TAMPERE UNIVERSITY OF TECHNOLOGY

Institute of Electronics
Personal Electronics group

Context Aware User Interface System for Smart Home Control

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Author: Markus Ritala, Tomi Tieranta and Jukka Vanhala
markus.ritala@tut.fi, tomi.tieranta@tut.fi, jukka.vanhala@tut.fi

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POSTAL ADDRESS:	STREET ADDRESS:	TELEPHONE:	TELEFAX:
PL 692	Korkeakoulunkatu 3	+358 3115 5347	+358 3115 3394
33101 TAMPERE	33720 TAMPERE		

1. Introduction

When there are several controllable devices in a certain space, controlling them all in an efficient way requires much thought on the user interface and usability issues. Today's solutions differ from a local mechanical switch to a complex distributed controlling system. One part of these is different remote controllers, which the people are using, in their everyday life.

An example of a possible scenario is the future home. The house itself is equipped with many sensors and can measure several different quantities such as temperature, humidity, air quality and lighting levels. People's basic needs for more cost-efficient and higher standard of living will lead to this. Although the principal goal should be to activate the user and not to let the home automation take over the control of everything.

In any case, the number of electronic devices in the future homes is huge and it is still increasing rapidly because both the size and the prize of the components are getting smaller. More and more components will be embedded into a single chip and the need of the incidental electronics will be decrease. Also the type of automation varies. The building automation is more about the whole building i.e. heating and sewerage. The home automation consists the automation for certain smaller space like one room or certain appliance like television.

In an intelligent home automation system there are many possible solutions for how and from where to control the automation system and single devices; a user interface can be a computer-based system, a mechanical switch, a single light, a loudspeaker with a microphone or a some kind of personal remote controller for all the home appliances.

Today we are used to control our televisions, videos and DVD-players using their own handheld infrared remote controllers. Setting up the home theatre system for movie may need the using of several different remote controllers. Every one of those has its' own unique user interface and the user has to remember how to use all of them. Moreover the user has to be in line-of-sight with the controllable appliance when using infrared communication.

In most cases in the intelligent environment systems all the appliances can be controlled using some centralized controlling device. The user needs some kind of user interface to control these controllable appliances and when there are many different kinds of appliances to control the user interface of the controlling device might be very difficult to use. Besides the changes in the infrastructure may need software or even hardware changes to the user interface as well.

This paper describes an easy to use handheld remote control device for controlling all the home appliances. The user interface is designed as simple as possible without losing the usability issues. With the remote controller described in this paper the user is able to control all the centralized controllable appliances in the environment using radio and infrared technologies.

2. Problem

Nowadays there is usually an own remote controller for every infrared controllable appliance (for example TV, DVD, VCR, amplifier,...) (Fig. 1). Every manufacturer has it's own style in their user interfaces and they can be totally unique. So, if a person can use a certain remote controller properly it doesn't necessarily mean the one can use all the possible remote controllers.

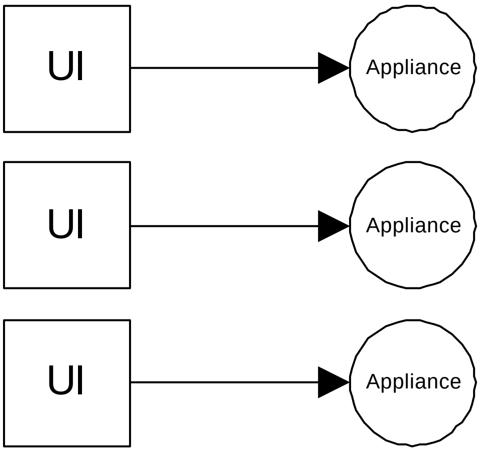

Figure 1: Traditional way to remote control

Even if the appliances would be from the same manufacturer the user interface of the remote controllers can differ a lot. Most of the appliances have some kind of special functions and because of this they might need some special controls so it might be impossible to use the similar user interface to control different appliances.

When we try to use the same remote controller to control different kind of appliances (Fig 2) there has to be several functions for one physical controller in different situations. In addition it is also possible that there is no function at all in some situations. Because a one physical controller has a limited power of expression the user has to remember the function in the current situation. This might be impossible especially for an elderly or a disabled person. With this kind of one-for-all remote controller we have to make some compromises between usability and universal applicability.

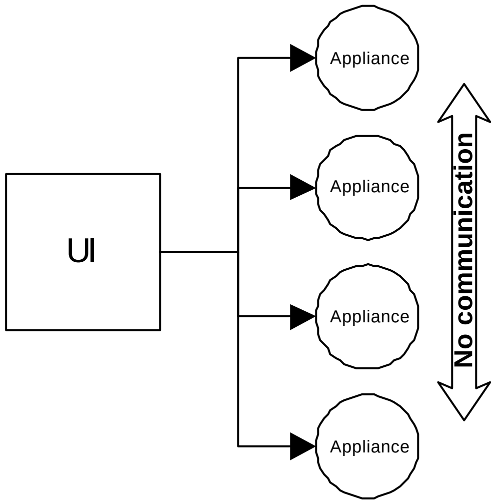

Figure 2: Remote controlling using an universal remote controller

In these days there are several universal remote controllers commercially available. One example of this type of universal remote controllers is a one from Sony [1] (Fig 3). It is a handheld learning remote controller. By this remote controller the user can control all of the infrared controllable appliances at home. Although these infrared commands have to be first taught to the remote controller. When using an infrared as an information carrier there are problems with the visual contact that is needed for the infrared beam. It is almost impossible to control devices in a different room. Also the range of this infrared beam is limited and even the daylight and normal halogen lights creates interference. So this kind of remote controller can only be used to control appliances equipped with infrared receiver in the same space.

Figure 3: Sony 18-device LCD Remote With Learning Function

Also this kind of infrared controlling is usually designed for one-way communication. It is impossible for the remote controller to notice if the command didn't get thru to the appliance. The user has to pay some attention into controlling. That is why it is also hard to create reliable timed actions even if the remote controller supports timers because the actions cannot be ensured. The other problem with the one-way communication comes in many situations when there are only toggle types of commands available. For example it is impossible to create a universal on or off command because the current state of the controllable appliance is unknown.

The other example of this type of remote controllers is one from Marantz [2] (Fig 4). One of their products is a handheld learning remote controller equipped with full-color touch screen, radio frequency and infrared transmission. There is no limitation from infrared because commands can be delivered using radio frequencies. Still, when using this kind of remote controller the user has to program the remote controller to send certain set of infrared or radio frequency signals when specified controller in the touch screen has been selected. This also means that if there are some changes in the infrastructure or in the appliances of the home the user has to reprogram the remote controller's software to take into account this new situation. Although this is not an every day situation but it can still be the stumbling block for many users.

Figure 4: Marantz RC9200 Universal Remote Controller

In the situation above it is also very difficult to show the state of some appliance to the user even if we have some two-way communication channel available. This is only possible if the remote controller remembers the state of every appliance. And if there is some other way to control these appliances all the interactions with controllable appliances should be informed to the remote controller too. The other solution is that the remote controller actively interacts with all the controllable appliances to determine their current state. This is a very inefficient way to solve this problem because most of the time these appliances are in the same stage and the remote controller still has to interact with them. This is a remarkable problem especially when there are several controlling devices in the area and the information about the current stage of the controllable appliances should be delivered to all of them.

3. Research Environment

In the Tampere University of Technology at the Institute of Electronics, we have had an intelligent home laboratory in our Living Room-project since the beginning of the year 2000. The first testing laboratory called Living Room [3][4] (Fig 5) consisted only small living room and kitchen. The room was equipped with an infrared-based single-master multi-slave network to communicate with room's appliances. This real home environment was used as a testing environment for future home automation techniques.

Figure 5: Intelligent home laboratory – Living Room

The current apartment includes hall, bedroom, living room, dining room, kitchen, WC and sauna. This environment is equipped with several controllable appliances. The general idea in these appliances is to keep them as simple as possible [5]. One appliance handles one simple function or few similar functions. To perform some complex action we use many simple appliances interacting with controlling system. The simplicity of these appliances keeps the prize as small as possible and the development costs stay low.

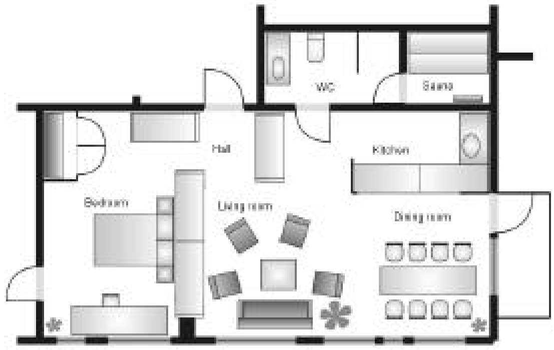

Figure 6: Current Intelligent home laboratory

In the other project called eKoti-project [6] we have equipped a normal two-room flat in an apartment house here in Tampere with a few additional appliances and a centralized controlling system. At the moment the residents are able to use these appliances via three different user interfaces. The first implemented user interface was a WWW-based application using a laptop equipped with a touch screen. The other user interface can be used using normal television remote controller and the view is shown in the television screen. The third user interface is designed to be used from outside of the apartment by mobile phone.

As an example of the appliances located in these testing environments are different sensors. The sensors monitor for example the air condition in the apartment and outside of it. There are sensors for temperature, humidity, carbon dioxide and an indoor odor sensor. The front door has an electric lock and a fingerprint scanner; all the windows have controllable Venetian blinds; lighting of the apartment can be controlled etc.

All the appliances are connected into custom made hub via wires or radio network. The communication protocol [5] is designed for simple and short command based communication because of the features of radio network. There is no difference in the protocol weather the signal is carried using radio network or wires. The hub is connected into control PC via serial port.

The main PC acts as a controlling server. The server organizes all the communication between home appliances. It keeps up the database about the state of the appliances. All the different user interfaces communicates with this server, not directly with the controllable appliance (Fig 7). The benefits of this structure occur when there are many appliances and several user interfaces. The information about the stages of the appliances is stored only in one database. The server is responsible for keeping the database up to date.

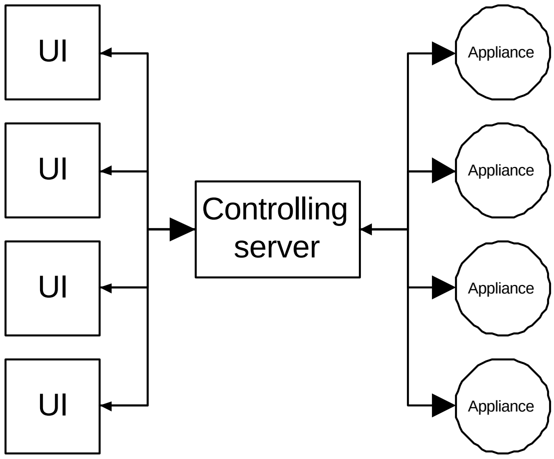

Figure 7: Basic centralized control system

As mentioned we have already implemented several different user interfaces in our projects. The home appliances can be controlled using normal PC, laptop or table PC by standalone software or web-based user interface. The user can interact with the home using a personal mobile device over GPRS network or by using normal TV remote controller via user interface in the TV screen.

We have also implemented a system that enables controlling the home appliances by using speech commands [7]. The user has a personal controlling device equipped with a microphone, an infrared receiver, a push button and a radio transmitter. This controlling device can be located using several infrared tags in the room and the speech commands are transmitted to the controlling server using radio frequencies. The system enables location awareness commands because the location of the user is known. Also the speech response is transmitted into the location of the user.

However, even we have these fancy ways to control all the home's appliances we have made sure that it is always possible to control the appliances in the traditional way. The lights can be switched on or off using the switch in the wall and the door can be opened with the key. In our opinion there is no need to remove these traditional ways to control things because people have gotten used to use them and these user interfaces are the product of a very long period of development and usability tests. These new user interfaces are only additional and sometimes easier way to do something.

4. The Solution

This new controlling device described here solves the problems explained in earlier sections. In our infrastructure it is only one user interface among others. Also from the controlling systems point of view it is only a user interface like any other described earlier. When the controlling system gets some controlling command it doesn't exactly know which kind of device has sent the command.

Figure 8: The user interface of the developed controlling prototype

From the users point of view the user interface is very similar to the newest mobile phones (Fig 8). The appliance consists of very few physical controllers and simple display for feedback. With the device the user can control all the home appliances attached to the controlling system. The appliances are not controlled directly from the device instead the controlling command are sent to the controlling system which controls the home appliance based on the given command (Fig 9).

All the actions like button pushes made by the user are sent to the controlling system. The controlling device itself doesn't know what is the meaning of the action it just deliver the information ahead. The controlling system knows the current situation and decides the next move. If necessary it sends commands to the home appliances and returns the information text to be shown in the display back to the controlling device.

The menu structure of the prototype is described in an appendix 1. Only two overlapped menu items are shown in the display. To the display it is possible to write eight characters in a row. All the menu items are seven characters long at most and the first character of the row is reserved for the mark to show into which direction is it possible to browse menu in current situation.

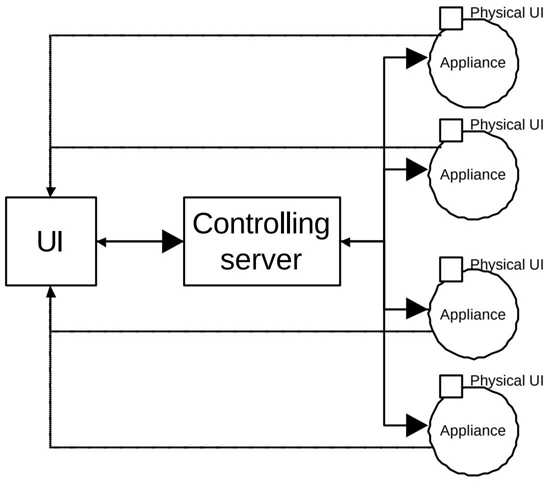

Figure 9: Controlling system with the new controlling device

There is also an infrared receiver in the controlling device to recognize the controllable appliance or the space if needed. There are very small infrared tags placed into controllable appliances and all over the apartment. The controlling device sends the signal from these tags to the controlling system and this information can be used for example to limit the possible actions at the moment or to enable some shortcuts for controlling the current appliance or space.

The benefits of this kind of procedure come out when there are several controlling devices. If the infrastructure of the home changes the configuration has to be made for the controlling system, not for every controlling devices. Besides if the controlling system is able to make the configuration by itself there is nothing that the user should do. For example when the new controllable appliance is plugged in to the system it can send some kind of description about itself and based on that information the controlling system can take this new appliance into account.

Secondly if we have a centralized control and knowledgebase of the current stages of the controllable appliances it is easy to combine this information and make some conclusion based on that information. When all the controlling commands for the controllable appliances are directed thru this centralized controlling system there will always be the newest information. And because the controlling device is connected wirelessly to the controlling system it is possible to control all the controllable appliances connected to the system.

Also because of the system described above it is easy to use this remote controlling device in very different controlling systems. Using the very same controlling device in two separate controlling systems is also possible as long as the systems are able to communicate with the remote controlling device using its' simple communication interface. It is very easy to implement the communication interface because it includes only very few simple commands.

Thus the physical user interface in the controlling device is very simple and still it is possible to control all the controllable appliances connected to the controlling system. The controlling of a specific user pointed appliance is also possible by using the infrared tags placed into this appliance. The most used function for the pointed appliance can be used directly for example by pressing the joystick.

5. Technical solutions

The hardware of the controlling device consists of two separate units: the handheld control unit and the PC unit. As the names imply the control unit is the actual controlling device with the user interface and the PC unit merely connects the RF network to the PC using serial port. Both of these units are based on an 8-bit Atmel AT90S8515 microcontroller [8]. The controller's power consumption in active mode is under 8mA@5V, and is therefore suitable for battery-powered designs.

The RF link between the control unit and PC unit was designed using Nordic VLSI's component nRF401 [9]. The nRF401 is a 433MHz single chip transceiver that features frequency shift keying modulation and demodulation capability. The nRF is controlled with three I/O pins and the data is transmitted serially between the microcontroller and the nRF using two I/O pins. The antenna is a 25x15mm sized differential loop antenna on a printed circuit board.

To this point the described hardware can be found in both units and the assigned I/O pins have the same functions. The units were designed as identical as possible because this way the same software for the RF transceiver could be used in both units.

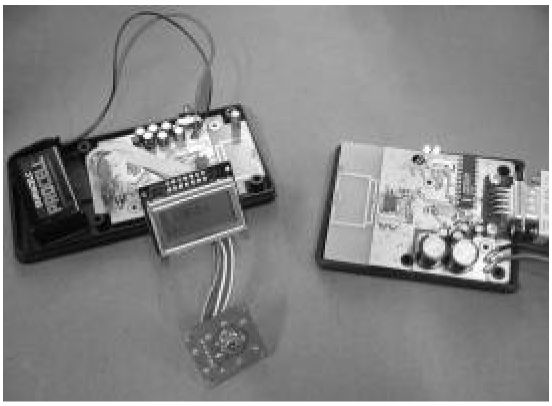

Figure 10: The controlling device (left) and the PC unit (right)

Because the PC unit is connected into PC's serial port an RS-232 driver/receiver is needed to convert the TTL signal levels into ±12V that the computer uses and vice versa. PC units supply voltage is generated from mains voltage by transforming and rectifying. The rectified voltage is then regulated to five volts and fed into components. Some extra capacitors were added to ensure that the ripple in the supply voltage was low enough. Especially the nRF was found to be quite sensitive to ripple voltage.

As mentioned earlier the handheld control unit is basically identical to the PC unit. However, some differences can be found between these units mostly because the handheld unit is the actual user interface. To achieve portability the control unit's power supply was designed using a 9V battery and a five-volt low dropout regulator. Again some extra attention was paid to filtering the supply voltage. The power consumption of the control unit is around 24mA in total.

For receiving infrared signals from different controllable appliances in a room the control unit has an infrared receiver. The receiver's center frequency is 38kHz.

The actual user interface of the control unit consists of an 8x2 liquid crystal display, a miniature joystick, a button to initiate IR reception and a slide switch for switching the device on and off. The LCD is driven in 8-bit mode and requires three additional control signals from the microcontroller. Because small size was a desired feature for the control unit a small display had to be used in order to achieve this goal. The LCD's outer dimensions are 40x35x8mm.

The miniature joystick is used to scroll the menus and select desired functions. The joystick has four directions and a push button for making a selection. The operation is similar to those used in modern mobile phones.

The goal for this project was to design a remote controller that doesn't know anything about the devices that it is controlling. This goal made it quite easy to write the programs for the two units, especially when the same RF control routines could be used in both units. Figure 11 shows the basic operating principle of the program running in the control unit. The data packet sent from the control unit to PC unit is always six bytes long that consist of two address bytes, three data bytes and a checksum. Of the two address bytes the first one is the PC unit's address and the second is the control unit's address. By sending the control unit's address the use of more than one control unit in the same household is enabled.

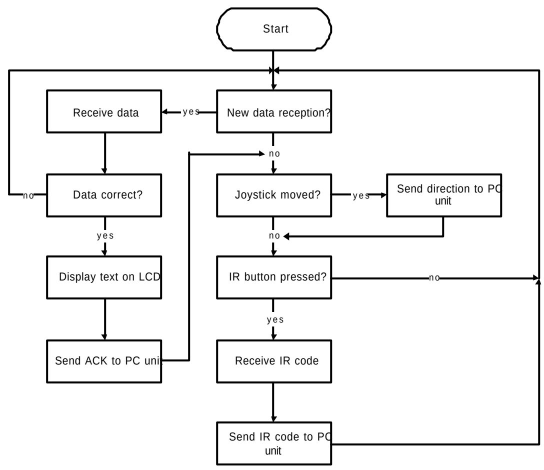

Figure 11: Operating principle of the program in control unit

Similarly, the basic operating principle of the program running in the PC unit is shown in figure 12. The data packets sent from PC unit to control unit are, however, slightly different. First of all the length of packet is eleven bytes. The first byte contains the address of the control unit that the packet is intended to. This is followed by nine data bytes and a checksum.

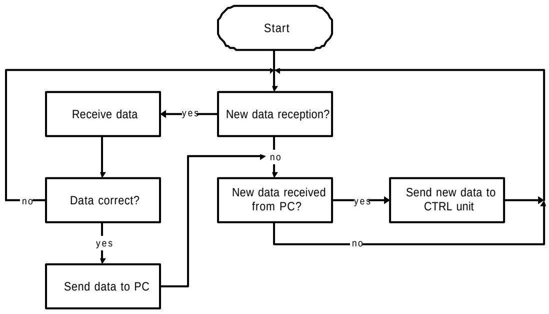

Figure 12: Operating principle of the program in PC unit

The infrared tags located into environment and into the controllable appliances are basically one-way infrared transmitters, which repeat their unique signal continuously [10]. Those tags are designed as small and cheap as possible and to consume as little power as possible.

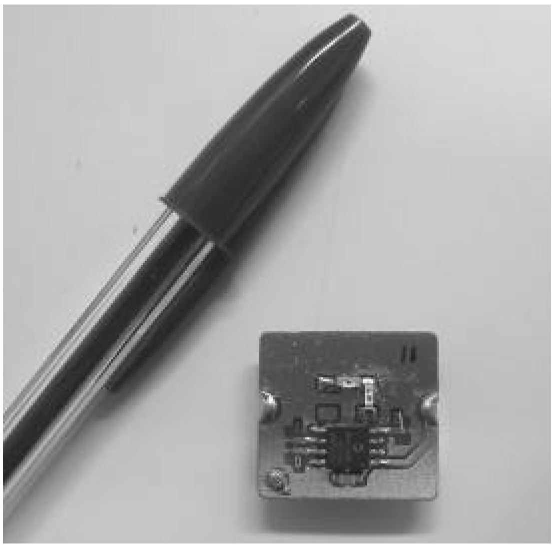

Figure 13: Infrared tag

The transmitting range of the tags shown in figure 13 is about four meters with the angle of the infrared leds is about 160 degrees. The overall size of the tags we are currently using is 20x27x7 millimeters mostly because of the size of the lithium coin cell battery. The battery is also the most expensive part of the tag. The tags uses 38 kHz square wave carrier signal that is used also in most of the commercial infrared remote controllers and the transmission of tags ID takes about 20 milliseconds. The interval of the transmission can be configured from the 0,1 to 11 seconds.

6. Analysis

In the early usability tests we noticed that the most important issue is the delay between the controlling and the response. Both the delay between the controlling command from the controlling device and the response to the controlling device and the delay between the controlling command from the controlling device and the visual response from the controlled appliance are significant.

The rough maximum for this delay can be about two hundred fifty milliseconds. And this is an ideal value for the delay. After this time from the controlling command the user needs to pay attention to the controlling situation. This delay is also used as a guideline in speech recognition and response systems [11].

When the user is controlling the appliance from the distance it is more acceptable to spend more time waiting for the response than in a situation where the user is browsing the menu of the controlling device.

When the user is browsing the menu of the controlling device the delay between the command and the change in the view has to be much more shorter that the delay above. In our tests we noticed that the user is able to move or push the joystick in the controlling device approximately ten times in a second. So the delay between two actions is about hundred milliseconds. The response between the menu scrolling command and the change in the view has to shorter than that. Thus the objective delay for the menu browsing is fifty milliseconds.

In our tests the delay between menu browse command and the change in the display is slightly under fifty milliseconds in ideal environment, but when there is some interference or the distance is very long there are so many errors from the transfer the delay grows longer. By sending additional menu items beforehand to the controlling device when there are no user actions to make can this problem be solved. Thus it is not necessary to send all the view changes from the controlling system to the controlling device.

Because the controlling system is able to identify every unique controlling device it is also possible to create own profile for certain controlling devices or for the certain person if they have personal controlling devices. This feature could be useful for example when there are small children in the family and it is not desirable for them to use unsafe home appliances like an oven or an iron.

Also the comfort and usability issues can be taken account by identification of the controlling device. It is possible to create different user interfaces and views for different users. Some people want to use only the most commonly used functions of the appliances and the others may want to have all the possible functions in their own controlling device.

When one is using traditional infrared remote controller or a mobile phone it is easy to select the right button or browse the phone menu without seeing the actual device because one knows the exact place of the button or the menu item in the menu structure. When the menu structure or the position of the menu items can vary depending of the situation or the location this kind of controlling without seeing can be impossible.

In our prototype this problem was solved reserving the very first item in the first menu level for the infrared signal dependent menu item. Into this menu location it is possible to place the most usually used action for fast control in the current location or the user's pointed appliance. In the further usability test we can discover if this solution is useful or are there any better solutions.

7. Conclusions

This kind of controlling system is very robust and adaptive. It is possible to configure the system in very different environments. And because the most of the calculations can be done in a powerful computer the controlling device itself can be kept very simple and cheap especially when it is manufactured in a large scale.

The user interface in this prototype has been kept very simple and easy to use. However the power of expression in this prototype is quite small but the idea of transferring the data to the screen from the more powerful computer can be used in much more advanced systems and user interfaces like in those commercial examples earlier in this paper.

When there is some graphical display to use the computer could be send the structural expression of the user interface and the functions of it for example using some markup language like XML [12] or UIML [13]. It enables usage of the user interface with multiple different devices without programming own software for every one of them separately instead it is possible to use the same described structure in all of them and just convert it for the certain device [14].

The introduction of the system described in this paper is vary easy because there is very much computing power available in the main computer and it is possible to set the system to configure itself automatically. For example in our prototype the system could detect all the controllable appliances and the commands of them and create the menu structure automatically. Moreover when there is a new controllable appliance detected the commands could be inserted into menu directly without user actions.

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- <Varying infrared based command>
- Lights
  - All
  - L. room
  - Kitchen
  - Bedroom
  - Hall
  - Dining
  - WC
  - Sauna
- AV
  - Comput.
  - TV
    - Chan. +
    - Chan. -
  - Video
    - Play
    - Stop
  - DVD
    - Play
    - Stop
  - Audio
    - Vol +++
    - Vol ++
    - Vol +
    - Vol -
    - Vol --
    - Vol ---
  - Close
- Blinds
  - L. room
    - Open
    - Close
  - Bedroom
    - Open
    - Close
  - Dining
    - Open
    - Close