitoring of radiation levels around the campus, and makes this data accessible to the public, in order to inform the public about radiation and its presence in the world around us. Ultimately, this framework has been created in such a way that more dosimeter modules can be easily created and integrated into our already existing network - think 'Plug and Play'. In this manner, the dosimeter network can be easily expanded within the UC Berkeley campus then to the Bay Area and beyond.

ACKNOWLEDGMENTS

Nathan Richner (UC Berkeley) also was a part of this team for Spring 2015 but is not participating in this competition. This material is based upon work supported by Joseph Curtis, Ryan Pavlovsky & Victor Negut. This project was sponsored by and conceptually led by Professor Kai Vetter.

APPENDIX

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