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Master's Thesis
Academic Year 2014

# Design and Implementation of User-centered Home Appliance Controlling Service Environment

Graduate School of Media Design,
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A Master's Thesis
submitted to Graduate School of Media Design, Keio University
in partial fulfillment of the requirements for the degree of
MASTER of Media Design

Dongyu Wang

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Abstract of Master's Thesis of Academic Year 2014

# Design and Implementation of User-centered Home Appliance Controlling Service Environment

Category: Science / Engineering

## Summary

Home appliances are becoming more multifunction and intelligent every day. Many manufacturers are promoting their new products, there are also many controller devices with smartphone applications. However, compatibility problems always happen between different products. On the other hand, the complex interface of those applications sometimes make users confused.

In this thesis, as a approach to provide a new experience of appliances controlling, the author proposed AnyControl: an User-centered universal controlling system. Task and condition based controlling process will be introduced so that users activities and environment condition can be connected with appliances. The system took advantages of Multisensor, single-board computer, web application and other technologies.

The result of the implementation and experiment has shown that the proposed system and interface can help to build a better interaction of Appliances Controlling.

Keywords:

Smart Appliances, Remote Control, Multisensor, Cyber-physical Environment

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# Chapter 1

# Introduction

## 1.1. Background

Recently, thanks to the large diffusion of smartphones and tablets, mobile communication technologies have advanced rapidly. Mobile devices have gradually become a central terminal for each user to communicate with the cyber world and even the physical world. [14] Many mobile devices and applications have been developed, besides smartphones and tablets, there are also smart accessories such as Google Glass[1] and Pebble watch[2]. As a result, our mobile devices have become a personal information center, like a portable Control Panel. People use them to collect and share information, also use them to control other devices that connected to the network.

As users demand for retrieving information and controlling things through mobile devices grew [18], home appliances are also becoming smarter and smarter. When talking about mobile controlled devices, the most popular topic should also be home appliances. And there are mainly two types of approaches. One is to make smart appliances with new technology, the other is to make smart controllers devices to control the existing appliances.

However, issues such as Compatibility and Usability often hinder a user's desire to use. Many home appliances companies are making multifunction products and dedicated applications, aiming at establishing a new platform for home and living environment. [9] But owning to each company is working behind a closed doors it's hard for one platform to take charge of products from different manufacturers.

Not to mention the old models which do not have the new functionality. On the other side, there are also many universal remote control products that provide an interface to manage and control home appliances. Most of these devices have built-in Infrared(IR) modules, they can record IR commands from the normal remote control, or use IR libraries so that even old models of appliances have become possible to be controlled. With those devices and applications on smartphone, users can combine all the remote controls in their home into one smartphone screen. Although it's convenient to control different appliances with one controller, the setting and controlling process are tending to become more complex to users. There are still a lot of room to take advantage of current technologies, to build some more user friendly platforms for appliances controlling.

## 1.2. Motivation

This thesis attempts to propose a new approach for Home Appliances Controlling Environment, which will improve user experience by enhancing the main two points as below:

**Compatibility**
: Support products from different models, brands

**Usability**
: Help users controlling appliances based on environment and activity.

Since the key of appliances controlling environment should not be only making appliances connectable and controllable by smartphones, but construct a User-centered controlling process. With that users can configure the application easily, and control the appliances based on their activities. This thesis focus on the structure and interaction of such system.

## 1.3. Objective

Because of the divers usage and environment, it's difficult to make a common platform for Appliances Controlling. But the roles of appliances in a user's activity are similar, that is to support and provide required information. Thus the technology of appliances controlling should be constructed based on users'activity.

In this thesis, a scientific study was conducted. The author evaluated the technology trend and related works, and sought for the new possibilities in appliances controlling environment. The expected results of the study are to verify the concept of activity based controlling process, and through the implementation and evaluation, provide an feasible model for related systems and products.

## 1.4. Thesis Organization

This thesis consists of 9 chapters. In the following Chapter 2, the basic structure and implementation approaches will be introduced. In Chapter 3, related works and their limitations are discussed. Chapter 4 proposes the concept and the architecture of users'activity based appliances controlling system. The implementation and evaluation of the system prototype are presented in Chapter 5. In Chapter 6, the issues of current system and future works are discussed. In the last chapter, are the conclusions of this thesis.

## Notes

1 http://www.google.com/glass/start/

2 https://getpebble.com/

# Chapter 2

# Overview of Appliances Controlling System

This chapter represented the basic structure and implementation approaches of Appliances Controlling System. As the base of this research, the current state of these information will help to find cues for directions of more possibilities. Such as the important factors of users need, merits of existing systems, also the appropriate approaches to make innovations.

## 2.1. Basic Structure

Home appliances are the most familiar devices that interact with human every day. Many interfaces were invented to help users to control them, such as button panel, remote control, sensor switch. Those interfaces provide a trigger to appliances functions, so that users can choose the proper function easily for their needs. As the number of appliances in home grows larger, it become more efficient and convenient to organize appliances as group, and make appliances collaborated with each other.

In general, an Appliances Controlling System includes 3 aspects as User Interaction, Function Organization, and Appliances Management. This basic structure also illustrated the work flow of appliances controlling. (See Figure 2.1) The characteristic and trends of those aspects are described as below:

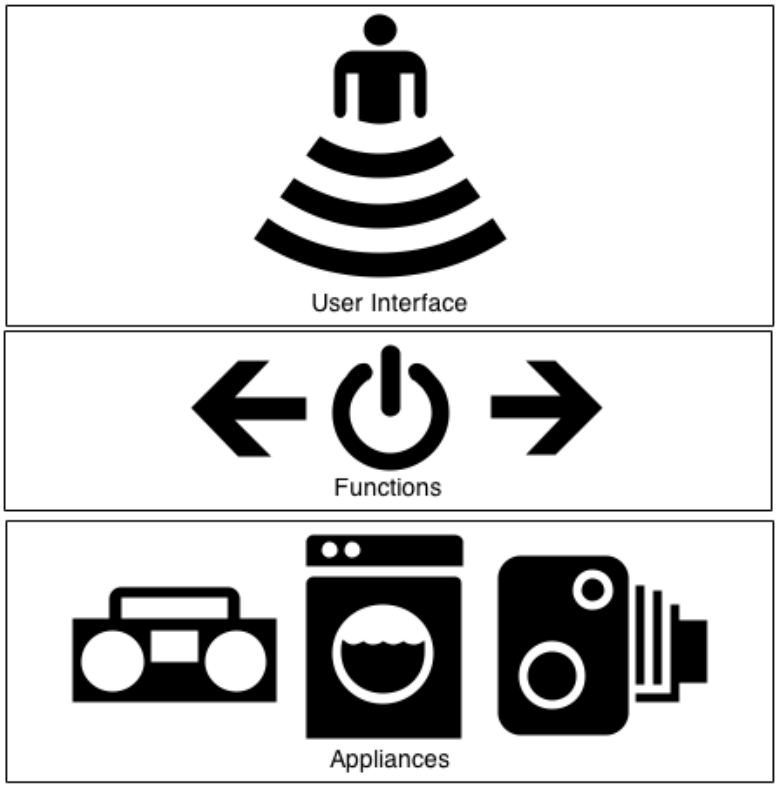


Figure 2.1: Aspects of Appliances Controlling System

### 2.1.1 User Interaction

In an appliances controlling system, the front end is the user interface. It determines the way how users control the appliances. The evolvement of the appliances interface could be described in Figure 2.2. In the beginning people are using control panels on the devices. To control the devices, direct touch interaction between users and devices is required. Then remote controls are invented, users can do the same operation without touching the device body. Until recently, smartphone applications started taking the places of normal remote controls. The last one is an sensor based automatic controller.

This development process indicated the users demand changes for controlling interface. The most common interaction with devices is touching it, like pressing a button, or turning knob on the surface of the device. After that, users need to control devices in a remote place. At this point, remote control and smartphone


Figure 2.2: Evolvement of the appliances interface

applications are working in a similar way. Although the smartphone applications have made the interface much more user friendly, the controlling process still require users to operate with devices. Then sensors are used to change this situation. With connecting sensors to appliances, the interaction between appliances and users has become more passive and transparent. Appliances now can be controlled automatically based on environment condition changes.

To summarize, Appliances Interaction is becoming more and more intelligent. A single way to control appliances could not satisfy users needs any more. Buttons on device and remote control will still be a indispensable part the most appliances. Therefore, a suitable combination of those basic methods, applications and sensors will become the trend of Appliances Controlling System. To provide more user-centered experience in the new wave of Cyber-physical environment, mobile communication and sensor network will play a major role.

### 2.1.2 Function Organization

The reason for users purchasing an appliance is to make use of its functions. Thus how the functions were organized will have have direct influence on the controlling process.

In general, functions are organized based on the mechanism and work process of an appliance. Then some interfaces like remote controls will express those functions to users. For example, a user want to adjust the temperature of the air conditioner, the normal way is to press the remote control buttons to change one degree by one degree. Meanwhile, a process in the user's mind is happening unconsciously. First the user should have a feel of the environment condition, like hot or cold. He knows that the air condition can help him changing the environment and make him more comfortable. Thus he takes up the remote control, finding the "+" or "-" mark which means the functions of changing temperature, then he uses those buttons to fit his need.

It can be seen from the process that the functions are appliance-centered. To take advantages of those functions, users have to understand what those functions means and how they can benefit the users. Somehow, the controlling process is more complicated than the real needs. It will be more helpful if the functions are user-centered, which means by understanding users need the appliances can execute the necessary functions without redundant users operations. In the case of air conditioner, the appliance should adjust the temperature by itself to the appropriate degree once the users need was detected. In this way the controlling process of Appliances Controlling System could become more user friendly and efficient.

### 2.1.3 Appliances Management

So far, most of the appliances controlling system are focusing on controlling one specific appliance at a time. There are many appliances at home, but they are working separately. One remote control for one appliance, and one button pressed to execute one function. There is no obvious relationship between appliances.

Similar to the Function Organization that was described above, sometimes users need is more than one function or one appliance. It could be a combination

of several functions from different appliances. Therefore, Appliances Controlling System need to make a view of all appliances in the environment. Appliances could be divided into groups based on different functions types. So that the system could help the users to concentrate on their tasks [10], instead of a complicated controlling process of appliances functions.

## 2.2. Implementation Approaches

Besides the basic structure, another important factor of appliances controlling system is how is it implemented. In general, to build a appliances controlling systems, there are mainly two approaches to implement. One is to build an integrated architecture for all appliances, the other one is to build an add-on module for existing appliances.

### 2.2.1 Integrated Architecture

An Integrated Architecture means that all appliances will have the same specific modules and protocols, so that those appliances can communicate with each other, or be controlled by an unified platform. This could provide features as below:

- Built-in communication module
- Multifunctionality
- Unified management interface

With these features, these appliances can work independently, but also they can work together to provide more functions like energy consumption management, or become part of a smart house system. This type of approach is often used by the appliances manufacturers for mass production.

### 2.2.2 Add-on Module

This approach is aiming at enhancing existing appliances with lower cost. The technology and mechanism would be different from different from one to another

depends on the appliances specification. The benefit is that the development could be more flexible. One add-on module can focus on one specific function. Therefore, comparing with integrated one, an add-on module will be more portable for implementation and installation.

# Chapter 3

# Related Works and Technology

Many researches about Appliances Controlling System have been conducted [3], there are also some related products have been developed. In the following part of this chapter, several works are introduced. After understanding each work's point of view, advantage and disadvantage, the issues and expected solutions are discussed.

## 3.1. Researches

Researches about Appliances Controlling System started from early on. It can be discussed from various angles. Since smartphone based home appliance controlling has become the main trend, works about smartphone and interaction will be introduced.

### 3.1.1 Smartphone-based Web User Interfaces

*Exploring Smartphone-based Web User Interfaces for Appliances* [6] created a system that can show control interface when users get nearby the appliances. They added an wireless module to the appliances to provide an Wi-Fi access point. Then they built a light weight web server so that the smartphone can access a web page as the control interface. With HTML5 and Javascript, the web based application could interact with the appliance.

The idea is very impressive, it provide a simple interface with no pre-installation

of software, no reliance on other networking infrastructure. But it might have compatibility issues for add-on module to appliances are required.

### 3.1.2 Tasks based controlling

As talked in Chapter 2, normal appliances controlling process has been focus on devices functions. It could be more user-centered by combine functions and appliances as group tasks based on users activity. Similar concept has been described in research of *From devices to tasks: automatic task prediction for personalized appliance control.* [10]

It adopted a approach of ubiquitous computing to realize the interaction. An IR receiver and a laptop was set in a living room. Then the users habits of using IR controlled appliances was recorded. By calculating and analyzing the results, the system could learn and predict the users activity.

### 3.1.3 Wireless Sensor Network Based Smart Home

The research of *Wireless sensor network based smart home: Sensor selection, deployment and monitoring* [2] is working on sensor based Smart Home. In this work many unobtrusive sensor are installed in different places of an user'house. With wireless connection, the system can collect all the sensors data to monitor the house environment.

### 3.1.4 Personal Universal Controller

*Personal Universal Controller* system(PUC) is about making a personal controller interface on mobile phones. [16]. Adaptors had been made as translation layers that are built between the PUC protocol and the appliance's proprietary protocol. This system was aiming to build a smartphone interface generator for Windows CE based smartphone. It will automatically generate appliance interfaces from abstract specifications of appliances' functions that are stored on the appliances. They refused to use web-based interface, because during that time, the performance and interaction of smartphones browsers were still poor. High quality interface can not be provided as nowadays.

### 3.1.5 Web 2.0 Service Platform

Another work *Web 2.0 Service Platform*(WSP) in [4] was developed for DPWS-based home appliances in the Cloud environment. WSP is composed of a cloud platform, home appliances and mobile users. WSP automatically records and observes user's behaviors to adapt related home appliances based on the ontology technique. Factors like date, weather and location are used for inference of users' behaviors. The system implements the DPWS appliances on a PC. Web2.0 Blog-based interfaces was built PHP and jQuery. It was easy to access from PC and smartphones, however users still need to concern with the information and functions of each appliance.

## 3.2. Standards

Public interest in topics of Home Energy Management System(HEMS) is increasing everyday. In order to connect energy generation, storage, and consumption equipment in house, a home network for appliances communication and controlling is required. Here are some standers for such systems. Before talk about appliances controlling, it is very important to understand the whole view of the home network.

### 3.2.1 ECHONET

ECHONET(Energy Conservation and Home care Network) [5] is a communication protocol for Smart House system. It was formulated by ECHONET Consortium[1] and had already become ISO and IEC international standard.

ECHONET aims at setting standards of communication technologies and utilization technologies for HEMS. The communications infrastructure for home network need to provide a reliable network that is compatible with conventional home appliances and equipment. [24] It defines the manage area as a domain, appliances or other electronics are the controlled resources inside of the domain. Then it separates equipment as different systems based on their functions and roles. Thus one appliance could be in different groups at the same time. It regards all equipment as objects, so that they can be controlled with a same interface. Then through

router and gateway system, the equipment are connected.

### 3.2.2 Homenet

Homenet(Home Networking) [8] is an IETF Internet-Draft[2], which is working on the protocol of network structure for devices at home. Main topics like IPv6, Subnet, Naming Method are discussed. Their focus is the networking technology within and among relatively small "residential home" networks. Particularly they are trying to develop an architecture based on IPv6. The structure will be a reference for the Appliances Controlling System. The scope of the architecture is described as below: [11]

- prefix configuration for routers
- managing routing
- name resolution
- service discovery
- network security

## 3.3. Technology and Trends

To control appliances, many communication technologies have been used. [13] [20] [1] The characteristics and trends of the main technologies of Appliances Controlling System will be discussed below. In Table 3.1, it shows the specifications of the major technologies.

### 3.3.1 Infrared

Infrared(IR) technology would be the oldest member in the remote control family. It is normal light with color, but its invisible to human eyes. Thus after modulating the blinking frequency of the IR light source, it can be encoded and send signal as command to appliances. Since manufacturers designed many protocols for their own products, here comes compatibility problems. It is also

| - | Infrared | Bluetooth | WiFi |
|---|---|---|---|
| Timeline | 1980 | 1994 | 1997 |
| Spectrum | Wavelength: 700 nm 1 mm | Radio frequency: 2.4 - 2.485 GHz | Radio frequency: 2 - 5 Ghz |
| Range | 10m | 10 m | 30-40m |
| Power Consumption | 0.163 mW | 0.147 mW | 0.210 W |

Table 3.1: Specifications of Major Technologies

limited by the environment such as line-of-sight, direction. But it is still the cheapest and most widespread solution for remote control, almost every family has more than one IR remote control at home. Although many new technologies are taking the place of IR [7], there are still market and room for improvement.

### 3.3.2 Radio Frequency

Instead of light, Radio Frequency(RF) is using radio waves as the signal transfer method. [21]. With longer wavelengths it can travel a further distance and also penetrate through objects like wall. This its great advantage. However, RF could be interfered by other radio signals like microwave ovens, cell phones. There are various RF standards, among them Bluetooth and ZigBee are the most popular choices in Appliances Controlling System.

#### Bluetooth

Bluetooth has been used in many fields in daily life, like PC, cell phone, speaker, and other accessories. It operates in the range around 2.4 GHz, and oriented toward eliminating short-distance cabling. Since created in 1994, it has been developed to the 4.1 version. With power-efficiency feature, many manufacturers have started to support Bluetooth communication as a built-in model.

#### ZigBee

ZigBee is based on IEEE 802.15 standard, which is similar to Bluetooth. They have some common characteristics in frequency band, small form factors and low

power. But different from Bluetooth, ZigBee protocols define a type of sensor network for residential and commercial applications. It aims more for grand-scale automation and remote control.

### 3.3.3 Ethernet and Wi-Fi

Another important technology using in Appliances Controlling System are Ethernet and Wi-Fi. It will be very convenient when connect appliances directly to the Internet. Since LAN or Wi-Fi network is no longer rare in normal homes, with corresponding module, the appliances will join in the home network. The module can either be a built-in function of appliances, or a controller device with network connection.

Ethernet can also be deployed as Power over Ethernet. So that it can supply power while transmitting data. Wi-Fi is actually one type of the RF technology, but since by connecting appliances to the Internet, it become more than point to point controlling method. Although with these two option it brings more possibilities, both of them are required more work and cost compare to other technologies above.

As table 3.2 shows, we can see that there is no perfect solution, each technology has advantages and disadvantages. Like the infrared is the cheapest one to use, but it is very easily to be interfered or blocked. Bluetooth and WiFi has the ability of penetration, they can work through walls and in a longer distance, and more flexible functionality, but the more possibility we want the more effort and hard work we need to take. Sometimes we need to combine the technology in proper way to provide best service.

## 3.4. Existing Products

Many related projects have also been developed to products and put into the market. Here is an overview of these products described in Table 3.3. Although they are using different technologies and approaches, there are some common characteristic from different aspects.

| Technology | Advantages | Disadvantages |
|---|---|---|
| Infrared | Low cost<br>Widely Used<br>Higher Security<br>Simple circuitry | Limited Reliable Range<br>Directionality<br>Light Interference<br>Clutter Protocols |
| Radio Frequency | Longer Range<br>Penetration<br>Duplex Communication | Signal Interference<br>Less Native Support<br>Deliberate Pairing Required |
| Ethernet and Wi-Fi | Functionality<br>Flexibility | Higher Cost<br>Complex Development and Deployment |

Table 3.2: Comparison of Major Technologies

### 3.4.1 Integrated Smart Appliances

Many appliances manufacturers are trying to transfer their products into an Smart Appliances platform. With integrated architecture, they have connect different appliances into their application on smartphones. Such as Panasonic Smart App[3] and TOSHIBA Feminity[4]. These systems provide more functions than normal appliances. For example they can record and analyse the power consumption, set timer for different appliances, etc. With this platform, the appliances at home can be managed very conveniently.

However, the price of these new appliances are much higher than normal ones. The applications on smartphones are only working for the few products of their own brand. This is the problems may cause by the Smart Appliances.

### 3.4.2 Controller Applications

Instead of Smart Appliances, many products as add-on controller device are also becoming popular. Because of the low cost and simple configuration, it is easier to make users to give a try on these products. Here are some typical examples to discuss the advantages and disadvantages.

| Product | Feature | Issue |
|---|---|---|
| Beacon | Combine IR and Bluetooth, IR command learning | Need IR Library support for accuracy |
| L5 Remote | Smartphone accessory, No installation need | Location and Devices limited |
| WeMo Switch + Motion | Sensor Trigger, Web API support | Only switch function |
| Nest | Habit learning, Condition detection, Auto control | Thermostat restricted |

Table 3.3: Products Features and Issues

### IRKit

*IRKit*[5] is an controller device which can connect with IOS applications through WiFi. It is an open source platform based on Arduino. User can use it to learn normal IR remote control commands and add them into applications. Then with IRKit and the application users can control their IR based appliances in any places. This device make it possible to enhance old appliances with smartphones. In additional, developers can also take advantages of the SDK to use API and other extensions.

However, normal users are expecting more integrated functions than API. Since the basic functions is like a combination of universal IR remote control, the controlling process and the interaction between users and applications is still based on appliances functions. There are also performance limitations on Arduino platform. Such as the stability of network connection, or the IR signal operation.

### Sensor Based

As the sensoring technology is developing, we've also seen the advent of various ranges of sensor-based smart controller and applications in our lives. *WeMo Switch + Motion*[6] can turn appliances, which plugged in the switch, on or off when the sensor detects movement. The WeMo devices are using Wi-Fi connection to communicate with each other and the user's smartphone. Application of IOS can

be used to setup and control the devices.

**Self-learning Support**

Another two products are kind of different from those above. *Nest*[7] and *Tado*[8] are both a portable thermostat and appliance controller device with pretty and tidy design. They can detect the users existence and switch the appliances automatically. With learning mechanism they can provide proper service based on users custom. They also have a nice look smartphone application as the basic interface. Users can monitor their appliances anywhere with Internet connection.

**Others**

*Beacon*[9] invented a universal remote control with no wires or power cables. The Beacon device is regarded as a bridge, smartphones can communicate with it through Bluetooth, through the smartphone application, users can send IR signal from Beacon to control there appliances. In addition, *Peel Universal Control*[10] and *Broadlink e-Remote*[11] are providing similar functions. For the Peel Universal Control an Ethernet cable is required, and Broadlink e-Remote needs Wi-Fi environment. Another product *L5 Remote*[12] is different from above, which is an accessory universal IR controller that can be plugged into iPhone or iPad.

## 3.5. Limitations in Appliances Controlling Systems

Several products have been discussed above, the common issues of current Appliances Controlling Systems could be seen.

### 3.5.1 Old Appliances Compatibility

As described before, to purchase the new Smart Appliances would cost a lot of money. Especially when users want to take advantage of the whole platform, they need to replace all the old appliances. But actually, normal family does not change their appliances just for some new functions. Most of the case they only


Figure 3.1: Remote Controls of old and new type of Air conditioners

change new appliances when the old one is broken or the family move to a new house. Thus compatibility for old appliances will help a lot on reducing cost.

Not only about cost, users demand for smart appliances are growing, but it is always to make the old appliance smarter. To explain the differences between old and new appliances, here comes an example. Figure 3.1 are two remote controls of old and new air conditioners. The remote could show the function differences of the two appliances. Left one is out of style with only 7 buttons. The right side is one of the newest, which have more function even a smartphone application besides the normal remote control. We can see the old one does not have the functions like sensor, smartphone support. The result is listed in Table 3.4.

### 3.5.2 Inflexible User Interactions

Since remote control has been invented, the interaction between users and appliances seems to be as simple as pressing buttons. Then as the functions becoming complex, more buttons need to be pressed by users. Even those smartphones applications, most of them are not more than a combination of remote

| . | OLD | NEW |
|---|---|---|
| Temp Control | + - | + -, Auto |
| Timer | 1 hour | Specific time |
| Smartphone App | No | Yes |
| Human sensor | No | Yes |
| Habit Learning | No | Yes |

Table 3.4: Function Comparison of Old and New Air Conditioner

controls on one screen.

For example the World Cup 2014 was finished last month in July 14th. As living in Japan, a fan who wants to watch the live game of world cup has to wake up in the early morning[13]. In normal case, after he get up, he need to make some interactions with appliances. Such as turning on Lights, turning on air conditioner and adjust the temperature, turning on TV and change to the right channel, etc. If those appliances have remote controls, the users would press buttons for many times. It is common, but actually the operation is redundant to some degree. So called Smart Appliances are not smart because of more functions, they should be smart also on the user interactions.

### 3.5.3 Summary

Many works and products were intruded above. The methodologies, features of those work are not identical with each other, nevertheless they have some certain limitation due to compatibility and usability of controlling process.

Owning to the diversity of communication technology, appliances in users home are always using different method, such as IR, RF, etc. Therefore it will be hard to use only one method as the solution, especially for existing products. Integration or expandability could help to improve this matter. Smart Appliances industry is not mature yet, more standardization work should be done.

The operation and interface of many of them are structured based on the appliances' functions and the normal remote control. The approach proposed in this thesis differs from them, because the target is to help users concentrating on their activities in daily life more than the appliances or devices. With the

sensor technology, users environment information could also be used as trigger of appliances controlling.

# Notes

1 http://www.echonet.gr.jp/

2 https://tools.ietf.org/wg/homenet/

3 panasonic.jp/pss/

4 http://feminity.toshiba.co.jp/feminity/

5 http://getirkit.com/

6 http://www.belkin.com/my/wemo/

7 https://nest.com/

8 http://www.tado.com/

9 http://griffintechnology.com/beacon

10 http://peel.com/

11 http://www.broadlink.com.cn/home/product.php?mod=RM2

12 http://l5remote.com.au/

13 http://www.asahi.com/worldcup/schedule/

# Chapter 4

# AnyControl: User-centered Universal Controlling System

## 4.1. User-centered Interaction

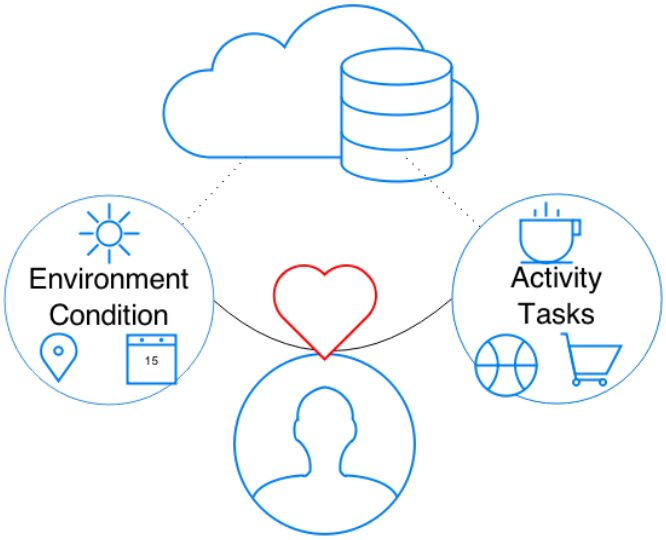


Figure 4.1: User-centered Controlling process

The study presented in this thesis is trying to provide User-centered experience for home appliances controlling. The concept is that users should not concern about the appliances, but their activities themselves(Figure 4.1). Users do not

need to look for the specific function of appliance on the remote control every time. For instance, there is a target user called Daniel who is a salary man. He is used to watch TV after coming back home in the evening. In normal circumstances, Daniel need to turn on the light, air conditioner, and the TV in his living room. There are several interactions between Daniel and appliances during the controlling process, however his goal is just have a relax. To simplify the controlling process could improve the user experience. The more transparent the operation could be, the convenient service he could enjoy.

Therefore, the controlling process should be organized based on tasks. The tasks will be defined by users according to their activities. With history record of the operations based on different activities, it could be also possible to support self learning and prediction service. And by tasks, the existence of appliances will be diluted. Only the functions that related to current activity will be added into the operation list of the very task. To trigger each task, not only applications interface can be used, but also sensors and other web services APIs. As a result, the controlling process will be executed automatically while users' activities are proceeding.

The system should able to deployed in normal home environment. So that normal user could apply it to the existing appliances easily. Instead of changing the appliances, an add-on module will be more convenient and fast. Compatibility and Usability are the two main terms need to be considered.

## 4.2. System Objectives

Based on the study of current appliances controlling system limitations and the user-centered concept, this proposed system has three objectives.

### 4.2.1 Enhance Old Appliances

In Chapter 3 the limitation of old appliances compatibility was talked. Every new generation of appliances will bring many new functions. For example, when we talk about the automation of air conditioner, normal ones have the timer function. Users can set a specific time to turn it on or off. But that is all they can do with the old ones. In the case of new model, the air conditioner can run

| . | OLD + AnyControl | NEW |
|---|---|---|
| Smartphone App | Yes | Yes |
| Human sensor | Yes | Yes |
| Habit Learning | Yes | Yes |
| Group Work | Yes | No |
| Task Macro | Yes | No |
| Multisensory | Yes | No |

Table 4.1: Enhanced Functions of Old Appliances

by itself based on the condition of human sensors, power saving plan, custom learning, human body comfort, etc.

The old appliances are lack of those functions, but if we add sensors, network connection, condition processor as an add-on module to the old ones, they can be enhanced and even have more functions than the new models. Thus the table of function comparison in Chapter 3 will be rewrite as Table 4.1.

### 4.2.2 Task based Appliances Automation

As the Daniel example and the one of watch live football games in Chapter 3. When the user want to watch the game, he has to make many operations to control appliances. But in fact the goal of the user is to enjoy the game, all the operation is serving for that goal. Therefore the appliances should be controlled based on the users need but not the appliances functions.

Task is defined for users need. Each task will have a list of appliances operations, and each task will also have a trigger event. The trigger event could be some specific users operation or based on the sensor condition change. Users can configure tasks based on their daily activity. They can add the appliances and functions they need and set the trigger condition of environment or operation. Then without too much attention on appliances, they can work automatically to help users.

### 4.2.3 Environment Sensor Data Streaming

Sensor data could help users to control appliances, on the other hand the environment condition information would be very useful in many cases. Users can monitor their house condition with the data in a remote place. Or the computer can analyse the data to make advises and provide the information in proper moment for users. Or the data could be used not only inside a family, it can be used in a range of community, to provide more helpful result in different fields.

## 4.3. Methodology

As described in Chapter 2, the basic structure of Appliances Controlling System consists of User Interaction, Function Organization, and Appliances Management. To apply the concept to Appliances Controlling System, the methodology need to start with this basic structure.

### 4.3.1 Controlling Interaction

The interaction of User-centered Appliances Controlling System should follow the principle of simple, nature, transparent. The interface should be easy to understand and self-explanatory, no matter what kind of interface to be used. It should take into consideration of user habits on traditional appliances controlling. So that even through interfaces like smartphone applications, web pages or dedicated devices, users can take advantages of their knowledge and custom from the normal control panels, remote controls, etc. Then, in terms of task based controlling and sensor trigger, the interaction should be transparent and unconscious from users activities.

### 4.3.2 Appliances Functions

Differentiate from general functions on remote control. In tasks based controlling, the functions should be more abstract to correspond and describe users activities. This requires to summarise and classify current appliances functions in normal controlling system. The system should provide explicit functions to users like "Cool the living room", and tell appliances what to do in a detail process.

### 4.3.3 Appliances Groups

Appliances are not working alone. Even without physical connection between each other, the logical relationship during tasks based controlling need to be defined. Task become the unit of controlling process, functions from different appliances make up the task. Thus appliances existence will be diluted during the task. But in order to manage appliances it is still important to organize each appliance as an object with their information and functions. Name, role, tag, group and other properties should be given to the appliances.

### 4.3.4 Environment Data Collection

Thanks to developing of sensor technology, there are many kinds of environment sensor can be used easily. As the sensor is also a part of the appliances controlling system, it need to be compact, less power consumption, and the generated data should be in simple format. The system will use the sensor data in two ways. One is to stream it in real time for monitoring and task trigger, the other one is as record database for analysis.

## 4.4. Systems Architecture and Components

## 4.5. Architecture

Figure 4.2 is the basic architecture of the system. Information as input are the users activity and environment data. Inside the system, tasks will be defined based on the input, and make a connection with appliances functions. On the other hand, environment sensor data will be used as trigger event and record input. Then as output, the system will control the appliances in the task, also provide useful information or recommendation to users.

In Figure 4.3, the essential components of the User-centered Appliances Controlling System is explained. The components include Universal Controller, Cloud Center, and Interface Application. Each part is playing the different role to contribute to the concept stricture.

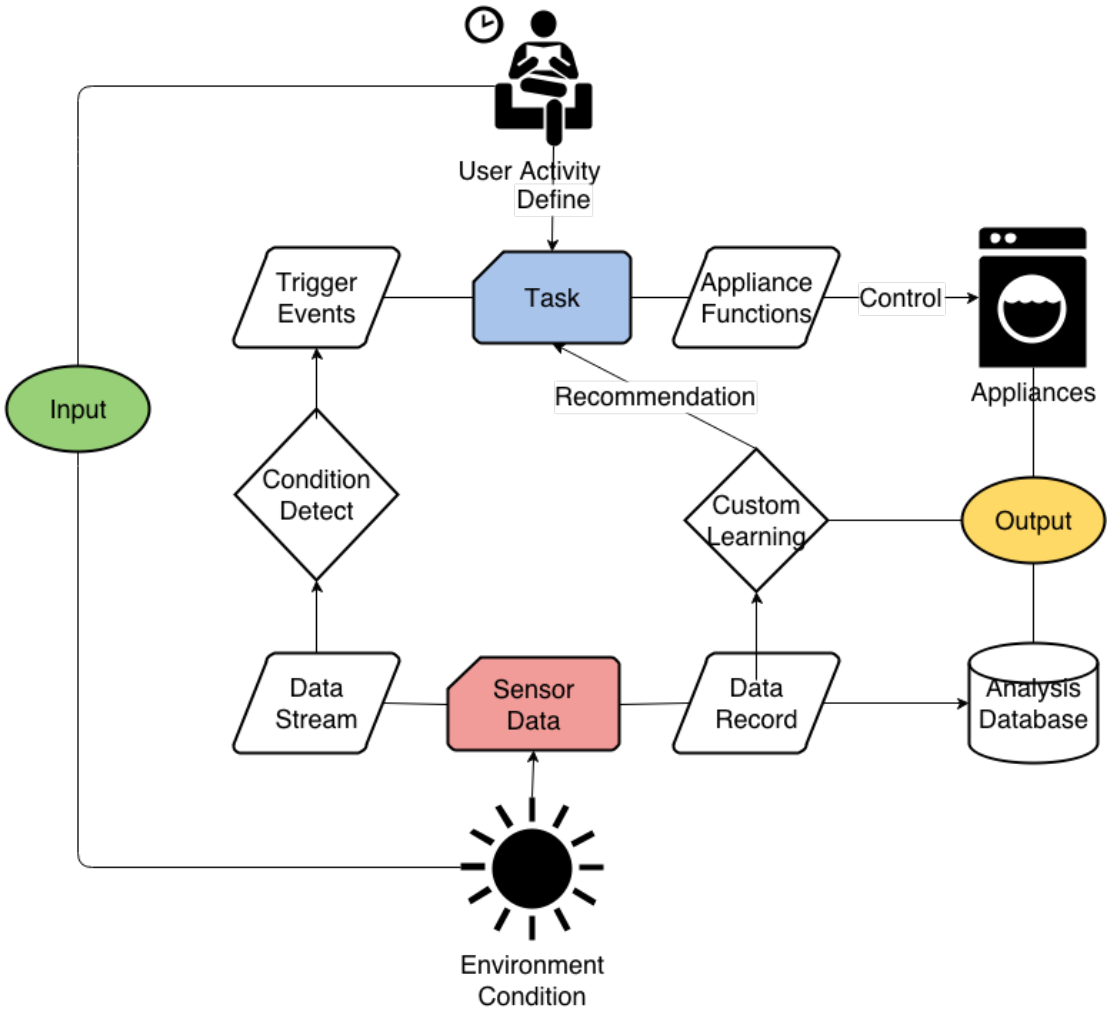


Figure 4.2: System Architecture Diagram

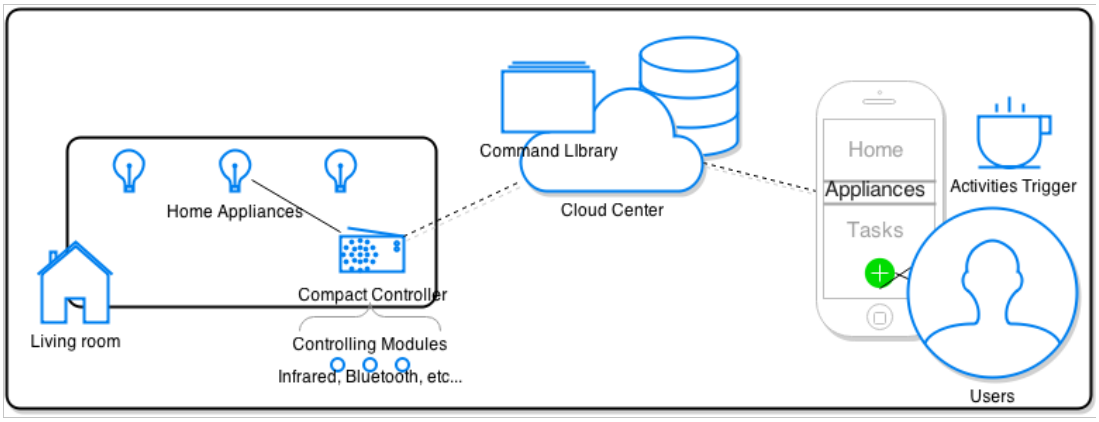


Figure 4.3: The System Components

### 4.5.1 Universal Controller

The Universal Controller is the part to communicate with home appliances. It should be a dedicated device with required features as below:

- Compatibility
- Modularity
- Portability
- Network connection
- Low Energy

Due to the divers controlling types of home appliances, the system need to be as much compatible as possible. Support controlling methods should include like IR, Bluetooth, WiFi, etc. So that the Universal Controller should be able to apply to different types of appliances. With module support, users can choose the control modules they need and add them to the controller. Thus the controller can work for a wider range of appliances.

To control appliances with one controller, the position to set up the controller will be different depends on different house. Portability means compact and simple. The required space need to be compact, also with low energy supply.

Therefore regardless of the environment, the installation can be finished with less effort.

### 4.5.2 Cloud Center

Cloud Center will be the communication and data center to support the Universal Controller and Interface Application. Its jobs are mainly in the aspects as below:

**Web Server**

Provide service for the Interface Application. Response requests from the application and send back results to users. It will also collect information from other web services APIs, sensors to connect with users' activities.

**Database**

Store the commands library, users' information, configuration of appliances, tasks and commands lists, and the record of usage data.

**Control Center**

Monitor the conditions and retrieve the corresponding task and commands list, then send them to the controller to make the appliances work.

**Analysis and Computing**

Analyse the usage and environment record data, learn the user habit, predict and provide recommendations.

### 4.5.3 Interface Application

The Interface Application is used to interact with users. It contains the layers of hardware and software parts (See Table 4.2). Hardware parts include the environment sensors, information displays like smartphone screens. Software part will be the applications working on different devices. With it users can setup the appliances configuration, controlling tasks and start tasks to control appliances by groups. To help users to control appliances more conveniently, the application should be accessible from different platforms, like PC, tablet, smartphones, etc.

| Layer | Element | Role |
|---|---|---|
| Hardware | Display | Prompt information, show interface of application |
| | Environment Sensor | Detect users activities, environment condition |
| Software | Applications on different platforms | Interact with user and transfer data with Cloud center |

Table 4.2: Hardware and Software Roles of Interface Application

This is the essential design of the User-centered Universal Controlling System. The implementation will be based on it.

# Chapter 5

# Implementation and Evaluation

## 5.1. Related Technology

Since this research is focusing on improving user experience of home appliances controlling, it is necessary to utilize technologies whereby prototype can be developed rapidly.

Nowadays, there are several main types of communication technologies are being used for appliance controlling. As described in Chapter 2, those include Infrared(IR), Bluetooth, ZigBee, Wi-Fi, etc. Although IR is the oldest remote control solution, it's still active in appliances controlling. And due to its widespread use in home appliances controlling, it will be more compatible for the old models in users' family. Thus IR will be used in the first step.

On the other hand, single-board computer like Arduino and Raspberry Pi has become a very popular platform for making prototype. With good processing capability, flexibility and extensibility. Such devices can easily connect to wired and wireless networks, work with IR and Bluetooth modules, and also take advantage of various types of sensors. Consequently, those devices will be very appropriate for development of universal remote control.

For the user interface, web-based application was selected instead of native applications for one specific platform. Because of the widely adoption of HTML5, Interface Applications are becoming more and more powerful and interactive. In the meanwhile, the advance of smartphones capabilities make it possible to browse same web pages as desktops. Therefore, the development, maintenance

will be more efficient especially for cross-platform.

There also a lot of sensors to collect environment information. In the appliances controlling environment conditions like temperature, humidity, luminance are required. Due to the need of compact and portable, an integrated sensor will be more appropriate.

## 5.2. Scenario Settings

A scenario that to help one user to enjoy watching TV was defined for prototypes. As described Daniel example in the Chapter 4, the purpose of the action watching is to relax. Therefor all the related appliances operation will be combined and defined as one specific task. User can enjoy the time by starting the very task instead of pushing buttons on the remote controls one by one. The implementation process was following this scenario.

## 5.3. Requirements

According to the concept of the User-centered Universal Controlling System and the related technology, the requirements of the system are listed as Table 5.1.

### 5.3.1 Universal Controller

The Universal Controller will be built on single-board computer. In the case of IR appliances, IR receiver and transmitter will be required. With the IR module, the controller can send IR signal command to control appliances. The IR command will be collected from normal remote control by self-learning function or downloaded from the server library. Network connection either by Ethernet or Wi-Fi is also indispensable. In the future, more modules could be added to extend the controllers' functionality. Such as Bluetooth or other control method, and sensors for triggering control tasks.

| Universal Controller | |
|---|---|
| Requirements | Usage |
| Single Board Computer | Communicate with Cloud Center through network, control appliances with corresponding command signal |
| Infrared Module | Process Infrared Signal |
| Cloud Center | |
| Requirements | Usage |
| Light weight Web service | Provide HTTP server for web application |
| Python | Analyse data and condition |
| Redis | Key to value database, to store realtime environment data |
| Interface Application | |
| Requirements | Usage |
| Flask | Basic Web site framwork |
| Angular | Build structure web appication |
| Multi-Sensor | Collect environment information |
| Others | |
| Requirements | Usage |
| Ethernet, WiFi | Network connection |
| AC adapter, battry | Power supply for devices |
| Test appliances | Evaluate system function |

Table 5.1: System Requirments

### 5.3.2 Cloud Center

At present, the scale of the system is still limited into one living room. Thus Cloud Center is not required too much function. Part of it could be integrated within the Controller device. Like simple web service and controlling command handling work. HTTP request will be the basic communication protocol to use. Thus light weight web framework need to be provided on the web service. A database is required for the sensor data recording in real time. NoSQL database such as Redis will be suitable.

### 5.3.3 Interface Application

This Interface Application will take the advantage of HTML5 features to ensure the best interactive experience for the users regardless of the accessing device. There will be two main menus on the interface, one is Appliances and the other is Tasks. First, users need add a new appliance. To make the setup operation as simple as possible, users do not need to input detail information of the appliances. After naming one new appliance, users can search and add the commands list from the server library by input the model number, or they can use self-learning function. Press the self-learning button, the controller will enter learning mode, it will record the IR signal sent to it. Then the application will ask for confirming, and adding a name and icon for that command. Users can customise their commands list with this function. Next, users can create tasks with the configured appliances. The appliances list will be shown beside the task editing panel. Users can select the commands from any appliance they need, and add it to the current task. At last, users can define the trigger for each task. Triggers can be provided with timer, web services APIs, sensors that related to users' activities. Or just one start button on the application. An environment initial prototype should have the basic condition sensory like temperature and lightness

## 5.4. Initial Prototype

### 5.4.1 Expected Result

During the development of initial prototype, complex functions are not involved. The main target of this stage is to confirm factors as below:

- Capacity of Universal IR Control
- Feasibility of Task Control Flow
- Usability of Web Application

### 5.4.2 Arduino based System

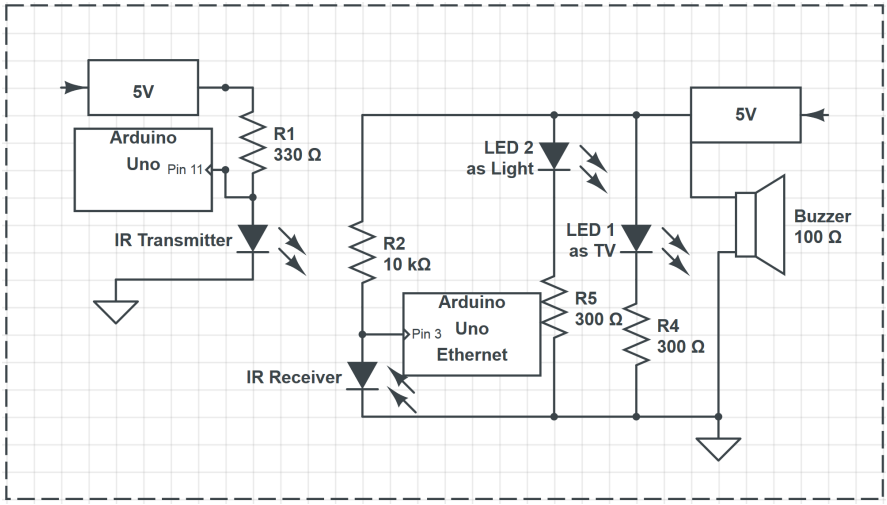


Figure 5.1: Circuit diagram

One Arduino is used as the Universal Controller, the other one is assumed as several appliances (see Figure 5.1 and 5.2). Although this prototype was not implemented with real appliances, the IR signals, which was used for the two Arduinos to communicate with each other, are recorded from existing IR remote control. The reason we choose virtual appliances is we want to test Arduino's capacity and the feasibility of our concept.

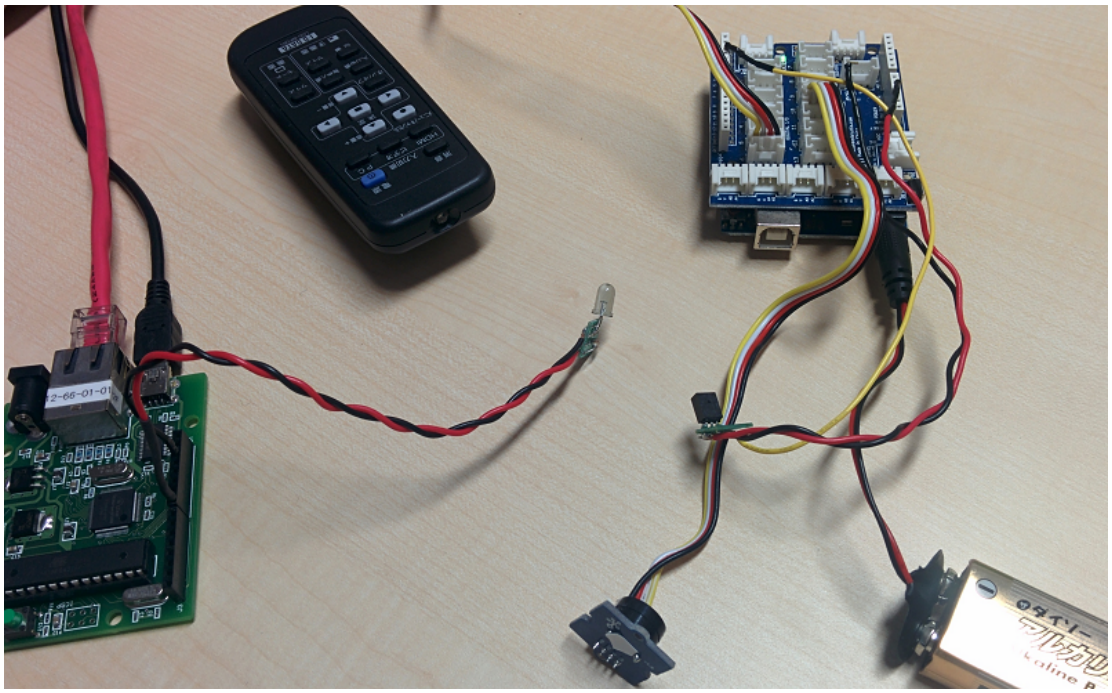

Figure 5.2: Requirements of the initial prototype

### Virutal Appliances

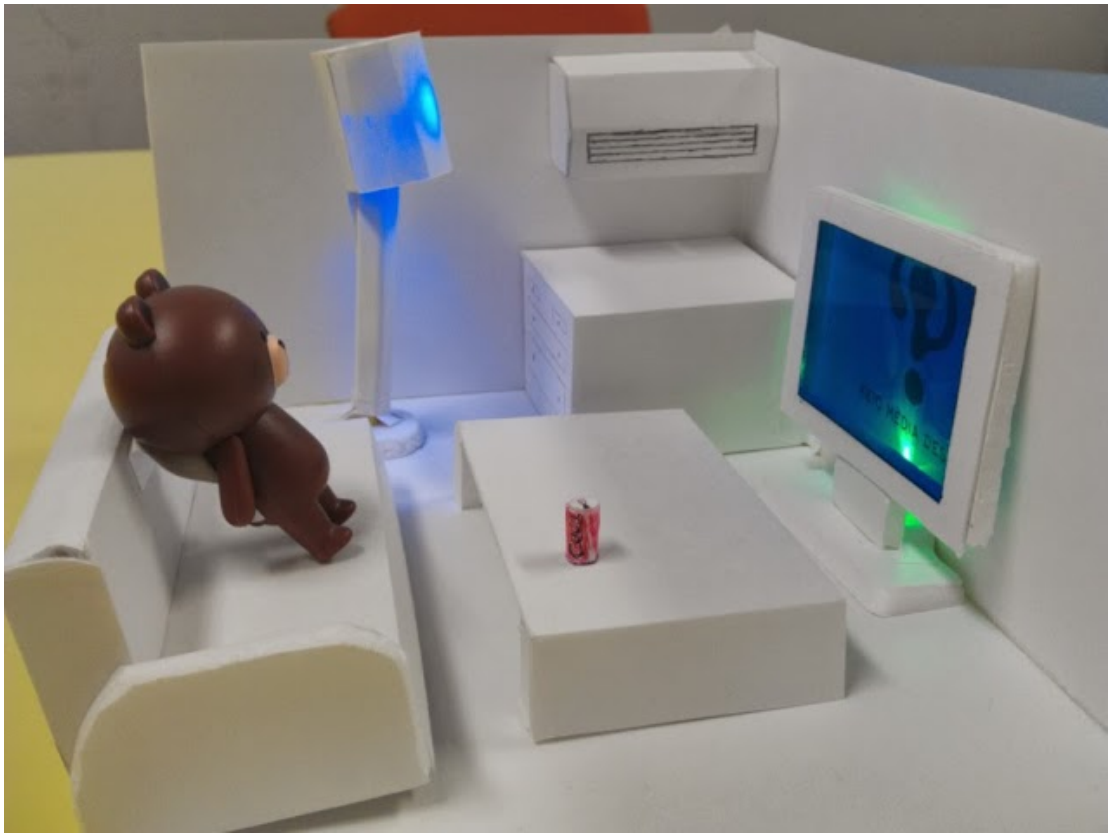

Figure 5.3: Virtual Appliances: front side

To begin with, we took advantage of Arduino IR library [25] to handle with IR signal. Several IR signals were recorded from a normal remote control with programed Arduino. Then a Arduino was used to build the living room prototype with three virtual appliances, two LEDs regarded as a TV and a light, and a buzzer regarded as an air conditioner. There is one common IR receiver for them, and the Arduino was programed to trigger different component according to different IR signal that were recorded before. The structure of the virtual appliances are shown in Figure 5.3 and 5.4.

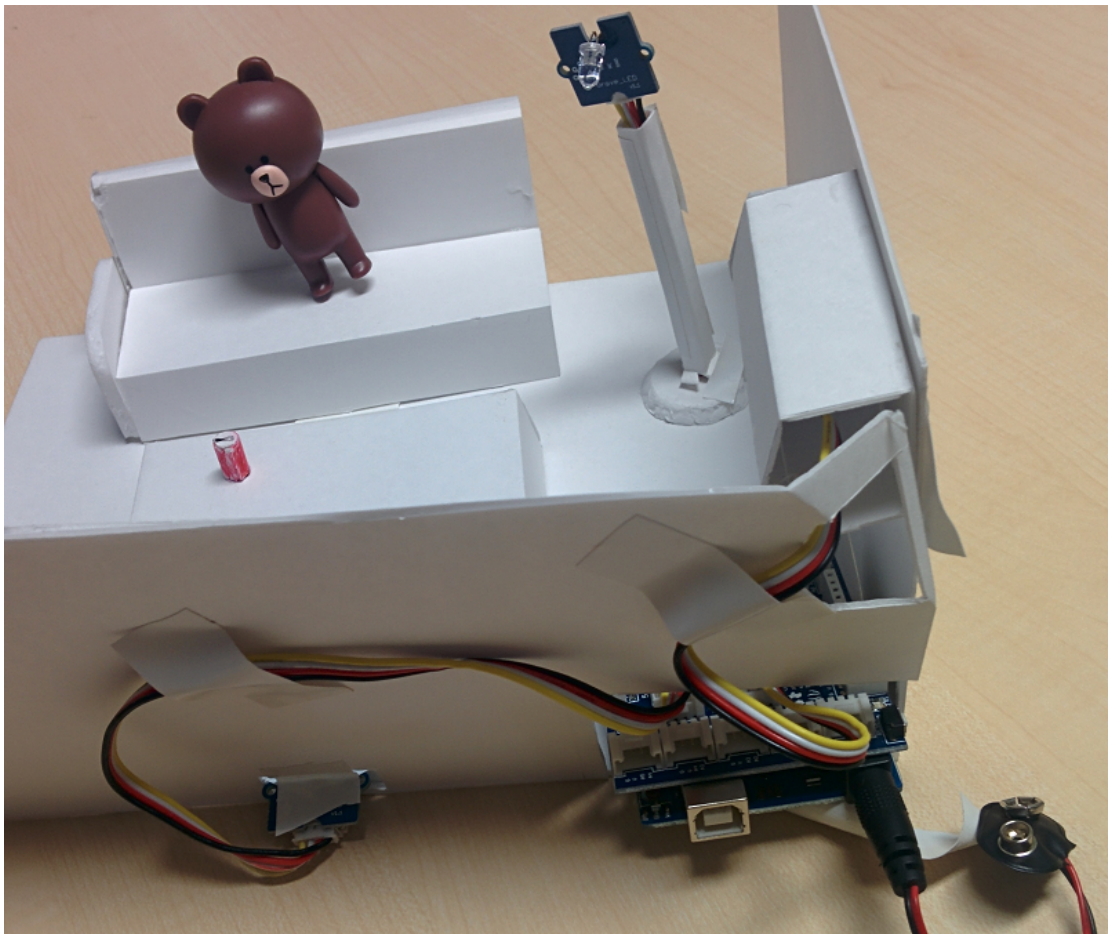

Figure 5.4: Virtual Appliances: back side

### Infrared Module

After that, to build the Universal Controller, an IR transmitter and Ethernet connection was added to the other Arduino. With Internet connection, there are different methods to communicate with Arduino. Since the user interface will be based on b application, HTTP request should be one good option, because it is easy to operate with URL and defined parameters through web pages. To response from user and control appliances, a simple web server on Arduino was created. According to parameters in the HTTP request, the Arduino will send different IR signals as response.

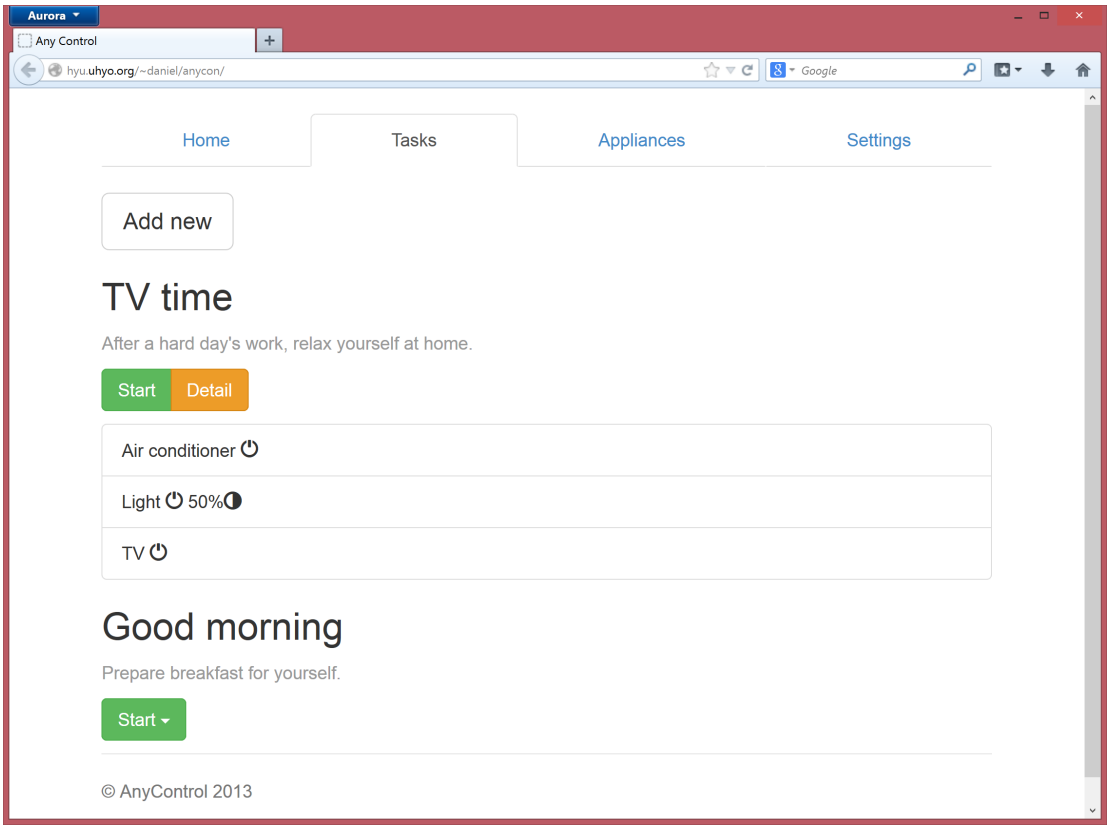


Figure 5.5: Task menu in the application

### Web Application

As Figure 5.5 shows, a demo Web Application was created with HTML5 and jQuery to interact with users. In the appliances menu, there is a list of the virtual appliances and some commands to control them. Such as turn on/off, adjust the brightness. Users can use these buttons to control the virtual appliances directly. In the tasks menu, there is one task called "TV time". It represent for an activity of watching TV. In the commands list the commands to turn on TV, light and air conditioner were added in order. By pressing the start task button, a series of HTTP request will be sent to the Arduino of virtual appliances. We also added a timer example, it can trigger the virtual appliances after a specific time.

**Specifications**

The initial prototype was built based on Arduino. In table 5.2 are the specifications for the prototype.

| | |
|---|---|
| Arduino Uno with Ethernet Shield | Receive controlling command from Cloud Center, calculate corresponding IR signal |
| IR transmitter | Send IR signal based on controlling command |
| Internet connection with Ethernet cable | Communicate with Cloud Center |
| Apache server | Provide service for Interaction Application and send HTTP request to Arduino |
| HTML5 based Interaction Application | Provide interactive function |
| Tablet PC | Show and test application Interaction Application |
| Multi-Sensor | Detect comprehensive environment information |
| Arduino Uno | Handle IR signal and turn on virtual appliances |
| IR receiver | Receive IR signal from controller |
| LED light * 2 | Virtual appliances as TV and light |
| Buzzer | Virtual appliance as air conditioner |

Table 5.2: Prototype Specification

### 5.4.3 Evaluation

After implementing the initial prototype, a test was conducted for evaluate the performance and the possibility of the proposed design. A tablet PC (see Figure 5.6) was used for accessing the application. With Wi-Fi connection test users


Figure 5.6: Testing with tablet PC

can communicate with the controller by click the buttons on the web application. Then the application will send HTTP request with specific parameters and call the corresponding function to control the virtual appliances. There are several factors evaluated.

- Response time of Universal Controller after a task or a controlling command was sent
- Response time of virtual appliances after the controller sent IR signal
- Working distance between the controller and the virtual appliances
- Duration time between each command in one controlling task
- Scalability for more commands in one controlling task

- Usability and interactivity of the application

The prototype was provided to random users in a demo showcase. First, users' were interviewed about their habit of home appliances controlling. Then, the concept and the operation of the prototype was explained to them. By understanding the prototype, tablet PC was provided to users to experience the process of task controlling. The performance of the prototype was recorded during the users' operation. The feedback and comments from users are also collected.

By the test of initial prototype, we found that the Arduino web server is not stable enough. Despite of the network condition, it takes about one second from pressing the button till appliances' reaction. Sometimes the Arduino server can not response the requests. There is also limitation in the IR commands library of Arduino, it will be hard to apply it to more of the real appliances. Due to only one general IR transmitter was used, only distance less than 3 meters was reachable. Theoretically, by defining a interval time of more than 2 seconds between each IR command, there will be no conflict while sending IR signal. However, when more than 7 commands were added into one task, sometimes the rest commands can not be reacted well. With these results, the implementation was revised and development of next prototype was conducted.

## 5.5. Advanced Prototype

### 5.5.1 Expected Result

Although the initial prototype has many limitation, the basic architecture of the system was exposing to users. To improve the prototype and solve the problems happened in the initial prototype. More results are expected in this stage.

- Improve IR Controller Performance
- Working Demo on Real Appliances
- Taking advantage of Environment Sensor

### 5.5.2 Raspberry Pi and Multisensor based System

#### LIRC

Due to Arduino has many limitation, the Linux based Raspberry Pi platform was used instead. Thanks to the LIRC(Linux Infrared Remote Control), the IR operation could be easier and powerful than the previous one. Figure 5.7 shows the Universal Controlling System built with Raspberry Pi. Using Infrared Module and LIRC(Linux Infrared Remote Control), it can easily record IR commands from normal remote control.

#### Appliances

For scenario setting, we choose a test user'house which has TV, air conditioner and light all can be controlled by IR remote control(Figure 5.8). The three appliances are from different manufacturers, thus the IR protocol is also different from each other. It can help to test the Raspberry Pi and LIRC compatibility.

#### Appliances Controlling

After the prototype was configured, we started the appliances controlling test. The three remote control were used to record the IR signals(Figure 5.9). The LIRC will generate the remote config file for each remote control. Inside the file, the IR signal was listed with corresponding button name. Using Flask web framework, the Raspberry Pi can provide a web service which can call LIRC functions by HTTP request. The appliances and the basic functions are shown on the web interface as Figure 5.10. With this interface, user can control appliances directly like normal remote control, or use the task interface implemented in the initial prototype. The next step is to add sensor to the system.

#### Environment Sensor

An Environment Multisensor(Figure 5.11) was provided by a cooperation company. It is an compact device with integrated sensor. A brief specification is shown in as Table 5.3, and Japanese inFigure 5.12.

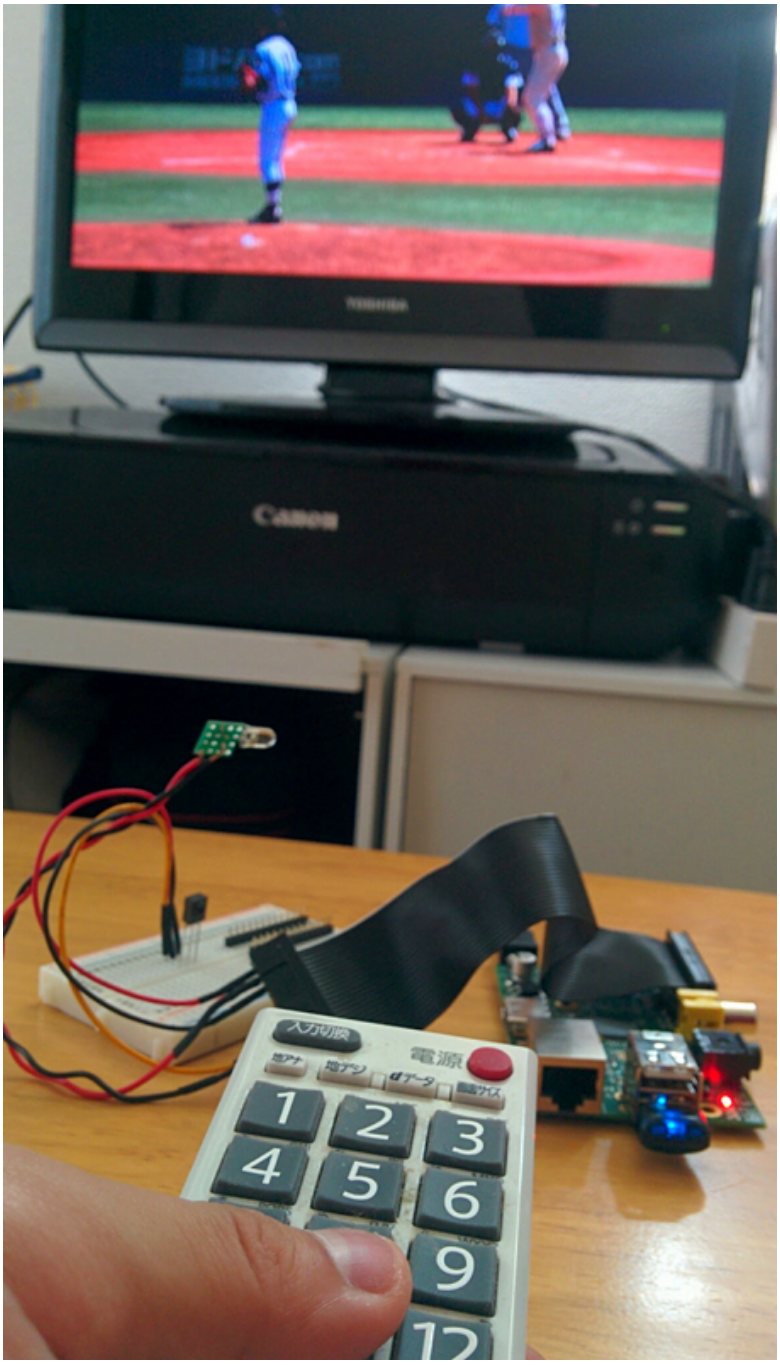


Figure 5.7: Raspberry Pi and IR module


Figure 5.8: Remote Control of Test Appliances

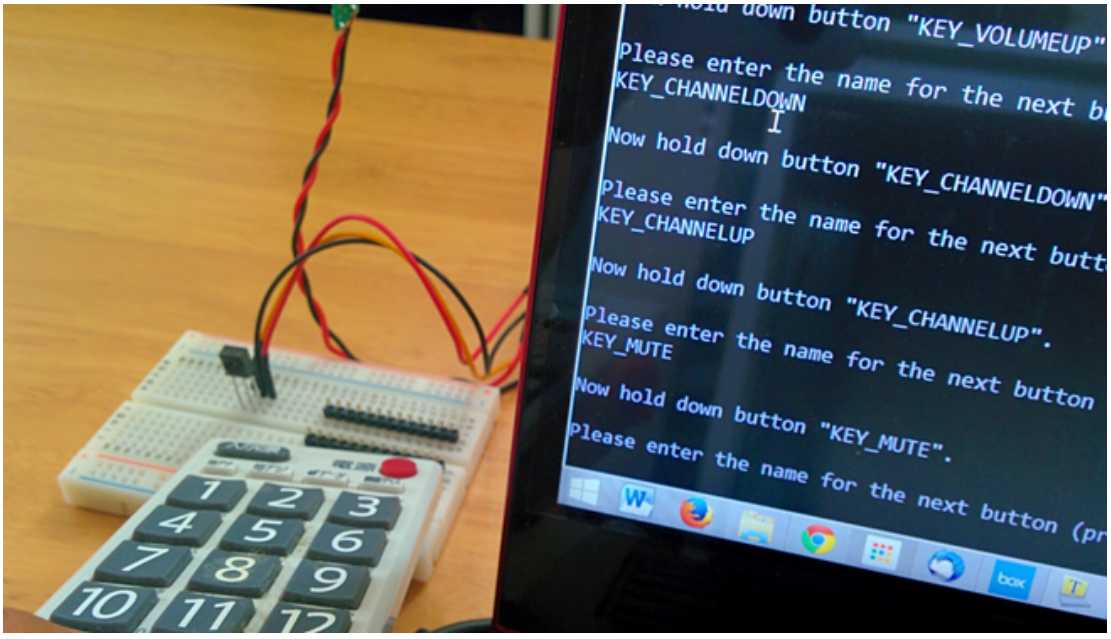


Figure 5.9: Recording IR signal from Remote Control

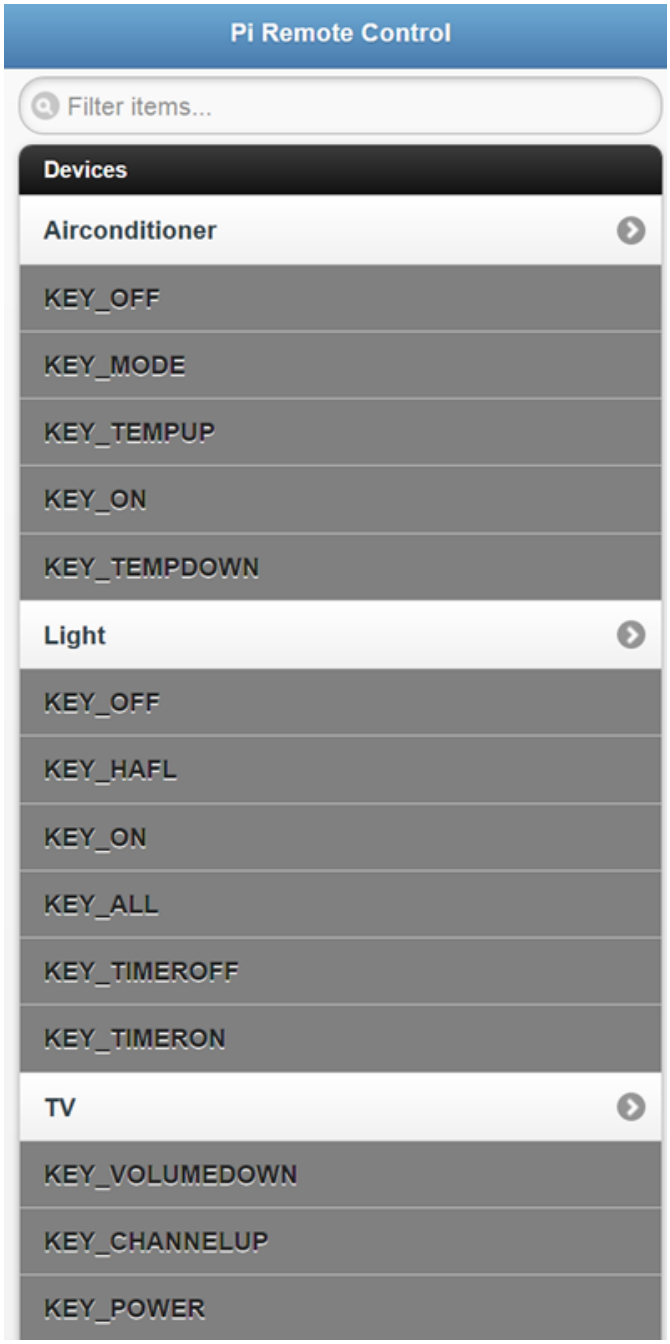


Figure 5.10: Web Interface for Appliances

Figure 5.11: Compact Environment Sensor

| Sensor | Specification | Other |
|---|---|---|
| Air current | +/- 1.0m/s | With wind direction |
| Infrared temperature | 5 50C | 4x4 Unit |
| Temperature | 0 70C | accuracy +/- 0.5C |
| Humidity | 0 100% | accuracy +/- 3%RC |
| Air pressure | 70 110 kPa | accuracy +/- 400Pa |
| Illumination | 0 1200 lx | Indoor |

Table 5.3: Products Features and Issues

| 項目 | 仕様 | 備考 |
|---|---|---|
| 気流センサ | +/- 1.0 m/s | 風向，風速検出可 |
| 赤外線温度センサ | 対象物温度範囲 5～50 ℃ | 4x4素子　視野範囲 約35° |
| 温度センサ | 0～70 ℃ | 精度 +/- 0.5℃　(typ.) |
| 湿度センサ | 0～100 % | 精度 +/- 3%RH　(typ.) |
| 気圧センサ | 70～110 kPa | 精度 +/- 400Pa (typ.) |
| 照度センサ | 0～1200 lx | （室内用） |
| 通信 | USB (シリアルポート) | |
| 電源 | USBによる給電 | |
| 外形寸法 | Φ60 x 46 | |

Figure 5.12: Brief Sensor Specification

The sensor can write log file every second. An Redis database was added to the python web server to collect sensor data in real time. Log data was converted to JSON format, a data sample is as below:

{"DateTime":"14/04/24 18:19:32:059",
"pmv":"−0.12","temp":"25.23","humi":"28.37","light":"838.00",
"pres":"1004.90","velo":"0.38","radi":"25.36","vx":"0.00",
"vy":"−0.38","ir00":"24.29","ir01":"24.39","ir02":"24.39",
"ir03":"24.19","ir04":"25.19","ir05":"24.39","ir06":"24.29",
"ir07":"24.19","ir08":"29.39","ir09":"27.09","ir10":"24.09",
"ir11":"24.19","ir12":"29.89","ir13":"27.69","ir14":"24.09",

"ir15":"23.89","vt":"3.23"}
{"DateTime":"14/04/24 18:19:33:152",
"pmv":"-0.30","temp":"25.23","humi":"28.37","light":"781.00",
"pres":"1005.10","velo":"0.30","radi":"25.20","vx":"0.05",
"vy":"-0.30","ir00":"24.29","ir01":"24.39","ir02":"24.39",
"ir03":"24.09","ir04":"25.39","ir05":"24.50","ir06":"24.29",
"ir07":"24.19","ir08":"29.59","ir09":"28.00","ir10":"24.09",
"ir11":"24.29","ir12":"27.19","ir13":"26.59","ir14":"24.09",
"ir15":"23.79","vt":"3.23"}
{"DateTime":"14/04/24 18:19:34:333",
"pmv":"-0.29","temp":"25.23","humi":"28.37","light":"777.00",
"pres":"1005.10","velo":"0.33","radi":"25.28","vx":"-0.07",
"vy":"-0.32","ir00":"24.50","ir01":"24.39","ir02":"24.39",
"ir03":"24.19","ir04":"25.39","ir05":"24.39","ir06":"24.29",
"ir07":"24.29","ir08":"29.39","ir09":"27.50","ir10":"24.09",
"ir11":"24.29","ir12":"28.09","ir13":"27.29","ir14":"24.19",
"ir15":"23.79","vt":"3.23"}
{"DateTime":"14/04/24 18:19:35:088",
"pmv":"-0.37","temp":"25.23","humi":"28.43","light":"767.00",
"pres":"1005.10","velo":"0.35","radi":"25.17","vx":"0.11",
"vy":"-0.33","ir00":"24.29","ir01":"24.29","ir02":"24.29",
"ir03":"24.09","ir04":"25.29","ir05":"24.29","ir06":"24.29",
"ir07":"24.19","ir08":"29.29","ir09":"27.39","ir10":"24.00",
"ir11":"24.09","ir12":"28.00","ir13":"27.19","ir14":"24.00",
"ir15":"23.69","vt":"3.23"}

Inside of the sample data, there are 4 records in 4 seconds. In each set, the first item is the date and time recorded. Then the detail environment condition value followed. For example the 'temp' is temperature, 'humi' is humidity, 'light' is Illumination, etc. Since JSON format is very flexible especially on web service, this data can be used as an API to provide different services. These are some usage purpose:

- Real-time environment condition streaming

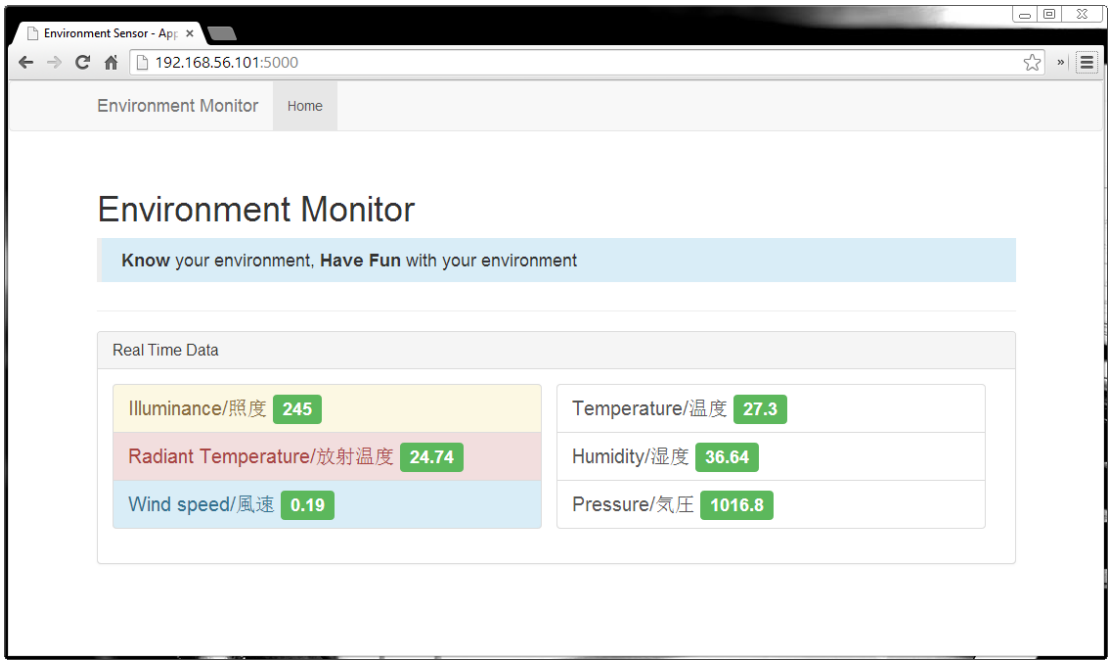


Figure 5.13: Web Interface for Environment Sensor

- Personal optimum environment learning
- Community environment analysis

The data could be accessed through web browser and streamed to users(Figure 5.13). This interface is used for browsing in real time. When the value of different item changes, the interface will change its style as well. A Listening function was made to monitor the sensor data change, if new data was detected, the server will send realtime JSON data to the user client. The sample data captured by the server is as shown like this:

The server Listening function code is as Figure 5.14. This function is used as the trigger function to control appliances. When the specific sensor data value change was detected, the server will call the controlling functions to send commands to appliances. By add the condition values as triggers to controlling task, the system can enhance the old appliances to have more smart functions.

```
def listening():
 # Listen to Redis operation on selected key
 sub = r.pubsub()
 sub.psubscribe("__key*__:" + mylist)

 # Initial data counts in Redis list
 count = r.llen(mylist)

 # print current_thread()

 while True:
  for m in sub.listen():

  # No Clients, Wait...
  if clients == 0:
    continue

  # When "rpush" operation was detected
  if m['data'] == "rpush":
    # Data counts after rpush
    count_new = r.llen(mylist)
    # Avoid error after delete Redis list
    if count > count_new:
     count = 0
    # Skip redundant listening
    if count_new != count:
     print "Pushed Data from " + str(count) + " to " + str(count_new)
     # Retrieve newest data
     data = r.lrange(mylist,count,count_new)
     # print json.dumps(data)
     # Push data to client
     for d in data:
      socketio.emit('push', d, namespace='/main')
      print d
      time.sleep(1)
     # Reset data counts to current value
     count = count_new

# Open new thread for Listening function
listen = Thread(target=listening,name="ListenRedis")
listen.daemon = True
```

Figure 5.14: Listening function code

### 5.5.3 Evaluation

LIRC has strengthen the IR capacity to a large extent, but there are still no absolutely guarantee that it can record all remote signals correctly. Since the system need to read from Redis database and then analyse the data, the communication between web server and Redis database generated a delay around 3 seconds for reactions. This will cause problems when accuracy of real time data is in demand. On the whole, current issues are at the software layer. This means the work on development is not enough yet.

# Chapter 6

# Discussions and Future Work

## 6.1. Discussions

It is difficult to manage appliances in different rooms. Due to the limited performance of IR, users who use the system in a remote place, would not be able to confirm the status of the appliances.

The Stability and Scalability of the system is not good enough. There is a 3 seconds delay for sensor data reacting. Controlling process can not operate too much commands in one task. Another problem is that there is no feedback after a control command was sent. User can not confirm the operation in remote places. Although there are many insufficient part in the demo application, the basic work flow of the proposed system has been evaluated, the test appliances have been enhanced by using sensor technology. More scenarios and appliances types are expected.

Besides the system performance, the evaluations proof that the concept could be helpful in providing new appliances controlling service, but the prototype is still too simple to experience the full proposed features. User survey and test are important to the evaluation which is insufficient in current implementation. More scenarios and situations were expected.

Although there are many insufficient part in the demo application, the basic work flow of the User-centered Universal Controlling System has been introduced and understood by test users. The application is still lack of functions, especially the task trigger part. More defined tasks and trigger method are needed.

## 6.2. Future Work

Although Infrared is widely used in appliances controlling, the trend is turning to Bluetooth and other Radio Frequency technology. The Universal Controller should extend the module to apply more controlling method. ZigBee should be one potential option, but then it needs more work on the improve appliances architecture.

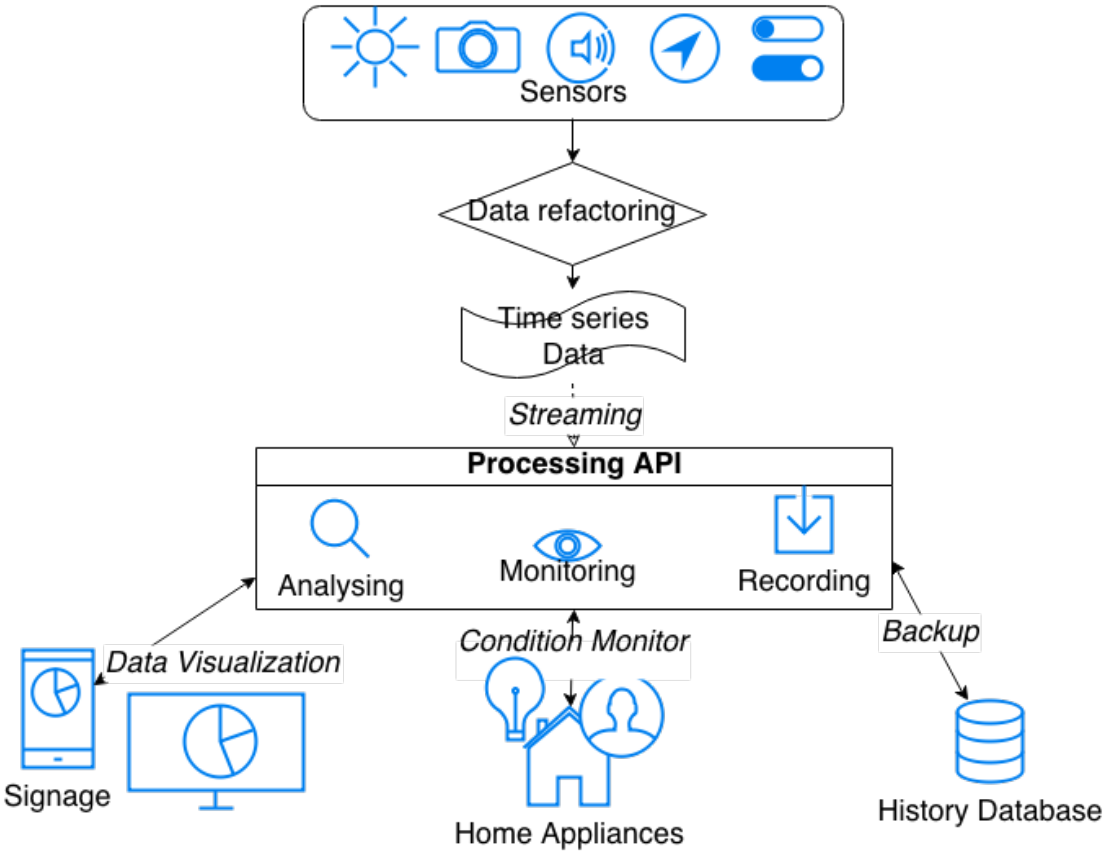


Figure 6.1: Cyber-physical Platfomr

Based on sensor data record analysis, the user custom could be studied. Self-learning function is also considered to enhance the automation controlling. The sensor data also could be used more flexible, not only a condition trigger for the controller, it could be a part of Cyber-physical platform (Figure 6.1). To provide a service for real-time environment information sharing and analysis. Issues such

as user privacy and security which are not included for current stage, also need more effort to work on.

# Chapter 7

# Conclusion

In the growing trend of smart appliances, many new devices and applications are coming into the market. To avoid users' confusion from the excessive devices' functions and control panels, more User-centered controlling process is demanded. Controlling appliances by tasks based on users' activities could help to reduce the operation and attention on appliances. Smartphones and single-board computer can be used to provide such services. In this article it has been shown that it is possible to send sequential IR commands according to defined tasks. By connecting with sensor technology, and other web services, home appliances controlling could become more user-friendly and enjoyable.

There are also many limitations in the proposed design. However those limitations server as a reminder to carefully consider the structure of our system, and give additional insights for future research. The relationship between users' activities and the home appliances environment needs to be studied further. In any case, appliances controlling is not the main matter, it is how could we take advantage of those technology and help us to enjoy the daily life.

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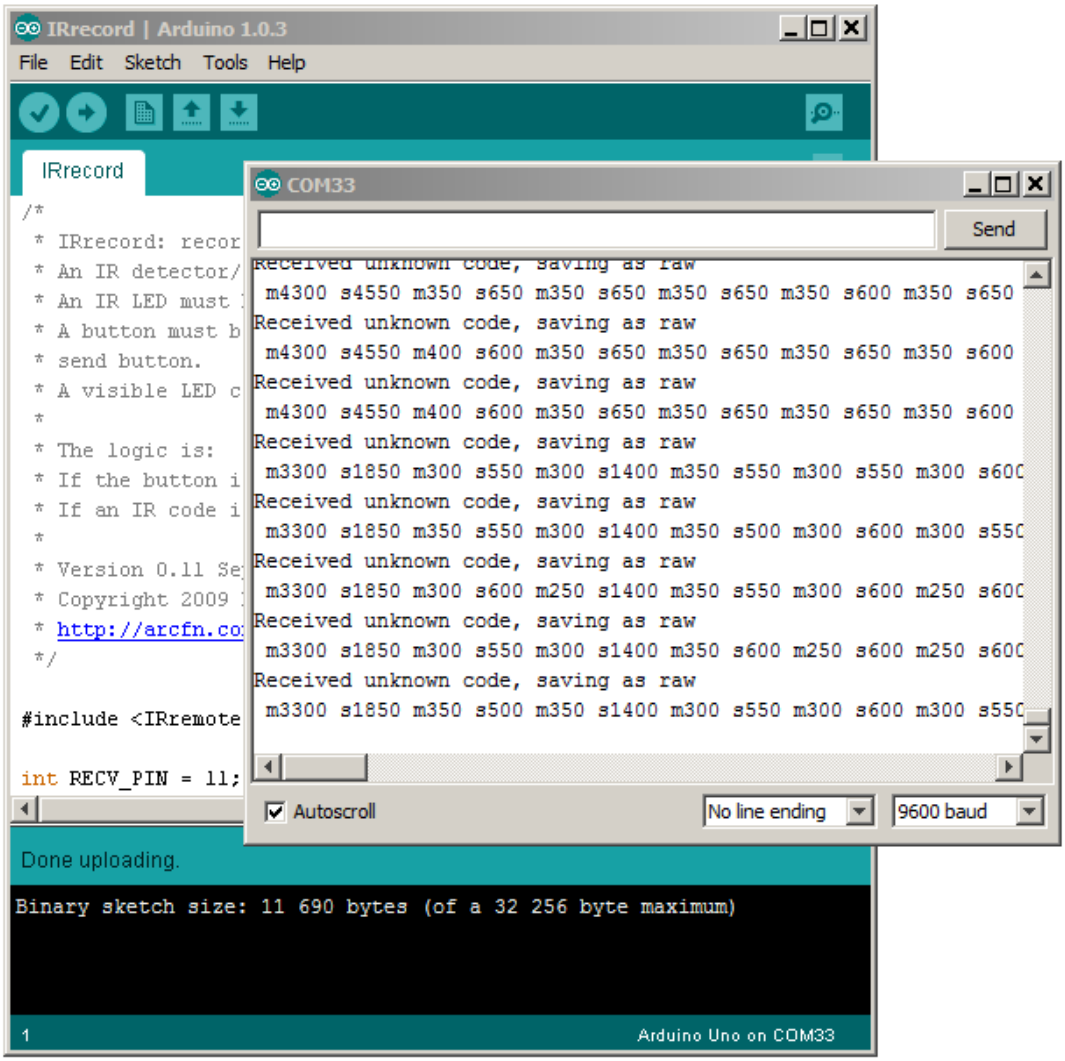
# Appendix

## A. Arduino Record Raw Infrared Signal



# B. Environment Sensor Specification

| | | | | | | | 例 | | |
|---|---|---|---|---|---|---|---|---|---|
| # | Data | Byte | Type | 解説 | 分解能 | 単位 | Data | | 単位 |
| 0 | Response Header | H | | 固定の応答ヘッダ | - | - | 0x4C | - | - |
| 1 | | L | | | | | 0x00 | | |
| 2 | PMV | H | Signed 16bit | PMV値の100倍値 | 0.01 | - | 0x00 | 0.31 | - |
| 3 | | L | | | | | 0x1F | | |
| 4 | Dummy Data | H | | ダミー (0x0000) | - | - | 0x00 | - | - |
| 5 | | L | | | | | 0x00 | | |
| 6 | Flow Velocity X | H | Signed 16bit | X軸流速の1000倍値 | 0.001 | m/s | 0xFF | -0.032 | m/s |
| 7 | | L | | | | | 0xE0 | | |
| 8 | Flow Velocity Y | H | Signed 16bit | Y軸流速の1000倍値 | 0.001 | m/s | 0x00 | 0.039 | m/s |
| 9 | | L | | | | | 0x27 | | |
| 10 | Temperature | H | Signed 16bit | 温度の100倍値 | 0.01 | degC | 0x09 | 24.71 | degC |
| 11 | | L | | | | | 0xA7 | | |
| 12 | Mean Radiant Temp | H | Signed 16bit | 平均放射温度の100倍値 | 0.01 | degC | 0x09 | 23.58 | degC |
| 13 | | L | | | | | 0x36 | | |
| 14 | Temp Pixel 00 | H | Signed 16bit | 00ピクセル放射温度の100倍値 | 0.01 | degC | 0x09 | 23.5 | degC |
| 15 | | L | | | | | 0x2E | | |
| 16 | Temp Pixel 01 | H | Signed 16bit | 01ピクセル放射温度の100倍値 | 0.01 | degC | 0x09 | 23.59 | degC |
| 17 | | L | | | | | 0x37 | | |
| 18 | Temp Pixel 02 | H | Signed 16bit | 02ピクセル放射温度の100倍値 | 0.01 | degC | 0x09 | 23.19 | degC |
| 19 | | L | | | | | 0x0F | | |
| 20 | Temp Pixel 03 | H | Signed 16bit | 03ピクセル放射温度の100倍値 | 0.01 | degC | 0x09 | 23.59 | degC |
| 21 | | L | | | | | 0x37 | | |
| 22 | Temp Pixel 04 | H | Signed 16bit | 04ピクセル放射温度の100倍値 | 0.01 | degC | 0x09 | 23.09 | degC |
| 23 | | L | | | | | 0x05 | | |
| 24 | Temp Pixel 05 | H | Signed 16bit | 05ピクセル放射温度の100倍値 | 0.01 | degC | 0x09 | 23.5 | degC |
| 25 | | L | | | | | 0x2E | | |
| 26 | Temp Pixel 06 | H | Signed 16bit | 06ピクセル放射温度の100倍値 | 0.01 | degC | 0x09 | 23.59 | degC |
| 27 | | L | | | | | 0x37 | | |
| 28 | Temp Pixel 07 | H | Signed 16bit | 07ピクセル放射温度の100倍値 | 0.01 | degC | 0x09 | 23.79 | degC |
| 29 | | L | | | | | 0x4B | | |
| 30 | Temp Pixel 08 | H | Signed 16bit | 08ピクセル放射温度の100倍値 | 0.01 | degC | 0x09 | 23.39 | degC |
| 31 | | L | | | | | 0x23 | | |
| 32 | Temp Pixel 09 | H | Signed 16bit | 09ピクセル放射温度の100倍値 | 0.01 | degC | 0x09 | 23.69 | degC |
| 33 | | L | | | | | 0x41 | | |
| 34 | Temp Pixel 10 | H | Signed 16bit | 10ピクセル放射温度の100倍値 | 0.01 | degC | 0x09 | 23.5 | degC |
| 35 | | L | | | | | 0x2E | | |
| 36 | Temp Pixel 11 | H | Signed 16bit | 11ピクセル放射温度の100倍値 | 0.01 | degC | 0x09 | 23.79 | degC |
| 37 | | L | | | | | 0x4B | | |
| 38 | Temp Pixel 12 | H | Signed 16bit | 12ピクセル放射温度の100倍値 | 0.01 | degC | 0x09 | 23.69 | degC |
| 39 | | L | | | | | 0x41 | | |
| 40 | Temp Pixel 13 | H | Signed 16bit | 13ピクセル放射温度の100倍値 | 0.01 | degC | 0x09 | 23.69 | degC |
| 41 | | L | | | | | 0x41 | | |
| 42 | Temp Pixel 14 | H | Signed 16bit | 14ピクセル放射温度の100倍値 | 0.01 | degC | 0x09 | 23.69 | degC |
| 43 | | L | | | | | 0x41 | | |
| 44 | Temp Pixel 15 | H | Signed 16bit | 15ピクセル放射温度の100倍値 | 0.01 | degC | 0x09 | 23.89 | degC |
| 45 | | L | | | | | 0x55 | | |
| 46 | Humidity | H | Unsigned 16bit | 湿度の100倍値 | 0.01 | %RH | 0x0F | 39.06 | %RH |
| 47 | | L | | | | | 0x42 | | |
| 48 | Light | H | Unsigned 16bit | 照度 | 1 | Lx | 0x01 | 341 | Lx |
| 49 | | L | | | | | 0x55 | | |
| 50 | Absolute Pressure | H | Unsigned 16bit | 気圧の10倍値 | 0.1 | hPa | 0x26 | 995.7 | hPa |
| 51 | | L | | | | | 0xE5 | | |
| 52 | Internal Supply Voltage | H | Unsigned 16bit | 内部基準電圧の1000倍値 | 0.001 | V | 0x0C | 3.235 | V |
| 53 | | L | | | | | 0xA3 | | |

# C. Config file for LIRC Remote Control

```
14
15  begin remote
16
17    name  hmtv
18    bits          16
19    flags SPACE_ENC|CONST_LENGTH
20    eps           30
21    aeps          100
22
23    header       9028  4429
24    one           615  1617
25    zero          615   513
26    ptrail        613
27    repeat       9016  2201
28    pre_data_bits   16
29    pre_data      0x2FD
30    gap          107587
31    toggle_bit_mask 0x0
32
33      begin codes
34          KEY_POWER               0x48B7
35          KEY_MODE                0xF00F
36          KEY_1                   0x807F
37          KEY_1                   0x807F
38          KEY_2                   0x40BF
39          KEY_3                   0xC03F
40          KEY_4                   0x20DF
41          KEY_5                   0xA05F
42          KEY_6                   0x609F
43          KEY_7                   0xE01F
44          KEY_8                   0x10EF
45          KEY_9                   0x906F
46          KEY_VOLUMEDOWN          0x7887
47          KEY_VOLUMEUP            0x58A7
48          KEY_CHANNELDOWN         0xF807
49          KEY_CHANNELUP           0xD827
50          KEY_MUTE                0x08F7
51      end codes
52
53  end remote
```