An Extensible Software Infrastructure for Computer Aided Sensor Based Custom Monitoring of Patients in Smart Homes

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Abstract—This paper describes the tradeoffs and the design from scratch of a self-contained, easy-to-use health dashboard software system that provides sensor-based customizable data tracking for patients in smart homes. The system is made up of different software modules and comprises a front-end and a back-end component. Built with HTML, CSS, and JavaScript, the front-end allows adding users, logging into the system, selecting metrics, and specifying health goals. The back-end consists of a NoSQL Mongo database, a Python script, and a SimpleHTTPServer written in Python. The database stores user profiles and health data in JSON format. The Python script makes use of the PyMongo driver library to query the database and displays formatted data as a daily snapshot of user health metrics against target goals. Any number of standard and custom metrics can be added to the system, and corresponding health data can be fed automatically, via sensor APIs or manually, as text or picture data files. A real-time METAR request API permits correlating weather data with patient health, and an advanced query system is implemented to allow trend analysis of selected health metrics over custom time intervals. Available on the GitHub repository system, the project is free to use for academic purposes of learning and experimenting, or practical purposes by building on it.

Keywords—Flask, Java, JavaScript, health monitoring, long term care, Mongo, Python, smart home, software engineering, webserver.

I. INTRODUCTION

HOME automation for the elderly and disabled is the next frontier in healthcare. The form of home automation called *assistive domotics* [1] focuses on making it possible for the elderly and disabled to remain at home, safe and comfortable, yet get monitored in case assistance is needed. Take a simple case: if a smart home system could keep track of when a person gets up and goes to bed, and follow him or her around during the day, it could furnish valuable information about how the person is doing. In the case of long-term-care patients, home automation is particularly useful because it can provide valuable means for health monitoring without moving the patients to a health-care facility.

Smart homes can provide both the elderly and disabled with many different types of emergency assistance systems,

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security features, fall prevention, automated timers, and alerts. In an intelligent environment like a smart home, monitoring can range from simple tracking of motion and sleep data to complex analysis of behavioral patterns via machine learning algorithms [2]. Conference and journal papers abound with details on concepts and technologies to monitor behavioral patterns and health status [3]-[7]. Taking the cue from this growing consciousness, government, academia, and business professionals have responded to the situation by designing educational programs, personal monitoring devices, and technology that transmits patient health data to the care provider [8]. For example, Mediware's [9] Alternate Care Solutions group has started providing software, implementation, support, and consulting expertise for the automation of home care. Similarly, LifeFone [10] has started producing medical alert devices that provide quick response in a medical emergency by connecting a patient to expert emergency care agents. Taking this one step further, Apple recently unveiled new software platforms during its Worldwide Developers Conference that will organize data from the growing number of mobile medical applications and smart home gear on its iOS operating system [11], [12]. And, not only is ADT Security Services now offering medical alert monitoring [13], Comcast is talking *telehealth* [14] and is getting ready to take the plunge into the health and wellness business. Moreover, company mergers and acquisitions centered around mobile health are also starting to happen [15].

A different class of companies has also sprung up to support and help grow the healthcare automation businesses. For example, Clear Care [16] and Boston Software [17] are providing automation and software solutions connecting families and care partners. Pegasystems [18] is offering agile healthcare software solutions that enable healthcare enterprises to intelligently automate their core business functions, including new customer acquisition and on-boarding, customer relationship management, risk management, and compliance management. Omnicell [19] automated healthcare solutions are enabling healthcare facilities to improve efficiency, patient safety, medication adherence, and regulatory compliance. The list goes on. In fact, Capterra [20] has provided on its website a list of top healthcare management software products.

An interesting recent development is that in order to advance the state of the art in healthcare automation, not only are companies like CitusTech [21] now offering healthcare software engineering services to accelerate product

development, universities [22] are also offering software engineering graduate programs in healthcare systems. But, even without sophisticated devices, plugins and apps, that cost significant money, a lot can be achieved by connecting simple sensors, monitoring personnel, and caregivers. A step in the right direction is Cornell University's Wireless Human Health Online Monitor project [23] that creates a portable device implementing wireless technology and taking full advantage of the wide-spreading Internet to provide a convenient solution to monitor human health. However, what is missing and really needed is a simple-to-use and extensible software system and infrastructure that allows tying in all the pieces together —registering patients, setting goals, incorporating sensors, collecting data (manually or from sensors), displaying patient data in an easy-to-understand format on a dashboard, and allowing the caregiver to act based on the data collected. The current project tries to achieve exactly that.

The primary objective of our project has been to create a fully functional, free, and open-source software system for monitoring patients. We wanted deploy well-known software-engineering principles to our design, and develop a system that anyone can use. Easy scalability, simple deployment, and clear and accessible code have been high priorities for the implementation as well. Finally, we also wanted to evaluate whether such a framework can help research into how data from many simple sensors can be combined to yield valuable information. The paper describes our journey to realize these goals.

The paper is organized as follows. Section II describes the overall front-end interface design of the project. Section III provides an overview of the software architecture and organization. In Section IV, we go into the software implementation details. Section V draws the conclusions and talks about future work.

II. PROJECT DESIGN

Simply stated, the project described in this paper provides functionality for patient tracking through a variety of different data types in an integrated software environment. Each type of data that is tracked is called a "metric". There are different types of metrics —ones that provide information directly related to a patient (*e.g.*, motion, sleep, photos, *etc*.), and others that yield information about the environment (*e.g.*, weather) that affects the patient. We have specifically chosen motion, sleep, photos, and weather as the metrics for our first implementation.

There are two different classes of metrics that we have designed – *standard* and *custom*. Standard metrics are obtained from files in a standardized data format. Custom metrics receive data from any programmatically accessible source. All of the information and data about the various metrics are viewed through three different web pages: *login*, *dashboard*, and *query*.

The "login" page, shown in Fig. 1, provides the functionality for adding and deleting users, as well as the functionality to log into the project to view patient data. The *Add User* button gives a series of options to create a new user

with specific health targets. The *Delete User* and *Login* dialogs show a list of users where one can delete or log in as a user.

The second page is the dashboard page as illustrated in Fig. 2. This page provides the functionality to view all of the metric data for a single day. The metrics can be displayed in four different ways: percentage, graph, raw text/numbers, and photo. Each metric has a display format field which determines how it is to be displayed on the dashboard page.
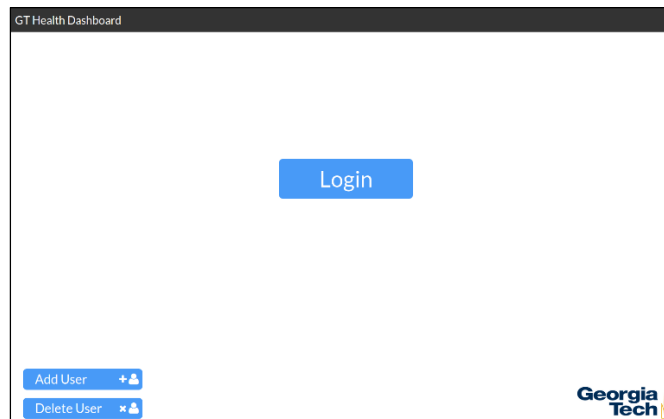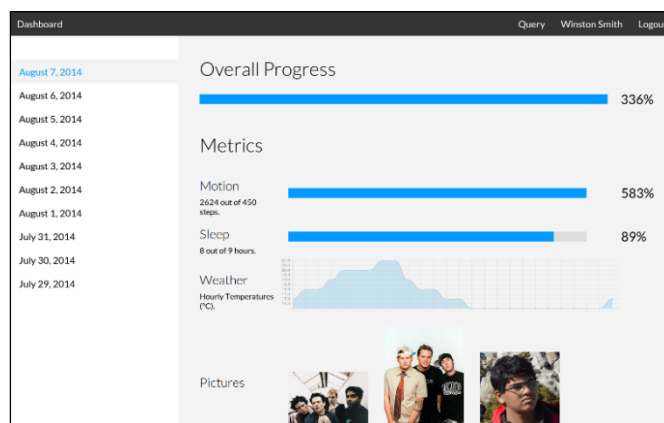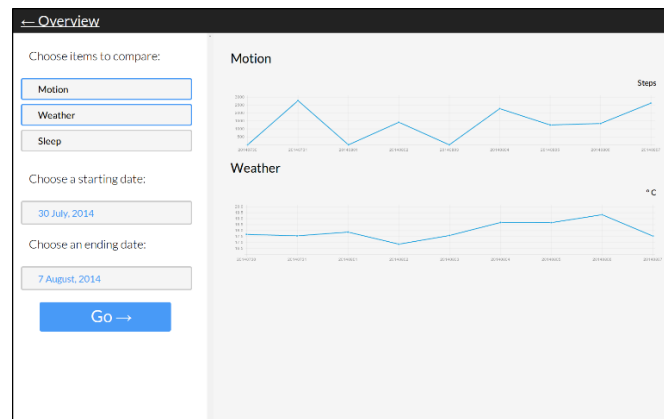

Fig. 1. Login page

Fig. 2. Dashboard page

Fig. 3. Query page

The dashboard page displays only a single day's (as

selected) worth of data at any one time; the user can view data for the last 10 days. In order to view data trends over multiple days, however, the user must go to the query page. The dashboard page is most useful for obtaining daily details — either specific (*e.g.*, motion or sleep) or general (*e.g.,* pictures or weather).

The query page, shown in Fig. 3, is where the user can select several metrics and a date range. Each metric's daily data is processed into a single number, and then each metric is graphed over the selected date range. This page can be used to view trends over time and make predictions about the future.

III. SOFTWARE OVERVIEW

The project essentially consists of a front-end and a back-end. The front-end includes the three different webpages described before to provide all the functionality on the user side. The web pages are written using a combination of HTML, CSS, and JavaScript. The back-end includes a Mongo database [24], a Flask server [25], and a Python SimpleHTTPServer [26].

The database stores all of the user metadata and the data for the user metrics. MongoDB was chosen over an SQL type database because it is easier to deploy and integrate. Documents are stored in the database in JSON (JavaScript Object Notation) format, and can be easily searched with complex queries.

The Flask server processes the requests made by the front-end, and returns the corresponding data from the database back to the webpage. Flask was chosen over the more common Django web framework due to the fact that it is lighter and simpler to use.

The Python SimpleHTTPServer is a bare-bones HTTP server and was chosen over more typical web servers such as nginx or Apache because it has no external dependencies; the only thing needed is that Python should be installed.

The project homepage is currently hosted on GitHub Pages [27] and the code is hosted on the GitHub repository system. The compressed version of the project is 15.7 megabytes, and the extracted directory is 40.8 megabytes. To run the application, the project needs to be downloaded and extracted first. One can then go into the project directory and type "./run start" to start the application; executing "./run stop" will stop it. Following the descriptions given in the paper one can not only download and execute the code, but add sensors and custom metrics as well.

IV. IMPLEMENTATION

A. Front-End

The entire front-end of the project has been written from scratch, without using any frameworks such as Twitter Bootstrap or ZurbFoundation. An entirely new implementation was chosen over using a framework due to the greater flexibility afforded by a fully custom design. The front-end is largely empty static content that is populated by data from the database. To obtain data from the database, the front-end JavaScript sends AJAX requests to the Flask server, which processes the requests, pulls the requested data from the database, formats the data, and returns it to the calling script. Once the data is obtained, the JavaScript formats the data further into HTML and inserts it into appropriate pages on the front-end.

There are several different formats to display the data. For the percent format, a progress bar is displayed by setting a width of a child $<div>$[1] element relative to a parent $<div>$ element, and a percentage is displayed to the right. For the *raw* format, the data is simply dumped into a text box, and if the text is formatted with HTML markup, the formatting will be visible. For the *picture* format, images are displayed in a lightbox that expands when clicked. The lightbox plugin selected is FancyBox due to its ease of use and compatibility with many different browsers. For the *graph* format, the data is displayed as a line graph; the graph library chosen for this is *Chart.js* due to its ease of use and responsive[2] nature.

B. Back-End

Flask is a framework for a full-fledged Python web server, but in the current project, it is only used for processing the back-end requests from the front-end JavaScript. The script for the Flask server itself is only partially custom-implemented for the project; the cross-domain request code was obtained from a public Flask snippet [28]. The Flask server script contains only request-processing functionality. The script includes several other custom-written modules for additional functionality.
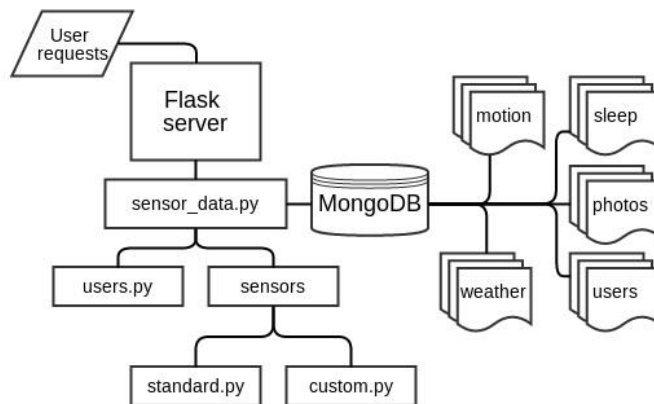

Fig. 4. Back-end component connectivity

The back-end component connectivity is illustrated in Fig. 4. The *sensor_data.py*[3] module contains the methods for logging all of the data, as well as the class to run the process that automatically logs the data. The *standard.py* and *custom.py* modules are included in the *sensors* module and they contain the sensor classes to log data for both the *standard* and the *custom* metrics. The *users.py* module contains the two classes that are used to add and delete users.

As mentioned earlier, there are two types of metrics:

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[1] A $<div>$ is an HTML container element used to display floating blocks that may or may not contain text.
[2] The library generates graphs that fit many different screen resolutions.
[3] The .py file extension denotes a Python script.

standard and custom. Every standard metric is automatically read and processed into the database from a file, but the custom metrics require a specific class per metric and a new clause in the control flow statement in *sensor_data.py*. There is no actual database handling in the sensor classes because it makes more sense to offload all database operations to an external class to ensure a uniform document format for both standard and custom metrics. All of the sensor classes return sensor data using a common function, *getMetricData*, and a method called from *sensor_data.py* then inserts that data into the database, keyed by date, metric, and username. The Python scripts use the PyMongo driver to interface with the database. The automatic logging runs on a thread independently of the Flask server thread. The Python back-end is multithreaded in order to ensure that any problems with the automatic data logging will not halt the process to deliver data from the database.

The database software used for the project is MongoDB. It is a NoSQL-type database that stores documents in JSON format. The structure of the database is relatively flat. At the highest level, there is the "data" database, which has several *collections* for the various different pieces of data (*e.g.,* users, motion, pictures, sleep, *etc.*). Each collection contains a series of *documents*[4] in JSON format, keyed by username, date, and metric. MongoDB supports key-value pairs for queries, which makes it easy to search for and find data keyed by date, metric, and username (or, any combination of the three). Each user in the database has his/her metadata (name, username, metrics) stored in a user object which is keyed by the username. Every username is dynamically generated by appending the epoch time to a whitespace-stripped version of the user's full name. This method ensures that every username is unique and prevents a name collision. All metrics are stored as JSON keyed by metric name in a larger JSON object that contains all the metrics. The JSON format is very easy to parse in both Python and JavaScript. A sample user object is shown in Fig. 5.

The *standard* metrics in the user object contain a path that defines the directory for files that correspond to the data for that metric. The *custom* metrics have no such path, and data can be obtained from any programmatically accessible source. For the two custom metrics currently implemented, motion and sleep, the data is retrieved from a third party source.

For the *motion* metric, the Jawbone UP band [29] is used to obtain motion data that Jawbone stores in the cloud. Jawbone's proprietary API provides the hourly number of steps a user has walked with the device on. The protocol used to authenticate with the Jawbone API is known as OAuth. The OAuth process requires an HTTPS server callback. In practice, an HTTPS certificate is very expensive, so a temporary setup is created —a one-time process —to generate an authentication code for the API used to pull the data from the cloud. The data is returned in JSON format. The steps are retrieved from the "steps" field of the JSON object and inserted into the database keyed by username, date, and metric

(motion). The code corresponding to a single day's worth of data is shown in Fig. 6.

```
{
  "name":"Ritwik Dutta",
  "username":"ritwikdutta1406421674",
  "metrics":{
    "sleep":{
      "source":"file", ... where the data will be pulled from
      "format":[
        "percentage", ... format that  data will be displayed in
        8, ... target goal for percentage-type data
        "hours" ... unit of measurement for  data
      ],
      "path":[
 ... specific folder where  data is to be retrieved from
        "mongo/data/db/",
        "sleep"
      ]
    },
    "weather":{
      "source":"custom",
      "format":[
        "graph",
        "° C"
      ],
      "type":"weather",
      "location":"ksfo"
    },
    "pictures":{
      "source":"file",
      "format":[
        "picture"
      ],
      "path":[
        "mongo/data/db/",
        "pictures"
      ]
    },
    "motion":{
      "source":"custom",
      "format":[
        "percentage",
        400,
        "steps"
      ],
      "type":"jawbone",
      "auth":"b6_3pfGGwEjReOXSnWIyQO0-
AlI3wvvmyZNaiuNHtPrR6_kAcLtg_W1PaWiav9FR8EvaJSu
mcI0GoYT-
V9UbpVECdgRlo_GULMgGZS0EumxrKbZFiOmnmAPChBP
DZ5JP"
    }
  }
}
```

Fig. 5. User object code example

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[4] A *document* in MongoDB is a specific piece of data.

```
{
  "time_completed": 1406874960,
  "xid": "PUDl9aE5chyt0sTPkkpIcA",
  "title": "2,781 steps", ...  total steps walked in a day
  "type": "move",
  "time_created": 1406851800,
  "time_updated": 1406924420,
  "details": {
    "active_time": 1487,
    "tzs": [
      [
        1406851800,
        "America/Los_Angeles"
      ]
    ],
    "wo_count": 0,
    "wo_longest": 0,
    "bmr": 1703.7847,
    "steps": 2781,
    "bg_calories": 100.284996,
    "hourly_totals": {
      "2014073117": {
        "distance": 1176,
        "active_time": 800,
        "calories": 58.641,
        "inactive_time": 1200,
        "longest_idle_time": 660,
        "steps": 1548,
        "longest_active_time": 756
      },
      "2014073118": {
        "distance": 716,
        "active_time": 576,
        "calories": 33.747,
        "inactive_time": 1920,
        "longest_idle_time": 660,
        "steps": 1016,
        "longest_active_time": 287
      },
    },
    "bmr_day": 1703.7847,
    "wo_active_time": 0,
    "sunrise": 0,
    "distance": 2055,
    "tz": "America/Los_Angeles",
    "longest_active": 756,
    "longest_idle": 9240,
    "calories": 130.12175,
    "km": 2.055,
    "inactive_time": 25920,
    "wo_calories": 0,
    "wo_time": 0,
    "sunset": 0
  },
  "date": 20140731,
  "snapshot_image":
  "/nudge/image/e/1406874969/PUDl9aE5chyt0sTPkkpIcA/U
DqByBVlzAY.png"
```

Fig. 6. Jawbone object code example

For the weather metric, the weather data is retrieved using a government-provided API that returns the past 24 hours of weather data for a given airport code. The data in this case is returned in METAR format, which is commonly used to store weather information. A sample METAR string is shown in Fig. 7.

KFSO 011955Z AUTO 19003KT 10SM CLR **27**/17 A3012 RMK AO2 T02740167

Fig. 7. Sample METAR string

The relevant data is the temperature (27) in degrees Celsius (°C). The METAR string is processed, whereby the temperature is extracted and appended to an array. After parsing every METAR string, the array contains the past 24 hours' worth of temperature data. This data is inserted into the database keyed by username, date, and metric (weather).

C. Adding New Metrics

This section talks about how a new metric can be added beyond what exists in the project today. A metric needs to be added as a key and a value in the *metrics* object in the user object. As mentioned earlier, the metric can have two possible sources on the back-end, which define how the data is collected. The metric can either have a *custom* data source, where everything has to be custom-implemented, or a *file* data source, where everything is automatically pulled from a directory. The path to the directory for a metric is currently defined as */mongo/data/db/user/<username>/<metric>*.

The metric can have four possible formats on the front-end, which define how the data is displayed. They are:

- Percentage: where the metric is displayed as a progress bar towards a target,
- Picture: where the metric is displayed as a series of photos,
- Graph: where the metric is displayed as a graph, and
- Raw: where the data is displayed as pure raw numbers or text.

Adding a File Metric

To add a new *file* metric, a new metric entry needs to be created in the user object with the selected options for display format and path. The directories for the user and associated metrics are automatically created, after which the folders need to be populated with data.

Adding a Custom Metric

To add a new custom metric, a new metric entry needs to be created in the user object with the *source* set to *custom* and the selected options for display format as well as any other fields deemed necessary (*e.g.*, a location for weather, or an API key for the Jawbone UP). A custom Python class needs to be implemented to pull and process the data, and inserted into the file *gt-dashboard/server/sensors/custom.py*. The custom class for the Jawbone UP is shown in Fig. 8.

Next, *gt-dashboard/server/sensor_data.py* is to be edited to insert the custom call to the class into the control flow statements shown in Fig. 9.

```
class jawboneLib:
    def __init__(self, userAuthorizationToken):
        self.userAuthorizationToken = userAuthorizationToken
    def getMetricData(self):
        apiAuthorizationHeaders = {'Authorization' : 'Bearer ' +
self.userAuthorizationToken.encode('ascii', 'ignore') }
        userJawboneData =
requests.get('https://jawbone.com/nudge/api/v.1.1/users/@me/mov
es', headers = apiAuthorizationHeaders)
        userJawboneDay =
json.loads(userJawboneData.text)['data']['items'][0]
        userJawboneDaySteps = 0
        currentDate = getFormattedTime("%Y%m%d")
        if (str(userJawboneDay['date']) == currentDate):
        userJawboneDay = userJawboneDay['details']['hourly_totals']
        for userJawboneHour in userJawboneDay.keys():
            userJawboneDaySteps +=
userJawboneDay[userJawboneHour]['steps']
        return userJawboneDaySteps
```

Fig. 8. Jawbone UP custom class

```
elif userMetricsList[metric]['source'] == 'custom':
    customData = ""
    if userMetricsList[metric]['type'] == 'jawbone':
        customDataObject =
custom.jawboneLib(userMetricsList[metric]['auth'])
        customData = customDataObject.getMetricData()
    elif userMetricsList[metric]['type'] == 'weather':
        customDataObject =
custom.weatherLib(userMetricsList[metric]['location'])
        customData = customDataObject.getMetricData()
```

Fig. 9. Custom metric control flow

The only thing that the custom metric class needs to return is raw data. It will be automatically tagged by date, username, and metric so that it can later be found in the database.

D. Creating Custom Displays

It is also possible to create custom display formats on the front-end. However, this process requires knowledge of HTML, CSS, and JavaScript for the front-end in addition to Python for the back-end.

A function needs to be written in this case to generate the markup for the desired format, append it to the table of metrics, and set it to the correct value. It also need to be consistent with the current theme. The functions for displaying metrics are in *gt-dashboard/web/js/metrics.js*. The code snippet for displaying a percentage is implemented as shown in Fig. 10.

The control flow statement in *gt-dashboard/web/js/dash.js* is also to be edited in order to add in the custom display format. The code snippet where this is done is illustrated in Fig. 11.

```
function addPercentMetric(metricName,          metricDescription,
metricPercent) {
    function genPercentMarkup(metricName, metricDescription) {
    var metricMarkupTemplate = ['<tr class="metrics element
container" data-metric="",
        '"><td class="metrics element info"><div class="metrics
element title">',
        '</div><div class="metrics element description">',
        '</div></td><td class="metrics element progress"><div
class="metrics element base"><div   class="metrics element fill ',
    ' "></div></div></td><td class="metrics element number ',
        '"><div class="metrics element percent ',
        '"></div></td></tr>'
    ];
    var metString = metricMarkupTemplate[0] +
metricName + metricMarkupTemplate[1] +
metricName + metricMarkupTemplate[2] +
metricDescription + metricMarkupTemplate[3] +
metricName + metricMarkupTemplate[4] +
metricName + metricMarkupTemplate[5] +
metricName + metricMarkupTemplate[6];
    return metString;
    };
    function setPercent(metricName, metricPercent) {
        $(".metrics.element.percent."+
metricName).text(metricPercent.toString() + "%");
    metricPercent = (metricPercent> 100) ? 100 :metricPercent;
        $(".metrics.element.fill." + metricName).animate({
            "width": metricPercent.toString() + "%"
        }, 250);
    }
    var generatedMetric =          genPercentMarkup(metricName,
metricDescription);
        $(".metrics.table").append(generatedMetric);
    setPercent(metricName, metricPercent);
    }
```

Fig. 10. Display code example

E. Software Security

It is very important that the desired level of security is implemented in a medical software database like ours. During the development of the project, we looked into implementing a security solution, but every worthwhile solution requires an HTTPS Security Certificate to be present within the project domain. Certificates are expensive and time-consuming to obtain, so we did not purchase one for the development of the current project prototype. However, using an HTTPS Certificate, many security solutions can be implemented, *e.g.,* using SSL/TLS layers to encrypt any private data online using AES-256 or a similar cryptographic algorithm. This would introduce sufficient security not only for the patients, but it would also help protect the platform itself against a man-in-the-middle attack, perhaps using a Public Key Infrastructure (PKI).

```
switch (requestedMetricFormat[0]) {
    //Show percentage
case "percentage":
tempDescription= loggedInUserData[requestedMetric].toString() +
' out of ' + requestedMetricFormat[1] + ' ' +
requestedMetricFormat[2] + '.';
requestedMetricPercent=Math.round(100*
loggedInUserData[requestedMetric] /
requestedMetricFormat[1]);
        //Add to array to determine final percentage
percents.push(requestedMetricPercent);
addPercentMetric(requestedMetric,
tempDescription,
requestedMetricPercent);
    break;
    //Show pictures
case "picture":
addPhotoMetric(requestedMetric,"",
loggedInUserData[requestedMetric]);
    break;
    //Show raw data
case "raw":
addRawMetric(requestedMetric,"",
loggedInUserData[requestedMetric]);
    break;
case "graph":
addGraphMetric(requestedMetric,
        (requestedMetric == "weather") ? "Hourly
Temperatures (&deg;C)." : "",
        loggedInUserData[requestedMetric]);
    break;
}
```

Fig. 11. Metric display control flow

V. CONCLUSION

We set out to create a free and open source system for patient monitoring. Combining cutting-edge front-end and back-end technologies, we have created a piece of software from scratch that has met our goals and performed well. Available on the GitHub repository system, the project is free to use for academic purposes of learning and experimenting, or practical purposes of extensions via building on it. The distinguishing features of our software are:

- MIT licensed and freely redistributable,
- Absence of any commercial or proprietary code,
- Easy expandability for additional metrics and sensors, and
- Simple download-and-run deployment

Some of the future work and extensions that we are planning comprise:

- Implementing a password system that would make the platform more secure for patients and caretakers,
- Moving user account controls to the admin page,
- Implementing data prediction for the query page,
- Using past data patterns to predict future trends

and analyzing the data to flag "interesting" patterns,
- Detecting anomalies in sensor data streams,
- Making the site design more mobile and tablet friendly to get all of the information on the go, where all of the pages on the site should be generated by a web framework rather than being implemented in static HTML and CSS,
- Transitioning the web framework to Django which, being more stable and mature, will lead to a better platform, and
- Converting the platform itself to C/C++ for more efficient and faster data processing for the project backend.

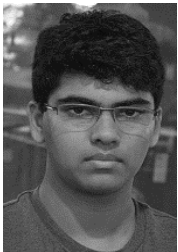## REFERENCES

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