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An electronic architecture for mediating digital information in a hallway façade

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AN ELECTRONIC ARCHITECTURE FOR MEDIATING DIGITAL INFORMATION IN A HALLWAY FAÇADE

A Thesis

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Guru Brahma Gurur Vishnu

Guru Devo Maheshwaraha

Guru Saakshat Para Brahma

Tasmai Sree Gurave Namaha

Meaning: Guru is verily the representative of Brahma, Vishnu and Shiva. He creates, sustains knowledge and destroys the weeds of ignorance. I salute such a Guru.

In ancient India, students left the comforts of their home to live and study in the ashram of the guru. At the ashram, the guru imparted knowledge, taught the students skills and prepared them for the life ahead. It was in some sense a wholesome education. In many ways, I believe that my time spent at LSU has provided me with a similar experience.

I dedicate this Sanskrit sloka (verse) to all my teachers and professors, but especially to Drs. Ullmer, Ram, Trahan, and Branton for their invaluable support and encouragement which has made this work possible.

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Abstract

Ubiquitous computing requires integration of physical space with digital information. This presents the challenges of integrating electronics, physical space, software and the interaction tools which can effectively communicate with the audience. Many research groups have embraced different techniques depending on location, context, space, and availability of necessary skills to make the world around us into an interface to the digital world.

Encouraged by early successes and fostered by project undertaken by tangible visualization group. We introduce now an architecture of Blades and Tiles for the development and realization of interactive wall surfaces. It provides an inexpensive, open-ended platform for constructing large-scale tangible and embedded interfaces. In this paper, we propose both tiles built using inexpensive pegboards and a gateway for each of these tiles to provide access to digital information. The paper describes the architecture using a corridor façade application.

The corridor façade uses full-spectrum LEDs, physical labels and stencils, and capacitive touch sensors to provide mediated representation, monitoring and querying of physical and digital content. Example contents include the physical and online status of people and the activity and dynamics of online research content repositories. Several complementary devices such as Microsoft PixelSense and smartdevices can support additional user interaction with the system. This enables interested people in synergistic physical environments to observe, explore, understand, and engage in ongoing activities and relationships. This paper describes the hardware architecture and software libraries employed and how they are used in our research center hallway and academic semester projects.

Chapter 1
Introduction and Motivation

The beginning is the most important part of the work.

Plato

1.1 Introduction

How can an electronic hardware architecture be used for a heterogeneous system over a relatively large surface area? How can the end user apply this concept and entangle large spaces with digital information?

Numerous methods have been employed to utilize relatively large spaces such as walls, shopping windows, buildings and so on. Large LCD/LED displays and signages such as 17000 sq.ft billboard at Times Square in New York City, and large display at Shinjuku (Tokyo) are used to display information. Arrays of displays are used to increase the efficiency of work and productivity gains [7]. A few examples of using an array of displays include astrophysicists navigating and annotating telescope imagery and biochemists visualizing and interacting with complex molecules [14]. Cameras are used to capture an image at specific intervals to recognize an event such as appearance, disappearance or movement of an item [25]. Gesture-based interaction is another popular method used in public spaces such as shopping malls [26] for digital augmentation to enhance the experience at the point of contact. These are only a few approaches and the list goes on. The hardware architectures referred to here are modular and tangible, and the physical structures are entangled with digital information.

The ancient practices like etching the name of the Japanese temple as shown in the figure 1.1, Nan'en-dō patrons [44] who extend their support towards the maintenance of temples and shrines is an example of entangling time (longer timescales) and physical structure.

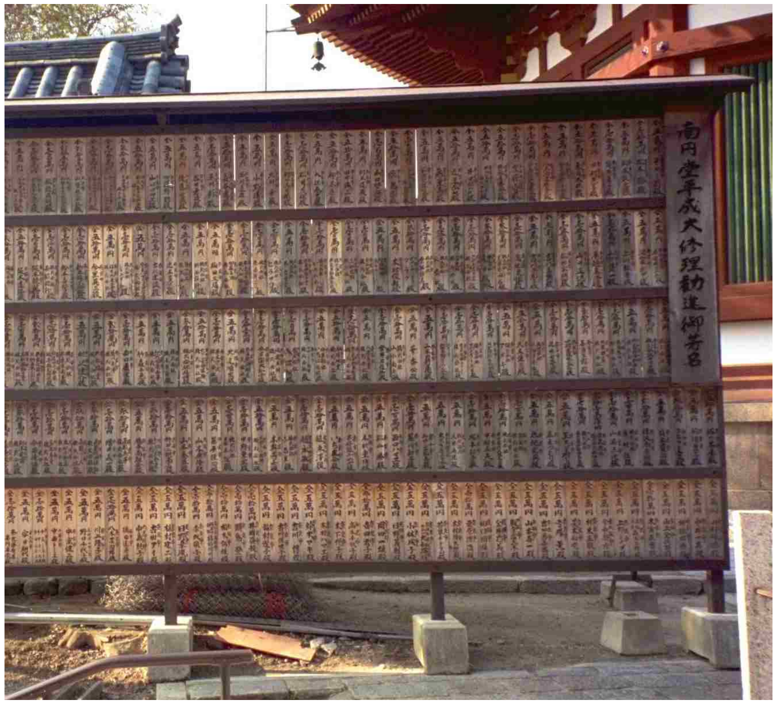


FIGURE 1.1. Sign recounting patronage of Nan'endō temple at Kōfuku-ji in Nara, Japan — from [44]

Consider each block as a data container that holds patron information. It can be used to access the information about the patron and year in which the offering was made. This requires an entanglement with information. Entanglement is the binding of physical object with the information. Now consider an arena such as a hallway that is a relatively large space. What if this space has to be binded with digital information like history of supercomputers, availability of a person or display of research activities.

This project started for building such architectures using a hardware/software technology. Realizing this kind of an architecture requires an electronic architecture that can communicate with the digital world. It requires middleware that can assist with accessing information from the virtual world and communicate with the entangled device. With many available and emerging technologies that can assist in realizing the required functionality, determining the appropriate kind of technology for a particular task is a difficult exercise. The choice depends on many constraints - cost, availability, fabrication, tools for development and skills for implementation. People across the globe building structures that are entangled with digital information should get the required materials to build the structure. Also, the development cycle should be relatively short and easy to implement.

Throughout this project, the work has been influenced by the concept of entangling physical space, particularly a hallway and cartouche with digital information. Ullmer et. al. describes cartouche tangibles of digital information. These serve as containers and controls which physically+visually reference and describe online digital information, cast within forms and conventions to aid their identification and passage between diverse interactive environments [39].The concept of entangling web, ubicomp, and tangibles both with each other and with crosscutting notions of space, form, light, and time [44] has fostered the development of this architecture which is modular, scalable and re-usable.

1.2 Digital Information, Ubiquitous Computing and Entanglement

The Oxford Dictionary definition of information is "knowledge communicated concerning some particular fact, subject, or event." Information exists everywhere, on sign boards, traffic signals, windows of the shopping malls, billboards, notice boards, posters, newspaper, magazines, and also on the Internet, but this advancement of Internet technology has made access to information very easy for any user of the Internet. The access to information on the Internet is confined to computers and smart devices.

Imagine a world where a wall is capable of processing information, tables in restaurants can take orders, and enable people to interact with friends, relatives and significant others who are living in another part of world objects woven into the fabric of the surrounding environment, without having to use computers or laptops or smart devices. Weiser in 1991 described the most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it [47]. Ubiquitous computing is an idea of seamlessly integrating information processing capability into the fabric of everyday life.

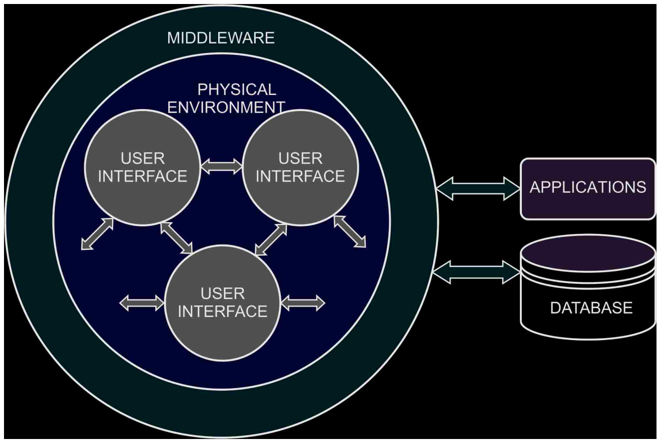


FIGURE 1.2. Block diagram of ubiquitous computing

Since ubiquitous computers are woven into the surroundings, it is necessary for a system to be aware of its space or location, the time and form in which it exists. Taysheng [19] describes a co-ordination infrastructure which involves integrating inputs from many heterogeneous devices and sensors. Each sensor has its own driver, requiring the integration of heterogeneous sensor data. Data integration necessitates a separate layer of system components in the back-end to generate an integrated high-level application context related to the interaction. Ubiquitous computing should be capable of perceiving human interaction with the surrounding environment. It should provide a suitable response to the input and in a given context. Therefore, the surrounding space needs to be entangled with information, space, time and form so the system running behind the structure understand the context.

Integration of physical environment and digital information need a computational structure necessary for ubiquitous computing. Figure 1.2 illustrates the structure and relationship among the layers of the ubiquitous computing. This environment-centric system is likely to have many different types of user interfaces. Ideally, objects that are present in a physical environment should be an interface to information or a computation. The objects should have the necessary sensors to obtain information and process it. This requires local computation to perform this operation. Based on the information, if a user requires information or performs a computation, then the object should be able to communicate with an external medium or among the interfaces. For external communication, there should be a middle-layer that can assist in getting information from a database or running an application. This is called middleware. There are many challenges and issues realizing this kind of system which will discussed in later sections.

1.3 User Interfaces, Interaction Design, Hardware & Software

User interface is the domain of human-computer interaction; they are computer entities between users and computers. Until the mid-1990s the concentration of interaction designers was largely on developing effective and efficient interfaces for desktop computers aimed at a single user. Advances in technologies such as graphical interfaces, speech recognition, mobile technologies, sensor technologies and handwriting recognition have fostered development of different types of interaction techniques. Examples include gesture based UI [38, 26], speech interfaces [22],shareable interfaces [46], and tangible interfaces [18, 40, 33], to name a few. Many of these interfaces incorporate electronic hardware and software that recognize user input. The user input is detected by a computer system via a sensing mechanism embedded in a physical object or a special gesture recognition device or a speech recognition device and so on.

Interaction design, according to [30], is designing interactive products to support the way people communicate and interact in their everyday and working lives. Thackara [37] said "interaction design can help shift the focus of innovation to the pure technology to the contexts of daily life." According to his views, interaction design creates value in three ways. First, by designing new ways to connect—with family, friends, significant others and colleagues. Second, interaction design allows richer and more varied forms of interaction. Third, interaction design creates value by emphasizing service and flow [30]. In this design, real and virtual space, matter and information, co-exist. This thesis deals with designing hardware and software architecture for the development of computing structures migrating from traditional computers and suffusing itself into the surrounding environment. The relationship between real and virtual, matter and information, requires an entanglement. Our architecture acts as a bridge between real objects and digital information.

The realm of interaction design involves people from many disciplines, ranging from social scientists to film-makers. From the perspective of the implementation which involves many interaction entities such as LCD, LEDs, sensors, motors, switches and many more. These interaction entities and physical objects need to be entangled with digital information in the context of ubiquitous computing. The implementation involves electronic hardware, firmware and software. Currently blades and tiles [32] architecture is used to realize interaction modalities. This architecture is extended to entangle the physical space, time and form with digital information. Section 3.3.2.1 provides complete description of extending the architecture to integrate physical and digital world.

1.4 Interface to Digital Information through Hallway Façade

Throughout history, walls have been used to present information-bearing content in many contexts. In academic contexts like colleges and universities, there is a constant need to convey information to diverse audiences. Traditionally, posters, flyers and notice boards have been used to convey static information of general interest in public spaces. However, modern technology provides the means of creating new systems of dynamic, interactive information displays. Our hallway façade architecture supports the development of such systems.

Our vision is to enable rapid development of inexpensive façades. To realize the goal, we have used inexpensive, readily available materials such as wood, paper, pegboards and relatively inexpensive off-the-shelf electronics. The use of inexpensive commodity material should help enable high schools and educational institutions in developing countries to design compelling interfaces to convey information.

In this project we are attempting to effectively utilize the hallway space. We are populating often unadorned space with physically and digitally bound tangible entities to build a persistent system. Figure 1.3 shows the prototype of an interactive hallway façade developed in Tangviz Lab. This hallway façade is a medium to discern ongoing research activities and also to know the status of members in a research group. The thesis discusses the system architecture, software libraries, electronics hardware architecture and interaction styles.

FIGURE 1.3. Interactive façade prototype—stencils above the monitor indicate dynamics of online research content repositories occurring during the previous week/day/year. Top stencils on the right are each person's availability in online/physical space. Three people are interacting with the façade with three different interfaces: Microsoft PixelSense (extreme left), smart phone (middle) and capacitive touch interface(right).

1.5 Motivation

Computers have penetrated a large part of our lives - cell phones, laptops, other devices like microwave ovens, refrigerators, washing machines, door handles, and lighting installation. In the present world, name the apparatus and it will have some electronic processing capability in the form of a microprocessor. According to a 2008 EE|Times news and analysis interview with Su from Freescale Semiconductor [1], there are around 150 microprocessors around a household in various appliances, media players and security devices. Another 40 to 50 can be added for devices in the car, and the trend is accelerating. By 2015 Freescale predicts that there will be 1000 embedded devices per person. For many people, awareness of computing is limited to desktops, laptops, and smart devices. Most of these 150 processors are invisible to people, and they are everywhere. They are encroaching on our environment with an unprecedented pace and making our environment smarter.

Even though our environment is filled with microprocessors to make our surroundings smart, it is not smart enough. There is potential to make it smarter. Most of the microprocessors are used in devices that are used in our daily life like televisions, water heaters and so on. Many of these devices are connected to a network making it a part of a network service. The access to information for some devices is limited only to them and inaccessible to others. For a person who needs to access information from across the network or perform a computation, it has to be done using desktops or laptops or smart devices.

Walls are a part of the surrounding environment. Walls are present in most of the places we visit office, home, shopping malls, museums, and war memorials. They could be an interface to access information or perform computation. Traditionally, walls are used as information bearing surfaces, a persistent visible surface where notes, post-its, posters, notices etc., are posted. The study of Whittaker and Schwarz [48] showed the advantages of using a physical wall in the context of two groups developing software. One group use a the wall, and the other group used a project co-ordination tool. Then also described the way the physical board engendered commitment to the schedule and the clarity it provides about people's work.

The information displayed by posters, pictures, paper documents, etc, is useful, but often it is brief and non-interactive. Recently LCD and LED displays have become common systems of conveyance in college campuses, office waiting rooms and in many more places, but display is typically limited to timed rotation of static content.

This project is inspired by the growing importance of social media and in the context of universities, the importance of research awareness to students. Displaying the physical/online availability of a person and research activities needs to be less accessible than displaying in the library and more accessible than confines of a room. A Hallway is a good fit for our requirements because it is less accessible to the general public and more accessible to students.

From the perspective of implementation, there were many challenges to designing relatively large circuit boards that cover the hallway, utilizing the processing capability of microprocessors, developing the software library and middleware,limiting cost, and ensuring availability of the required material.

Prototyping smaller systems like smart systems or laptops is easy. The prototyping technique has evolved over the years and has become relatively easy. There are many experts who can develop systems like these. Also, there are many tools aiding developers in designing more efficient and multi-layered system. Following this procedure for developing ubiquitous systems has many limitations.

- Designing a single large circuit boards is a tedious process. It requires expertise designing such systems and is error prone.

- In ubiquitous computing, most of the functionality is distributed and requires a modular approach to develop pervasive systems.

- Designing and prototyping such systems are very expensive. It often requires a large amount of time and a very specific set of skills.

Single large circuit boards reach their scalability limits because of a variety of reasons. From a hardware realization perspective, the processing capability of the primary processor is limited by its speed and number of input/output pins [1]. From printed circuit board (PCB) designing perspective, maintaining signal integrity, separating analog and digital sections on the board to avoid noise, which dictates component placement, presents a challenge. Even though the single board design has attained maturity for relatively small PCBs, it suffers from a scalability bottleneck for large PCBs such as the size of the hallway. The system needs a modular structure that can be woven into the surrounding environment and can eliminate the scalability bottleneck. This provides comfort, freedom, flexibility and re-usability for an interaction designer.

1.6 Philosophy

There has been considerable work in the tangviz group, LSU is focused on developing prototyping techniques for developing interactive devices. This project is particularly aimed at moving beyond the screen, and integrating the world around us with digital information.

User interface designing involves people from different disciplines such as hardware and software designers, artists, and mechanical designers and many more. If an artist is developing a user interface, for all practical purposes it is unrealistic to expect the artist to have expertise from other disciplines such as hardware and software designing. The architecture presented in thesis is not limited to artists or any other designer from different disciplines. This provides a development method to educational institutions to build interactive systems that use the idea of a hallway façade to visualize information. The thesis describes tools for developing systems, the software libraries and the middleware.

If an educational institution is passionate about developing a system similar to the hallway façade, then the system should be less complex and easily replicable. The electronics behind the system should be easy for potential designers to understand the working and design their systems. This can

[1] Usage of CPLD for the expansion of I/Os and FPGA for the sharing of work might help in increasing the size of the board, after certain the board will become complex which limits the scalability

help them modify the functionality according their requirement. It can also bring an improvement in the system.

Many of the educational institutions in developing countries lack funds. Therefore, cost is an important consideration while designing the hallway façade. If the hardware is expensive and inaccessible, potential designers will be hesitant to use it. Designing hardware from scratch is time consuming and requires skill sets such as PCB designing, circuit designing, and testing. Also, newly developed hardware requires software, therefore software development and testing skill sets will also become necessary. In order to realize the complete system, hardware, software and mechanical components need to be integrated to give a shape or form to the system. If many of these entities are readily available and if the system can be realized with minimal changes to a few entities, then it can potentially motivate people from different fields to employ systems like the hallway façade.

1.7 Thesis Concept

Ubiquitous computing consists of several computing devices. In the case of the hallway façade, many computing devices are distributed across the surface. They are required to realize functionality such as SVN updates and group member availability. These computing devices are secondary objects; physical objects are considered as primary objects. This follows the philosophy of disappearing computers, placing the computing devices in the background of the hallway façade.

Another concept explored in this thesis is to provide an architecture to digitally augment the physical objects and use some of the digital objects to express the information. The defining aspect of this concept is to enable attaching smart technology to physical objects. Another distinct concept is enabling those physical objects to entangle with online information.

The basic implementation of our architecture is as shown in the figure 1.3. At the core of this architecture is to implement three basic capabilities: processing, interaction and communication with peers and online digital information.

1.8 Thesis Overview

This thesis is organized into five chapters. Chapter 2 explores the previous work and discusses various research efforts related to the pursuits in this thesis. The previous work include effective wall space utilization, ubiquitous computing, the chapter discusses the merits of different hardware platforms and various tangible interfaces.

Building upon the previous work, Chapter 3 provides descriptions of the about hallway façade and the rationale behind usage of LEDs and touch sensors. It provides implementation, describes a concept Pegboard as Tile, hardware design working behind the façade and communication method required for this hardware to communicate with external system, describes the software libraries which assist in realizing the system and middleware which is required for obtaining information from database (online repository) or from online.

After understanding the actual implementation, we describe the rationale behind some of the user interfaces, the design behind the system. In Chapter 4 we evaluate this concept by introducing it in an Interface Design and Technology course. It describes our vision in the year 2032.

The conclusion and discussions are presented in Chapter 6. The chapter summarizes the research contributions. It elaborates envisioned future directions. It describes the challenges and limitations associated with such kinds of systems. Also, it discusses previous disasters associated with interactive systems on the wall.

Chapter 2
Related Work

> The problems are solved, not by giving new information, but by arranging what we have known since long.
>
> Ludwig Wittgenstein

In the previous chapter, we presented the motivations behind this research and summarized the research contributions. This chapter will explore the various research activities that are aligned with our interest. Also, we explore the different techniques previously employed to realize the functionality of the system.

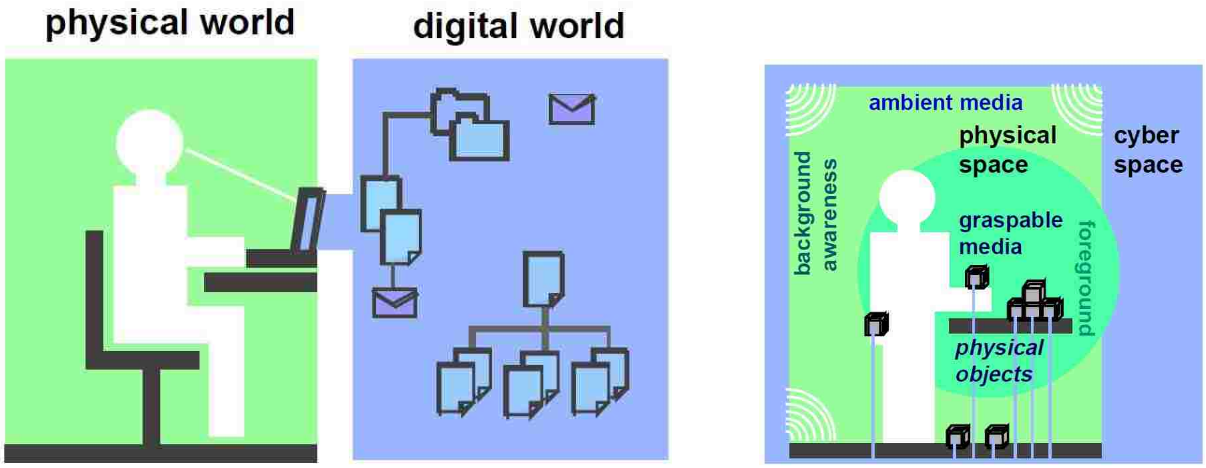
2.1 Related Work

In 1991 Mark Weiser, the head of the Computer Science Laboratory at the Xerox Palo Alto research center, described ubiquitous computing, which has now come to be seen as the next revolution in computing. In his words, "the most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it" [47].

Computing then moved out of the ugly boxes called desktop computers. There have been profound advancements in technology. The size of hardware components has shrunk considerably, sensor technology has improved and has seen a wide application in smart devices, and communication has interconnected whole world. Many of these products and systems have become economically viable.

Despite achieving rapid improvement on the technology side, we are still way behind Weiser's concluding vision:

> There is more information available at our fingertips during a walk in the woods than in any computer system, yet people find a walk among trees relaxing and computers frustrating. Machines that fit the human environment instead of forcing humans to enter theirs will make using a computer as refreshing as taking a walk in the woods [47].



(a) Typical interaction with digital world

(b) Interface with digital space through world around us

FIGURE 2.1. Subfigure (**a**) shows, personal Computing through small window of display. Subfigure (**b**) shows, interaction with world through augmented architectural space—from [49]

Weiser says that the ubiquitous computer will come in different sizes, each suited to a particular task. The paper [47] takes an example of a typical room and looks around for pads, label on controls, wall notes, thermostats and clocks, as well as small pieces of paper. Depending on the room, there will be plenty of tabs, pads and boards. Weiser and his team have developed tabs, pads and boards that approximate existing tabs, pads and boards. The goal of Weiser and his team was to deploy embodied virtuality: hundreds of computers per room which people will use unconsciously to accomplish everyday tasks.

In this research, we attempt to bring computations to an everyday hallway. Depending on the hallway, there can be plenty of elements like posters, light, card readers, switches, and thermostats. Before describing how these elements can be entangled electronically with digital information, let us explore various research efforts that led to the pursuit of this thesis.

This research project builds on a number of other efforts that have explored different aspects of wallspace interaction. These projects have utilized available space in rooms, offices and public areas [35, 49, 26] to develop meaningful interfaces with digital information. Currently, most of the computation remains inside personal computers and the interface to this system is either through

(a) Grease board—from [2]

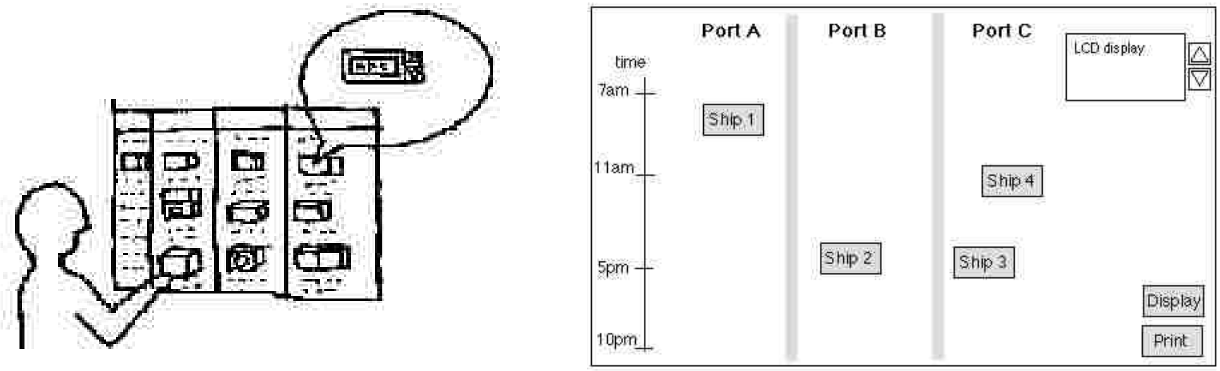
(b) Typical control board—from [3]

FIGURE 2.2. Figure (**a**) shows, Grease board on which inbound and outbound flights are written. Figure (**b**) shows typical control room of large power grid or nuclear power plant

keyboard and/or mouse. The figure 2.1(a) shows that interactions between users and display of digital information is almost confined to the small screens.

The usage of walls has long been present, and they have served many purposes. A simple example of large wall space utilization is large black or white boards used in classrooms. In many institutions, these boards are still used as notice boards to communicate information to large groups of people. There are many different types of boards which are large wall space. Grease boards like that in Figure 2.2(a), are extensively used in professional services. These are different from familiar white board in the way the contents on the grease board stay for a longer time and are much harder to erase. Nevertheless it has served many purposes - for example where all inbound and outbound traffic is written as shown in Figure 2.2(a).An Advanced version of this kind of board is a magnetic board which lets users not only write information and erase it whenever necessary, but allows users to stick paper to the board using magnetic pins. It is not limited to paper; it can be used for many purposes including different kinds of manipulable physical elements. Magnet board can be used for displaying class schedules and can use magnetic cards to represent individual persons.

Wall space is also very commonly used in control rooms of large power grids, nuclear power plant and many other places. Typical control rooms would look similar to that shown in Figure 2.2(b). There are plenty of controls and many light emitting devices of different colors. These devices are



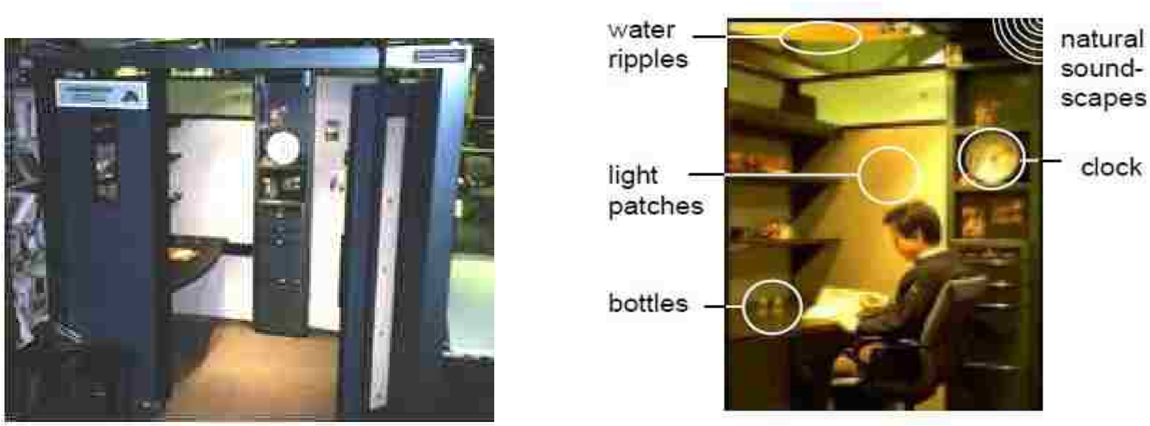
(a) LegoWall (b) Application of LegoWall

FIGURE 2.3. Subfigure (**a**) is a LegoWall prototype. Physical bricks can be moved around on a wall mounted panel. Subfigure (**b**) is a ship scheduling application—from [11]

either controlled by the technician or control data received from far distance. In the case of large power grids, these controls are to ensure power is supplied to the end user. In the case of adversity such as power shortages, controls like shutting off the power supply to a particular area are present in the control room. This can be extended to many other applications. Moving forward let us explore some of the efforts towards effective utilization of large wall spaces.

The LegoWall interface prototype developed by Molenbach and described in Fitzmaurice dissertation [11] consists of specifically designed blocks that fasten to a wall-mounted panel composed of a grid of connectors. The connectors supply power and a means of communication from the bricks to a central processing unit (CPU). This CPU runs an expert system to help track where the bricks are and what actions are valid, as shown in Figure 2.3(a).

As an example,a ship scheduling application is presented in Figure 2.3(b). The application has bricks, each brick represent a ship. When the bricks are attached to the grid board, they are uniquely identified and located on the board. Thus, the bricks are spatially aware devices. The user can obtain required information by placing the Display or Print bricks closer to ship brick. For example placing the Ship brick next to the Display brick causes the shipping schedule for that given ship. Positioning the Print brick next to a Ship brick and pressing the print button generates a hard copy of that ship's traveling schedule.



(a) AmbientROOM based on personal harbor^{TM} (b) Ambient media displays and controls

FIGURE 2.4. Ambient environment—from [49]

This, could potentially be applied to many other applications, such as displaying the schedules of research group members, by assigning bricks to each person. Also, one could obtain information about the group as a whole or individual persons with in that group.

Wisneski et al [49] present the concept of ambient displays, which use the overall physical environment as an interface to digital information. Figure 2.4 illustrates the digitally augmented physical space as an interface to digital information. It is a means to keep users aware of general states of large and complex systems such as network traffic and weather. The vision of the ambient displays is to blur the boundary between the physical and digital worlds to create an interface between humans and the digital information in cyberspace. The paper describes ambientROOM shown in Figure 2.4. This is an enclosed mini-office installation. Figure 2.4(b) shows some of the ambient media displays and controls available in the ambientROOM. The room has many interfaces in different forms which can provide awareness and make people feel connected to others:

- Water ripples: This provides the user with an interface to have some awareness of the activity of a significant other. The actions of the other person are transferred to a solenoid in a shallow water tank, which then vibrates upon input. Light reflecting off the water then produces rippling shadows on the ceiling.

- Active Wallpaper: This setup has sensors to sense the human activity in an area. This activity is projected on the inner wall of the ambientROOM in the form of illuminated patches.

- Global system awareness: The ambientRoom contains interfaces which can change based on the number of unread email messages or the level of the stock portfolio. Also, lighting of the room changes according to the time of the day.

- Pinwheels: It is a visual representation of airflow. The speed of the spinwheel changes based on the input information. It can also be used for many other applications, like network traffic, solar wind and so on. It is controlled by a simple DC motor.

The ambientROOM provides an easy way for users to interface with digital information which is otherwise difficult to perceive information. Our system adopts this ambience idea to impress upon users the active nature of research, virtual and/or physical availability of the person, and quintessence of interfacing physical world with digital world.

Moran et al [25] present the concept of collaborative collage called Collaborage. It is physically represented information on a surface that is connected with electronic information. The informational items are arranged on a board. Upon an event called the Collaborage Event, the system recognizes these events and triggers application-specific events based on them. The event can be the appearance, disappearance, or movement of an item. The paper describes a persistent, low-cost system for displaying members' availability and a group's active tasks information on the wall. In/Out board, like that in Figure 2.5(a), is located in the hallway which members of the group pass on their way to and from offices. Each person is given a badge with their name, photo, and glyph tag which attaches itself magnetically to the board. Each person passing by the hallway moves the badge to display the status of their availability in the office. The Collaborage system recognizes these movements and updates the database. This enables a small group of people in an office environment to be aware of other members' availabilities. Another application of Collaborage is a project task wall, like that in the Figure 2.5(b), located in the group's meeting room. The board is used to post the group's

(a) In/Out and Away board

(b) Project task wall

FIGURE 2.5. Figure (**a**). Hallway wall with In/Out and Away board. Figure (**b**). Project task wall located in group's meeting room—from [25]

current active tasks during weekly group meetings. This has many advantages, it shows progress from previous meetings and enables the group to plan for the coming week. Tasks are posted on the board, and the badge of the person responsible is posted next to the task. The Collaborage system tracks the items on the board and updates the database. The system captures the images of the task wall so that application programs can put the information on the web. The system's dataglyphs tags are similar to barcodes. Dataglyphs are designed in such a way that the camera is able to detect the location of and decode the glyphs even in low resolution. This is achieved through computer vision technology to identify and monitor the location of the tags and by keeping track of the changes on the board. The Collaborage system explores the utilization of large physical spaces with electronic augmentation.

Another interesting research activity is i-Land. Streitz et al [36] presents an interactive landscape to create innovative workspaces. This research aims to create innovative workspaces, supporting cooperative work of dynamic teams with changing needs. These workspaces integrate physical and informational environments based on a concept called roomware. Roomware refers to computer augmented objects resulting from the integration of room elements, like walls, doors, tables, and chairs, with computer-based information devices. There are three sets of roomware: DynaWall, InteracTable, and CommChairs.

(a) Aarhus by light (b) Projected poetry

FIGURE 2.6. Figure (**a**). Aarhus by light is an interactive media façade at the concert hall. Figure (**b**). Projected poetry used as a forum for public debate —from [13]

- DynaWall is an interactive electronic wall covering one side of a room completely. This enables two or more people on a team to interact with large information structures collaboratively on the DynaWall.

- CommChairs are mobile chairs with either built-in slate computers or a docking station to facilitate the use of personal laptops. The chairs allow people to share information with individuals other chairs, interacting with the DynaWall, or using the InteracTable.

- The InteracTable is a mobile interactive table that allows two to six people to create, display, discuss and annotate information objects.

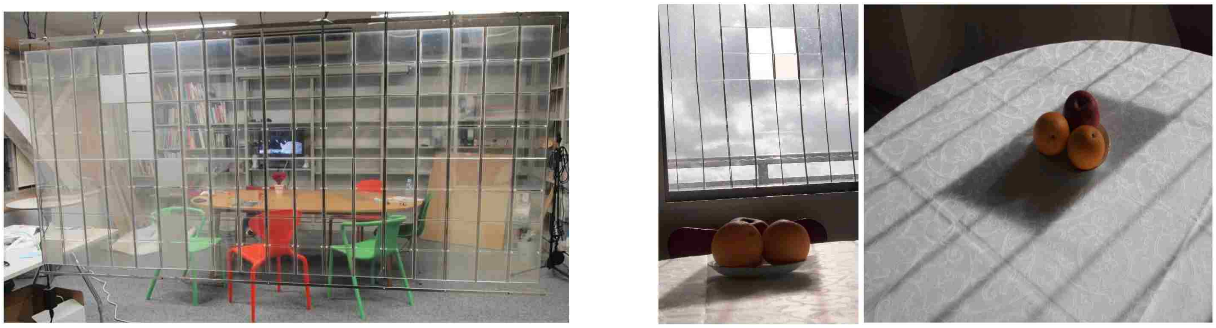
More recently under the umbrella term of urban informatics [12], researchers are exploring urban space arenas for information systems design of interactive systems and installations. This includes a series of media façades developed in an urban setting. Aarhus by Light [13] is an interactive media façade present in conference hall. On the central path leading visitors to the hall, there are three illuminated zones. In these zones, camera tracking translates the visitors' presence and movements into digital silhouettes on the façades. Visitors can move, lift, and caress the silhouettes on the façade creating an interaction with the visitor Figure 2.6(a), Interaction is achieved beyond the physical and embodied, which is affective and emotional [9].

Projected poetry [13] is another public installation aiming to raise public awareness about carbon emission in Aarhus Figure 2.6(b). Projection technology is employed to display information onto the façade of a prominent cultural institution. The information (words, pictures) floats above the passers-by. If a person stops, the word above him grows and is turned into a speech bubble. This provides a platform to communicate information about topics like climate change, which can foster dialogue, debate and public participation in such key topics.

A Dynamically Transport Window (DTW) [10] is an interactive window in an urban setting which responds to the movement of people passing in front of it. The intention is to attract the attention of potential shoppers. The window is fitted with electro-chromatic foil that can change from opaque to transparent upon current flow. The glass is opaque when there is no movement, but when someone walks by, it becomes transparent. This is an element of surprise for the passer-by and attracts the attention. The system uses camera technology to detect the movement of people by interpreting the changes in the video signal as people move along the façade. Perry et al discuss a similar interactive window called WaveWindow [26], an interactive see-through display allowing users to interact with digital content overlaid on physical items behind a semi-transparent screen. Users can interact with WaveWindow by waving in specific regions in the air and by knocking on the screen. Both of these systems are composed primarily of webcams and custom reactive software in open environments.

Gjerlufsen et al [14] describes a method of interaction which combines conglomeration of display devices and heterogeneous interaction devices. Their system "presents a novel middleware for developing flexible interactive multi surface applications", especially by employing large arrays of monitors. In comparison, our system utilizes a mixture of display and input devices to provide an overview of dynamic activities.

Recently, Rekimoto presented programmable physical architecture called Squama [29]. Squama is a programmable physical window or wall that can independently control the visibility of its



(a) Programmable physical architecture

(b) Programmable shadows

FIGURE 2.7. Figure (**a**). Squama: modular programmable window or wall for dynamic architecture. Figure (**b**). Shadow defined area by the user protected from the direct sunlight—from [29]

elemental small square tiles. This envisions façades which can be dynamically changed and reprogrammed according to need.

Rekimoto presents the concept of real-world pixelization Figure 2.7. Squama is designed as a window, a partition in the physical architecture Figure 2.7(a). It controls transparency in a modular way, providing privacy to people living in a condominium. Sometimes people living in condominiums may be distracted by people living in nearby buildings. This situation can be averted by obscuring the visibility of the windows according to the user requirement. It uses Kinect and its SDK for people tracking.

Another application of Squama is the programmable shadows shown in Figure 2.7(b). These control the amount of sunlight entering a and even create shadows, serving to protect adults and children alike from ultraviolet rays. Squama allows people to define things that must be protected from sunlight. The system then computes the direction of the sun and automatically obscures that part of the window nearest to the protected objects or people. The user interface provides for manual control the shadow areas.

This paper presents the interesting concept of programmable physical architecture, which lets the user change physical features in real time, according to the user's demand. Another interesting concept similar to the concept of Pegboard as Tile presented in this thesis is real-world pixelization. A detailed explanation is provided in next chapter.

Many efforts have been made over the last two decades to integrate digital information systems with physical architecture. Based on prior work and previous experiences, we have developed the hallway facade using relatively simple, modular, reusable and scalable hardware architecture. We have also developed the required software libraries and middleware to assist the interaction designer with developing these systems easily.

2.1.1 Visual Comprehensibility

Any visual representation on the façade should be accessible, understandable and comprehensive. Therefore greater insight is required about the visual representation on the façade. Many important aspects need to be considered for displaying information on the façade, including secondary notations in diagrams and the apprehensions of dynamics. The familiar adage asserts that "a picture is worth a thousand words". The truth of this saying is knowable with the help of appropriate secondary notations. As briefly discussed in Ullmer's thesis [43], the area of diagrammatic representation offers more specific investigation into the role of external representations upon cognition. These assertion are studied in conjunction with the development of visual languages and visual programming languages for human-computer interaction. In a paper by Larkin and Simon titled "Why a Diagram is (Sometimes) Worth Ten Thousand Words," the authors say:

> The advantages of diagrams, in our view, are computational. That is, diagrams can be better representations not because they contain more information, but because indexing [such as spatial juxtaposition of related elements]... can support extremely useful and efficient computational properties [20].

Building on the Ullmer thesis [43], Lewis and Toth presented an interesting interpretation of this conclusion:

> The primary advantage of visual representations such as diagrams is attributed to apprehension of dynamics rather than the explicit representation of state [20], although the model accounts for both. [Lewis and Toth 1992]

In this context,the 'apprehensions of dynamics' concerns the changing content of visual representations. If the displayed content is dynamic, accordingly the secondary notations associated with that visual representation also need to be changed. Therefore, dynamic visual representation contributes to the apprehension of dynamics, This has several implications on the façade. The hallway façade's visual representations and tangible interfaces utilize substantial visual representations. Several of these visual representations are dynamic, creating the advantage of up-to-the-minute information, while simultaneously contributing to the apprehension of dynamics. Therefore, it is important to make sure the content on the façade is understandable by updating the secondary notations along with the content.

Larkin and Simon offer an important assessment about graphical diagrams:

> ...none of these points insure that an arbitrary diagram is worth 10,000 of any set of words. To be useful a diagram must be constructed to take advantage of these features. The possibility of placing several elements at the same or adjacent locations means that information needed for future inference can be grouped together. It does not ensure that a particular diagram does group such information together [20].

This argument is further strengthened and elaborated by Petre's article, "Why Looking Isn't Always Seeing: Readership Skills and Graphical Programming". Petre argues that text and graphics are not necessarily an equivalent exchange; he instead calls for balance and consideration. The article discusses the comprehensibility of a graphical representation and the importance of secondary notation. Petre elaborates upon this point, saying:

> The strength of graphical representations... is that they complement perceptually something also expressed symbolically. For instance, when functionally-related components are placed close together, which is typical practice in electronics schematics, an analog mapping is being used to supply extra information over and above the information explicitly represented by the components and their connections. Expert designers regard this 'secondary notation' as being crucial to comprehensibility.
>
> ...Much of what contributes to the comprehensibility of a graphical representation isn't part of the formal programming notation but a 'secondary notation' of layout, typographic cues, and graphical enhancements that is subject to individual skill [27].

His comments support the intuition of representational strengths of diagrams. The hallway façade is about information visualization with many graphical and electronic elements. The elements as such may not convey relevant information. As Petre says "graphics do not guarantee clarity:

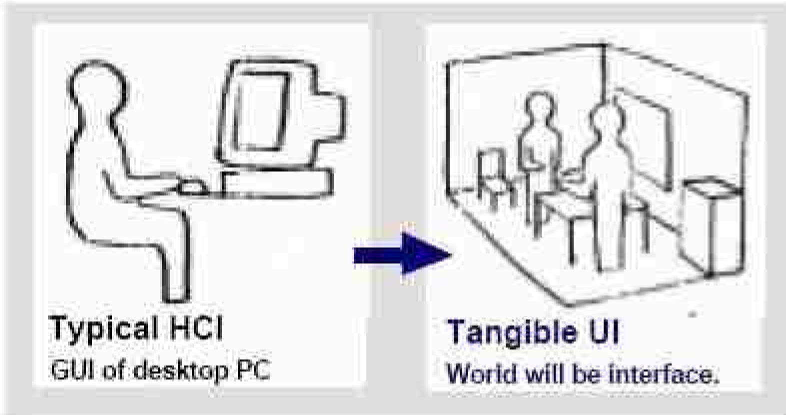


FIGURE 2.8. From GUI based Interface to tangible user interfaces—from [18]

’good’ graphics relies on secondary notation" [27]. Therefore the elements on the façade should be supported by secondary notation to make them more sensible. Once again, as Petre says, "good graphics usually means linking perceptual cues to important information, which means both identifying and capturing what is important and guiding the reader with appropriate cues" [27].

2.2 Tangible User Interfaces

Ishii and Ullmer established a new type of Human Computer Interaction (HCI) called Tangible User Interfaces (TUIs). TUIs augment the real physical world by coupling digital information with everyday objects and environment. The paper [18] that presents "Tangible bits" is an attempt to bridge the gap between cyberspace and the physical world by making digital information tangible.

> Tangible Bits allows users to "grasp & manipulate" bits in the center of users attention by coupling the bits with everyday physical objects and architectural surfaces [18].

Figure 2.8 illustrates the transition from GUI-based interfaces to tangible user interfaces, turning the world around us into an interface to the digital world.

Tangible interfaces are sensor-based interaction devices. When a physical object(/s) is manipulated, a computer system detects this via the sensing mechanism embedded in the physical object. The corresponding digital effect can take place in a number of ways, including sound, display, or vibration. Several incarnations of tangible interfaces have followed Ishii and Ullmer’s paper and preceded our work on the hallway façade. The MusicCube proposed by Alonso et al [6], allows the user to interact physically with music collections. The wireless cube object uses gestures to shuffle music and a rotary dial for song navigation and volume control. Underkoffler and Ishii [45] introduced an interactive workbench for urban designing and planning. The workbench collects the functions addressing the concerns associated with urban planning such as shadows, relfections, wind, airflow, visual space. 'Urp: A luminous-tangible workbench for urban planning and design' uses physical models placed over an I/O bulb infrastructure. Digital shadows are cast from physical models that are moved around the table under different lighting conditions.

Both MusicCube and the other physical models are tangibles for interactions with the system. Tangibles are the manipulable physical elements of user interfaces which serve as representations and controls for digital information [41]. In order to bring greater flexibility to the utilization of tangibles, Ullmer et al [42] are pursuing the idea core of tangibles: physical interaction elements which serve common purposes across a variety of tangible and embedded interfaces. Two such examples are tangible menus and interaction trays. Tangible menus are tagged, printed structures and surfaces used to represent and access diverse data, parameters, operations, and other associations. Interaction trays are devices which integrate different combinations of interactors with receptacles for tangible menus.

For tangible menus and interaction trays to be active or recognizable, some kind of sensing mechanism is necessary. The menus and trays in [42] are tagged, and tracked on instrumented workbenchs with RFID or vision-based infrastructures. The media façades described in the previous section [13, 9, 26] use cameras to sense the gestures of the user; the computation either happens in the object itself or is centralized. In the case of menus and trays, computation is within the object using existing toolkits [15, 17]. AudioCubes [33] employ custom electronics suitable to the application. Each cube contains a digital signal processor (DSP) with optical sensors and emitters. The sensors and emitters receive and send audio signals generated or processed by the signal processor in the cube.

TUI research encourages the development of tangibles or physical objects to interact with the digital world. The concept can be extended to the surrounding physical environment. It can also act as a manipulable interface to bridge the gap between the digital world and the physical environment. The advantage is that the physical objects and digital representations can be positioned, combined, and explored in creative ways, enabling dynamic information to be presented in different ways [30]. Physical objects can be used in many different ways, providing an opportunity to explore the problem space in many different configurations. This can lead to greater insight and more learning and problem-solving than is offered by other kinds of interfaces [21].

2.3 Hardware Platforms and Prototyping

The previous section presents several different initiatives towards the integration of the digital world with the physical environment. Also, the tangible user interfaces section describes tangibles or physical objects as tools, containers, or tokens to interact with digital world.

This section briefly describes several hardware platforms that can be considered for ubiquitous systems. The platforms include embedded hardware and the software necessary for building interaction devices. Realizing ubiquitous systems requires hardware and software developers, architects, and product and interaction designers. Often ubiquitous computing requires strong collaboration among different fields of designers. Implementation of ubiquitous systems additionally requires distributed computing and communication with the external world.

Distributed computing in the context of the hallway façade refers to the processing capabilities of the embedded devices to realize various user interfaces, the ability to communicate between themselves, and the ability to communicate with the external system. Some of the functionality of embedded modules is to read the various sensor data, actuations, processing and communication with the external host. These modules will be distributed and interconnected by a network for communication among them. Each module should be capable of working independently. For distributed systems, the hardware platform should be scalable and functionally extendable.

In ubiquitous systems there is a constant need for embedded devices to communicate with the external world and among themselves to obtain information. In the context of the hallway façade, the digital information displayed is primarily available online as opposed to the local non-relevant information. Therefore the platform should support communication to obtain the required digital information. Also, communication among the embedded devices is necessary to obtain information such as sensor inputs and to activate the output (LEDs, motors, speakers and so on).

In order to achieve distributed computing for the ubiquitous system, the appropriate hardware platform is necessary to develop fully functional systems like the hallway façade. The following sections explore some of the existing hardware platforms, briefly describe each of these platforms, and discuss their advantages and shortcomings in the context of the hallway façade.

2.3.1 Phidgets

Phidgets or physical widgets are a prototyping platform for developing interactive interfaces. Similar to widgets, phidgets abstract and package input and output devices. They hide implementation and construction details and, expose functionality through a well-defined API [16]. Phidgets consists of a device, software architecture for communication and connection management, a software API for device programming, and a simulation capability.

2.3.1.1 Hardware

Phidget is a physical device which is a packaged unit given to the interaction designers to develop user interfaces. The physical device includes the primitive input and output device components such as sensors, motors, switches, etc., a circuit board with micro-controller, and a communication layer. Communication with the computer is based on the USB communication standard. Phidgets are designed to be easy-to-use hardware platform targeted at interaction designers unfamiliar with hardware design. Furthermore, phidgets are not designed for extensibility of the hardware. The GlabInterface kit in Figure 2.9 is a general purpose kit for developing interaction devices. Off-the-shelf LEDs, solenoids,and sensors can be connected to an interface kit; the programmer can

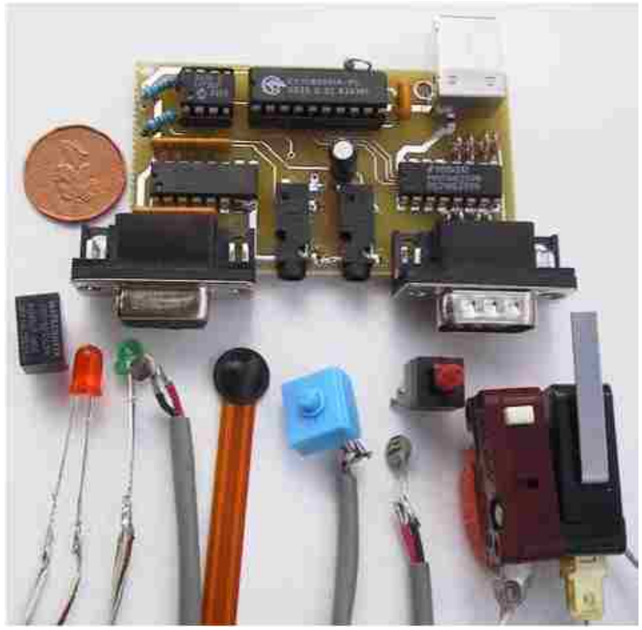


FIGURE 2.9. GlabInterfaceKit and a host of sensors, switches, LEDs and solenoids that can be connected to it - from [16]

control these devices by using APIs. It can also inspect the state of various analog sensors that can be connected to it.

2.3.1.2 Software

The phidgetManager is a COM object. It provides an event-based API to end-programmers for connection management. The major elements of the API include onattach() and ondetach() of the devices. When a device is plugged in, there are two other kinds of interfaces to that object, the IGlabPhidget interface, and the phidget-specific interface. IGlabPhidget interface provides information about devicetype, Isattached, and serialnumber. Phidget-specific interface exposes an API specialized to the particular phidget-specific COM object. With this interface programmer can detect the number of devices, position, and any changes in position of the phidgets.

2.3.1.3 Discussion

Phidgets are one of the simplest hardware platforms for interaction designers to develop user interfaces. The hardware functionality is, to a certain extent, fixed. This leaves the designer with much less flexibility. The non-availability of wireless communication, coupled with the relatively larger sizes and the lack of flexibility to modify the functionality of the phidgets is less suitable for distributed systems.Also, communication with external systems is only achieved through the USB standard. However, the software support provides a good abstraction from the hardware and simplifies application development. Despite the good abstraction and easy application development, it lacks an overall framework that provides useful guidelines and concepts for application development.

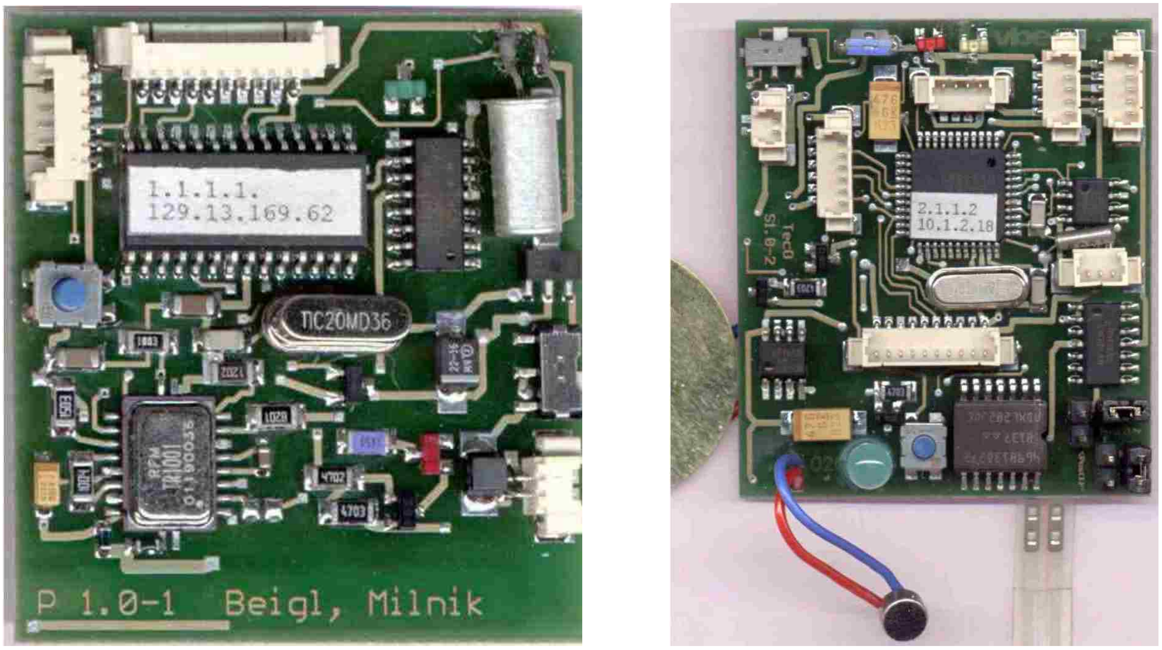
2.3.2 Smart-Its

Smart-Its [8] is an embedded platform for developing networked smart objects. The current transition from personal to ubiquitous computing is marked by the integration of the physical world around the computer. The physical objects are an integral part of the overall system. The means to achieve such physical integration is through embedding computing into the objects and artifacts that are the subject of everyday activity.

Smart-Its are generic computing devices with an open-ended platform specifically designed for the augmentation of everyday objects. The point of Smart-Its is to support post hoc attachment of smart technology to common objects. The larger goal is to enable active objects with tight coupling between their physical context and digital state, and with a large degree of autonomy and control over their digital selves.

2.3.2.1 Hardware and Software

The core functionality is mapped onto two hardware modules, one for communication and the other for physical I/O, with processors in each module. The Communication module has a microprocessor, RF transceiver, basic I/O and various hardware interfaces to connect boards, sensors and serial line Figure 2.10(a). Sensor boards have their own microprocessor and RAM to perform the computation of context information from sensor observations and application specific code. The Figure 2.10(b) shows the sensor board with audio, light, and a variety of sensors and actuators with many connectors for interfacing with the interaction devices. Software executed on the system is task-specific and customized for a particular physical object. Smart-Its communicate via short range radio frequency.



(a) RF communication module

(b) Sensor module

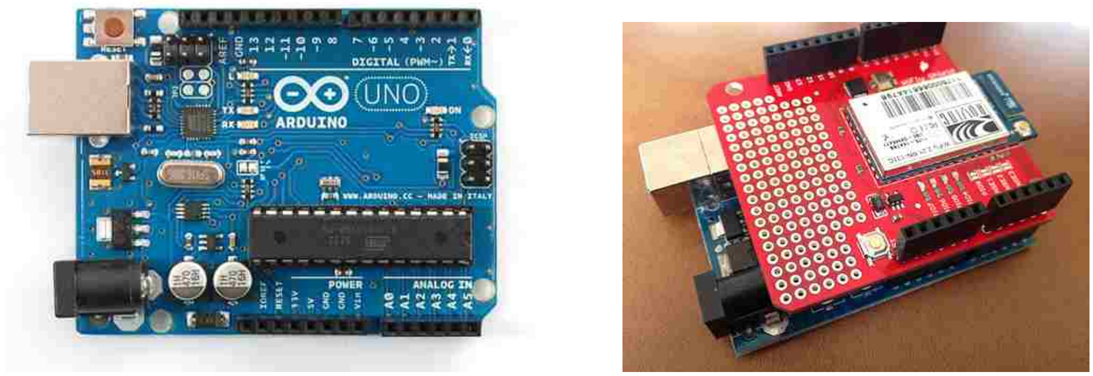
FIGURE 2.10. Communication board with RFM transceiver,and the sensor board with audio, light, acceleration, pressure and temperature sensors, LEDs and piezo loudspeaker, and a variety of connectors for additional sensors and actuators. — from [8]

2.3.2.2 Discussion

Smart-Its applications are largely based on the processing of the sensor input, computation and communication of context, and reaction to particular events. Smart-Its are a concept aimed at developing a platform on which computing is decentralized and placed in the background of physical artefacts. Smart-Its are commercially not available for interaction designers. However, they provide a wireless interface communication with an external system which is useful for distributed systems and entanglement of digital world with physical space.

2.3.3 Arduino

Arduino is a tool for making computers that can sense and control more of the physical world than the average desktop computer can. It is an open-source physical computing platform based on a simple microcontroller board and a development environment for writing software for that board [4]. Arduino lets users create working electronic prototypes. It can read from a wide range of sensors, controls a broad spectrum of output devices, and can communicate with software running on a computer or talking over a network [23].



(a) Arduino Board

(b) Arduino shield snapped on top of the arduino board

FIGURE 2.11. Typically arduino board with connector at the periphery provide access to I/O pins. Shield of same footprint can snapped onto those connectors as in the second figure

2.3.3.1 Hardware

Arduino is a printed circuit board (PCB) that has a microcontroller and, power supply components. A majority of arduino versions have USB ports enabling communication with a computer. It consists of I/Os pins for interfacing with other devices or to drive LEDs, motors or speakers. It also provides analog pins to read the sensor output. The Figure 2.11(a) shows a typical arduino board with accessible I/Os.

Since I/Os pins are accessible through the connector, the functionality of the arduino can be used via the extension shields like other circuit boards can be snapped on to the arduino board. This provides extra functionalities such as wireless connectivity, RFID readers, or small breadboards that can be used to mount circuits in a compact form. In the Figure 2.11(b) shows a wifly module snapped onto the arduino board. The wifly device provides wireless connectivity (wifi) with online space.

2.3.3.2 Software

The arduino software consists of two parts: the development environment and a core library. The development environment is a complete source code editor. It can be used to manage, edit, compile, and upload programs. The arduino core library consists of AVR C/C++ functions that are compiled along with the user's sketch [23].

2.3.3.3 Discussion

Arduino provides a platform to build interactive devices. It has also proven to be popular among artists seeking to incorporate electronics and interactivity into their works [23]. There are many reasons for its popularity:

- Reusability: External modules can be snapped onto the arduino, and this plug-in type of interfacing enables reusability of the arduino.
- Scalability: The functionality of the arduino can be extended by using an extension shield or other devices that match the footprint of arduino.
- Availability: Arduino is an open source project (both hardware and software), allowing people across countries manufacture the arduino locally.
- Functional Augmentation: There are many devices which are commercially available that follow the footprint of the arduino to develop shield.

2.3.4 Blades and Tiles

Blades and Tiles [31] is an approach to hardware design for middle to late stages of implementation and deployment. Substantial amounts of time are required for prototyping different interaction designs and testing them for usability. Blades and Tiles provides flexibility and rapid prototyping of hardware. In ubiquitous computing several copies of different interaction devices exist at several locations. The architecture is aimed at maximizing the reuse, and minimizing the cost and waste of the hardware.

FIGURE 2.12. Blades and Tiles installed within interaction devices — from [31]

2.3.4.1 Hardware

Blades and Tiles hardware architecture is structured in several hierarchical levels. From the "bottom to top" of hardware hierarchy, these include blades, tiles, and interaction devices. Blades are the circuit boards with active microcontrollers to realize interaction device for a given ubiquitous computing system. Tiles circuit boards typically have no active processors; instead, they typically host switches, LEDs, RFID tags and other blade-mediated interactors. Blades mechanically fixes on to the tile board and tiles electronically interconnects the blades. There are three classes of blades: core, function, and resource.

- Core blades are the communication backbone of the blade-based systems. Gateway blades link the internal bus of the bladed system with the external network. Intracomm blades hierarchically route messages and power between global and local buses.

- Functional blades perform specific operations necessary for developing interaction devices like driving the LEDs, driving the motors, sensor blades, RFID readers, actuation blades and so on.

- Resource blades provide system-level resources. Examples include battery, compute, and storage blades.

Blades physically connect to tiles. The tile provides a platform for the blades to communicate with the other blades, intracomm and gateway. A single tile may not host all the blades. Hence blades are usually chained to extend the functionality of the system. The Figure 2.12 shows the blades and tiles arrangement and chaining of the tiles to meet the functionality requirements of the system. There are two tiles in the Figure 2.12 one to the right of the middle black line and other one to the left of the line. The circuit board held by a person is a blade. Many of these blades are sitting on the tile both to the left and right of the middle line. Since all the blades cannot fit on a single tile, two tiles are chained as shown in the picture 2.12 using USB ports which is in the middle.

2.3.4.2 Software

The functional blades execute a program aimed at realizing a specific functionality to implement different interaction capabilities. Some of the examples include: LED blade programmed to drive LEDs using PWM; and sensor blades taking analog input. processing the input, and performing any necessary actions. If a sensor blade has to communicate an LED blade, then there should be a communication path between two blades. Therefore, the Blades and Tiles architecture internally uses I^2C communications network. Gateway and intracomm execute proprietary algorithms for blade discovery, data transport and system control. The transport protocol has been modeled in part based on TCP/IP and embedded protocols like CANbus.

2.3.4.3 Discussion

The Blades and Tiles architecture for hardware design has the potential to reduce the prototyping duration of interaction devices. The toolkit is composed of a series of functional modules, each providing interaction modalities that can be rapidly interchangeable to build various interfaces. This architecture provides hot swappable communication infrastructure, and is scalable for the large systems necessary for ubiquitous computing. This architecture provides modularity, scalability and re-usability of the hardware. A significant amount of time is required to manufacture the Blades and Tiles. Since these are commercially unavailable. Blades can be built using different processors. This necessitates the interaction designer to have some knowledge about programming the processor being used. There is no standardized size and form of Blades and Tiles for its universal usage.

2.4 Comparison of Different Platforms

We have explored some of the hardware platforms in order to utilize them to realize the hallway façade. It is necessary understand the requirements before comparing different platforms. The major computational requirements of the hallway façade are: distributed computing, communications between computers on the façade, communication with the external world, commercial availability, open-source hardware, and software support.

TABLE 2.1. Characteristics of different hardware platforms

Platforms	Distributed computation	Communication Integration	WiFi communication with external world	Commercial availability	Software support
Phidgets	concentrated	fully integrated	USB	not available	not available
Smart-its	dispersed	varied	Wireless	not available	not available
Arduino	dispersed	specific	Various communication protocols using additional module	available	available
Blades and Tiles	dispersed	modular	USB, bluetooth or WiFi	not available	not available

Based on the requirements and the comparison in table 2.1, we discuss in the section § 3.3.2 the platform suitable for realizing the hallway façade.

Chapter 3
Architecture and Implementation

> We can't solve problems by using the same kind of thinking we used when we created them.
>
> Albert Einstein

In the previous chapter we presented some of the existing work towards an integrated physical and digital world. This chapter describes the architecture, implementation, software and middleware we developed to achieve our own integrated environments.

3.1 Hallway Façade

As a prototype we have developed a system covering 56sqft of hallway wall space. The structure of the surface is built using wood mounted to an 80-20 extruded aluminum frame. The interactive surface integrates a number of input and output components such as LEDs for visual representation of an individual's physical and digital status and touch sensors as an input to the façade.

The system manifests research activities in the form of subversion repository commits, and member availability in physical/online space such as Skype, iChat, G-talk and AIM. Each of these online and physical spaces is designated with a color. Similarly, the range of SVN commits per day/week/month/year is also assigned a color. Each of the group members and SVN folders is represented by a stencil Figure 3.1. A group member's availability is notified by lighting a set of

FIGURE 3.1. Person and SVN folder stencils

LEDs with the color designated for that researcher. For example, Skype is ascribed the color red; if a member is online on Skype, then the set of full-spectrum LEDs associated with that person stencil will light up and with the color red. The legend for different spaces and SVN commits are provided at the center of wooden structure as in Figure 1.3. Similarly if a member from a research group uploads a file to the subversion repository, the set of LEDs associated with that folder stencil will light up. There are two sets of LEDs above and below the stencil. The top set of LEDs indicates the availability of a person in a specific room on the university campus. The bottom set indicates the availability of a person online. Similarly the LEDs light up based on the number of SVN commits made in a specific folder in a day/week/month/semester. The bottom set of LEDs for the SVN commit stencil indicate the day/week/month/semester; the top set of LEDs indicates the number of commits (range) made to a specific folder. The touch sensor on the wall surface acts as a means for a user to explore the group's research activities and the people involved.

According to Pousman and Stasko [28], the designers' decision to strive for visually pleasing displays is most clear in the cases where the display is intended to leverage the work of existing artists. Consequently, we have used bright warm LEDs at the bottom of the wall, as seen in Figure 1.3, to provide pleasant ambience and to allure passersby to engage with the system. These LEDs are also used to illuminate the posters. They serve two purposes: aesthetic appeal and visibility in the dark. We have used full-spectrum LEDs to manifest information, these LEDs give a colorful appeal to the system and are diffused using rice paper to reduce glare.

3.2 Rationale

As discussed in the previous section, we are using light as medium of communication and LEDs as a source of light. Touch sensors act as a input interface to the system. The following two subsections describe the rationale behind using light as medium of communication, LEDs as a source of light, and touch as an input interface.

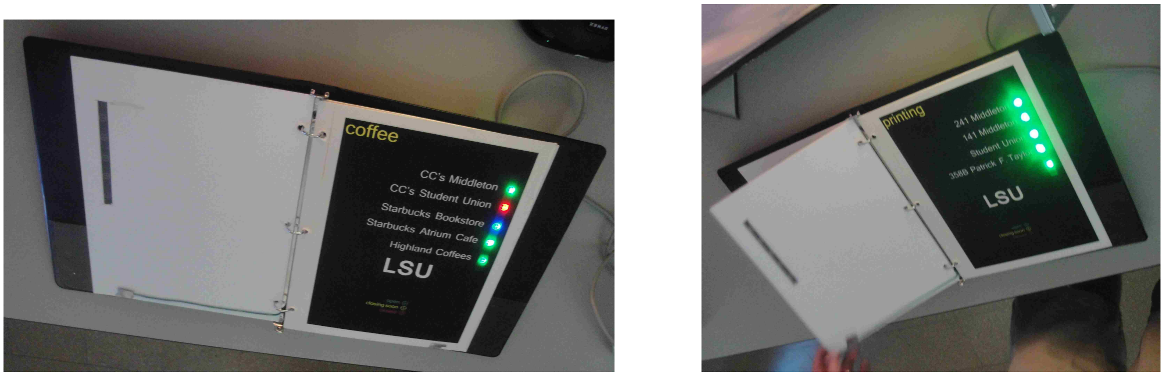


FIGURE 3.2. Student project from interface design and technology course offered in spring 2012 uses the concept of semantic light and also employs the architecture described in this thesis

3.2.1 Light and LEDs

Light is fundamental to everyday life. It is a source of energy and is intensely relevant to the human experience. It determines days, and nights, and the sleeping patterns of the human being. Across many cultures, light is used as a metaphor for knowledge, enlightenment and reason. Harbors also used to have light-houses, used to flash bright beacons to guide ships to ports. At the micro level light is used in optic fiber to transmit data at higher bandwidths. Light has thus been used as a means of communication for many centuries.

In the recent past, LEDs have caused significant change in lighting systems, and have brought new ways for light to be used. This is due to some key LED: physically small (semiconductor material), high luminance, high efficiency, digitally controllable, very cheap to manufacture, long life-times, and the ability to emit intended light, among others. Due to its small structure, an LED can be positioned or embedded into luminaries, materials and even the very fabric of a building or environment [5]. Many other light sources such as incandescent bulbs, and fluorescent lighting are controlled by simple on/off switches. LEDs are much more complex, they have multiple controllable parameters such as color, intensity, and saturation. This gives us a means to express different activities, emotions, events, and so on using a single LED. With these properties, LEDs are used in many different applications such as DLP micro projectors, televisions, inexpensive cameras, home lighting systems, and sensors.

For a long time, light was used as a means of communication. Segall et al. [34] describes a "semantic light", which communicates meaning to the user by overlaying information by means of color, text, image, animation, video and other data [34]. LEDs have an aesthetically pleasing appeal while simultaneously conveying information. An example of a very common semantic light is a simple traffic signal, where red indicates "stop" and green indicates "go". Another example of semantic light from the 1980s and 1990s is the light outside a surgeon's operating theater. If the light color was red the operation is underway; otherwise the operating theater was assumed to be empty.

Figure 3.2 shows the utilization of the idea of semantic light. This is a student project from interface design and technology course offered in the spring of 2012 by Dr. Ullmer. Students created a book containing pages of information. Figure 3.2 shows two pages. One page lists all of the coffee shops on LSU campus; the other lists public printing machines in different buildings. If a particular coffee shop is open, the color of the corresponding text lights up green; if it is closed, the color text shows red. Similarly, if a given printer is working, it is indicated by a green light, while a red light means the printer is not running. As is evident from this example, light is still used to communicate meaning to the user by means of both color and text.

3.2.2 Touch Sensors

In the era of smart technology, and hand-held devices virtually every smart-device has touch sensors int its user interface. The touch-based interface is more intuitive compared to the traditional keypad-and-mouse systems. There are many different types of touch sensors, including capacitive, resistive, infrared, and optical imaging. Of all these types, the capacitive touch sensor is the most widely used for different applications. Touch screens in smart-phones, tablet computers, home appliances and smart devices in automobile, are driving the demand and acceptance of touch sensors as a device interface.

The intuitiveness and popularity of touch sensors was a driving factor in our choice to use them as interaction entities in the hallway façade. The capacitive touch interface is also relatively easy

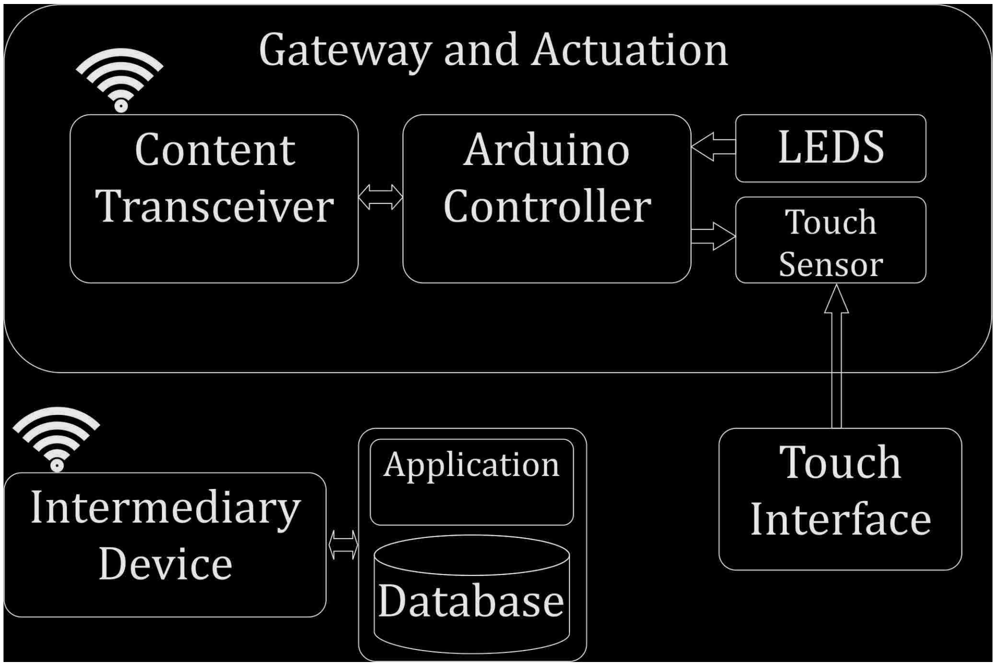


FIGURE 3.3. Arduino controller drives the LEDs, content controller communicates with database for information and touch sensor is an input to façade.

to implement. Moreover, the touch interface can be implemented using low cost materials like aluminum washers and screws.

3.3 Implementation

The system uses the concept of Blades and Tiles [32], a modular and extensible hardware architecture for our distributed embedded system spanning a relatively large surface area. We are using arduinos as controllers to drive the LEDs. WiFi is used for communication between the database and the content transceiver(gateway) on the façade Figure 3.3. The content transceivers are WiFi devices which receive data from the database and pass it on to the arduinos. After interpreting the data, the arduinos drive the appropriate LEDs. The arduinos also receive information from the touch sensor modules. Based on the sensed touch element, the arduino will either request information from the database through the gateway or drive the appropriate LEDs. The Figure 3.3 shows an individual unit; many such units exist on the wall.

The most important aspect of using LEDs as an information medium is that any such medium should make sense to the user. In the case of the hallway façade, LEDs are used for showing

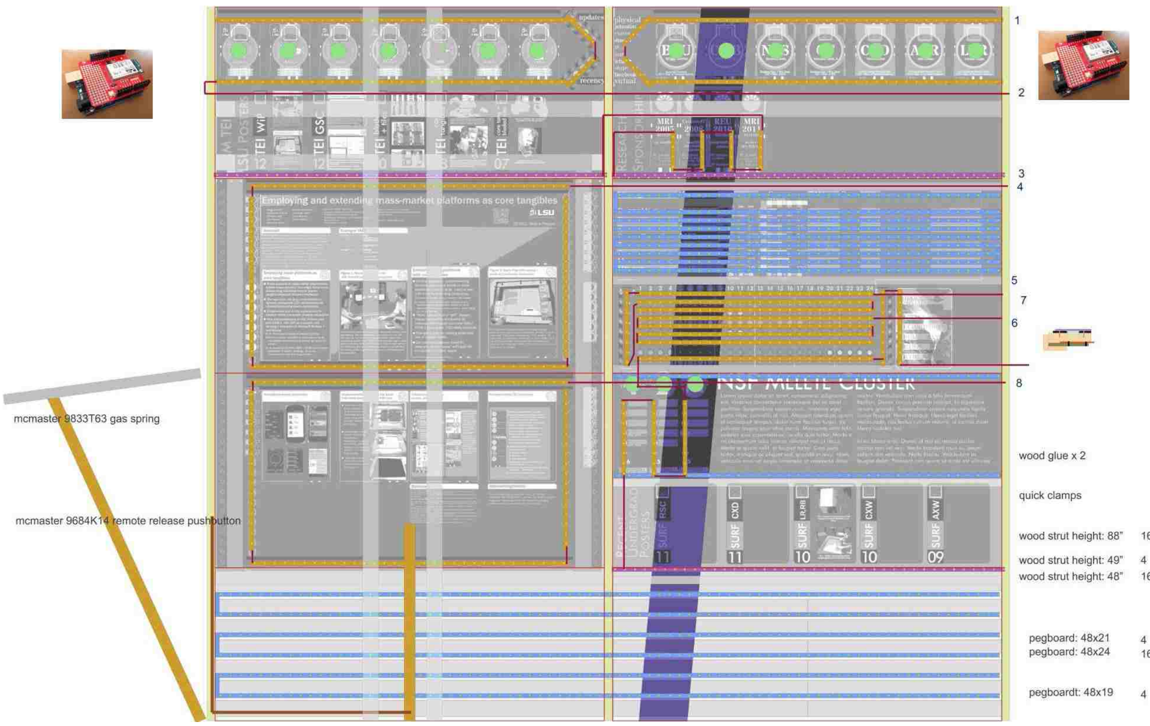


FIGURE 3.4. Façade LED Layout

the presence or availability of a group member in a particular room or online space like Skype, i-Chat, G-talk and others. The particular colors assigned to building and online spaces help the user distinguish easily between different spaces. The next important aspect is to ensure user understands the color coding. The user, without prior knowledge, will not be able make sense of the colors glowing beneath each stencil Figure 3.1. Therefore, a legend is provided at the top of the façade, as seen in the Figure 3.1. The legend shows the color assigned for each building and online spaces. A legend for the colors of subversion repositories (SVN) is also legend is provided. Each file is represented by a stencil at the top left of the façade Figure 1.3. Whenever a particular file is updated in the subversion repository, the LEDs beneath its stencil will glow in the color assigned to it. Along similar lines, there is a matrix of LEDs at the right lower middle part of the hallway façade Figure 1.3. These LEDs indicate the status, schedule for a week (7 days and 24hrs) and servicing research collaboration and training in computational science, technology, engineering, arts, and mathematics (STEAM).

Figure 3.4 shows the arrangement of LEDs on the façade. There are two arduinos-one on the left and another on the right. The left most arduino controls the LEDs beneath the SVN repository stencils. The right side arduino controls the LEDs beneath the group member stencils and the LEDs behind the matrix of the touch interface in the right middle of the façade. The red lines indicate the wiring of the LEDs on the façade. There are LEDs at the bottom lighting the pathways while improving the aesthetics of the façade. These lower LEDs are non-controllable and non-addressable.

The challenge for this project was to design a system that is easily realizable in limited time, replicable in most parts of the world, and reuasable. We used off-the-shelf arduinos available in many countries. The software was developed on an arduino platform, hence software is portable and can be reused. Many electronic devices are compatible with arduinos, matching the dimensions and pin configurations. Many of the daughter board manufacturers provide example code for arduino-based devices gives a head start for development. These arduinos are low cost and open source, and are thus appropriate for this application.

3.3.1 Pegboard as a Tile

The wall façade offers large real estate. While the space/area provides an opportunity to populate sufficient amount of electronics, it also poses many challenges. To Covering the relatively large area by a breadboard or a printed circuit board can be difficult and using it as a placeholder for LEDs and touch sensors may not be economically viable. We had to find a tile of low cost, feasible for placing the electronics in such a large space. These requirements can be met using the pegboard. It is functionally similar to breadboard, large in size, and has many holes enabling the designer to place electronic devices on it with relative ease.

This pegboard as a Tile achieves modularity, re-usability and dynamism. As described in Rekimoto's paper [29], pixelisation of the wall or window lets the user control the squama in a modular way. It is comparable to a computer display, but squama is a low resolution display. Again, the granularity of coarse pixels can be increased in order to make the system more similar to standard computer displays, which can assist in displaying information. Similarly, the pegboard as a Tile is

FIGURE 3.5. Pixelised pegboard assembled on the wall

a modular architecture which can be controlled in a modular way. The sizes of the Tile can vary depending on the application, size of the wall, and the content to be displayed. Figure 3.5 shows the pixelised pegboard assembly.

The concept of pegboards as Tiles provides myriad ways to populate the façade with electronic circuits. Every opportunity comes with a challenge. Since pegboards are non-conductive, the wiring of the pegboard can be labor intensive. In the first iteration we used multi-stranded wires for the connections on the board. This was a basic and simple method of wiring to interconnect electronic devices. In the second iteration, we changed to CAT3 cables and corresponding plug points to make it cleaner. These points are mounted on the wall, and it is devised as an access point to drive the LED strips. CAT3 provided the necessary insulation, reduced hanging wires and provided flexibility.

3.3.2 Hardware Design and Communication Method

Hallway façade implementation required specific hardware and communication methods. As shown in the table 2.1, systems similar to the hallway façade require certain characteristics for this façade like system. Since the wall covers a large space, decentralized computation is necessary. Yet, the devices mounted there must communicate each other. Therefore, we needed a platform to achieve this communication. As the façade constantly communicates with the external world, the platform should support communication such as wifi and Bluetooth. One of the motivations is to enable people across the disciplines to utilize this platform and develop their own systems similar to façade. Therefore, the platform should be available commercially and necessary software support. In order meet these requirements, we have explored some of the platforms as described in the Hardware Platforms section of the Related Work. In this section some of those hardware platforms are revisited. We discuss there advantages and disadvantages using those platforms.

- Phidgets provide the hardware platform for interaction designers, but the functionality of the phidgets to a certain extent is fixed. Hence, there is less flexibility for the designers. Also, it does not provide for wireless communication. Therefore phidgets as a hardware platform lack the basic requirements to realize the hallway façade.

- Smart-Its is another hardware platform which provides wireless communication and the design is aimed for decentralized computing and which can be placed at the back of the physical artefacts. Even though this seems to be apt for the hallway application, due to of its lack of commercially availability, and lack of software support Smart-Its is not the best choice for this application.

- Blades and Tiles provides an excellent hardware platform to realize the hallway façade. The computing is decentralized and it can provide the required communication protocols to communicate with among other devices. Communication with the external world can be realized by developing the necessary Blade. It provides greater flexibility in realizing the required functionality. The disadvantage with Blades and Tiles is that they are commercially not available they requires specific skills for developing necessary Blades and it is expensive.

- Arduino also makes an excellent hardware platform for this application. The hardware is commercially available, many other devices can work in tandem with the arduino and it has

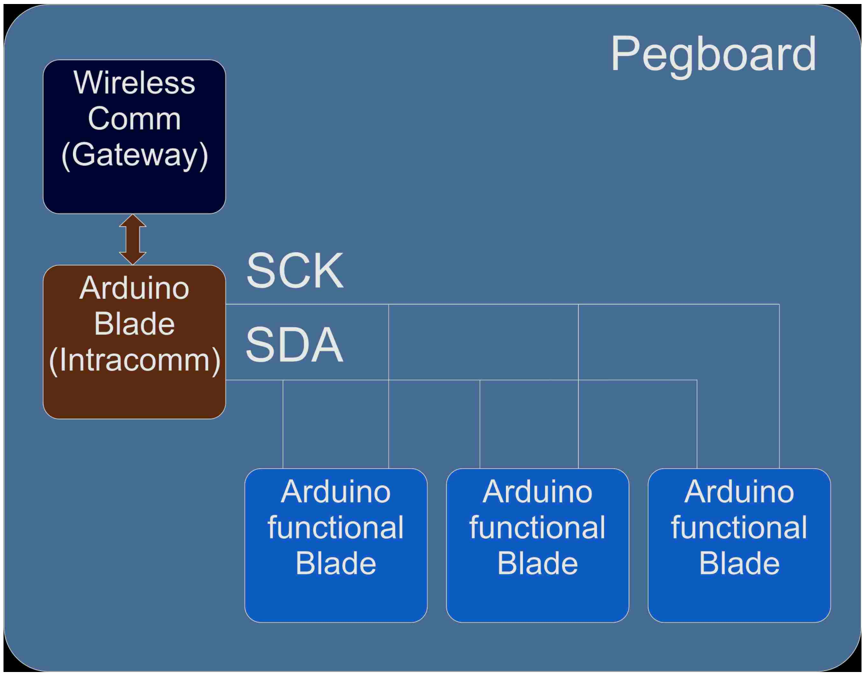


FIGURE 3.6. Hardware architecture behind hallway façade

to strong software development environment support. Arduino can provide decentralized computing and wireless/wired communication with external devices with/without another device. Arduino provides the flexibility of developing required application by accessing I/Os pins. Arduinos do not have in-built communication protocols to communicate among the arduinos as is the case with Blades and Tiles.

It appears that individual choosing a particular platform is not suitable for this application. The combination of arduino and Blades and Tiles seems to be apropos for this application. This led us to combine the features of both the arduino and Blades and Tiles to realize the hallway façade.

3.3.2.1 Hardware Design

In this project, we apply the concept of Blades and Tiles [32] on a larger scale considering pegboards as Tiles and arduinos as Blades and WiFly as gateways. The Blades and Tiles concept has three types of Blades: core Blades, function Blades and resource Blades as discussed in hardware platform section.

Core Blades are the communication backbone of Blade-based systems. Gateway Blades link internal bus system with the external world. In case of the hallway façade WiFly shield is employed as a gateway between the Blades of the façade and the external world. The WiFly shield equips the Bladed system of the façade to connect to the 802.11b/g wireless networks. There are two types of WiFly shield: One of WiFly uses SPI-to-UART bridge to allow for faster transmission speed with Blades, another type of WiFly uses simple UART communication with the Blades. WiFly is a simple and standalone TCP/IP wireless networking module making it suitable for embedded applications.

WiFly devices need to communicate with arduino intracomm connected to other arduinos which act as functional Blades. In this architecture, an intracomm is a bridge between functional blades and WiFly devices. Since the hallway façade is envisioned as an information visualization and a computation niche, there is a constant need for Blades to communicate with the external world. Intracomm enables this functional Blades to communicate with external world, to send and receive the necessary information. Intracomm described in the Blades and Tiles architecture enable communication with functional Blades in other Tiles.

Functional Blades perform operations independently. The function of each Blade depends on the kind of interface to be realized. Since arduino provides many I/O pins, more functionality can be realized. Therefore, each arduino Blade performs multiple operations as compared to original Blades and Tiles. The functionality implemented in this project are LED Blade, RFID reader Blade, and Touch sensor Blade.

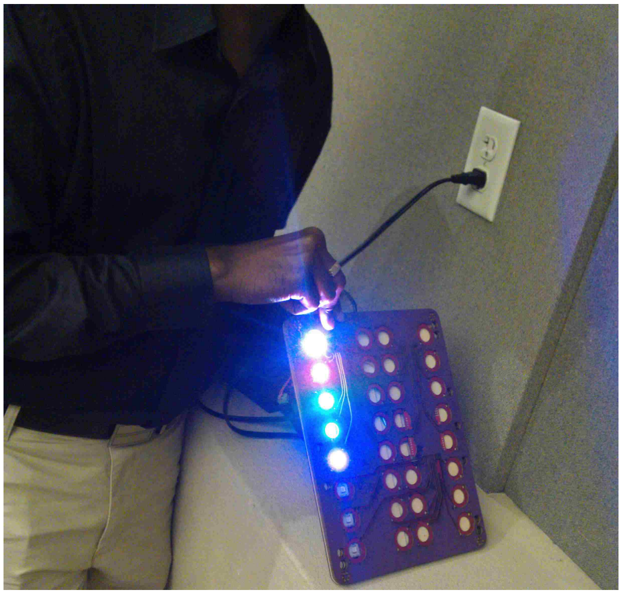
1. LED Blade: The hallway façade uses full-spectrum LED strip to convey information. The strip is 1m in length and has 32 RGB LEDs. Brightness and color of the each LED are individually controllable giving flexibility to user in terms of changing the parameters dynamically. The LEDs are controlled through 2-wire communication protocol, one is serial data and another one is clock. The color and intensity of these LEDs depends on the the information received

from the external world. Each LED requires 24 bits of greyscale data. This means that there are 256 levels of red, 256 levels of green, 256 levels of blue for the RGB LED.

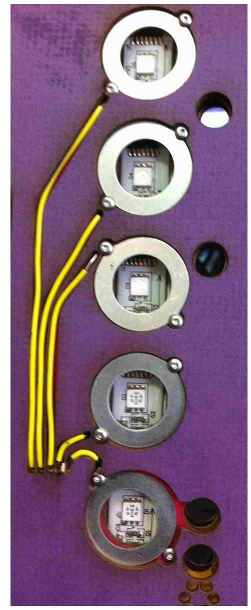
The control of the strip is relatively simpler, data is clocked in continually to the strip. Each IC of the LED automatically passes the data to the next IC. Once the data input is paused for more than 500µs, each IC posts or begins to output the color data that is just clocked in. For 32 LEDs 24bits $\star$ 32 = 768bits need to be clocked in, then pause for 500µs. Repeat the same procedure to display something new. The LEDs can also be cascaded to increase the number of LEDs and it reduces the burden of using many I/Os required for driving each strip.

2. Touch sensor Blade: As shown in the Figure 1.3 tin the right middle there is a matrix of touch interface which are realized using low cost and commercially available aluminum washers. At the back of the this matrix, there is a capacitive touch sensor breakout board which can sense the touch from the user. Each breakout board can recognize 12 touch interfaces, there are 24$\star$ 7 = 168 aluminum washers. Hence 14 breakout boards are necessary to detect all the touch interfaces. These breakout boards are connected to the arduinos. Depending on the input, the arduino performs the necessary functions such as requesting information online, turn on LED and so on.

   Before implementing the touch interface on the façade, touch interface is implemented and tested on a hand-held active cartouche as shown in Figure 3.7. LEDs at the center turn ON and OFF upon touching the aluminum sensor. Figure 3.7(a) shows the glowing LEDs which are turned ON upon touching the corresponding sensor. The implementation is as shown in the Figure 3.7(b). The yellow wire in the Figure 3.7(b) is wound around the screw which is below the washer and is securely fixed with the help of a bolt. The other end of the wire is connected to a breakout board to sense the touch. This concept is yet to be implemented on a large touch interface matrix.



(a) Active electronic cartouche



(b) Closer look at touch interface

FIGURE 3.7. Touch interface on active electronic cartouche. LED turns ON and OFF upon touching the sensor that is aluminum washer.

3. RFID Reader Blade: The user of the facility is identified using RFID tags attached at the back of the LSU ID or any other ID structure.

Power Supply

The challenging aspect of the system is to provide enough power supply to drive the LEDs which are used for conveying information and improving the aesthetics of the façade. As in the Figure 1.3, the LED strips at the bottom are non-addressable. It requires 12V and approximately 1.5A of current for each strip. Since there as many as 6 strips, it is driven using a 12V, 10A power supply. The full-spectrum require 5V power supply, therefore it can be driven by arduino. But, under extreme scenario such as, all LEDs are ON and glowing at full brightness (white = 0xffffff) each strip requires 2.5A of current. Arduino can supply <500mA, therefore an external power supply of 5V, 10A is used to drive the LEDs. This power supply can drive three cascaded LED strips limiting the number of strips that can be cascaded to three. The 5V power supply also drives arduinos, WiFly, touch sensing device and RFID reader. The number of power supplies required depends on the number of LED strips to be driven.

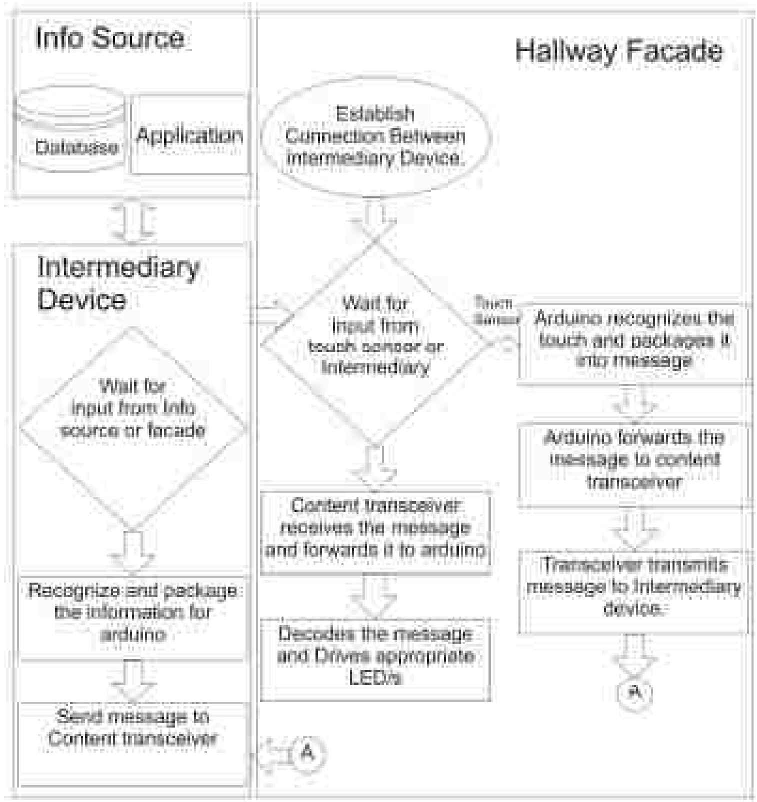


FIGURE 3.8. Communication of arduino's with the external world

3.3.3 Software and Middleware

The flowchart in the Figure 3.8 describes the flow of actions from the touch interface to online information repository to driving a LED. The following description provides elaborate information about flow of actions, software and middleware.

As the system is powered up, connections are established between the gateway and the external system. The external system is associated with the database and holds the online information of a person's availability. The external system can either be supercomputer (Melete Cluster) or a locally available computer. If a commit is made to SVN the repository or if a person from a research group appears online in social media platform such as Skype, Facebook, G-talk, and iChat, the middleware in the external system recognizes the events and communicates the information to the façade. The control system working behind the façade receives the information and decodes it. Based on the information this control system convey information by turning the LEDs ON/OFF which are below the stencils of the SVN repository or the group member which is in the top as shown in Figure 1.3.

Similarly, there is a flow of action from the touch interface to intermediate device or the external system. Upon sensing the touch, arduino recognizes which sensor has been touched. Based on that information, the arduino will package an information request to the external system. The gateway will communicate with an external system. Based on the information, the intermediate system will either obtain information online, or from the database or perform some computation as requested by the user. If information is requested, again flow of actions starts from intermediate device to driving the LEDs or displaying information as described before.

In order to achieve this functionality, corresponding software is necessary for the control system working behind the façade. Middleware in the intermediate system assisting with getting online information, SVN repository information and many other relevant information. Also needs to have the relevant software. The next two sections will describe software and its associated libraries, the middleware which is residing in the intermediate system.

3.3.3.1 Software

We have developed a number of software libraries that can support interaction with the wall elements. These include libraries for sending and receiving OSC messages, managing content and interaction across separate computers and devices, specifying layout and behavior of various interaction devices, etc. Here we describe two of the libraries which we have used most extensively in our system.

The first library was written to control the full-spectrum LEDs, which are used extensively in the system to indicate presence and status. This library was written in C++ for the arduino platform and handled all of the timing and memory management necessary to drive the LED strips. Using this library allowed us to control the lights using as few as 15 lines of arduino C code as shown in the algorithm 1. The second library we wrote was designed to control a 802.11 WiFly wireless module for the arduino board. This provided the ability to wirelessly control all LED strips and touch sensors through the use of a central interaction server. This library was also written in C++ for the arduino and allowed for wireless communication with the arduino board with as few as 20 lines of code as shown in the algorithm 2.

Algorithm 1: Simple example of driving an full-spectrum LED of the LEDstrip

```
DataPin ← 4;
ClockPin ← 5;
StripLength ← 32;
Color ← PURPLE;
// Initializing the pins of arduino to drive the LEDstrip
InitializePins(DataPin,ClockPin,StripLength);
for i ← 1 to StripLength do
    // Initially turnOff all the LEDs
    SetLED(i, 0x00);
    LEDdrive;
// Based on the received information from the external system, arduino
   drives the appropriate LED
for i ← 1 to StripLength do
    SetLED(i, Color);
    LEDdrive;
```

Algorithm 2: Simple example of establishing communication between façade control system and intermediary system

```
Network ← NETGEAR;
Password ← tangible;
Port ← 80;
WiflyInit(Network,Password,Port);
if WiflyDataAvail then // This will be true if wifly has received data from
external system
    // Receive data from wifly
    Receiveddata ←WiflyRead;
    else if Request information then
        WiflySend;
```

In addition to allowing us to design and implement the interaction façade more rapidly, these two libraries also allowed other groups to quickly and simply design their own interaction façades with minimal code modification.

3.3.3.2 Middleware

Middleware is a bridge between distributed computers on the wall and online information. As a part of demo/prototype, we generated a events from Microsoft PixelSense (a.k.a Surface) and database of SVN commit logs was generating all the content for the LED controller on the wall.

The Surface is displaying a 24x7 grid of colored buttons which is a mirror image of 24x7 grid on the wall, known as the DateTime Grid. The 7 rows represent the 7 days of the week and the 24 columns represent the 24 hours of the day. There are 3 larger buttons on the bottom half of the screen: SVN, Users, and Entangle; each representing a different Surface "mode". Clicking one of these larger buttons changes the "mode" of the Surface and changes the content and LEDs the Wall will use. The colors of the buttons in the DateTime Grid give some indication of the amount of SVN activity for the given date and time represented by that button. Clicking a button in the DateTime Grid, the LEDs of the Wall also change. In "user mode", the LEDs of the User stencil at the top of the wall change to reflect SVN commits on the chosen date and time. In "svn" mode, the LEDs of the SVN Folder stencil at the top of the wall change to reflect recent SVN activity in that SVN Folder. In "entangle" mode, the DateTime Grid becomes entangled with the 24x7 grid on the wall such that touching a button on the Surface, changes the corresponding LED on the Wall and touching the capacitive button on the Wall grid, changes the corresponding button on the Surface's DateTime Grid.

There are two important components of middleware, an event generator and controller. Event generator is a stem from which communicator receives the required/requested information. In our case the Microsoft PixelSense and the SVN commit log database are two event generators.

3.3.3.2.1 Controller

Controller is a program which using python program running in background which receives information from the event generators; interprets the received information and generates appropriate information required to drive the appropriate LEDs on the wall. As a demo, we created a user-interaction space of the wall on the PixelSense to generate events. The PixelSense will send the OSC messages to python controller program. The controller sends output to two different devices: the WiFly controlling the User cartouches and LED grid on the wall and the WiFly controlling the SVN Folder cartouches.
Output to Wiflys:

The messages sent to the Arduino Wifly were sent over port 80 and included the following information:

1. Region (used for the Arduino that controlled both the User cartouche LEDs and grid)
2. LED number (which LED on the strip)
3. Red value
4. Green value
5. Blue value

Each message was prefaced by a hash (#) to delimit different messages. An example message to region 1, LED 02 to turn white would look like #102FFFFFF

Chapter 4
Discussion

> Self-evaluation directs us to prepare our next performance from the past and today's experiences.
>
> Unknown

In order to meet our goals for the façade project, we used readily available materials like off the shelf electronics, and software libraries. These allow for inexpensive and fast development of façades for any group desiring to display dynamic and compelling content in their corridors.

A compelling example of a group who used our architecture to design a new and unique façade was a group of students working on their capstone course. They used our architecture as the basis to quickly develop the physical and electronic structure they wanted for their interactive system. These students added a HDTV connected to a Mac Mini computer which could be controlled using a web interface designed to be accessed by smartphones and tablets. By pointing the browser on their smart device to a specific URL, the user was able to interact with the interface that the group designed. As the user navigates through the information on the screen, a dynamic ambience is provided by glowing cubes attached to the façade and surrounding the screen.

The façade developed by this group demonstrated two concepts related to our system. The first is that rapid development of façades is a real possibility using the architecture we have developed. In approximately two weeks, this group of four students developed the entire façade including the physical and electronic structure needed, the software needed to drive content, and the graphics needed for the interfaces. This project also demonstrated that our architecture and supporting libraries are capable of supporting a number of different applications of the façade implementation and interactions. This group was able to use our architecture to design a system quite unlike what any of us had envisioned for a façade. This is important because it shows that the idea of façades will grow and change with each group that chooses to use its components to make their ideas come alive in a corridor.

The hardware architecture described in this thesis is used effectively by the students in two mixed undergraduates/graduate courses. The project directed students to utilize the hardware architecture and supported the realization of such systems with software libraries.

4.1 IDT2012 Projects

Interface Design and Technology course offered by Dr. Ullmer at LSU primarily focuses on developing novel interaction devices. In the Spring of 2012, nearly 10 teams each constituting of either 2 or 3 students developed innovative interaction devices using the hardware architecture presented in this thesis, that is arduino used for local computation and WiFly used for communication with external world for information. The following description provides the different purposes for which this architecture can be used.

The following is a brief description of each project carried out by the students as a part of the Interface Design and Technology course.

- The Figure 4.1 shows one of the projects carried out by the students, where the status of the group members is indicated using LEDs which is above the keyboard in the picture. Red indicates time critical and busy, yellow indicates important work, green indicates not time sensitive. Touch OSC (Open Sound Control) control surface is used for communication with wifly and for controlling the LEDs. Touch OSC is a modular OSC and MIDI control surface for iPhone/iPod Touch/iPad/Android. It sends and receives OSC messages over a Wi-Fi network using the UDP protocol.

- Another interesting project is indication of electricity production by different countries using different natural resources. The Figure 4.2 shows the type of natural resource used in electricity production. The team had built their own customized Android application for selecting the country and the year. Based on that information, the LEDs indicate the

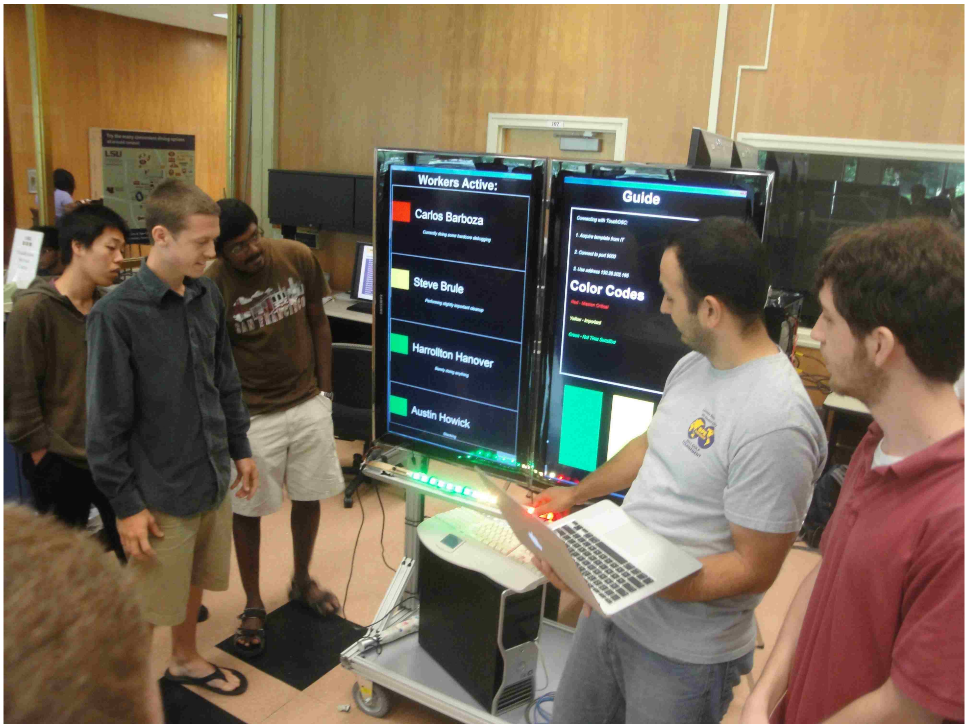


FIGURE 4.1. IDT12 Student project - Worker activity status indicator

FIGURE 4.2. IDT12 student project - Percentage electricity-production using a particular natural resource by a country

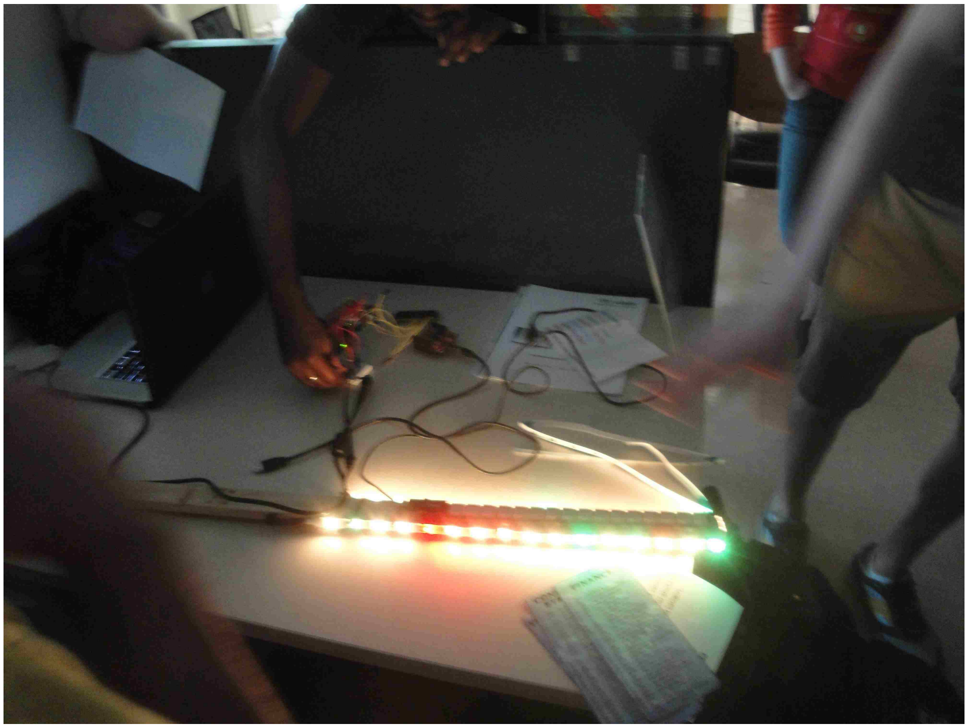


FIGURE 4.3. IDT12 student project - Stock update indicator

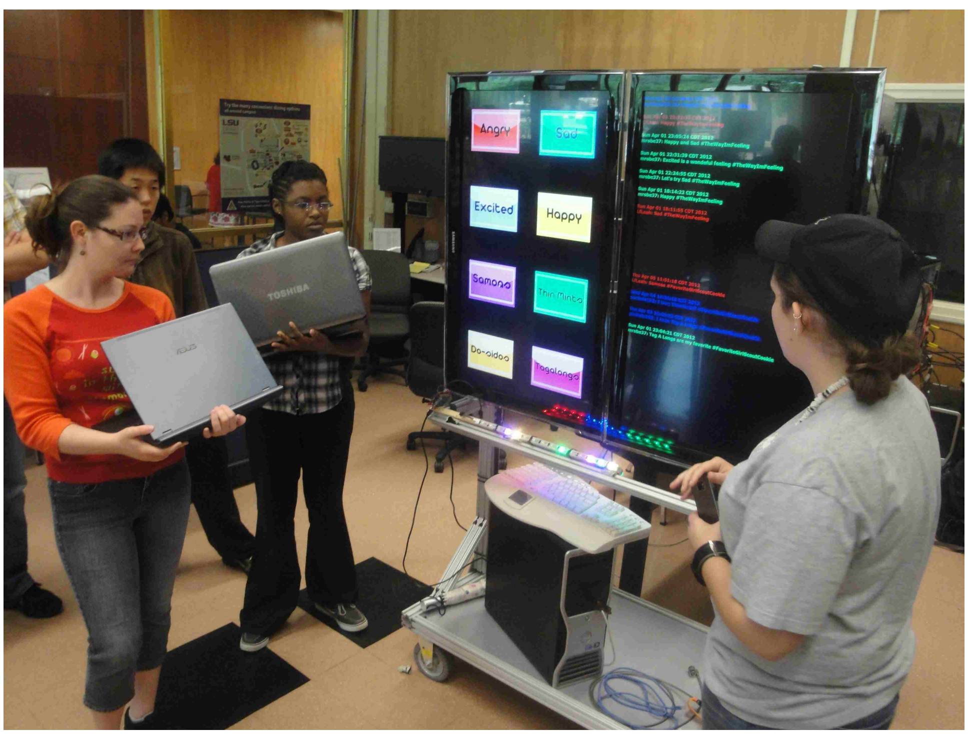


FIGURE 4.4. IDT12 student project - Twitting indicator from twitter along with emotional nature of twitting

percentage of energy production using a particular natural resource. For instance, if a country is generating 50% of electricity using coal and another 50% from hydel generation, then half of the LEDs will glow in a particular color that is assigned to coal and the another half of the LEDs will glow in a different color that is assigned to hydro-power generation. Legend for each natural resource is provided on the big screen.

- Another interesting project was where the LEDs indicate frequent stock updates. A particular company can be selected to see the stock rise/fall. Green and red indicates rise and fall of stock prices respectively and yellow indicates no change. In this project, as shown in Figure 4.3 each company is assigned a LED to indicate the status of stock.

- Another interesting project is the integration of social media and LEDs. When a person starts tweeting from Twitter account, the glowing LEDs indicate the tweeting. It also indicates the nature of tweeting such as angry, sad, excited, happy and so on. As seen from the picture 4.4, three group members are tweeting live and accordingly the LEDs above the keyboard are changing the color to indicate the nature of tweeting.

4.2 Kanakapura and Scott in the Year 2032

The vision of this project is to enable, motivate and equip people with systems similar to the hallway façade. In this section we discuss the effect of systems like the hallway façade can have when placed over the façade of Srinivas clinic located in Kanakapura, India and Scott located in Louisiana.

4.2.1 Srinivas Clinic and Acadia Walk-in-Clinic

Before discussing the usefulness of having hallway façade like systems, let us understand the context of the two clinics. Srinivas clinic is located in a small city called Kankapura with a population of approximately 50000. Acadia walk-in-clinic is located in a small city called Scott with a population of approximately 8000. The commonality between the two clinics is the wide variety of patients who visit the clinic. Therefore, it can be a good forum to display important information on the wall. The reason for choosing small cities is that people in smaller cities have less access to the medical

FIGURE 4.5. Acadia walk-in-clinic in Scott, Louisiana

facilities for certain type of medical problems compared to people in urban areas. Therefore, it is important to display information pertaining to such diseases, awareness about the symptoms and the closest hospital to reach for further treatment.

Before exploring the way façade shown in the picture 4.5 can used as a information visualization center. Let us understand the motive behind developing such kind of façade. Consider an example of Baton Rouge, Louisiana which has been in top 5 on the list of cities in the US with the most per capita AIDS cases for long time. Similarly, India is home to the world's third-largest population suffering from HIV/AIDS. Yet people hesitate to be vocal about these issues, and very few places display information about HIV. The people is bigger in places like Kanakapura.Therefore, we believe this kind of façade can help conveying information to the people even in smaller cities like Kanakapura and Scott

Today, as seen in the picture 4.5, the façade of both the clinics are desolate surfaces. The vision of this project is to enable these clinics to have a hallway façade like system on those surfaces. It can be used for displaying awareness information about the contagious diseases, HIV related awareness and so forth. It can become an information visualization center for medical issues which are less known to people and diseases about which people less vocal owing to rigid cultural backgrounds. However, more information should be given to people about these medical issues for the well being of the society. For instance, snake bites, are very common rural parts of the country. Despite knowing snake bites are common, people are unaware of first aid that should be provided to the victim. Another example, in the case of srinivas clinic where most people who visit are pregnant women. Due to lack of knowledge, many pregnant women usually end up with some complication resulting in undesired situation. People might be uncomfortable displaying this in public places. We believe façade like systems can achieve these objectives at a relatively low cost.

The picture shows 4.5 the façade which is located outside the clinic. There are places where people have maximum access to clinic. As shown in the picture, façade outside the clinic and another location is waiting room of the patients. There is a good scope for utilizing both the spaces. The façade outside could be used for providing generic information to the people where as waiting room can have information specific to the clinic. In the case of srinivas clinic, it could of female pregnancy which cannot be displayed in public.

Chapter 5
Conclusion

> Each work has to pass through these stages—ridicule, opposition, and then acceptance. Those who think ahead of their time are sure to be misunderstood.
>
> Swami Vivekananda

In recent years, ubiquitous computing has emerged as a prominent domain for human computer interaction. Increasingly the user interfaces to the digital world is through world around us. The type of user interface will depend on the application, location, situation, content and location. Depending on this the interface may be generic or for specific application. This user interfaces are used for different kinds of application. Accessing online information may require different way than performing some computation. Accessing online information still remains within the small area of desktop or laptops. Going beyond the desktops or laptops require suitable architecture either to accessing information or perform some operations.

In this hyper connected world there is huge scope to build systems which integrated into physical world which can access necessary information online. With the growth of online social media, which occupies significant time in one's life. There is constant craving to need to know about your significant other, friends and families. In the constant academics there is a requirement to know about particular professor and the research activities carried out by that professor. This thesis discusses structured approach, important design aspects and necessary implementation entities to achieve necessary functionality. The design is relatively generic, so the system is flexible at the same basic structure is unaltered to maintain stability of overall structure.

In this project hallway façade is built using this architecture as information visualization and computation user interface. Based on the prior work carried out by others to effectively utilize the wall space, we have introduced a type of hardware architecture suitable for ubiquitous or distributed embedded computing which constantly need information from the external world (online space).

The project supported the feasibility and utility of this architecture with a system of bladed arduinos and tiled pegboard. The prototype of this architecture is implemented in the hallway of the lab.

The concept presented in this thesis is distinct in providing embedded platform for computation and communication for establishing connection between physical entity and online information turning a mundane object into interaction artifact. Essentially turning desolate hallway space into information visualization computational center. Based on this the following section provides several research contributions.

5.1 Research Contributions

The following itemized description provides the overview of research contributions supporting the thesis statement

- The thesis emphasizes the importance of wall space utilization and turning it into an interactive surface. Transforming this space into information visualization niche.

- We have endeavored different dimension of entangling the online information with the world around us.

- The thesis employs the concept of semantic light where light communicates meaning to the user by overlaying information by color, text,and other data.

- The thesis presents modular, programmable and dynamic physical architecture. This concept is referred to as pixelisation of pegboards and turning it into a placeholder many entities such as electronics, and posters.

- In order to assist speedy prototype of systems similar to hallway façade we have developed using off-the-shelf, software libraries and a middleware.

- The system employs different way of communicating with external system. It uses off-the-electronics to establish communication between façade and external system.

This all contributions culminate into helping passionate, motivated and creative people utilize these techniques to realize system which can bridge gap between physical world and online information repository.

5.2 Challenges and Hard Lessons

The previous described the specifications, strengths, functionalities, technical aspects and each of these sections are discussed elaborately and provides intricate details of hallway façade. I believe hallway façade seems to be promising, different and enduring means for information visualization to the people. The thesis is attempting bring the information out from the small monitors to the world around us. The concept and its implementation has limitation and challenges. There are few hard lessons from previous experience requires significant attention before venturing into the future work.

Large-Scale Technological Accidents

Three mile island, Bhopal and Chernobyl reminds of a disastrous industrial accidents which led to death many people and had long-lasting effects on the people who survived. These three major accidents provides greater insight about the responsibility of human-machine-environment systems errors was one of the factors responsible for these fatal accidents.

Let us begin with Three mile island (TMI) accident nuclear power plant accident which is the most investigated accident in the history of the commercial nuclear industry. The investigation has revealed that apart from human error there are many other factors responsible for this disaster. Human-machine-environment systems and control design is one among them. The lack of human factors considerations at the design stage was most evident in the TMI control room. It was poorly designed with problems including: controls located far from instrument displays, cumbersome and inconsistent instruments that often looked identical and were placed side-by-side, but controlled widely differing functions, instrument reading were difficult to read, obscured by glare or poor-lighting or hidden from the operators, contradictory systems of lights, levers or knob — a red light means valve closed in some cases and open in some case. Some indicators were behind the panel which made operator job difficult [24].

The above mentioned are consistent with the Larkin and simon's observations about diagrammatic representation [20], just as a picture is not worth 10,000 words. As in the case of TMI there were many misleading arrangements of the controls which had potential to deceive the operator. As related in 2.1.1 by Larkin, Simon, and Petre for the case of diagrams, large-scale systems such as hallway façade intuitive, non-deceptive, clarity by providing secondary notation, and consistent visual indicators. Therefore potential success of systems similar to hallway façade largely a consequence of good design. This thesis has taken early steps toward exploring this design space, still lot of this design principles remains to future work

Bhopal accident is caused lack of human factors considerations, both at the design and operating stages. The inherent problem of overall design and safety of the plant's control room played a significant role in the accident. Some of the critical pressure gauge were missing from the control room and they are located close to valve assembly, an important panel in the control panel was removed perhaps for maintenance, but it was not replaced by temporary panel or backup panel, there were problem with visual display of gauges and meters. At the time of accident, the operators were extremely overloaded and found it virtually impossible to look after the 700-odd panels, indicators and console and keep a check on all the relevant parameters. This signifies the major role of control system's design errors in the accident [24].

There are many lessons to be learnt from this disasters. When a panel is removed from the control system, whether it is for maintenance or upgrade meanwhile it should mitigated by installing temporary panel or replacement panel. In this thesis we have discussed about pixelization of the system which may address this issue, still significant amount of effort in future towards the method replacing or upgrading the existing panel without affecting the overall design of the system. As discussed, lot of efforts towards design principles remains to future work to address the issue of information overload.

Chernobyl accident is attributed to human error and problems with the man-machine interface. Failure to understand the man-machine interface is described as "a colossal psychological mistake" [24]. Although complete analysis of the design and operations of control room is not available. It appears the general sloppiness of the control room was one of the factors caused the accident [24].

In all three accidents, control room design errors played a significant role in the accident. It is necessary to have thorough consideration of human factors such as information overloading, consistency in the design, proper training, disaster training and so forth. This design principles remains to future work for exploration.

5.3 Future Work

This research work has pursued the hallway façade as an information visualization center. In the process of designing and implementing the system, the team has learnt several lessons, gained insights and have identified some opportunities for future work. While some of the ideas are already in progress, some of them can be realized in the near future and some ideas are for long term plans.

To begin with, let us start with future work which is in progress. It has always been our focus to develop a generic architecture for both the movable and the immovable. In this application, most of the entities are immobile and do not provide for the user to carry information along. We need an architecture which can help realizing both static and dynamic interaction for the user. We are inclined towards the Sanskrit word carAcara, which means movable and immovable. Since our architecture is focused towards developing a common hardware architecture for both portable and static structure carAcara is a compelling fit name for our interface. The Figure 3.7 shows the primitive prototype of the carAcara concept.

In the first iteration of the hallway façade, we have used simple end to end wiring technique which messy and ugly if the number of devices is more. It is not a desirable way of interconnecting the devices. In the second iteration, we have CAT3 wiring which provides insulation, is much less messier than simple end to end wire connection. We believe this is a good way of interconnecting, but not the best method of interconnection. The system requires wiring techniques which can reduce cross coupling, antennae effect which can pick up noise, less confusing, and is easily replicable.

In the longterm, the system needs an efficient means of communicating with the external system. The system behind the façade uses the Blades and Tiles protocol whose framework is built upon the I^2C communication protocol. Even though the system is efficient in communicating with other devices on the façade, the communication with the external system will get complicated if the number of gateways increase. This reduces efficiency of communication. A different protocol is needed to communicate with external devices which can increase efficiency and bring completeness to the system. At present, the external system communicates with two WiFly devices (Transceivers or gateway). The number of gateways increases as the system scales up. Therefore, a more robust communication protocol is necessary for realizing such systems. The challenge is to build a protocol for off-the-shelf hardware and it should be portable.

In future, we envision to go beyond the realm of visualizing online information. Some examples include monitoring the power consumption in a building or house, controlling the household devices remotely using the hallway façade. This architecture opens up innumerable opportunities, as they say sky is the limit, for the way in which the wall space can be used as an interactive surface.

The above mentioned future work ideas are more towards implementation which work behind the systems. Beyond this technical work, significant effort is required in future towards cognitive aspects of the hallway façades. When a person is interacting with this installation it is necessary to explore the extent to which the desired functionality is achieved. We need to study the kind of effect it will have on the person, in our case, the extent to which the information has motivated the people to pursue ongoing research activities. Also, there is a need for exploring the relevance of the information displayed on the façade. Even if it is relevant, the question is, does that invade the privacy of the individual. It is necessary to determine extent to which an individual's information can be displayed. We also need to determine how of the information from the research activity can be displayed on the façade. Another opportunity for future work is to explore these issues by evaluating these systems using different techniques as described in the book [30].

5.4 Closing Remarks

This thesis has introduced a different approach to utilize wall space for information visualization. This can be either static or dynamic display of content. The thesis emphasizes dynamic display by integrating physical space with digital information. In the introduction, § 1.1 of this document, we saw the example of a thousand years old Japanese temple which had enduring information about the patrons. The wall has been used as a medium for information visualization since ages. In this thesis we are re-purposing and digitally augmenting the wall space to express digital information that is available online.

The benefits of having information on the wall is enormous, the intuitiveness and visual comprehensibility provided by the physicality is not achieved with the mere displaying of information on the wall, but with the good design of the façade. The importance of good design is reiterated by many people as described in § 2.1.1. Our hope is to transform the often desolate wall space into an interactive surface for information visualization. The concept can be applied for a wide variety of areas and purposes as described in 2.1. We aspire to see systems similar to hallway façade or an advanced version this system in many parts of the world.

The power of knowledge and connectivity has profoundly impacted the world in the form uprising of Middle-Eastern countries. Also, mobile connectivity has empowered people in India and many African countries who are deprived of other traditional means of connectivity. Having this information façade remote areas of the developing countries can provide the required information such as prices of grains, scheduled visit of a doctor/specialist/government executive, medical emergencies, natural calamities and so on.

With the advancement in technologies, more importantly low cost technologies, and lower connectivity prices, we believe systems similar to the hallway façade are realizable. Therefore, we aspire to see many such systems to take different shapes and form according the specific requirements.

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