Reward-based Thermostat Interface Project Final Report

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1 Introduction

Heating and cooling system account for almost half of the energy consumption in a typical North America household. More and more homes are using a smart thermostat to help them save energy related cost. We are interested in using the thermostat and a mobile application to find a way that will further influence the user to perform energy conserving actions with the help of smart user interface (UI) designs and reward mechanisms.

The project consists of two parts: a client-side application and a backend server. The application connects to a smart thermostat via the internet and the users are able to adjust various thermostat settings through the application. The UIs of the application are designed to provide more information about potential energy related savings and should have an impact on user decisions towards energy conservation. All related user actions will be recorded and stored in our backend server for further analysis. The project enables the researchers to investigate the effectiveness of different factors that contribute to energy saving behaviors.

2 Statement of Functionality

Among the popular smart thermostats available on the market, the Nest thermostat is the preferred choice since it is the most developer friendly and has a large user base. The company provides tools like Home Simulator and Virtual Device so that developers do not need to install a real device and have a total control of the environmental variables. It also provides a cloud API for custom applications to access a number of features of the thermostat over the Nest Cloud Server.

2.1 Project Infrastructure

In order to study the effectiveness of our application, we need a server to store the data gathered from the client side application for analysis, therefore the infrastructure in Figure 1 is developed for the project. The server receives the data from the application and the researchers are able to evaluate the data and push different configurations to the application used by a specific group of users. For example, changing a UI component of the application for only male users.

2.2 Client-Side Application

The client-side application is developed for the Android platform. Currently, there are three UI designs are available to be deployed, which are shown in Figure 2, 3 and 4. By using the remote configuration feature (details in section 2.3), the researchers could remotely switch the UI for users.

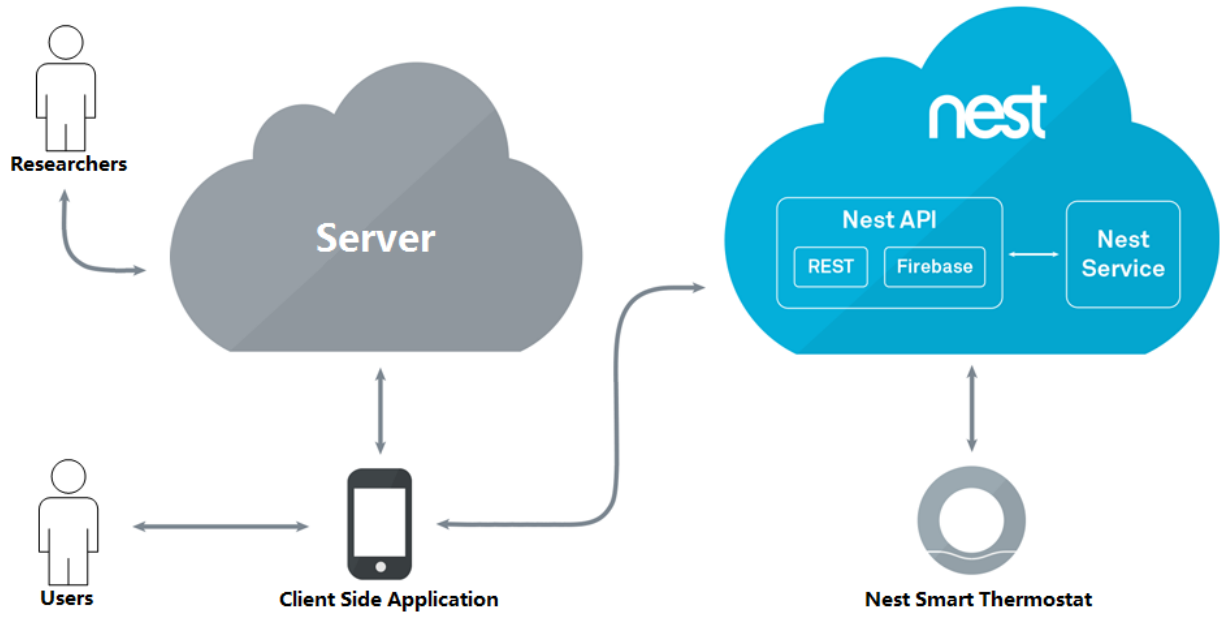

Figure 1: Infrastructure Developed for the Project

All the designs provide the basic thermostat control functionalities. The users are able to switch between cooling, heating and off mode of their thermostat by pressing the corresponding buttons. It also estimates the potential money savings/cost of the new target temperature setting with respect to the initial temperature setting, and the estimated value is displayed in various ways depending on the chosen UI style. The method of changing target temperature setting also varies for different UI design, however, they share a common "Confirm" button to confirm user decision. The text above the "Confirm" button indicates how long it will take to reach the target temperature and the cost per hour to maintain the temperature. The menu button located at the top-right corner lists several additional buttons which are "Refresh UI", "I'm Away/Home", "Settings" and "Logout" (Figure 5). The "Refresh UI" button is for developers, it can be used to update the UI after the design is changed remotely through the server. The "I'm home/away" button toggles the home/away status of the user. The "Settings" button offers the user to manually enter some parameters such as AC unit power. Finally, pressing the "Logout" button will log the users out of their Nest account.

The design in Figure 2 has a "+" and "-" button in a circular controller to change target temperature and a coin to show potential savings. It has a unique feature that when the user clicks the coin, the size of the coin and the temperature controller will switch place. The big coin allows the user to adjust the potential saving amount and see the corresponding target temperature change. The design in Figure 3 features a thermometer style temperature controller (sliding the mercury to change temperature) and a stack of coins to visualize the potential savings. The maximum height of the coin stack will be displayed if the new temperature setting will turn the AC off. The design in Figure 4 combines the two earlier designs. It has a stack of coins as well as a circular temperature controller.

The amount of potential saving is calculated by multiplying the follows:

- How long it will take to reach target temperature (time-to-temp)
- Power of AC unit (default value = 3.5kw)
- Hydro price (varies based on time of the day)

The Nest thermostat doesn't provide access to time-to-temp and AC power data. For the current

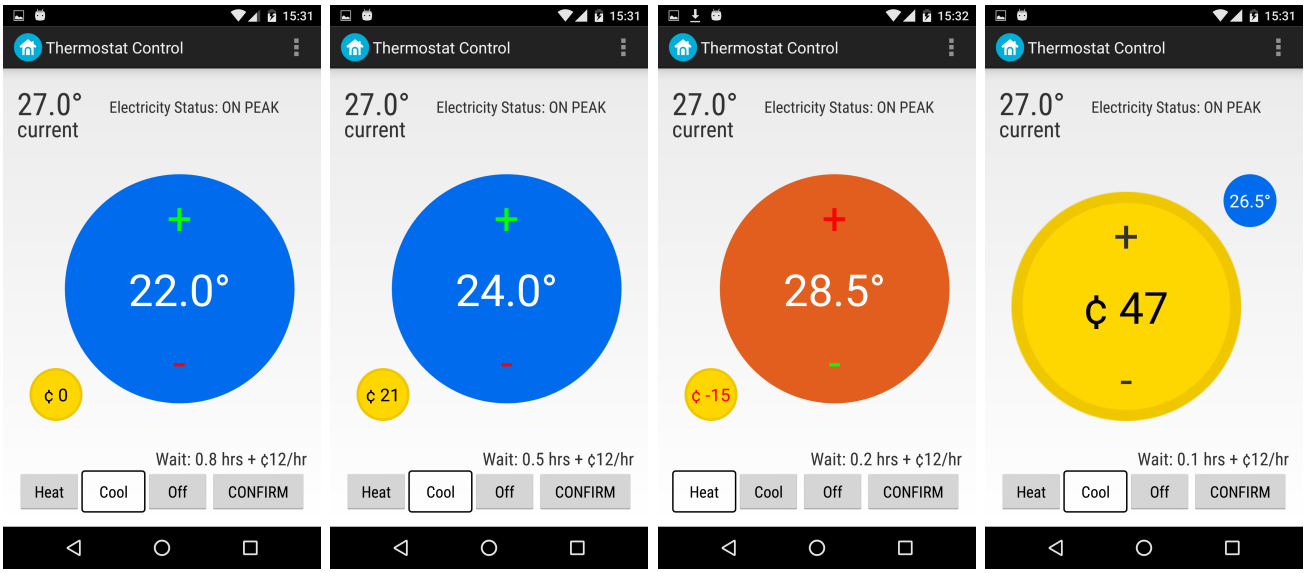

Figure 2: The UI with a Coin and Circular Controller

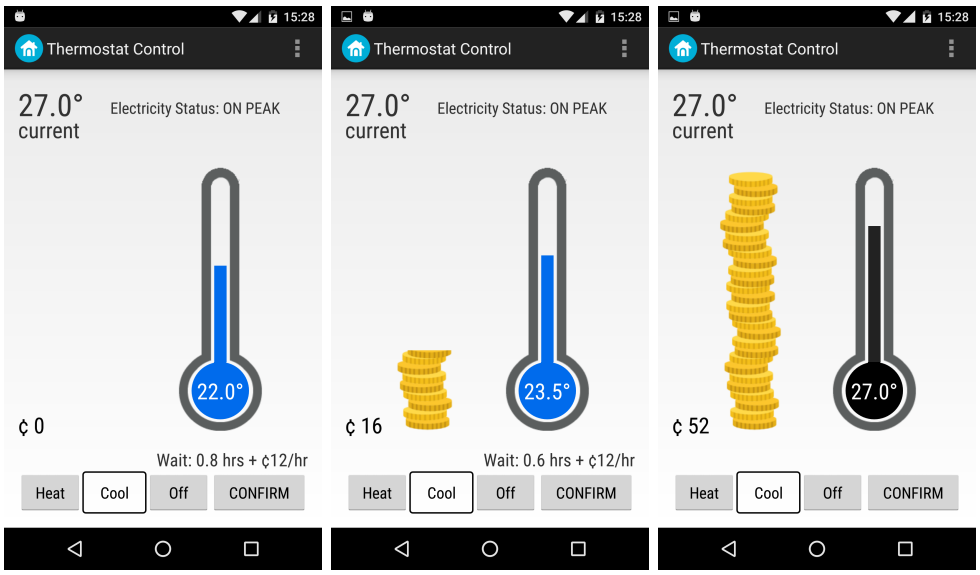

Figure 3: The UI with a Coin Stack

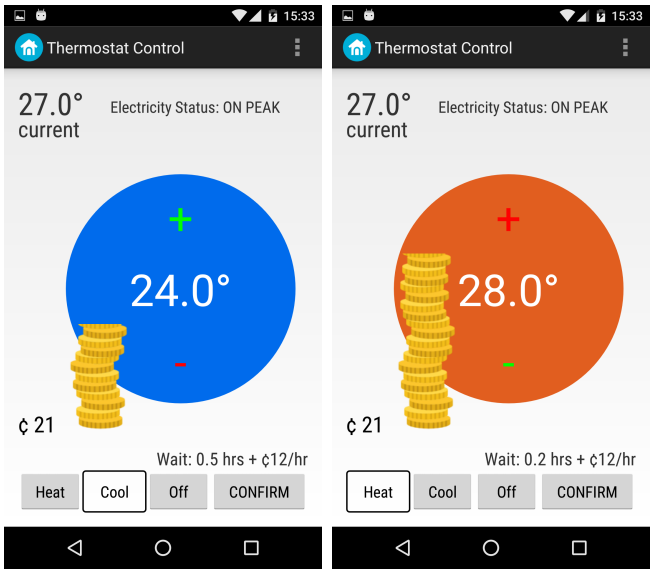

Figure 4: The UI combines coin stack and circular controller

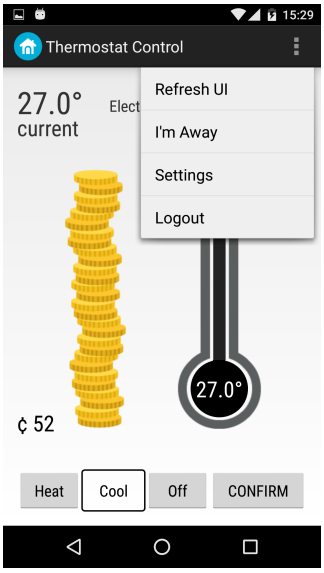

Figure 5: Additional Buttons in the Menu

build, the time-to-temp is calculated by using a default value of [target temp difference]/[0.1 C per minutes] and the AC power is manually entered by the user. Hopefully, Nest will open the access to the time-to-temp data in the near future or we have to implement the time-to-temp auto-calibration function which calibrates the time-to-temp value automatically over time.

2.3 Backend Server

The backend server is built by using Firebase[1]'s cloud server and API. It has the following features: user authentication, user action database, remote configuration and Firebase analytics.

The user authentication ensures the user is legitimate and have the right to access our server and it enables the other features we have implemented. The sign-up process is implicit: a new server account is created when a user login the application for the first time with his/her Nest account[2] and the two accounts are bounded together. For signing in the server, the only account the users need to know is their Nest account.

The user action database stores user actions gathered by the application in real time. The stored information includes time stamp, room temperature, HVAC mode, initial and new target temperature, potential saving amount and the UI style the user is using.

The remote configuration means that certain parameters used by the application can be changed remotely by researchers for all users or a specific group of users. For example, the researchers could re-configure the UI style of the application remotely for only the users using the application for more than a month.

The analytics provides insight into application usage and user engagement. Detailed user related information such as the number of active users, retention cohorts and general user location are reported by the analytics and they can be used in conjunction with the remote configuration feature.

3 Design Process

Similar to the design process used in [1], the first step is to identify the user needs for a mobile thermostat control application. The design goals of our application: 1. it should satisfy the basic user needs; 2. it should have features that encourage energy conserving behavior and at the same time not available in common products currently on the market. The user needs generally can be represented by the following:

- **Information.** The user should be able to know information about the environment and thermostat settings.
- **Context**. The application should help users to establish a connection between temperature setting and energy usage.
- **Control**. The individual should have full control of the thermostat settings.
- **Convenience**. The application should have a clean and intuitive user interface.
- **Reward**. The application should provide incentives to influence behavior change of the user for greater good.

One of the focuses of our application is providing reward by displaying potential saving amount. Even though the reward amount is considerably limited, there are studies show that small rewards could sometimes produce big motivational impact and attitude change[2, 3]. Also, since our users

[1]Firebase is a cloud service provider and a Backend as a Service (BaaS) company owned by Google.

[2]A Nest account is required to use a Nest thermostat.

are all smart thermostat owners, and one of the reasons behind the thermostat purchase is reducing the cost of energy consumption, our reward mechanism should have an extra influence on our users compare to people who have no interest in saving energy. In addition, the UI design in Figure 3 and 4 are expected to have a larger effect on the users than the design in Figure 2, because the amount of potential savings are visualized by the height of the coin stack [4]. Finally, the displayed information about electricity status and the rate to maintain target temperature should further help users to make better decisions.

The other focus of our application is providing context by coloring some of the buttons and saving information. Coloring the buttons with red/green is a good way to inform the users that higher temperature in winter costs more and lower temperature in summer costs more, since explaining the implication behind the green/red coloring is not necessary for the majority of people. As shown in Figure 2, the "+" and "-" buttons are colored: green means pressing the button would resulting more savings and red means the opposite. In a similar fashion, the color of saving amount text turns red when the value becomes negative.

The infrastructure build for the project will be able to help the researchers to study the effectiveness of the designs.

4 Future Work

The basic infrastructure including the application and server is built for the project, however, there is more work need to be done before deployment. First, compare to other mobile thermostat applications on the market, our application lacks the sense of design as well as some advanced functionalities such as scheduling and range temperature control, which should be implemented in the future. Second, as mentioned at the end of section 2, the accuracy of energy usage estimation need to be improved. Third, building a summary of accumulated savings over a period of time for the users should be useful. Finally, the application should support heating/cooling devices that do not consume electricity, for example, natural gas furnaces.

References

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