

# **Domestic Situated SMS Messaging with Digital Photo Frames**

**John Patrick Downs**

Under the supervision of Dr. Beryl Plimmer

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## Abstract

SMS messaging technology allows for short messages to be exchanged between individuals at a relatively low cost. Current SMS messaging technology is limited to person-to-person messaging; many other forms of social communication also allow for person-to-location messaging. This is particularly important for domestic messaging since messages may need to be broadcast to an entire family or household. Some previous work has discussed the creation of display technology to receive SMS messages, but these projects all required custom hardware development in addition to the software components that received and displayed the messages.

In this project, I created a comprehensive person-to-location SMS messaging system built on digital photo frames. These photo frames are relatively inexpensive and are readily available. I designed and implemented a software platform and hardware infrastructure to receive, deliver, and render messages to digital photo frames that are located in the home. By rendering messages as images in JPEG format and delivering these images across a local wireless network the photo frames can display SMS messages overlaid on digital photos.

I conducted an evaluation study with two families and two flats. Each household was provided with a photo frame and accompanying infrastructure for approximately one month. Households used the photo frame messaging technology regularly, sending 100 messages over the period of the study. Usage patterns varied by household, but overall I found that family members mostly used the system to send informational messages about their location and status, while flats used the system primarily for social communication and for facilitating social interactions.

The evaluation study also assessed the use of photo frame technology for this type of situated display application. The limitations of digital photo frames became apparent over the course of the evaluation. Household members found that the inability to scroll through previously received messages, as well as the lack of audible notifications when new messages arrived, precluded their use of the system for urgent messages or for requests that required action. Nevertheless, the households adapted to the characteristics of the technology over the period of the study and found it useful for broadcasting particular types of social and informational messages to the entire flat or family.



# Table of Contents

1. Introduction .....	2
1.1. Definition of Terms .....	2
2. Related Work .....	4
2.1. Domestic Social Communication .....	4
2.2. Ambient Awareness and Situated Displays.....	6
2.3. Digital Photo Frame Technology.....	7
3. Design.....	10
3.1. Functionality .....	10
3.2. SMS Messaging .....	11
3.3. Screen Layout.....	12
3.4. Interactivity and History .....	13
3.5. Summary .....	15
4. Implementation .....	16
4.1. Hardware and Networking.....	16
4.2. Software Components .....	18
5. Evaluation Study .....	24
5.1. Pilot Evaluation .....	24
5.2. Study Design.....	25
5.3. Household 1 .....	27
5.4. Household 2 .....	29
5.5. Household 3 .....	31
5.6. Household 4 .....	32
5.7. General Discussion.....	34
6. Future Work .....	38
6.1. Fundamental Issues with Situated Displays.....	38
6.2. Digital Photo Frames.....	38
6.3. Software Improvements .....	39
6.4. Additional Applications .....	40
7. Conclusion.....	42
Appendix .....	44
References .....	46



## List of Figures

Figure 1. High-level functionality.....	10
Figure 2. Decomposition of high-level functionality.....	11
Figure 3. Example layout for SMS messages on a digital photo frame.....	13
Figure 4. Sample message area with history bar.....	14
Figure 5. Sample message area with scroll bar.....	15
Figure 6. Initial network topology with a single (wireless-capable) network.....	17
Figure 7. Modified network topology.....	18
Figure 8. Architecture of the Digital Photo Frame Manager system.....	18
Figure 9. Architecture of the Common SMS Server.....	19
Figure 10. Sample rendering output.....	22
Figure 11. Historical Message Viewer.....	23
Figure 12. Notice boards used by household 1.....	28
Figure 13. Cumulative number of messages sent by household 3 as a function of time and message category.....	32
Figure 14. Categories of messages sent by flats (A) and families (B). .....	34
Figure 15. Cumulative number of messages as a function of time.....	35
Figure 16. Number of messages as a function of time of day (in hours) for all households.....	35



## List of Tables

Table 1. Definition of terms. ....	2
Table 2. TxtBoard message taxonomy. Adapted from O’Hara et al. (2005).....	26
Table 3. Message taxonomy used to categorise all SMS messages in this study. ....	27
Table 4. Evaluation study message counts by household and category.....	44



# 1. Introduction

SMS messaging has enjoyed great success since its inception. It allows for short, ad hoc messages to be sent between individuals at a reasonably low cost. Despite its advantages, SMS messaging is fundamentally limited in that it is restricted to person-to-person messaging. In contrast, other forms of communication such as postal mail and landline telephones allow for both person-to-person and person-to-location messaging. Person-to-location messaging is particularly useful for broadcasts. Digital displays to present these messages can be situated in specific locations within an environment, and can take advantage of the physical and semantic context of particular locations.

This dissertation discusses the development and evaluation of a system to use inexpensive, commercially available digital photo frames as home appliances to receive person-to-location SMS messages. Chapter 2 reviews the literature on domestic communication, SMS messaging, situated display technology and digital photo frames. Chapter 3 describes the design of a system to combine each of these technologies into a single unified system. I discuss the implementation that was used for this project in chapter 4, and chapter 5 describes the ethnographic evaluation study of this technology I performed with four households. In chapter 6 I outline areas of future work that will be of importance in this field, and conclude in chapter 7 with a review of the technology and its integration into the everyday lives of households.

## 1.1. Definition of Terms

Table 1. Definition of terms.

Term	Definition
<b>Digital photo frame</b>	A device that is primarily designed to display digital images. These images may be retrieved from a memory card or other storage attached to the device, or accessed across a computer network.
<b>Handset</b>	A mobile phone, usually assigned to a single person.
<b>Short code</b>	A number that is recognised by telecommunication networks as requiring special handling, such as routing to an application on a Web server.
<b>SMS gateway</b>	A hosted service that aggregates and receives SMS messages from telecommunication networks and delivers them to custom applications.
<b>SMS message</b>	A text message that has been sent from a mobile phone. The message may have been sent to another user's mobile phone, to an application, or to a device such as a digital photo frame.



## 2. Related Work

This chapter provides background information on the areas that this project draws from. Section 2.1 reviews studies of social communication within domestic environments, and discusses some preliminary work that has attempted to augment this type of communication with technology. Section 2.2 continues this theme by describing and outlining the types of technology that can be used for integrating digital information into physical spaces such as homes. Section 2.3 discusses digital photo frame technology and describes some limited previous studies which extend the capabilities of these devices.

### 2.1. Domestic Social Communication

Intra-family communication, and, more broadly, intra-household communication – to include non-family households – occurs for a variety of reasons (Khan, Markopoulos, Mota, Ijsselsteijn, & Ruyter, 2006). From a practical perspective, communication allows members to share experiences, coordinate schedules, and handle emergencies and novel situations. Communication also serves psychological and social purposes: intra-family communication is important for social cohesiveness, and parent-child relationships are forged and strengthened. According to Kraut, Mukhopadhyay, Szczypula, Kiesler, & Scherlis (1999), households generally prefer communication activities such as email over information activities such as browsing the Web.

The content of a message is only one aspect of its overall meaning. A number of contextual factors can also affect the interpretations of both the message author and recipient or recipients. For example, the communication channel provides intrinsic and implicit normative rules that can govern social behaviour around communication. Grinter, Palen, & Eldridge (2006) describe the adoption of SMS messaging technology by teenagers and note that the asynchronous nature of the messaging system reflected changes in social behaviours; while previously it was necessary to pre-arrange places and times to meet, teenagers could now defer these decisions until the last minute, and adopt a more laissez-faire approach to communication and coordination with their peers and family.

The value of context is particularly evident when examining the physical locations in which messages are placed and viewed. Elliot, Neustaedter, & Greenberg (2005) studied ten separate households and found that the members of each household shared a common understanding of the places that particular information is typically kept and made available to others. Typically these conventions are established based on a shared knowledge of household members' routines – for example, a parent may leave a message for their children in a hallway they know they are likely to walk through when arriving home from school. The locations, and the shared knowledge of what they embody and

represent, take time to establish in each household; they also may evolve over time as behavioural patterns, expectations, and requirements change.

While the information locations within a house are often specific to that house, a number of studies have isolated common areas which are likely to be associated with particular types of information. Swan & Taylor (2005) found that fridge doors often contain memorabilia and sentimental artefacts, as well as family schedules and other artefacts of a more functional nature. They argue that the combination of the central location of the fridge, the fact that the fridge is an integral part of household daily routines, and the large amount of free space upon which to place artefacts serve to enable a variety of uses. Neustaedter & Brush (2006) found that family calendars are typically located in high-traffic areas of the home, often in the kitchen or family room, and while family members are aware of the calendar's presence they do not generally look at it more than once or twice each day. Crabtree, Rodden, Hemmings, & Benford (2003) found that certain types of artefacts – such as bills, letters, and intra-family notes – typically follow a discernable workflow, and that the locations of each of these items in time gives an indication as to their status. For example, an unopened bill on a table next to the main door provides implicit information about the nature of the bill (i.e. it is unpaid), while the same bill, when removed from its envelope and pinned behind a series of other bills in the kitchen, provides markedly different information. In each of these cases – fridge artefacts, calendars, bills, letters, and notes – the locations of the artefacts are chosen for specific and phenomenologically functional purposes.

With an understanding of the artefact types, content, and locations, Elliot, Watson, Neustaedter, & Greenberg (2007) argue that it is possible to begin to design technology to facilitate and augment the intrinsic meanings, patterns, and workflows that are present in households. According to Elliot et al. (2005), most intra-family communication is paper-based, and while some households do use electronic communication channels, this is considered an adjunct to paper rather than a replacement. When designing electronic or computer-based communication channels, O'Hara, Perry, & Lewis (2003) argue that it is crucial that the technology “supports social mediation rather than automation”. Researchers should focus on facilitating, augmenting, and simplifying the messaging process. O'Hara et al. (2003) argue that communication technology users will, over time, develop and orient to normative rules that govern the types of communication that can and should occur using the technology. For example, Grinter et al. (2006) compared teenagers' use of SMS messaging with their use of PC-based instant messaging software and found that a complex set of implicit social rules and norms governed their choices of which channel to use, who they would chat

with, what types of messages they would send, and what their expectations were for replies and contact list management.

## **2.2. Ambient Awareness and Situated Displays**

Home PCs tend to be placed in out-of-the-way areas of the home (Mateas, Salvador, Scholtz, & Sorensen, 1996) and are therefore inappropriate devices for displaying information that household members should be continually aware of. Elliot & Greenberg (2004) and Elliot et al. (2007) created a variety of 'smart' information appliances that encoded and presented different types of information in different ways, such as small LCD displays, coloured lights, the extent to which an artificial flower has opened, and the location of coloured beads next to a computer monitor. When placed in appropriate places in the home (Elliot et al., 2007), this type of ambient awareness technology has been shown to be successful in enabling users to quickly understand the overall nature of an information source without expending time or overt attentional resources.

Situated displays provide another opportunity to integrate digital information into physical environments, through the placement of screens into appropriate locations. Typically the screens are intended to show one specific type of information, and provide continued access to updated versions of that information. A number of studies have examined the use of situated displays in a variety of contexts, mostly workplace-related. Bardram, Hansen, & Soegaard (2006) constructed an interactive situated display for use in hospital operating theatres and found that the constant updating of information afforded by digital displays improved the efficiency of clinicians. Kray, Kortuem, & Krüger (2005) described the construction of location-aware navigation displays that automatically oriented to a target and displayed the appropriate arrows and directions. O'Hara et al. (2003) placed small situated displays outside meeting rooms and enabled the displays to show current and upcoming room bookings. In each of these cases, the physical location of the device was chosen to add context to the device's digital content.

Situated displays have also been used for communication, often within workgroups. McCarthy, Costa, & Liongosari (2001) constructed three types of situated displays, each designed to display team messages to specific people or groups of people. They note the value of sending messages to groups as well as individuals, and their GroupCast device embodied this principle. The Hermes display system (Cheverst, Fitton, & Dix, 2003) allowed visitors to an office to leave messages for the occupant, and the SPAM system (Cheverst, Fitton, & Rouncefield, 2005) used shared displays to show text messages sent to a team of workers at a psychiatric hospital. Despite the limited feature set and rudimentary interaction available on the SPAM device (for example, users could not reply to messages), team members regarded it as a very useful piece of technology and again recognised the

value of messaging to the team as a whole rather than sending messages to individual team members.

Some researchers have started to study the value of using situated display technology in the home, to make digital information more accessible and to assist with some of the more mundane aspects of running a household. The Whereabouts clock (Sellen, Eardley, Izadi, & Harper, 2006) receives notifications from household members' mobile phones that allows it to update a digital display with coarse-grained information about each person's physical location. LINC (Neustaedter & Brush, 2006) is a digital family calendar intended for home use, and is designed for use in the kitchen or other common family room, although it also has the advantage of being able to be accessed remotely. TxtBoard (O'Hara et al., 2005) is a situated display that can receive SMS messages from family members, and HomeNote (Sellen, Harper et al., 2006) extends this to allow household members to leave ink messages for one another on a small tablet display. Each of these devices provides a way to easily integrate digital information into a physical household space.

### **2.3. Digital Photo Frame Technology**

Digital photo frames might be considered to be a type of situated display. They provide access to digital information – namely photographs (and, in the case of more recent devices, video and music). However, unlike PCs, digital photo frames are intended to be placed in useful locations in the home and to 'blend in' with their surroundings. Because they are not tethered to a computer they can easily be moved from place to place.

Digital photo frame technology has been commercially available for several years. Frames typically consist of a colour LCD display, a series of input ports (such as USB and flash memory cards), buttons for rudimentary interaction, and a microcontroller responsible for retrieving and rendering images and handling the user interaction.

More recently, digital photo frames have emerged that include built-in wireless networking capabilities. These frames can communicate with computers and other devices on a wireless network, and retrieve and display images without the need for memory cards or cables. This approach has a number of advantages: photos can be displayed on frames as soon as they are available on a PC or camera, and a computer can perform digital manipulation on the photos as they are sent to the frame for display. Computers typically implement a standard protocol such as the Universal Plug and Play (UPnP) Media Server (UPnP Forum, 2002), enabling their content to be accessed by a range of devices including other computers, game consoles (e.g. Microsoft Corporation, 2008a), and wireless digital photo frames (e.g. Kodak, 2008).

Taylor et al. (2007) notes that digital photo frames are becoming increasingly common in households, perhaps due to the proliferation of digital camera technology and the corresponding ability for users to place digital photos directly onto Web sites and social networking sites. Digital photo frames enable a user or household to have an end-to-end digital photo experience, without the need to photographically develop or print photos at any point in the process.

Given the increasing prevalence of this type of technology, it is worthwhile to examine the ways in which it can be used beyond the original intentions of the designers, thereby reusing their computational and display resources for multiple different purposes. Kim et al. (2004) describe a prototype of a photo frame that is able to receive and display short messages, intended for use by families and designed to enhance and increase intra-family communication during a work day. However, this project required custom-built technology, and to date has not become commercially available. Similarly, Mynatt, Rowan, Craighill & Jacobs (2001) used a combination of sensor technology and digital photo frames to support awareness of family activities. Non-located grandparents could place a digital photo frame into their home, and the frame would update itself with photos and icons representing the activities and states of family members. Again, however, this project required custom technology: sensors to detect family state were embedded into a 'smart house' designed specifically for the research project.

The use of custom technology for these types of projects is commonplace. The Aware Home (Kidd et al., 1999) used a variety of commercial and research technology, presumably at great expense, and PlaceLab (Intille et al., 2005) likewise required custom technology to be built directly into a home in order to integrate the types of ubiquitous computing technology into the users' environments. Even LINC (Neustaedter & Brush, 2006) – an impressive albeit less comprehensive example of ubiquitous technology – used a specially modified tablet PC that was placed into a household environment. While these research projects have provided a great deal of useful information about how technology can be integrated into households' everyday routines, they are also limiting in the sense that they have required relatively large budgets and have therefore not been easily made available for continued and long-term use. They are also more difficult to prototype and require both hardware and software skills and resources. Edwards & Grinter (2001) note that domestic ubiquitous computing is unlikely to be achieved all in a single step or through the adoption of a single technology, and instead will require the gradual introduction of technologies into the home. With this in mind, I argue that it is unlikely that many homes in the foreseeable future will be built with technology embedded into them in the way that some of the above projects have required. In addition, Frohlich, Dray, & Silverman (2001) note that some resistance exists against moving from

current multifunctional PCs in the home to more specific-purpose appliances. Expecting households to move completely from PCs to information appliances is – for the time being, at least – unrealistic.

Digital photo frames provide a unique and valuable opportunity to achieve some of the goals of ubiquitous computing and situated display technology. Because of their increasing prevalence and acceptance in homes, households are less likely to reject them on the basis that they are too difficult to obtain or too unfamiliar. Additionally, with the improvements in photo frame technology and the introduction of wireless networking, photo frames can be used to display arbitrary content that is controlled by a central computer and broadcast throughout the home. They also present the advantage of being relatively easy to prototype new solutions on, since no hardware modifications are required and the software architecture required to render content is relatively simple. This project illustrates this by enabling digital photo frames to display SMS messages.

### 3. Design

The previous chapter reviewed related work in situated display research and in domestic communication. This chapter discusses a system which combines both of these technologies in order to allow household members to send SMS messages to a digital photo frame located in their home. I begin in section 3.1 by discussing the high-level functionality required in such a system. Section 3.2 describes the options available to integrate with mobile telecommunication networks in order to receive SMS messages from mobile phones, and section 3.3 outlines the considerations involved in creating a suitable user interface for displaying these messages on a digital photo frame. Finally, section 3.4 details the issues that are inherent with non-interactive displays and how these issues affect the system design.

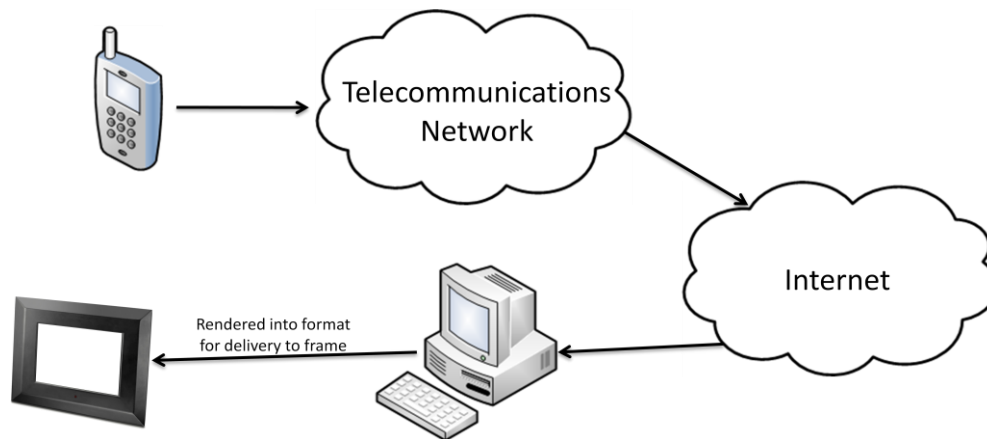
#### 3.1. Functionality

The principal function that this system provides is to deliver SMS messages to a digital photo frame. Sending a message to the frame's phone number should work in the same way as sending a message to a person's phone number; users should not be required to adjust their mental model of the text messaging process in order to use the system. Figure 1 illustrates this high-level conceptualisation of the system's functionality.



Figure 1. High-level functionality.

This process can be decomposed into a number of steps which in turn correspond to system components. SMS messages are first sent from a handset to the appropriate telecommunications carrier. This carrier then routes the message through a communication system such as the Internet, with the goal of reaching a device such as a computer in a household. The message is rendered into a content format that is suitable for display on the frame. Finally, this content needs to be sent to the frame to be shown on its screen. This process is illustrated in Figure 2.



**Figure 2. Decomposition of high-level functionality.**

In addition to the primary function of displaying SMS messages, the system also requires a function that allows users to view previous messages. This is particularly important in the case of a digital photo frame, which has no opportunity for user interactivity such as scrolling or deleting messages. Due to the finite amount of screen space available, only a subset of the received messages can be displayed on the frame at any given time. Section 3.4 discusses some alternatives for the design of a solution to this problem and outlines the option I have implemented in this system.

### **3.2. SMS Messaging**

Software applications can interact with the SMS network infrastructure in a number of ways. One possible approach is to connect a mobile phone handset to a computer, thereby assigning a specific mobile number to a computer. Some mobile phone manufacturers provide application programming interfaces (APIs) to access the contents of their devices from software, so text messages can be sent to the phone and then received by the computer.

SIM cards can also be directly connected to a computer. SIM cards are smart cards that contain information allowing a device to join a mobile network. Telephony stacks running on the host computer allow applications to intercept and receive SMS messages directly from the mobile network, rather than using an intermediary mobile phone handset. Similar technology is also available for CDMA networks, which do not use SIM cards.

Mobile networks also provide a set of numbers (short codes) which are subject to special handling. In New Zealand, short codes are between 3 and 5 digits in length; other countries vary in the length of codes their mobile carriers assign. Messages sent to short codes are routed to a Web application on a server rather than to a handset, allowing a great deal of automation and flexibility in their processing. As short codes eliminate the requirement for a dedicated handset or SIM card to receive the messages, they can be more reliable and less subject to network problems such as congestion

and reception issues. Due to these advantages, I elected to use short code-based messaging rather than using handsets or a direct network connection.

I chose to use a third party, Altaine Ltd, who provides message routing and shared short code services (Altaine, 2008). Shared short codes allow multiple applications to coexist while using a single short code – this is advantageous given the high cost of registering and maintaining a short code. Messages are routed to the appropriate application based on some aspect of the message (for example, the sender’s mobile number, the body of the message, or the time of day). This system used the mobile number of the sender. I provided Altaine Ltd with a list of mobile numbers who were permitted to use the system, and the Altaine SMS Gateway was then able to route messages from these numbers to the application.

### **3.3. Screen Layout**

The design of the user interface for this type of system is of critical importance. As noted in section 2.2, good situated displays require user interfaces that are relatively ‘calm’ and that do not require constant attention. Nevertheless, when a new SMS message arrives, household members should be subtly notified of its presence – but without distracting them from any tasks which they may be engaged in.

While designing this system, I made the decision to display digital photos in addition to the SMS messages that the system received. This decision was based on a number of factors. Firstly, digital photo frames are beginning to gain acceptance as consumer electronic devices (Taylor et al., 2007), and this project attempted to augment the device’s functions rather than simply overriding them. Secondly, I anticipated that households may be more likely to accept this type of technology if they were able to personalise it to some degree. Finally, I believed the aesthetic appeal of the frame would be greater with both photographic and textual content (i.e. photos and SMS messages), as opposed to a screen that was filled entirely with text.

Figure 3 shows the layout design for the frame. The screen contains two panels: a photo panel, situated on the left of the screen and taking up approximately 60% of the width of the frame; and a message panel, situated on the right of the frame. The photo panel contains a single photograph, taken from a set of photographs on the computer. The message panel lists each SMS message in reverse chronological order, as well as the sender’s name and the time the message was received. In order to subtly highlight new messages without interrupting users with audible alerts, the most recent SMS message is coloured red. As new messages arrive they displace any messages that may already be on the frame. Based on the TxtBoard study, I did not expect that this would pose a

problem, since their usage patterns suggested that households would send one or two messages every few days.



Figure 3. Example layout for SMS messages on a digital photo frame.

### 3.4. Interactivity and History

As noted in section 2.3, digital photo frames typically present little opportunity for interactivity. Frames are designed to cycle through a set of images without requiring user input. While some frames do include simple buttons and a remote control, these are intended primarily for controlling the frame itself rather than for manipulating the content of the display. As such, digital frames are essentially non-interactive displays; there is no way for a user to directly control or modify the images that appear. In addition, digital photo frames are typically small devices with screen sizes between 7 and 10 inches.

These limitations become particularly evident when considering the number of messages to display on the screen. Due to the small screen size, only a limited number of messages can be shown at any given time. However, it is possible that an important message may not be able to be displayed due to more recent messages having been received and rendered. The non-interactivity precludes the possibility of the user interacting with the display to request a list of non-displayed messages.

One potential solution is to add a visual 'history bar' component to the frame which provides a glanceable indication of the messages received over time (for example, over the preceding 24 hours). Figure 4 shows an example of such a history bar. By glancing at this component, users could determine that there were more messages available in the system than could be shown on the frame; adjustments to this concept could use iconic representations of messages or senders rather

than circles. However, in order to access these historical messages they would need to use an alternative device, such as a Web-enabled computer. In addition, the history bar would use valuable screen space that could otherwise be used for displaying SMS messages.



Figure 4. Sample message area with history bar.

This bar shows messages as a function of time. Each circle represents a single message.

A similar solution would be to adjust the size of the messages that are displayed on the screen, by either setting the global text size for each message to be smaller or to use a fisheye-based visualisation technique to distort historical messages. However, due to the size of the frame, the resolution of the screen, and the core requirement that this display be viewable without requiring excessive cognitive effort, this alternative is unlikely to succeed.

Because the photo frame cycles through images on a regular basis, it is possible to have each rendered image display a different version of the message area. This would mean, for example, that a non-interactive 'scroll bar' could be displayed, with each image showing a different point along this scrolling timeline. Figure 5 illustrates such a layout, using a standard scroll bar from a GUI. However, this approach compromises a fundamental tenet of situated display technology: they should always display the most current information, allowing users to simply glance at the display to parse its meaning. Showing different views of the image would potentially require users to wait for an entire display cycle to be complete before they could view the most recent message.

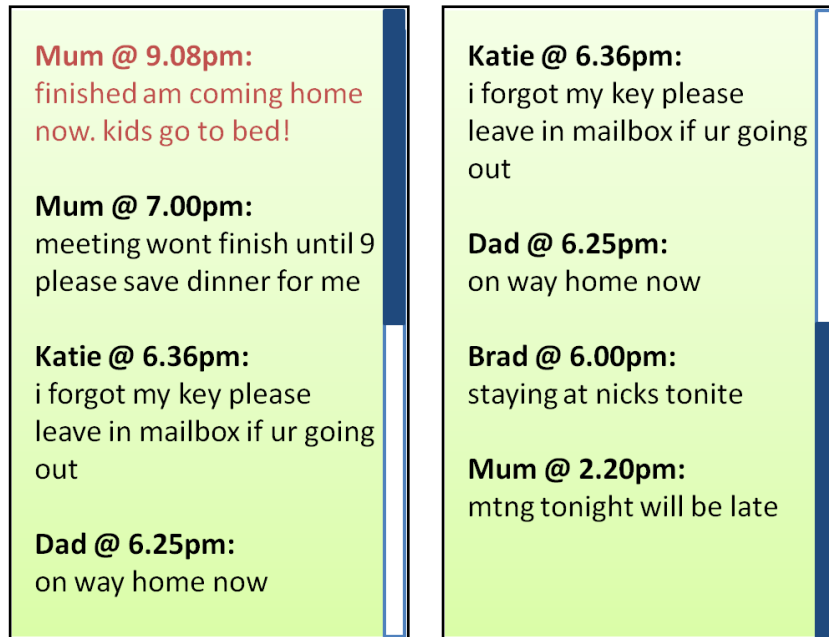


Figure 5. Sample message area with scroll bar.

The left image shows the most recent messages, while the right image shows historical messages. The scroll bar (on the right of each image) changes depending on which view is displayed.

A final option is to have a separate application which provides access to historical messages, but without altering the frame's display. This application could be accessed through a computer (presumably using a Web browser) and would be capable of displaying the entire message history for a particular household. Based on the TxtBoard usage patterns, I ultimately decided to implement such an application for the prototype system, and to analyse the results of the evaluation study to decide whether this solution was appropriate.

### 3.5. Summary

In this chapter I have outlined the high-level design of a system to receive SMS messages and display them on a digital photo frame. A number of components work in conjunction to achieve this goal, including the telecommunication networks, server-based components to receive and route SMS messages, and client software to render and display the messages. Additionally, a separate component allows users to review the messages that have been sent to their household. In chapter 4, I discuss the implementation of this system and the details of the hardware and software components it comprises.

## 4. Implementation

Modern digital photo frames often include features to display multiple types of content. However, these content types are typically restricted to multimedia (images, video and audio). Arbitrary content such as SMS messages are not able to be directly rendered onto a digital photo frame; an additional component is required to receive and store these messages and to translate their contents into a suitable format for the frame to render. The previous chapter discussed the high-level features and components required for this technology; this chapter describes the technical structure of my implementation of these components. I begin in section 4.1 by discussing the hardware requirements and network infrastructure required to support such a system. Section 4.2 then outlines the software architecture.

### 4.1. Hardware and Networking

Due to the design and implementation decisions made during this project, there were several hardware devices required for this prototype system. First, I required a digital photo frame that was capable of connecting to a network and displaying images. Second, I required a computer that was physically located near the device and was capable of running the appropriate software components to receive and display messages. Finally, network hardware was required for the devices to communicate.

The digital photo frame I used was the Kodak EX1011 (Kodak, 2008). This device was selected based on its size, feature set, availability, and price. At 10 inches in diameter, it is one of the larger digital photo frames currently available. It provides wireless networking (802.11) support, implements the UPnP MediaServer AV protocol stack, and the ability to cycle through images supplied by a network computer. It is the only network-capable photo frame I was able to source locally in Auckland, New Zealand. Additionally, the price of the frame (approximately NZ\$400), while higher than other non-network capable frames, was reasonable for my requirements.

As frames are not directly capable of receiving and rendering arbitrary content, I wrote custom software to receive the SMS messages and create images at a suitable resolution for the photo frame. This software is discussed in section 4.2. The software is designed to run on Microsoft Windows-based computers, and requires a computer which is capable of running Microsoft SQL Server 2005 Express Edition (Microsoft Corporation, 2008b) and Windows Media Player 11 (Microsoft Corporation, 2008c).

In order for the computer and photo frame to communicate with one another they must be connected to a network that has wireless (802.11) capability. Additionally, the computer requires Internet connectivity in order to receive SMS messages. Figure 6 illustrates a potential network topology that fulfils these requirements.

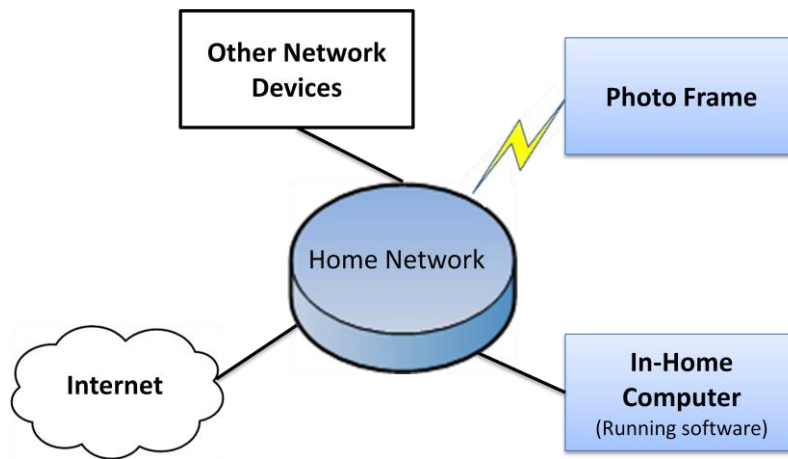


Figure 6. Initial network topology with a single (wireless-capable) network.

During the pilot evaluation study (discussed in section 5.1) I discovered a number of issues with network configurations and made adjustments to the hardware requirements. Ultimately, I concluded that in order to obtain a reasonable degree of reliability, the photo frame and computer should be on a separate wireless network to any other devices. I used a secondary wireless-capable router to create this independent network. Figure 7 illustrates the network topology following these modifications. This modified architecture also required that the computer have at least two separate network interface cards; as many computers do not meet this requirement, a USB to Ethernet adapter was used to add the additional network capability.

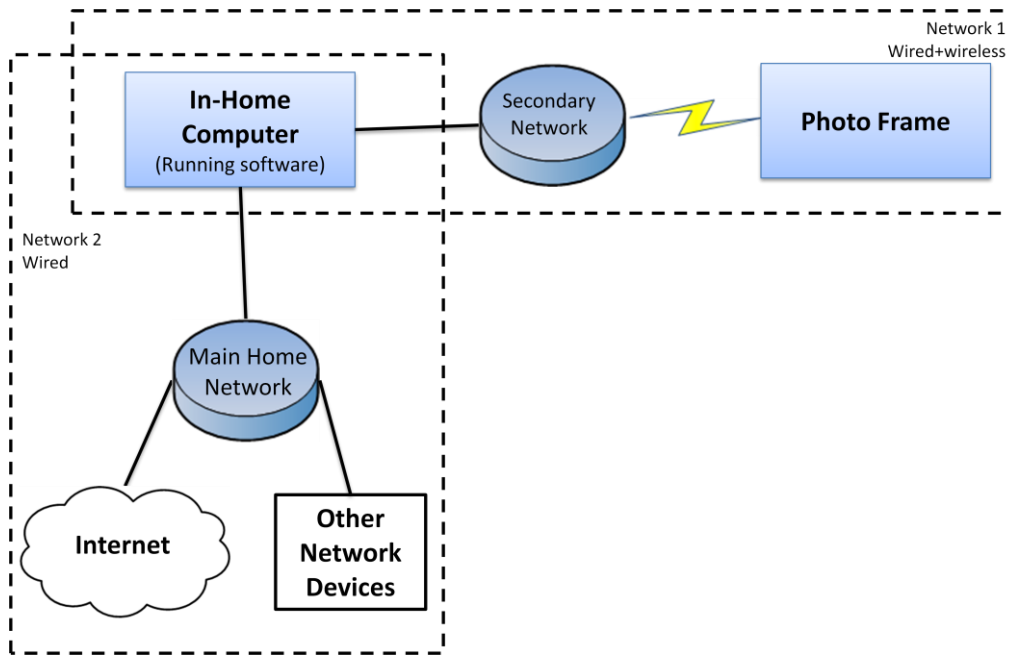


Figure 7. Modified network topology.

## 4.2. Software Components

A number of interdependent software components were required to enable the functionality that this system required. Figure 8 shows the architecture of these components and their relationships. All software was written in C# 3.0, using Visual Studio 2008 and the Microsoft .NET Framework version 3.5. All Web service-based communication used the Windows Communication Foundation (WCF), a SOAP-based communication system for .NET.

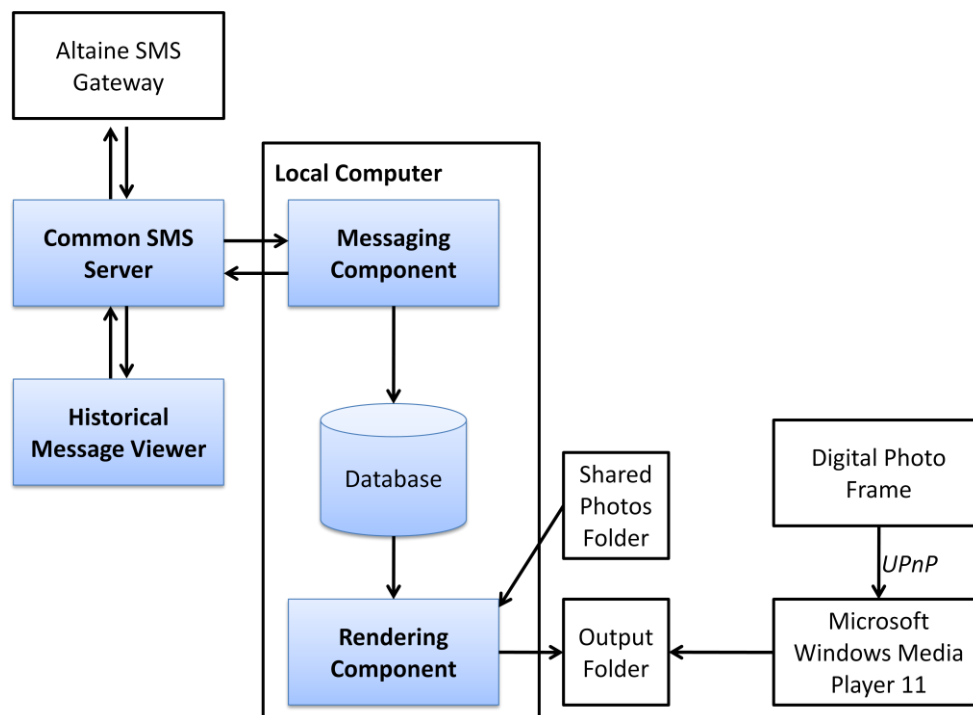


Figure 8. Architecture of the Digital Photo Frame Manager system. Components created specifically for this project are coloured blue.

#### 4.2.1. SMS Gateway and Common SMS Server

Because a partner organisation provided the SMS messaging infrastructure, I required a component that could interact with their SMS gateway to receive messages as they arrived from handsets.

Altaine Ltd publishes a specification for an XML-based Web service that partner organisations can host at a known URL. When an incoming message arrives for an application, the Altaine SMS Gateway makes a request to this Web service and provides the message and message metadata.

While it would be possible for the Altaine SMS Gateway to communicate directly with the computer running in the household, doing so presents a number of disadvantages. The computer must be able to host a Web service at a static URL and be able to receive messages at this URL at any arbitrary point in time. Since most households use broadband connections with dynamic IP addressing, this would be a difficult requirement to meet. In addition, permanently running a live Web server at a household without industrial firewalls and security infrastructure may present a security risk. For these reasons, I elected to add a separate server-based component that would receive all messages for all households and perform the message routing as required. This component is the Common SMS Server (Figure 9).

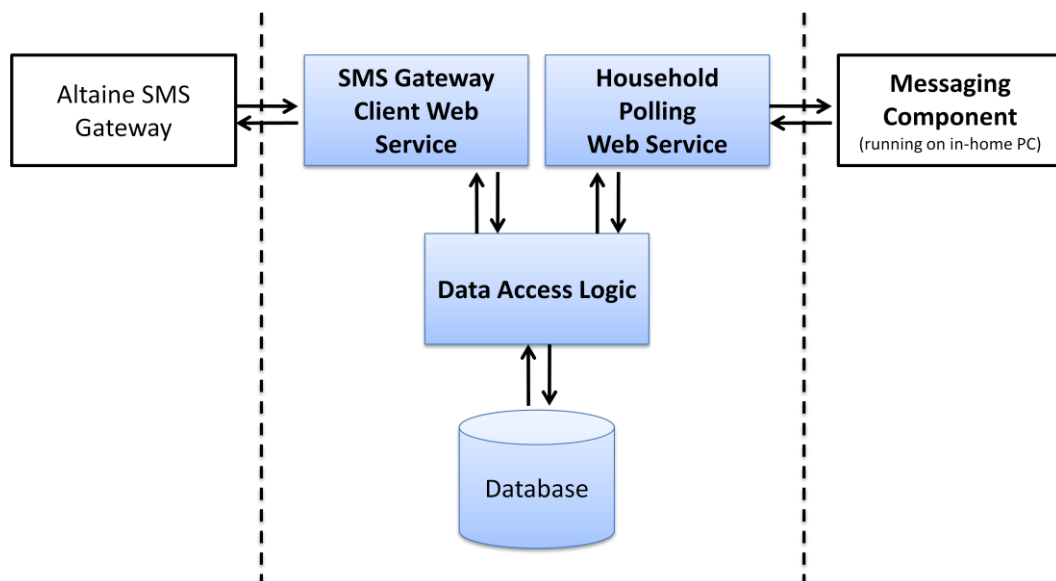


Figure 9. Architecture of the Common SMS Server.

The Common SMS Server includes an implementation of a Web service that conforms to the Altaine SMS Gateway specification. In this implementation, incoming messages are received and logged to a database. This database also stores the list of mobile numbers for each household, and as messages arrive the Common SMS Server determines the household which should receive the message based on this information. This also ensures that the messages are not delivered to an incorrect household, thereby reducing the likelihood of privacy violations.

The Common SMS Server does not directly deliver the messages to the household. Instead, the household polls a separate Household Polling Web Service. On each poll request, the Common SMS Server determines if there are any undelivered messages for that household and, if so, returns them and marks them as delivered. This ensures that messages are only delivered once, and that messages are only delivered to the correct household. If a message arrives from an unknown sender, the Common SMS Server simply logs the message and does not attempt to deliver it.

#### **4.2.2. Local Computer Service**

A Windows service runs on the in-home PC. This service has two separate threads of execution which operate independently. The first thread is responsible for polling the Common SMS Server and receiving incoming SMS messages. The second thread is responsible for rendering these messages to a series of image files.

This multithreaded design was chosen to ensure that messages are received by the in-home PC as quickly as possible. The rendering algorithm can take time to process due to its disk IO requirements, so separating the rendering concerns from the message-receiving process ensures that the two threads can work in parallel. In addition to the Windows service, the in-home PC also hosts a database which stores configuration information, SMS messages, and user information. This database is hosted in Microsoft SQL Server 2005 Express Edition (Microsoft Corporation, 2008b).

The following sections discuss the algorithms that the messaging and rendering components use.

#### **4.2.3. Messaging Component**

Messages are received from the Common SMS Server only when the in-home PC service specifically requests those messages. This pull-based architecture was chosen over a push-based architecture based on the complexity of designing a push system over HTTP and within a household environment.

The messaging component is designed as an infinite loop, which only terminates when the hosting Windows service process is stopped. During each loop iteration, the component constructs and sends WCF-based requests over HTTP to the Common SMS Server. If an empty response is returned, the component waits 30 seconds and then retries. If a non-empty response is returned, the component logs the message to the local database and then waits for 30 seconds before continuing.

The messaging component is only responsible for logging incoming SMS messages to the database. The database's Query Notifications (Microsoft Corporation, 2007) infrastructure then triggers an event in the rendering component which causes the rendering process to begin.

#### **4.2.4. Rendering Component**

The rendering component is also an infinite loop which terminates with the host Windows process. The component uses event-based notifications from the database which are triggered when a new message is written to the database, or when the system configuration changes.

Upon receiving such a notification, the rendering component retrieves a list of all SMS messages in the system and sorts them into reverse chronological order. It then builds the message area in memory, by first constructing a canvas with the dimensions and background colour of the message area and then writing the message text onto this in-memory image. This process also includes a provision to display the most recent message in a different colour; configuration settings specify whether the most recent message is always rendered in a different colour, or if this colour change should only apply for a specified time period. At the conclusion of this process, the message area is constructed.

The rendering component's next task is to iterate through each image in the photo input folder on disk. This folder contains the images that the user would like to have displayed on the frame to the left of the message area. As the rendering component processes each image, it first reduces the size of the image to a suitable resolution for the frame while maintaining the input image's aspect ratio. It then adds the message area to the right side of the image. If no images are present in the photo input folder, the rendering component fills in the entire background with the message area's background colour.

The final phase in this process is to write the image to the output folder. My original implementation deleted the images from the output folder at the beginning of the rendering process, and then rebuilt the file structure by adding each image as it was rendered. However, as discussed in section 5.1, the pilot evaluation study demonstrated reliability issues with this behaviour, so the algorithm instead modifies the existing images in the output folder. At the conclusion of this process, a complete set of images with the most recent SMS messages is available in the output folder; Figure 10 shows a sample output image from this process.



Figure 10. Sample rendering output.

#### 4.2.5. Computer-to-Frame Communication

The rendering process described above constructs the JPEG images that are to be displayed on the frame. The process of sending these images to the frame requires the use of a communication protocol. Kodak EX1011 frames (Kodak, 2008) implement the Universal Plug and Play (UPnP) Media Server protocol. This protocol enables the frame to connect to libraries of media (such as video, music, and images) that the frame can then iterate over and display. The UPnP Media Server protocol can work over wired and wireless networks; the Kodak frame has only a wireless networking stack.

The UPnP protocol allows any network-aware application to become a UPnP server and to host media libraries. A number of commercial media applications also implement these UPnP protocols. One such application is Microsoft Windows Media Player (WMP) 11 (Microsoft Corporation, 2008c). WMP provides a comprehensive implementation of the protocol, allowing client devices to access virtually all content within the WMP media library. Users can also customise the content they want to be shared in this manner. In addition to its UPnP server, WMP also includes a folder monitoring system. This system maintains a record of all changes to media items within a specified folder. When used in combination, the UPnP and folder monitoring features allow images placed in a specific folder to be made available to a digital photo frame immediately, without any manual library management.

While it would be possible to create a custom UPnP Media Server implementation to host the final rendering output from the rendering component, I decided to use WMP instead. As with all custom development, creating such a component would require additional development effort and comprehensive testing. As a stable, commercially available product, WMP provided a more suitable platform for my purposes. However, using WMP in this manner did require that the rendering

component be given exclusive access to the WMP library; any other images placed in the library by third party software would appear on the photo frame without the SMS message panel.

In order for the images generated by the rendering component to reach the photo frame, the rendering service ensures that the images are saved into the output folder. This folder is monitored by WMP. As each image is placed in the folder, WMP discovers it and adds it to its library. Similarly, images that are overwritten or deleted from this folder cause WMP to update its library accordingly. Any UPnP Media Server devices (such as the Kodak frame) connected to the WMP library will discover and have access to the new content when it becomes available. This ensures that images generated by the rendering component are available to the frame almost immediately. The frame is able to copy and display these new images according to the refresh period specified in its firmware settings.

#### 4.2.6. Historical Message Viewer

The Historical Message Viewer is an ASP.NET 3.0 application which is hosted with the Common SMS Server. The Common SMS Server has access to all historical messages and their delivery status, and is hosted as a standard Web application, accessible from any Web-enabled device. Households are assigned unique user IDs and passwords and can view the messages which the Common SMS Server has received for their household. Figure 11 illustrates the Historical Message Viewer.

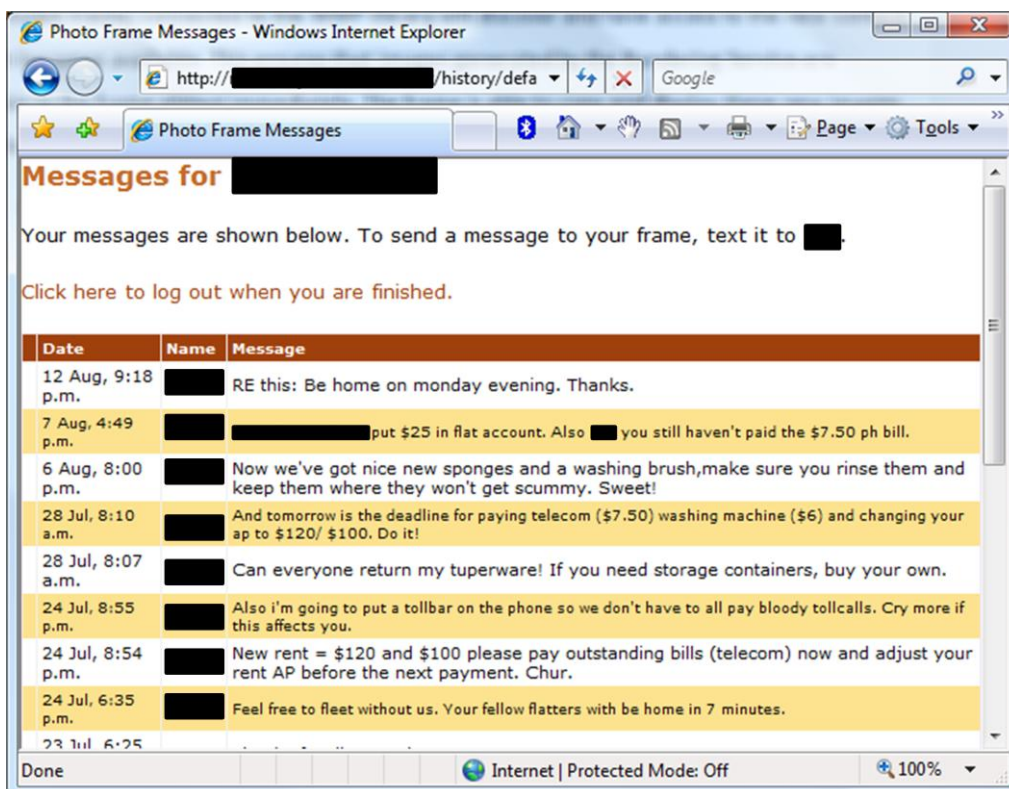


Figure 11. Historical Message Viewer.  
Names and identifying details have been hidden to preserve anonymity.

## 5. Evaluation Study

The previous chapters described the system architecture and its implementation in both software and hardware. This chapter outlines the evaluation study that I performed. I begin in section 5.1 by discussing the pilot study that took place during the development of the system. I then examine the main evaluation study design and rationale in section 5.2. I separately discuss the studies performed in each of the target households, and conclude in section 5.7 with overall comments drawn from all four households.

### 5.1. Pilot Evaluation

During the development of the system, I placed a photo frame in my home and used a dedicated computer to test the software as it was constructed. In addition to testing the design and functionality of the software, this presented an opportunity to ensure that the network infrastructure used by the system was reliable and that the photo frame and computer were able to communicate successfully when used for long periods of time.

Approximately 3 days after installing the system in my home, I found that the photo frame would spontaneously terminate its network connection and return to the frame's main menu screen, without indicating any reason for doing so. When the frame was reinitialised to the network display mode it would resume cycling through the images, but would eventually terminate its connection again after a time period ranging from one hour to one day. Following some investigation, I discovered that this problem could be alleviated to a large extent by changing the network configuration. First, the reliability could be increased by ensuring that only the frame-to-network connection was wireless, and using a wired connection for the computer-to-network connection. Second, reliability was further increased by placing the frame and computer on a separate network to other devices in the household. In this case the computer was required to use two network connections in order to communicate with both the frame and the Internet (to receive incoming messages). This topology is illustrated in Figure 7 on page 18.

I also discovered that the frame would occasionally get 'stuck' displaying a single image and not continue cycling through the images. This meant that it would fail to display any new messages that arrived. By logging the activity of the software and correlating this with the timing of the issues I found that this problem occurred while the system was in the process of deleting and re-rendering the set of images, at the point when there may only be a single image in the library. At this time, the frame would load that single image and would then discontinue its polling. (It is not clear whether this behaviour is an intentional feature of the frame's firmware or a bug.) I was able to mitigate this

issue by ensuring that the rendering component never deleted any images; instead, it would overwrite the contents of each image file, thereby ensuring that the frame would always find multiple images in the library.

Finally, I discovered an intermittent rendering issue whereby the frame would display some images in a pixelated and unreadable form. The occurrence of this issue was lessened by reducing the JPEG quality level in the rendering component, suggesting that the issue was caused by a problem with the frame's JPEG rendering component. This resolution required a trade-off between the incidence of the problem and the quality level of the output image (which is particularly important when the image contains text, as a lower quality level can make the text too blurry to read). I settled on a quality level of 90% (from a baseline of 100%, which is the standard for JPEG).

Having discovered and resolved these issues, I found that the system would run for at least one week (and, in many cases, much longer than one week) without requiring the system be restarted. I considered that this level of reliability was sufficient in order to begin the evaluation study.

## **5.2. Study Design**

The evaluation study had two main goals: to determine if digital photo frames are appropriate as a situated display technology, and to see how different households adapted to the technology and integrated it into their routines.

Four households used the prototype system for approximately one month. I chose this ethnographic methodology to obtain the most realistic and useful data possible, rather than the artificial data that may be collected during a laboratory session. This design was similar to that used by O'Hara et al. (2005) and Sellen, Harper et al. (2006). I considered the one month time period to be an acceptable length of time to allow the participants to adjust to the system and to integrate it into their household routines.

Each household study consisted of a number of phases. Before the study began, I contacted the household and obtained their mobile phone numbers in order to set up the short code routing for that mobile number. I also arranged a time for an initial one-hour visit. During this visit I enquired about the household's communication patterns and their use of different types of technology. I also set up the photo frame system and demonstrated how the family members could use it. Participants were asked to use it as they felt appropriate, without any specific guidance as to the types of messages they might send. Approximately two weeks after this initial visit I returned for a short follow-up interview to ensure the household was not experiencing any issues with the system and to get an overview of their initial impressions. Finally, at the conclusion of the month-long evaluation, I

returned and conducted a final interview focusing on how the household used the system, the messages they sent, and whether they found the technology useful. At this time I removed the system from the household.

The households were recruited based on word of mouth. Each household was provided with a Kodak EX1011 digital photo frame, a laptop computer configured to run the messaging and rendering components, and supplementary networking appliances including a wireless router to connect the frame and computer. Participants were reimbursed for the cost of all SMS messages they sent and were given small gratuities in appreciation of their participation.

The message contents and interviews were mostly analysed qualitatively. I also classified messages according to a taxonomy based on that used by O’Hara et al. (2005). This taxonomy identified four main types of SMS messages and is outlined in Table 2. Messages were also classified by a co-researcher, and any inconsistencies were reviewed and discussed before a final decision was made.

**Table 2. TxtBoard message taxonomy. Adapted from O’Hara et al. (2005).**

<b>Category</b>	<b>Description</b>	<b>Example</b>
<b>Call to action</b>	Messages intended to support management of household activities. Typically broadcasted to all household members rather than sent to a specific member.	<i>“please put the oven on”</i>
<b>Informing, awareness, reassurance</b>	Messages intended to inform other household members about the sender’s activities, but without necessarily requiring any action on the part of the recipients.	<i>“I’ll be home late”</i>
<b>Social touch</b>	Messages intended to support intra-household social bonds.	<i>“good luck for your exam”</i>
<b>Reminder</b>	Messages intended to remind household members of a particular task or activity.	<i>“don’t forget we’ve got guests coming for dinner”</i>

It became apparent when categorising the messages that O’Hara et al.’s taxonomy was insufficient in two ways. First, some messages had content that spanned multiple categories (for example, *“Coming home! For yoga :-D can Kate stay for the night?”*). In these cases we categorised the messages as being in both categories. Additionally, our analysis indicated that the ‘call to action’ and ‘reminder’ categories overlapped to a large extent, and the assignment of messages to one of these

two categories often required a great deal of contextual information that we did not possess. For example, a message such as “*we have guests coming for dinner*” could function as a reminder (if household members had previously been informed of the guests) or as an implicit call to action (for example, to prepare the meal or clean the house). Accordingly, we combined these two categories into a single category which we named ‘functional’. Our final taxonomy is provided in Table 3. Table 4 in the appendix (page 44) lists the number of messages by household and message category,

**Table 3. Message taxonomy used to categorise all SMS messages in this study.**

<b>Category</b>	<b>Description</b>	<b>Example</b>
<b>Functional</b>	Messages intended to support management of household activities, including reminders. Typically broadcasted to all household members rather than sent to a specific member.	<i>“please put the oven on”</i>
<b>Informing, awareness, reassurance</b>	Messages intended to inform other household members about the sender’s activities, but without necessarily requiring any action on the part of the recipients.	<i>“I’ll be home late”</i>
<b>Social touch</b>	Messages intended to support intra-household social bonds.	<i>“good luck for your exam”</i>

### **5.3. Household 1**

Household 1 was a flat made up of six young adults (three male, three female) aged between 19 and 24. Some flatmates worked full time, some studied full time, and some divided their time between working and studying. One flatmate, Emma, took central responsibility for ensuring that rent and bills were paid on time, and for reminding the flatmates about paying their share of these bills.

The flatmates commented that it was unusual for everyone to be home at the same time, so they relied on a number of different communication channels for intra-flat communication and coordination. All flatmates had at least one mobile phone and used text messaging for interpersonal communication, although typically not for messages sent to a group of people. Email was also used, particularly when a message needed to be broadcast to all flatmates irrespective of whether they were home or not; such messages included reminders to pay bills. Most of the flatmates used Facebook, and sometimes they communicated using this site - typically when these flatmates wished to communicate among themselves without involving the flatmates who did not have Facebook accounts.

A series of notice boards were situated in and around the kitchen (Figure 12). Each notice board had distinct functions: one (A, left board) was a whiteboard for communicating messages to individual or multiple flatmates; another (A, right board) was a corkboard for placing bills and other artefacts requiring attention or action; and the third (B) was a corkboard for placing photographs and notifications about outstanding bills. In addition, a flat cleaning notice was attached to the fridge door as well as a table (C) that flatmates could use to track who was doing their cleaning duties.



Figure 12. Notice boards used by household 1.

Notice boards A and B were primarily used for social and household coordination; notice board C was located on the fridge and was used for tracking cleaning duties.

### 5.3.1. Results and Discussion

Household 1 sent a total of 17 messages during their 5-week study. Approximately half of these messages (7/17) were functional in nature. A typical examples of such a message was “*New rent = \$120 and \$100 please pay outstanding bills (telecom) now and adjust your rent AP before the next payment. Chur.*”

Of the six flatmates, only 3 sent messages to the frame. Two of these flatmates used the frame purely for social messages; the third (Emma) used it almost exclusively for functional messages. However, all of the flatmates reported that they paid attention to the frame and the messages it displayed, even if they did not send messages themselves.

**Reactions.** The flatmates in household 1 had varied reactions to the frame technology and to the ability to send messages to a physical location. Emma noted that she found it useful to be able to capture the attention of flatmates in the living room; she tended to use the system as an electronic notice board. At the other extreme, one flatmate disliked the system so intensely that she refused to participate in any of my interviews; she did not give any reason for her strong reaction, leaving other

flatmates to speculate that it was simply because she did not want to participate in the flat's activities.

Another flatmate, Jessica, said that she had a general dislike for the frame itself because of the electricity it consumed – her concerns were from both economic and environmental perspectives. However, she commented that it was useful to have the frame on at all times as it illuminated the living room at night, and she felt sad to see it go at the end of the study, commenting that it had become “a part of the flat”.

The flatmates commented that they would have preferred the system to be enabled for anyone to send messages in, but understood that technical constraints made this impossible. However, they requested that two non-resident friends be granted access to the frame's short code. Only one of these friends sent messages to it, and his messages were both classified as social touches.

Household 1 was the only household that replaced the sample images I had placed on the laptop computer for the rendering component to render messages onto. Emma went through her Facebook account and chose a selection of photos, then saved them to the laptop so they would be used by the frame. She then sent an SMS message to the system so that the frame would refresh itself with the new images. (This would also have happened automatically after one hour.)

During the final interview, the flatmates described the lack of an audible alert of incoming messages as a good thing. They argued that this device was not intended for urgent or time-critical messages, so they did not see this as a requirement. They also did not have any strong opinion on the ability to send outgoing messages, which is consistent with their treating the device as an electronic notice board.

#### **5.4. Household 2**

Household 2 consisted of a professional couple, aged 44 and 50, and two children aged 20 and 15. The 20-year-old daughter studied software engineering at university level, and the 15-year-old son attended high school. While all four members of the family had mobile phones and used them when required, the children tended to use theirs more than the parents.

Prior to the study the mother was working a night shift and was out of the house most evenings and sleeping during the day. This meant that she did not generally see her family during the week, in particular her son who was at school during the times she was home. Before she left for work each evening she generally left a note for her son on the kitchen table, and he would read and respond to this when he returned home. The mother then read his response when she arrived home from work

in the morning. She would then remove the previous day's note and write a reply on a fresh piece of paper. However, the mother changed to a regular day shift a few days before the study began, so the family expected that this communication pattern would change.

The family communicated with each other in a number of ways. Notes between family members and urgent correspondence were generally left on the kitchen table as this was the first place everyone would look upon entering the main living area. Bills and letters for the family were placed on a table in the living room next to the television. This location was chosen based on the likelihood that family members would see these items when they sat down in the living area. These items were generally considered less urgent than the items that were placed on the kitchen table. Family members would also use text messaging to communicate with one another, but this was typically reserved for immediate, action-based communication such as the children asking to be picked up from school or university, or for the children to remind the father to buy an item at the supermarket.

The family decided to place the digital photo frame in their living room, on the table next to the television. This location was chosen based on its existing contextual meaning as a place for intra-family messaging, as well as for the practical reason that family members' attention would be drawn to it while they were seated watching television.

#### **5.4.1. Results and Discussion**

Household 2 sent a total of 11 messages during the trial, 9 of which were reassurance messages from the daughter. A typical example of such a message was "*hi i wil b home by 8:30.*" The remaining 2 messages were from the father, asking if anyone was home. The mother and son did not use the photo frame at all.

The family commented that the lack of an audible alert to announce incoming messages was the primary reason they did not use the device more regularly. This reinforces their perception of text messaging as a medium for messages that require immediate action. The father commented that he was reluctant to send urgent messages or requests to the photo frame because it was unlikely that anyone would notice the message in time – assuming they were even at home. On the two occasions when he did use the frame to ask if anyone was home, the messages were not received in time. Because of this, he continued to use person-to-person messages.

The family members also said that they would have appreciated the ability for their overseas family to be able to send messages to the frame.

## 5.5. Household 3

Household 3 was made up of a professional couple aged in their 40s, and three children (two sons and one daughter) aged 16, 19 and 20. Two of the children attended university and the third studied at a local high school. The family had emigrated from Poland 13 years previously and spoke both Polish and English at home. Typically the children spoke English to one another but used Polish when communicating with their parents. In contrast, their parents spoke Polish to each other as well as to their children. This selection of languages also extended to the family's use of text messaging; indeed, the mother commented that the children's use of text messaging had improved their written Polish.

The family members stated that they used text messaging as their primary means of communicating with one another, particularly for child-to-child messages and for child-to-parent messages. Typically these messages would be functional in nature, taking the form of requests such as "*can someone pick me up?*". While the parents did use their mobile phones to communicate with each other, they tended to use voice calling more often than text messaging due to the payment plans they were subscribed to. Family members said they did not generally leave physical notes for one another in locations in the house.

The family members seemed enthused by the technology and expected to use it regularly. They placed their frame in their central entryway, adjacent to the staircase that led to the bedrooms. They commented that the frame's placement in this location meant that everyone would look at it as they entered and moved around the house.

### 5.5.1. Results and Discussion

Household 3 sent 27 messages during the study, although 2 messages had multiple parts and were categorised as two separate messages. Most of these messages were sent in Polish, and the older son translated these to English to allow us to analyse them.

Twelve messages were categorised as being functional in nature, and most of these were from the sons asking to be picked up. Thirteen messages were in the 'informing, awareness and reassurance' category and were almost exclusively sent by the older son to inform his family when he would be home. Four messages were categorised as social touches; some of these were messages from the father, sent early in the morning, saying "*have a good day*".

The older son often sent messages to the frame when he was on his way home. He said that he would not otherwise do this, and his parents appreciated the fact that he was keeping them up to

date with his activities. They said that there was no particular urgency with these types of messages, and were happy to occasionally look at the frame to see if he had sent a status update.

The family initially attempted to use the frame to make requests of one another, but soon discovered that the lack of an audible alert meant these messages were unlikely to be received in a timely manner. One of the sons gave the example of a message he sent in which he was at the supermarket and wanted to enquire if the family needed him to buy tea. Nobody was aware of the message until it was too late. Related to this was the inability to reply – he argued that “*I needed the reply right there and then*”, so if the message had in fact been received then the frame would have been the obvious place to reply to the message.

Based on this, this family said they found that the device was most useful for non-urgent awareness/reassurance messages, but was not appropriate for urgent messages or coordinating household activities. Despite this, Figure 13 shows that the household continued to send functional messages throughout the entire study.

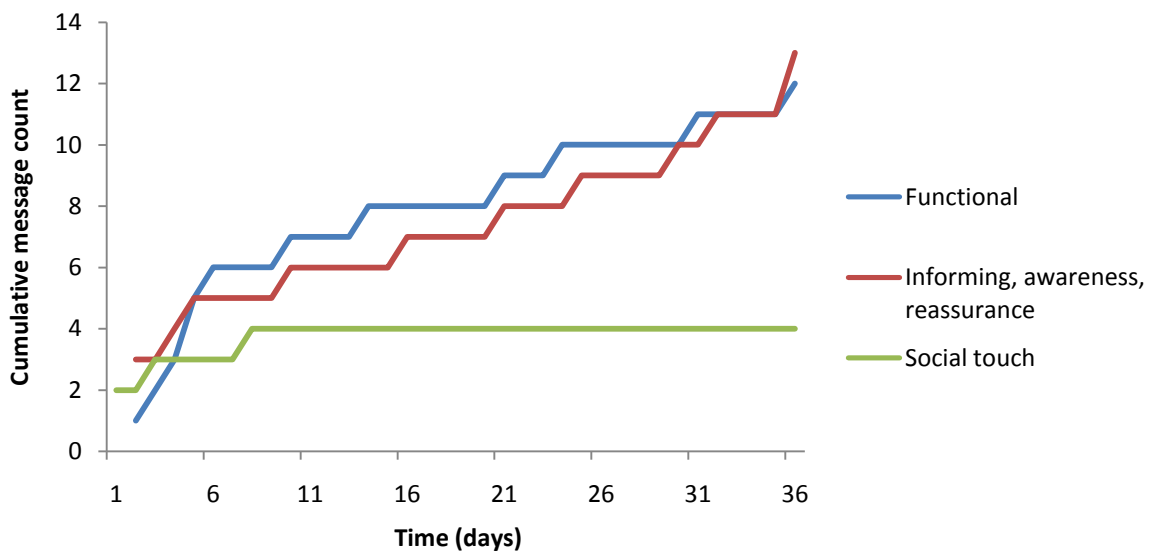


Figure 13. Cumulative number of messages sent by household 3 as a function of time and message category.

The family did not mind that access to the frame was restricted to family members. They said that they would be unlikely to get messages from friends and extended family members even if it were technically possible, as they viewed this as a device for intra-family communication only.

## 5.6. Household 4

The final household in the study was a flat of five young adults (four male, one female) aged between 20 and 22. Four of the flatmates were studying at university level and the fifth had recently started working as a doctor. The flatmates were friends before they moved in together and their flat

had a casual organisational structure. One flatmate received the telephone bill each month and would verbally inform the other flatmates that they owed him money; he said he did not generally need to give further reminders. Communication between flatmates was typically for social purposes such as invitations to visit to a park or a bar. Flatmates did not generally leave notes for one another, with the only exception being when a flatmate's mother phoned – in this case, a note would be left on their door.

The flatmates placed the photo frame on the wall in their kitchen. They chose this location as it was a central place that flatmates would visit regularly.

### **5.6.1. Results and Discussion**

Due to project time constraints the household 4 evaluation study period was shorter than those for the other households, lasting approximately 3 weeks. Despite this shortened time period, the flatmates sent 45 messages to their photo frame during the study – the highest number from any of the four households.

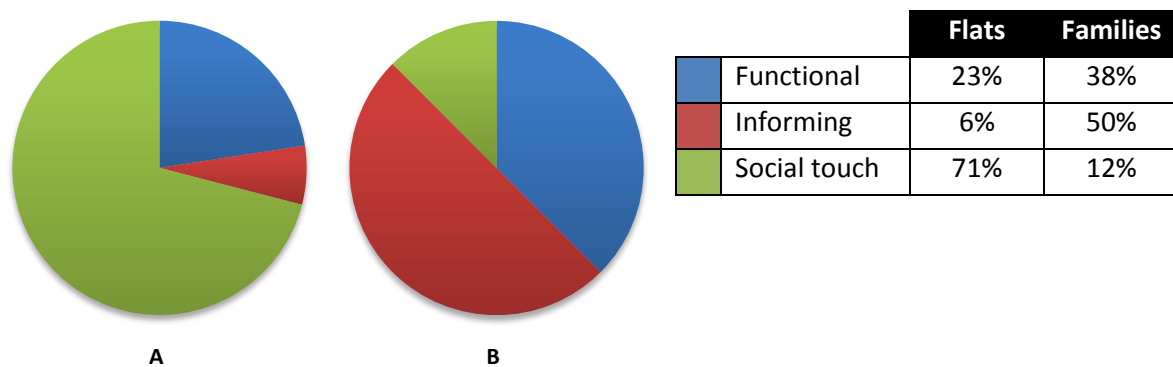
The majority of these messages (36, or 80%) were classified in the 'social touch' category. Of these, most had little useful content, and tended to be nonsensical messages, 'in'-jokes between the flatmates, or quotes from movies and television advertisements (for example, "*Ok guys.. milk. soup. bread. but 8 dozen nutbreak bars. 8 dozen? who'd do that?*").

The flatmates sent only 2 messages that were classified in the 'informing, awareness, reassurance' category. During one of the interviews, one flatmate commented "*I don't really care about knowing who's going to be home when*", again reflecting the flat's casual organisational structure.

Household 4 used the system to send 7 functional messages. Some of these messages were from friends who were not living at the flat and were intended to broadcast messages to all of the flatmates. An example of such a message was "*Going to bottle beer in 20 mins. If anyone available to help would be good*". The flatmates also used the frame to invite one another to various social occasions. They commented that they found it useful to be able to broadcast invitations in this way, although the location-based nature of the device meant that some flatmates did not see the message if they were not at home. They also found that the lack of an audible alert meant that some flatmates occasionally missed messages or did not see them until it was too late. Overall, however, the flatmates in household 4 said they enjoyed using the frame and found it to be both useful and fun.

## 5.7. General Discussion

The four households sent a total of 100 messages. There were substantial differences between the usage patterns of the flats and families; as shown in Figure 14, family members primarily used the technology to broadcast information about their status (i.e. ‘informing, awareness, reassurance’ messages) while flats mostly used it for social messaging. Due to the laissez-faire organisational structure that typifies most flats, the need to track one another’s whereabouts was very low. This meant that messages from flatmates informing each other of their locations were not generally required.



**Figure 14. Categories of messages sent by flats (A) and families (B).**  
**Table 4 in the appendix (page 44) shows the number of messages for each household.**

For some of the households, usage patterns changed over time. Figure 15 shows the cumulative number of messages sent by each household as a function of time; if overall usage was stable over the study period this graph would show an approximately linear relationship. However, in the case of households 1 and 3, there was an initial 10-day period where their usage was high; it then decreased over the remainder of the study. This could be considered to be a ‘novelty factor’: household members initially used the system regularly due to its newness, and during this time they assessed how it would be useful for their particular household patterns. Over time, the novelty factor wore off, and the households adapted to using the device in particular ways that were meaningful to them, taking into consideration the features and limitations of the device.

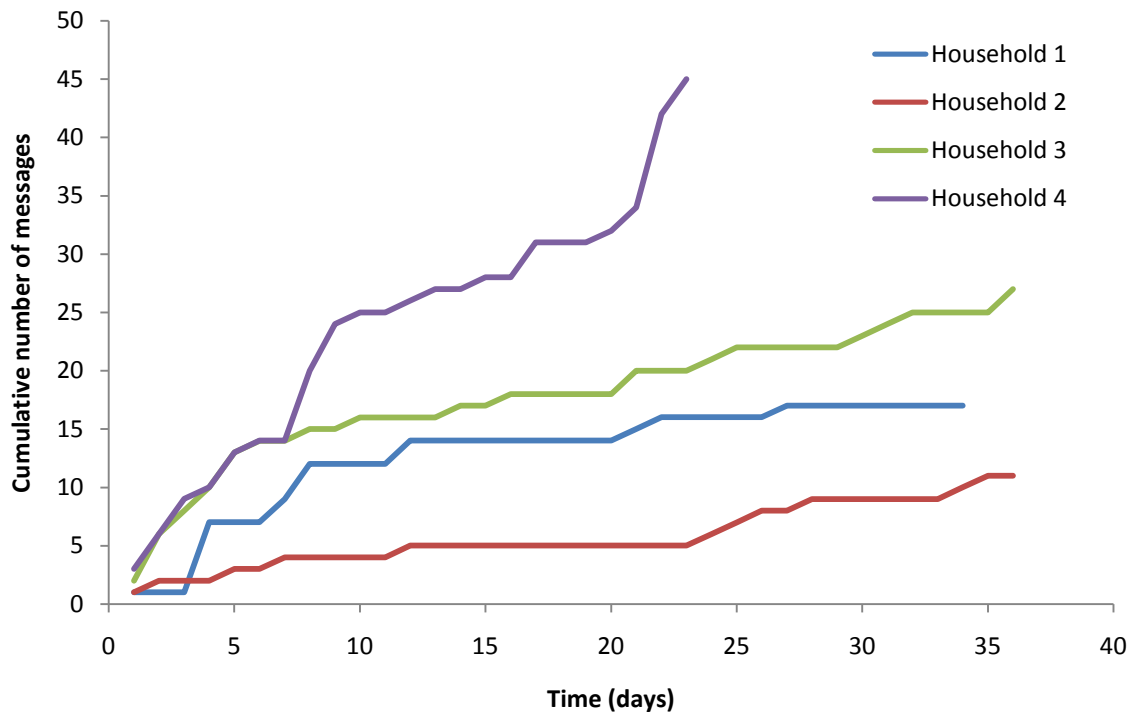


Figure 15. Cumulative number of messages as a function of time.

Households tended to use the system more frequently in the late afternoon and evening (Figure 16). This is unsurprising as most household members were typically arriving home in this time period; this is also consistent with the finding that family members were mostly using this system to notify one another of their expected arrival times or after-school activities.

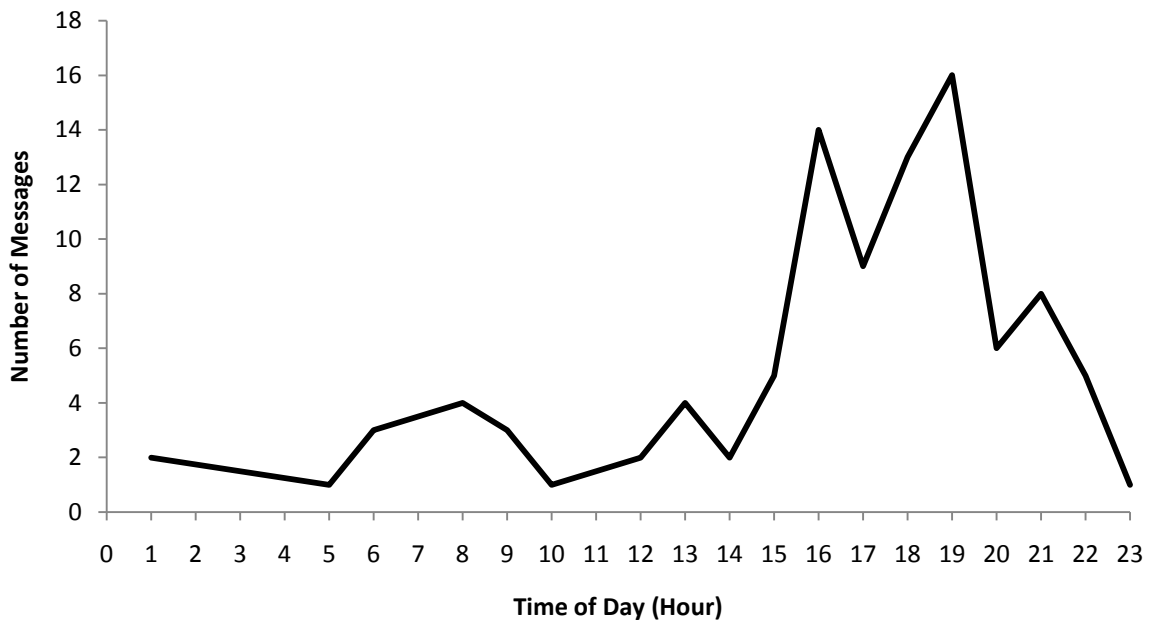


Figure 16. Number of messages as a function of time of day (in hours) for all households.

Both families, and one of the flats, commented that the lack of an audible alert was a barrier to them using the technology more regularly. In the case of the families, they said they felt reluctant to send urgent messages or messages of a functional nature since there was a possibility that the intended recipients would not see them in time, even if they were at home. Because of this, all households continued to use person-to-person messages for high priority messages.

Both flats and one of the families would have appreciated the ability for extended family and friends to be able to send ad hoc messages to the frame. This finding is in contrast to the TxtBoard study (O'Hara et al., 2005) which found that household members thought it inappropriate for non-household members to use the device. In this case, two of the households were flats with common sets of friends, and one of the households was a family with many overseas extended family members.

Relatively few technical problems were encountered with the photo frame technology. In all four of the households, participants observed that parts of the images would occasionally appear pixelated and unreadable, as discussed in section 5.1. Additionally, household 4 found that the photo frame would reset itself sporadically, presumably due to issues with the wireless network. Other households did not have this same issue.

An unexpected finding was that the cost associated with sending messages to the device was a barrier to some participants using the system. Despite the relatively low cost of these messages (\$0.20) and the fact that we told all the participants that they would be reimbursed for the cost of the messages they sent, the flatmates and children in household 3 commented that they sometimes could not afford to send messages to the system. This was largely due to the SMS message plans that these participants had subscribed to; short code-based messaging is exempt from these plans and charged separately, so the participants needed to have enough credit on their phone account to send the messages.

Finally, the limited screen size and non-interactivity of the photo frame sometimes caused some participants to miss messages due to other messages replacing them on the frame. A participant in household 1 commented that one of the messages he saw appeared to be a follow-up to another message, but the first message had disappeared. He noted that although he knew he was able to view the message history on a web site he was not particularly motivated to do so. Similar sentiments were expressed by other participants in other households. This suggests that the inability to scroll through messages is an issue with this device; this also suggests that simply making participants aware of the fact that they have missed messages is insufficient to solve the problem.

In summary, all households did find some use for the device. The flats used it primarily as a notice board and mostly left humorous messages for one another. They also used it for some types of flat organisation such as reminding one another of upcoming events. In contrast, the families generally preferred to use the frame for low-priority informational messages in which family members would send a message home that indicated what they were doing or their expected arrival time. These distinct usage patterns indicate that the households managed to integrate the frame into their routines and began to work around the limitations of the device. The fact that the households encountered these limitations suggests that they would have liked to use the system more but felt they could not rely on it for some purposes. Chapter 6 discusses technological improvements which may be able to mitigate these concerns.

## 6. Future Work

Previous chapters discussed the design, implementation, and evaluation of a prototype system to enable person-to-location SMS messaging using digital photo frames. Based on the findings from the evaluation studies, as well as my own reflections, this chapter presents a series of recommendations for future work. I begin in section 6.1 by discussing the core issues which I encountered while designing and implementing this system, and the possible areas of research into these fundamental problems. Section 6.2 summarises the issues that are specific to photo frames and suggests possible improvements. Section 6.3 outlines modifications to this software to enable it to be more performant, less reliant on external components, and more useful. Finally, section 6.4 describes the potential for this technology to be used as a platform for general research into situated display technology.

### 6.1. Fundamental Issues with Situated Displays

Situated displays present unique challenges for user interaction as they are inherently non-interactive. For some types of content (such as weather information, sports scores, or traffic updates) interactivity is not required. For other types of content, however, a limited degree of interactivity is desirable to ensure that users can view the information that is topical and relevant to them. My evaluation study highlighted the importance of being able to view historical messages. This could be stated as a general problem: how do we enable non-interactive situated display technology to display large amounts of content without compromising the glanceability, low attentional requirements, and ease of deployment? Section 3.4 discussed some possibilities I considered when designing this system. However, the evaluation study found that even when participants were aware that a message was not displayed, they did not feel motivated to use the message history site to view the message contents, so displaying a history bar may not be appropriate. Other alternatives may include a scrolling-based interface. Further evaluating and refining these and other similar ideas may provide clues as to the direction in which non-interactive situated display technology should head.

### 6.2. Digital Photo Frames

This evaluation study highlighted a number of limitations in the digital photo frame technology I was using. These can be broadly divided into specific problems with the Kodak frame's firmware and fundamental limitations of today's digital photo frames.

With regards to specific issues with the photo frame I was using, I found that the wireless networking stack had a lower level of reliability than I expected from a commercial device. As described in section 5.1, the pilot evaluation study provided the opportunity to work around the networking issues, and only one of the households in the evaluation study encountered network-related problems. However, the additional hardware and configuration effort required to increase the frame's reliability is a barrier to future work with this particular device. Future firmware releases or switching to another model of photo frame may resolve this issue.

The use of a digital photo frame rather than a general-purpose display had implications on the types of features I could implement. Both families in the study commented that the lack of an audible alert was a major limitation, and prevented them from using the frame more regularly. The frame itself does have the ability to play audio, but this cannot be triggered during a slideshow. Further work may be required to implement an audio system that integrates with the photo frame content, taking into consideration the fact that an audible alert may need to repeat until a message is read.

### **6.3. Software Improvements**

The prototype system I have developed was intended as a first attempt at creating a messaging platform for digital photo frames. As discussed in section 3.2, the shared short code-based SMS messaging infrastructure is restricted to known users; friends and family who have not been explicitly added to the SMS Gateway are not able to use the system. The evaluation study showed that, for most of the households, this limitation precluded their using the frame more regularly. Future versions of this system or similar systems should consider using a standard mobile number unique to the system instance, either by connecting a handset to the computer or by using a mobile telephony stack.

I elected to use Windows Media Player (WMP) 11 to provide a UPnP server, rather than building this directly. However, future versions of this system should consider building and hosting a custom UPnP server instead of sharing another. Doing so would eliminate the requirement for this application to have exclusive access to the WMP library. This approach would also have the added advantage of allowing images to be constructed as they are required by the frame, rather than having a rendering component prepare an entire set of images in advance. This, in turn, would increase the performance of the system by decreasing the disk IO required.

Similarly, while digital photo frames can operate entirely independently of a computer, this was not possible for the particular system architecture I used. I provided the evaluation study households with computers that needed to remain switched on and connected to the network in order to serve

the images to the frame. Other photo frames (or other frame firmware) may be able to work around this limitation and allow the frame to generate its own images; alternatively, work may be done on constructing network rendering devices that can act as an integrated SMS receiver and UPnP server.

#### **6.4. Additional Applications**

This project has validated the use of digital photo frames as low-cost situated displays. While not appropriate for all situations, these displays are relatively straightforward to develop applications for, and provide an excellent platform for some types of situated displays.

This software could be extended to provide a general-purpose rendering system for digital photo frames. Developers could create custom plug-ins to render their content, and the platform would integrate these into a single runtime environment. Such a platform should also provide a centralised management system to allow users to specify what content types should be displayed on the photo frame. This type of system could further be extended to allow a single household to run multiple photo frames simultaneously, managed by a single system but each displaying content specific to that frame's location. For example, a photo frame located outside a bedroom may display messages and photos specific to a particular person, while a photo frame in the living room or kitchen may have more general information.

Potential plug-ins for this type of system may include social networking integration (for example, Facebook and Bebo integration), news, weather, photographs, and traffic updates, as well as the SMS messaging technology discussed here.



## 7. Conclusion

This dissertation has discussed the design, implementation, and evaluation of a person-to-location SMS messaging system built using digital photo frames. It has outlined the opportunities and limitations inherent in digital photo frame technology, and has investigated their effects in building a comprehensive messaging platform for domestic use.

Chapter 2 discussed the work that has previously been conducted in situated display technology and looked at the use of situated displays for messaging. This chapter also reviewed some of the ways in which digital photo frames have been used beyond their designers' original intentions.

Chapters 3 and 4 outlined the design and implementation of a system to enable household members to send SMS messages to a digital photo frame. Messages are received through a single server-based application and then routed to individual households. A computer in each household is responsible for retrieving the messages from the server in a timely manner and rendering them into an appropriate format for display on the photo frame. The design of this rendering format needs special consideration given the inherently non-interactive nature of digital photo frames.






Chapter 5 discussed the evaluation study that I conducted to assess the usefulness of this technology. The study focused on two main areas. First, I wanted to assess how households (both families and flats) would use person-to-location messaging. All four households integrated the technology into their everyday routines, although each of them used it in different ways: families tended to use the system for informing one another of their status and location, while flats mostly used the system for social communication and facilitating social encounters with one another and with friends. Second, I wanted to determine whether digital photo frames are a useful technology for creating applications that run on situated displays. I found that while photo frames provide an inexpensive platform for developing these systems, their limitations soon become apparent: the lack of interactivity and their inability to seamlessly integrate multimedia precludes the development of features that would be important for this type of technology to gain widespread acceptance.

Finally, chapter 6 listed some ways in which this work could be extended. Like all consumer electronics technology, digital photo frames are constantly improving and becoming cheaper, so future studies may re-examine the type of frames that are used and the limitations that each model has. Additionally, there is wide scope for developing further applications, even for today's photo frame technology. Future work might be conducted to determine which types of applications are useful for digital photo frames and for non-interactive situated displays in general.



## Appendix

Table 4. Evaluation study message counts by household and category.

Message Category	Household 1 (Flat)	Household 2 (Family)	Household 3 (Family)	Household 4 (Flat)	Total
					
<b>Functional</b>	7	3	12	7	<b>29</b>
<b>Informing, awareness, reassurance</b>	2	7	13	2	<b>24</b>
<b>Social touch</b>	8	1	4	36	<b>49</b>
<b>Total</b>	<b>17</b>	<b>11</b>	<b>29<sup>1</sup></b>	<b>45</b>	<b>102</b>

Note 1: Some messages were counted in multiple categories, so the total message count may differ from other calculations in chapter 5.



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