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ORIGINAL ARTICLE

PostBits: using contextual locations for embedding cloud information in the home

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Abstract Placing information at specific locations in the home provides rich and intuitive ways for people to cope with information, as they leverage semantics of the locations within the home. However, there is no deeper investigation yet on how users would embed digital cloud-based information into various locations in their homes, partly because previous systems were not robust enough to be deployed in real settings for an extended period of time. To this end, we have developed *PostBits*, a system of display blocks that integrate cloud information with contextually rich physical space. *PostBits* were designed for long battery life, robust communication and simple interactions, to enable a field deployment. A field study was conducted with 6 families, each using the system in their home for 1 week. We have identified patterns and strategies of how users embed cloud information at contextual locations in the home, and reflect on future design opportunities.

Keywords Pervasive displays · Ubiquitous computing · Smart home · User interfaces

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1 Introduction

Traditional media such as handwritten notes and paper calendars are still used extensively in domestic settings as effective means of communication [4, 9]. Although this inexpensive and ubiquitous medium may seem primitive, the ability of contextualizing the information adds significant amount of richness. For example, a post-it note left on a wallet would provide a just-in-time reminder to pick something up before leaving to work. In fact, previous research has shown that information such as reminders/alerts, schedules and notices is *created and understood by home inhabitants as a function of contextual locations within the home* [9].

On the other hand, digital information on the cloud brings other significant advantages such as searchability and ability to update itself. However, accessing information on the cloud through a single block of screen on a personal device (e.g. mobile phone, smartwatch or personal computer) misses the important cues provided by the contextual locations. There is a large body of small and everywhere displays proposed in the literature (e.g. [3, 7, 8, 12, 18, 21, 22, 25]. However, to our knowledge, there is limited understanding of how such systems would be used in a home setting for an extended period of time. Such real-world understanding is critical to guide the design of future situated display interfaces.

In this paper, we developed a pervasive platform, *PostBits*, to investigate how users would integrate digital information on the cloud into their physical spaces at home. *PostBits* are a set of small tangible rectangular displays that non-expert users can easily deploy in a domestic setting. User can assign digital contents such as free text or information feed (weather, news) to each of the *PostBits*. Depending on the type of contents, the blocks could auto-update themselves (e.g. weather feed) or wait for the users to manually update (e.g. text message). The platform has similarities to traditional media in terms of being able to be placed in the physical space. It also brings in additional advantages such as being able to read/write remotely, update contents dynamically and reusability. Our focus was to understand the emerging usage patterns and strategies when *PostBits* are used at home and how these differ from the usage of traditional media. We present the following main contributions:

- First, we share findings from a field study conducted with six families to understand how non-expert users would use, manage, deploy and redeploy *PostBits* in their homes. We visited each family three times during a week to conduct semi-structured interviews and observations. Our findings suggest a set of unique patterns and strategies that emerged when the participants used *PostBits* to integrate information on the cloud to their homes through contextual placement. We highlight how these emerging usage patterns differentiate *PostBits* from traditional media. For example, one family had multiple *PostBits* in the living room connected to Twitter feeds of two political parties which kept them aware of the ongoing general election. We describe implications of *PostBits* system in a home setting and explore further design opportunities.
- Second, we share the technical details of the *PostBits*. Elliot et al. [10] have indicated the technical challenges of developing a prototype that is ready to be deployed in a home setting. We developed customized hardware and made robust *PostBits* prototypes that are energy efficient and reliable enough to be left with end-users at home. Also we developed a scalable communication hierarchy and content management system to embed both user-generated and publicly available information with *PostBits*. Our current custom-made *PostBits* are energy efficient to operate for more than a week without recharging. This technical development made the domestic evaluation of *PostBits* possible.

2 Related work

2.1 Contextuality of information at home

Home is characterized by a variety of user groups that differ in age and general abilities [5, 19]. Previous examinations of households revealed the importance of the routine work of communication [4]. Furthermore, locations of information used in communication are often determined by the daily routines of the inhabitants [9]. Also certain "typical places" within home are designated for specific family members that provide information on the social organization of communication within the household [4]. It is important to understand the routines and behaviours of the family members in order to place contextually sensitive information [6]. Elliot et al. [9] used contextual semi-structured interviews to reveal that the main types of communication information at home shared using paper-based and electronic media included "reminders and alerts", "schedules", "notices", "visual displays" and "resource coordination". Chetty et al. [2] examined the relationship between home networking and the house itself—how technologies interact with the house infrastructure and how it affects the householders.

These studies show the importance of the contextual location of the message displayed and how it attaches meta-information about action, activity, time, ownership and awareness. These studies are limited to exploring how "traditional" media are used within a home context. With *PostBits*, we aim to investigate how "small and everywhere digital displays" perform in conjunction with existing physical practices as well as the unique advantages they offer in comparison with traditional media.

2.2 Small and everywhere displays

Early on, research has explored and verified the efficiency of increasing communication and awareness in collaborative workplaces through ambient and contextual information interfaces. Dourish and Bly presented a system to increase awareness through *Portholes*, a regularly updating image bulletin [8]. Fitton and Cheverst showed how an office door display can enhance the awareness and communication utilizing the location of display [11]. *Notification Collage* is another example of how a secondary display monitor and strategically located public displays enhanced office collaboration and communication [13]. However, these interfaces lacked the mobility to change their location according to the user needs.

In home environments, one approach to leverage on contextual nature of information is to embed existing domestic objects with information. Hazlewood et al. [14] showed how domestic lights can act as an ambient communication medium. *Casablanca* is another example of embedding household object with information and extending it to other mediums such as sound [15]. Furthermore, Mynatt et al. also demonstrated the utility of sounds in ambient communication context [18]. Due to the limitation of expressivity of the medium, types of information displayed through these interfaces were few and abstract.

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StickySpots introduce a distributed display system combining physical and digital data to make an ambient communication medium at home [10]. *StickEar* is a multi-function input/output device that enables sound-based interactions for applications such as remote monitoring, remote triggering and controlling of digital devices using sound [30]. *SparKubes* are a set of stand-alone tangible objects that are corded with simple behaviours and can be used to create a variety of low-resolution tangible widgets that can control different appliances, e.g., an application on a nearby computer, wall-sized display or mobile device [22]. In the *Augmented ForeArm,* the forearm has been used as a display space given its hybrid nature as a private and a public display surface [20]. *Digital Family Portraits* and *Hermes@Home* bring the contextual ambient communication between elderly parents and their children through augmented displays [25, 19]. Though these enable rich and wide variety of information in context, form factor and the power requirements may have restricted the usage patterns that would have emerged from a true pervasive displays. Many a self-contained units have been developed as ubiquitous information displays [29, 16] for a specific applications focus. Alternatively, projection systems have been used to remotely embed digital information in different locations [28, 31]. Projection systems present new challenges at home settings such as occlusion, durability over long period of time and lack of tangible feedback. In contrast, *CloudDrops* is a prime example of utilizing information location to enhance the communication and awareness, which inspired the development of *PostBits* [21]. Our goal was to study the use in a longer-term deployment of CloudDrops-like system. However, CloudDrop's system was not designed to be deployed in a real setting for long period due to energy issues. As such the technical development of *PostBits* focused on creating a low cost, reliable and power efficient small and everywhere display platform. Table 1 provides a structured overview of small and everywhere displays, their characteristics and evaluation methods (Fig. 1).

3 PostBits

3.1 System design and interactions

3.1.1 System overview

The primary design goal for the system was to ensure robust operation over a long period of time without recharging the *PostBits*. In order to achieve this, the processing power and memory requirement of the system were distributed among three hierarchical levels as shown in Fig. 1. A server side back-end application coupled with a database server at the top-level handles, processing heavy tasks such as content management, data persistence and image processing. At the middle level, an intermediary processing unit was used in order to reduce processing and power overhead when connecting to the remote server. We placed *PostBits* at the bottom level to perform lightweight user input and information presentation tasks. With this system architecture, the *PostBits* could last more than 8 days of continuous operation.

3.1.2 Interactions and feedback

There are three ways users can interact with *PostBits*: shake, swipe and switch ON/OFF. These can be directly performed on the *PostBits* devices (Fig. 2). Shaking a *PostBit* (Fig. 2a) will reset its content and appear as a new *PostBit* (Fig. 2d). In order to lower the power consumption, we set the data update rate of the *PostBits* to once every 2 min. In other words, *PostBits* send content requests to remote server every 2 min. Users can manually trigger a refresh using the swipe gesture (Fig. 2b). When user performs a swipe on the screen of a *PostBit*, it immediately sends a content request to the server and refreshes the display (Fig. 2e) with the latest content. Users can simply switch OFF a *PostBit* (Fig. 2c) to make the existing content static and last

Table 1 Recent efforts in academia on small and everywhere displays

Publication and year	Name	Display type	Focus	Development	Evaluation type	Ubiquity
Elliot et al. [10]	Sticky spots	Existing displays in homes	Home	Conceptual design	None	
Fitton et al. [11]	Hermes office door display	Custom-made displays	Office	Special set-up	Field study	No
Saslis-Lagoudakis [25]	Hermes@Homes	Custom-made displays	Home	Special set-up	Field study	No
Greenberg [13]	Notification collage	Existing displays	Office	Conceptual design	Laboratory study	No
Kalanithi [16]	Connectibles	Custom-made widgets	Home	Laboratory set-up	Laboratory study	Yes
Ziola et al. [31]	Desk Jockey	Projection	Office	Special set-up	Field study	No
Olberding et al. [21]	CloudDrops	Custom-made displays	Home	Early prototype	Pilot	Yes

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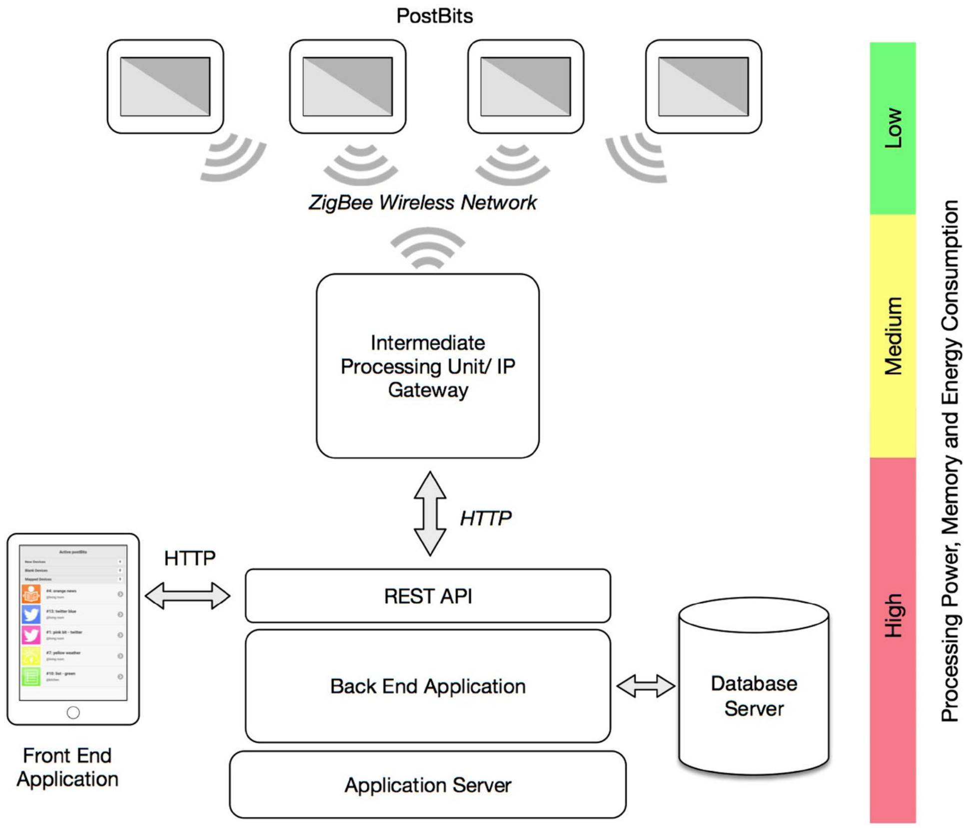
Fig. 1 System overview and architecture



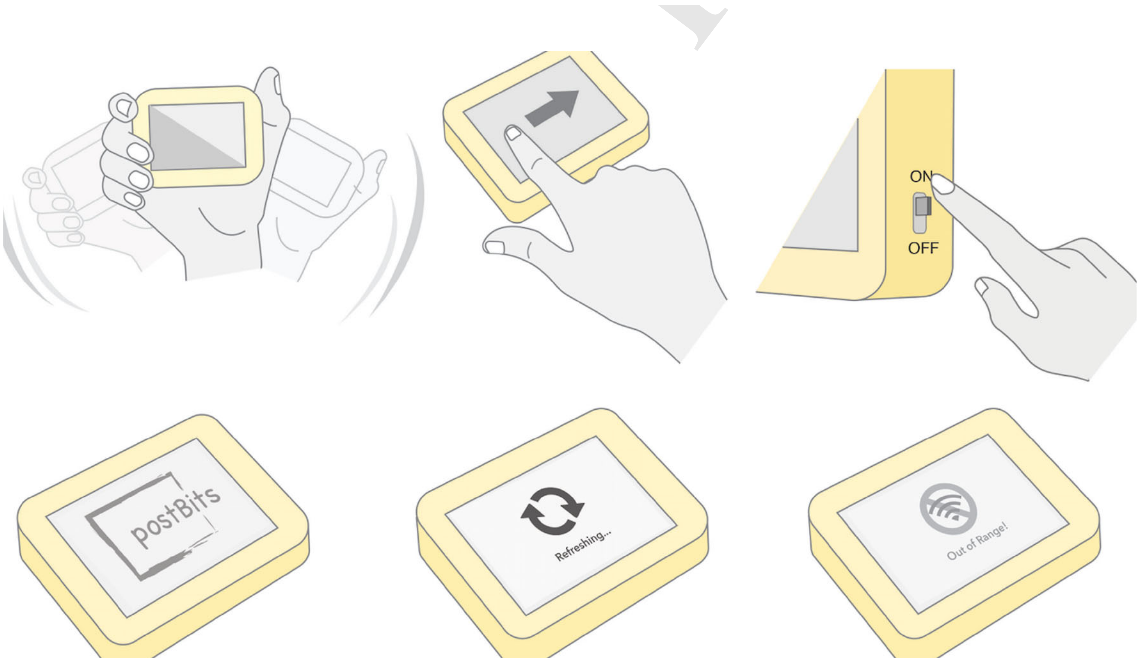


Fig. 2 Interacting with *PostBits* by **a** shake **b** swipe and **c** switch ON/OFF. Shaking the *PostBit* will **d** reset a *PostBit*, Swiping will **e** refresh the display and **f** if the *PostBit* is out of range it displays the message

forever (since it uses E-Ink display). If a *PostBit* goes out of range, it will display an out of range message (Fig. 2f) and will connect automatically after returning to the signal range.

3.1.3 Content management

Providing an easy, reliable and device-independent end-user input interface to link the digital content was another

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key design goal. We decided to implement a mobile friendly Web UI as the front-end user interface of the system and a REST API to access the back-end operations. Once a new *PostBit* is added, it will be displayed in the Web UI as a new device icon with corresponding colour of the device packaging. Users can then access this device from anywhere via the Web UI. At the configuration step, users can add a name and set the physical location of the device as desired. After the configuration, the new device will be displayed as a blank device in the UI, ready to be assigned with a content type. Depending on the content type, server sends updates to the corresponding *PostBit* (Fig. 3).

The current prototype system supports two main categories of contents: *user input* and *information feed* (Fig. 4). *User inputs* include plain text input, bullet list of text and static images, in which users needed to manually update. *Information feeds* include weather forecast of a city, latest tweet of a person and news headline of a selected category. Once user assigns a given *information feed*, the system will fetch updates and refresh the *PostBits* periodically with relevant information.

3.2 Implementation

3.2.1 PostBits

Internal electronics of *PostBits* (Fig. 5) were carefully selected keeping in mind performance, power consumption and design requirements appropriate for domestic use. In order to maximize energy efficiency, we incorporated a 2.7″ electrophoretic ink (E-Ink) display, which was selected for its view angle, lower power consumption and pixel density. In addition to that, *PostBits* consist of an 8-MHz ATmega2560 as the microprocessor, a 4-GB microSD card as a buffer for the E-Ink display, a resistive touch panel (3.2″, with a TSC204 controller) and three axes accelerometer (MMA7660FC). When an image is being

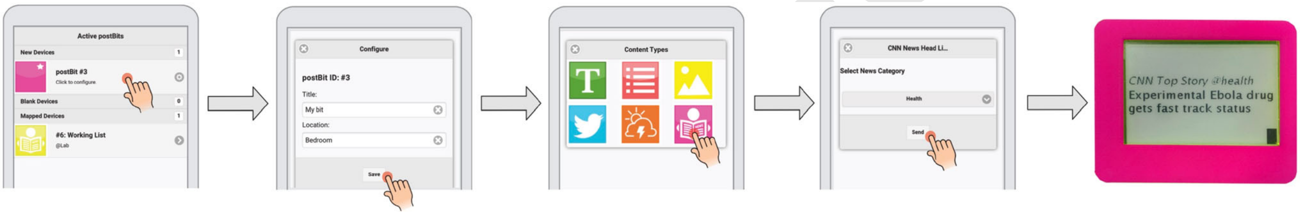

Fig. 3 Accessing *PostBits* through the web UI and making content updates

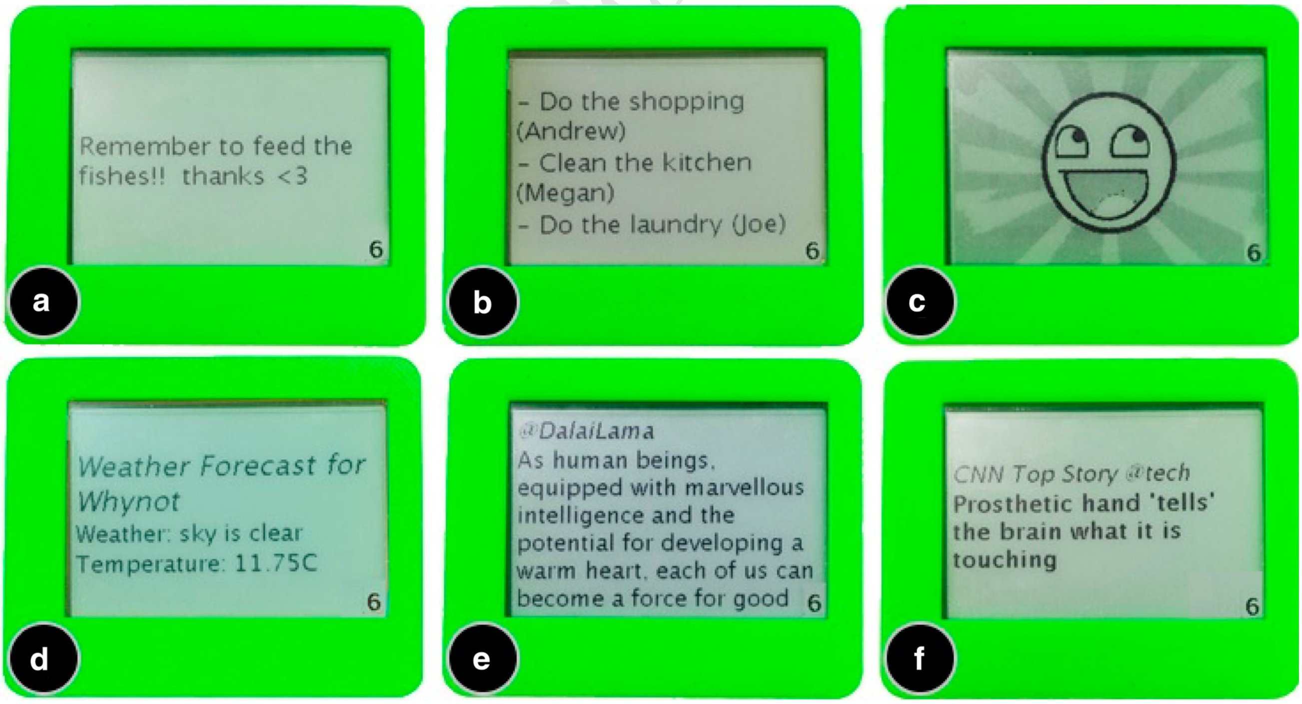

Fig. 4 Different types of user input and information feed currently supported by *PostBits*

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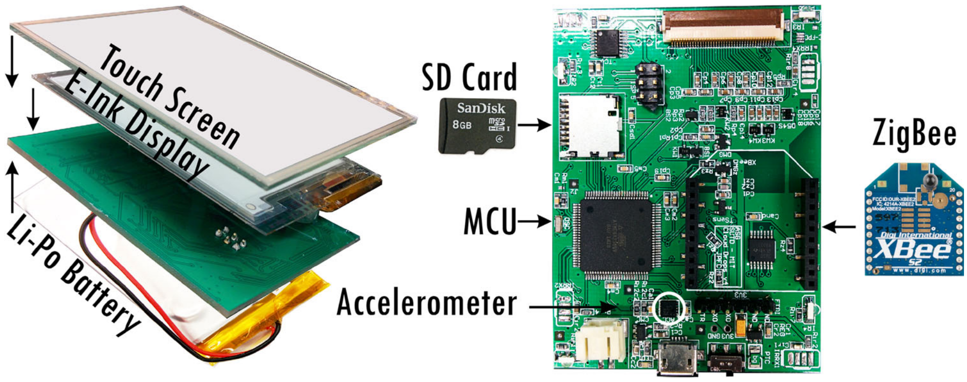

Fig. 5 Internal electronics of *PostBits*

refreshed, the screen draws 10 mA. Once the image is set, E-Ink technology is able to hold it indefinitely without any energy consumption. Basic user interaction consumes very low energy consumption. When activated the touch screen shows a consumption peak of 780 µA and accelerometer continuously drains 47µA. This set-up provides approximately 8 days of continuous operation with a 2000-mAh battery.

3.2.2 Server back end

Server side back-end application was implemented using Java and deployed in a production-level application server which is hosted on an Amazon EC2 virtual machine. At the core of the back-end application, an image processing module was implemented to transform contents into the format supported by the E-Ink display. Text formatting and image re-scaling operations were implemented directly using native Java2D functions. Custom-implemented image binarizing and image dithering algorithms were used to convert colour input images to *PostBit*-supported binary format. A MySQL database server that runs on the same EC2 instance was used as the data persistence mechanism.

3.2.3 Content management front-end

Web UI was designed to provide an easy interface to manage the contents in *PostBits*. We implemented the front-end user interface using JQuery mobile Web framework, because of its compatibility with all major desktop and mobile browser applications.

3.2.4 Communication

We used ZigBee low-power short-range wireless communication mechanism between *PostBits* and the intermediate router. Commercially available programmable XBee to IP gateway device is used as the intermediate processing unit. A Python program was implemented to fetch image data via REST API from the server as per the incoming requests from *PostBits*. Since low-power XBee modules are not capable of transmitting a complete image of nearly 6 KB at once, we used the memory of the gateway device as the intermediate cache to store incoming image data from the server. The stored image data were then sent to the *PostBits* chunk by chunk, 64 bytes each. In addition to the image requests and responses, shake and touch events were also being sent to the remote server via REST API through the gateway. HTTP over TCP was selected as the protocol for connecting the remote server. This gateway is connected to the Internet through users domestic Wi-fi or Ethernet network.

4 Field study

4.1 Participants

In order to explore how users would use and manage *PostBits* in a home setting, we randomly recruited six families in different households. Each family consisted of at least 2 adults. The houses ranged widely in size and architecture from one-bedroom studio-type apartments to houses with three bedrooms. Adult members from these families have been using smartphones and personal computers for at least five years and are comfortable with the technology. We code these families as *F*1, *F*2, *F*3, *F*4, *F*5 and *F*6 (Table 2). As we were interested to understand the use of *PostBits* over a period of time, each family was involved in the study for a duration of one week. One of these families, *F*6, received the *PostBits* for 2 more weeks to explore if usage is influenced by the *novelty effects*.

4.2 Procedure

At the start of the study, each family was given a demonstration of how the *PostBits* work and were handed a set of 5 *PostBits* with the option of asking for more if they

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Table 2 Summary of study participants

ID	Family composition	House structure
F1	Husband—working professional (34 years), wife—homemaker (37 years), one child	2 bedrooms
F2	Husband—working professional (34 years), wife—homemaker (32 years)	2 bedrooms
F3	Husband—working professional (32 years), wife—homemaker (26 years)	2 bedrooms
F4	Husband—working professional (34 years), wife—homemaker (34 years), one child domestic helper (43 years)	3 bedrooms
F5	Husband—student (28 years), wife—homemaker (26 years)	1 bedroom studio
F6	Husband—working professional (33 years), wife—homemaker (36 years)	2 bedrooms

needed. We conducted three semi-structured interviews, each lasting 30 min, with family members from each household, one at the beginning, one after 4 days into the experiment and the last one at the end of the week. Semi-structured interviews included a tour of the home, in which participants showcased how they had placed the *PostBits* and who was using them. For pragmatic reasons, we did not interview children/teenagers below 18 years.

Initial interview explored the structure of the participant's family and existing communication means they used at home. Core questions of the intermediate and final interviews revolved around how the participants used the *PostBits*, the number of *PostBits* used, types of content frequently shared, who used them often and whom the messages were intended for. We also obtained their opinion on why they found certain features of *PostBits* favourable, what did not work for them and their suggestions for what they would like to see. In addition, we captured photographs of the *PostBits* as placed in various locations at home. Moreover, we logged the contents of the *PostBits* via the server to get a deeper understanding on the interview data.

4.3 Data analysis

The interviewers took detailed handwritten notes during interviews and home walk-throughs. We open coded the data and qualitatively analysed the observations of user behaviour and user reports from interviews [1]. During the study, *F*1 faced Internet connectivity issues at home, thereby making server logs inconsistent. As such, we have not analysed the server logs from *F*1 to avoid any discrepancies. However, we have analysed the interview data of *F*1.

5 Findings and discussion

From the semi-structured interviews and server logs, we observed several usage patterns and strategies in terms of how participants deployed and used *PostBits*. We discuss findings with reference to parameters revealed in existing literature such as integration within architectural space, sense of awareness, ownership and urgency. In addition, we identified a set of emerging usage patterns with *PostBits* including *spatially directed remote postings*, *active* in situ *communication* and *spatially filtered information feeds*. In the following paragraphs, we summarize these findings and offer comparison to traditional media.

5.1 Existing information systems at home

During the first semi-structured interview, we explored the existing information systems participants are already using at home. We analysed them along two aspects: type of content shared and the tools used to share the content. The participants shared all the content types revealed by Elliot et al. [9], namely reminders/alerts, schedules, visual displays, notices and resource coordination. Out of these, reminders/alerts were the most dominant type. These messages were conveyed using a variety of media like sticky notes, handwritten notes, text messaging through phones and emails. For example, *F*2 reported that they use "to-do lists" on the fridge doors in the form of shopping lists or notes of what is inside the fridge and little pin-up notes at study desk mostly with reminders about upcoming meetings. *F*3 reported to use smartphone applications for resource coordination for activities like shopping and other household chores. However, most of the families shared that for urgent communication and messages, they often resorted to phone calls to the relevant person directly.

5.2 PostBits in the home environment

5.2.1 Integration with architectural space

We observed that the participants identified certain specific sites for deploying *PostBits*. These "prime" sites remained the same across the families. They included the kitchen, study, dining area/living room and bedroom (Fig. 10). However, every household had its own way of choosing these specific prime sites to deploy the *PostBits*. Some

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users chose the site depending on whether the message was intended specifically for someone who was meant to act on it (including self). For example, study room was commonly used for self-reminders and alerts. When asked whom the message was intended for, member of *F*2 mentioned, “that’s where I do my work in the mornings, so I leave myself some reminders about the day, so I can see it before I leave home for work” (Fig. 6b).

In contrast, *F*3 and *F*5 deployed *PostBits* that followed the routines of the family members as they served as “resources for action and knowledge of others’ routines” [27]. The participants identified these locations to be the “centres of activity” and one where much of communication/information had to be shared. For example, one member of *F*3 said, “We have placed a PostBits in the kitchen because lot of activity happens here” (Fig. 10d). The choice of the locations follows some of the criteria outlined by Elliot et al. [9], namely relevance of the location to the message, visibility of the information, pathways and routines of the family members. The users almost always chose to deploy *PostBits* in locations where the other family members were bound to look for any message such as attaching a shopping list to the refrigerator or leaving reminders on the study table. One of the novel strategies we observed was leaving newsfeed and weather content in “public” areas like living room (Fig. 6a). These feeds were relevant to most of the family members and were placed in more commonly accessible areas (Fig. 7).

5.2.2 *Number of PostBits*

Throughout the study, none of the participants asked for extra *PostBits* than the 5 given, even though they were given an option to ask for more. Some of the users attributed this to the size of their apartment, while others attributed it to the fact that there were only 3–4 locations in the house where they thought placing messages made sense. For urgent messages, they continued to use other media like smartphones. This could also be due to the relatively small size of the households, usually 2 inhabitants with the exception of *F*4 (4 members). Further, *F*1 and *F*3 used *PostBits* as complementary device, along with traditional media. While *F*1 used paper notes for lists and *PostBits* for information feeds, users from *F*3 used both sticky notes and *PostBits* for reminders depending on what was more convenient at that point in time. The

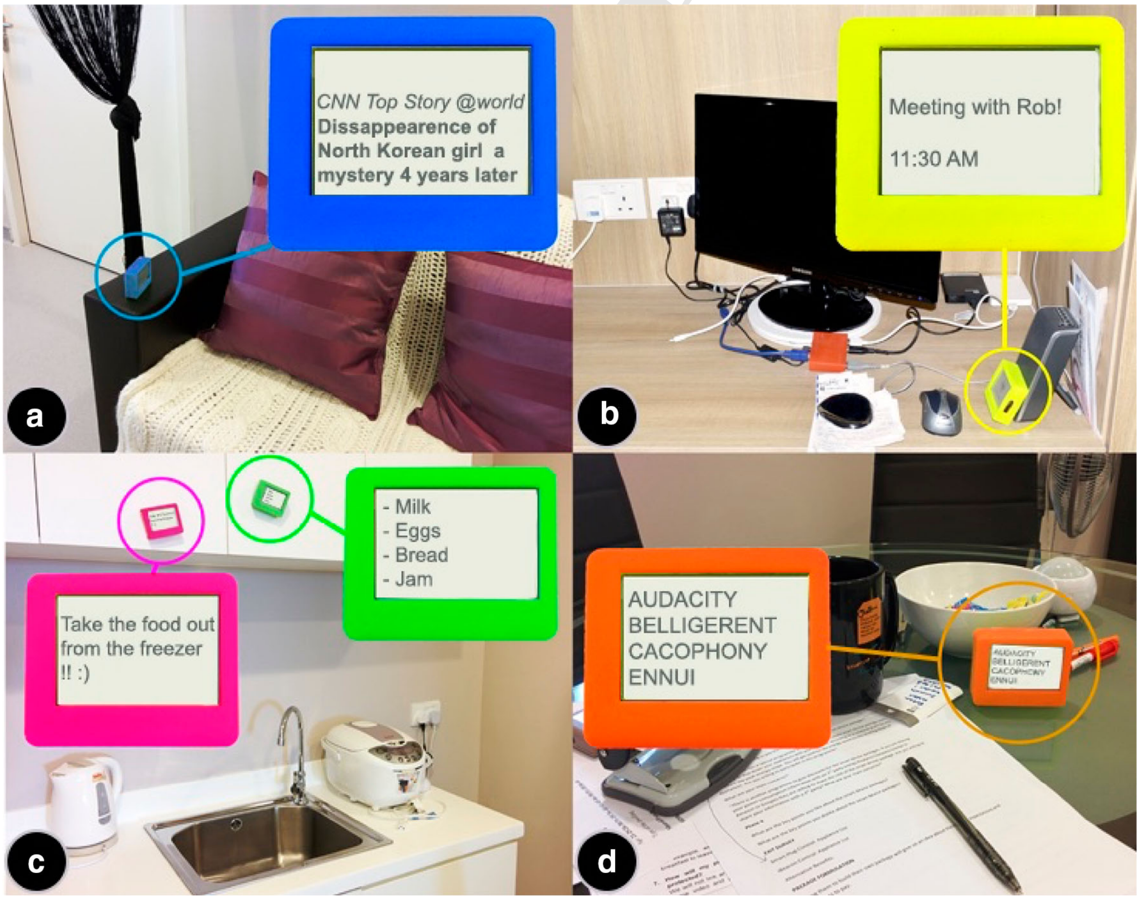

Fig. 6 Assigning specific content types to *PostBits* based on location

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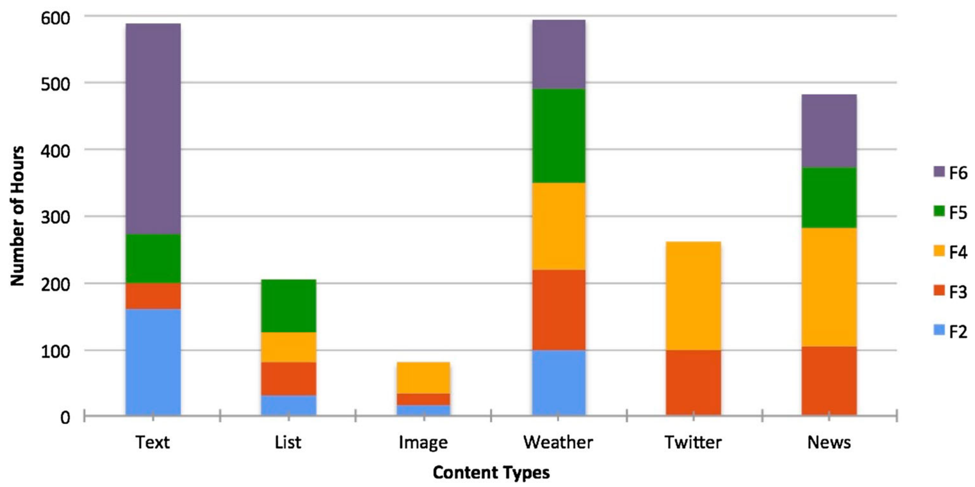

Fig. 7 Duration of display of information feeds and user input

shared use of *PostBits* and sticky notes for certain message types may also have impacted the number of *PostBits* used as families did not use *PostBits* for every message. If the users found a pen and paper more accessible than their mobile phone or laptop, they resorted to writing a reminder on a paper. As *PostBits* are ubiquitous, the inhabitants were able to reconfigure domestic spaces and the *PostBits* to meet the demands (e.g. [24]) such as moving them from the kitchen platform to the fridge depending on the content. For example, *F*6 shared that, "I leave a PostBit on the fridge that reminds my wife to take the food out from the freezer. After she removes the food, she sometimes puts it on the kitchen platform with a different message" (Fig. 9b).

5.2.3 *Type of content*

Analysing the server logs, we found that cloud-based information feeds were displayed on the *PostBits* more than the manually entered feeds. According to logs, people mapped *PostBits* to cloud feeds and let them display for longer periods of times without changing the content (Fig. 8). *Information feeds* (weather, newsfeed and twitter) were on display for the longest duration. In contrast, *user inputs* (list, text and image) were displayed for shorter periods. Text and lists were used only when they needed to communicate something and modified more frequently (Fig. 7) than the cloud-based feeds (adding new texts, create new lists or appending items). People rarely used images which may have been due to the reduced and monochrome image quality.

5.2.4 *Sense of awareness*

PostBits have the ability to retrieve assigned cloud information automatically and update itself with relevant content. The fact that they can assign these information feeds into specific locations differentiated the *PostBits* from other traditional media. For example, *F*4 had multiple *PostBits* in the living room, assigned with different Twitter

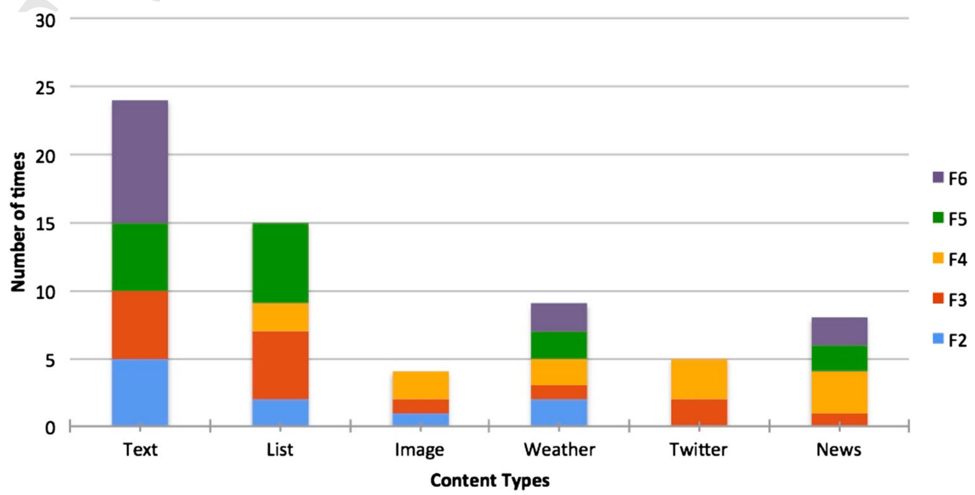

Fig. 8 Frequency of content-change by users

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handles. In fact, *F*4 mentioned that it was convenient to be able to see tweets from the two main parties contesting in the election (study was conducted during the general election) near the television. Also, we observed that some people moved the weather feature to their private space to know the weather of places where their loved ones were travelling or living. One of the users from *F*2 shared, "I really liked the weather feature. My wife is mostly in Tokyo and I would like to see the weather of the place or before her flight. If I am alone, I may even keep this PostBit with weather on my study desk" (Fig. 10a). Moreover, one of the participants from *F*6 shared that it is important for her to have a sense of the air quality index for the day. In fact, they had visitors during the study and the host used one *PostBit* in the living room showing local weather conditions so that visitor could better plan sight-seeing. This also revealed how daily life practices were build around a working data connection [17].

5.2.5 *Sense of ownership*

We observed specific patterns in how content varied across "public" (accessible to all members of the family and no dominant user) and "private" (dominant user). Information that determined the planning of the personal schedule, was placed in more private spaces as compared to information for resource coordination that was always placed in more "public" spaces such as kitchen and the living room. This was logical given that resource coordination was among different members, while personal schedules seemed more relevant to specific individuals. For example, one of the users from *F*2 pointed to a *PostBit* on his study desk and shared, "This is my PostBit. I work here very often. Sometimes, I keep a reminder on the PostBit and before I leave for work, I just look at it to know when I have a meeting etc. I do this with sticky notes too. I am used to checking reminders here" (Fig. 10b). It was interesting to see how users referred to the *PostBit* in their private space as "my *PostBit*", one that only they would change. This is in contrast to the *PostBits* that were placed in the living room or kitchen that had shared ownership. For Twitter feeds, we observed that more general tweets such as news channels were placed in public spots (Fig. 10a), while personal favourites like sportsman or scientists were placed at private areas like study desk. If the message was meant for a specific member in the family, then the *PostBits* were placed in the private space of that person.

5.2.6 *Sense of urgency*

It has been shown that when situations demand immediate attention, people usually feel the *need to be there, meet the person and the last thing they want to do is typing into their phone or writing a sticky note* [26]. Therefore, the choice of *PostBits* as a communication device was also influenced by how urgent the need to communicate was. To address immediate concerns, users still resorted to phone calls and text messages to each other. Since all users had smart-phones and access to various text and image sharing options, they used these smartphones for urgent communication. However, important information that had to be seen at certain times of the day and at specific locations, for example, meeting schedules before leaving for work, was still shared on *PostBits* (Fig. 9a).

6 Emerging usage patterns of PostBits

We observed three emerging interaction scenarios where users leveraged on unique features of *PostBits* (e.g. remotely updating the contents, linking to an information feed), which are not available in traditional media such as sticky notes.

6.1 Spatially directed remote postings

PostBits enabled *spatially directed remote posting*: posting of information to a specific location from a remote place. One use-case of *directed posting* was demonstrated by a user in *F*5. She used *PostBits* as a tool to learn and rehearse some of the key words she had learnt over the day as part of preparing for a language proficiency examination. She shared, "While in the lab, I learn new words and I immediately enter 5 words in each PostBit placed in my kitchen top. When I go home, these words are there and it helps me remember and revise them over and over when I see them". It can be inferred from the user's comment that the location *kitchen top* plays an important role, more like a trigger for her to restart remembering and revising the words (possibly while attending to another task such as cooking). And she would like to see all the words she learnt over the course of the day to be summarized there. *PostBits* capability of *direct posting* let her cumulate information at a meaningful location without being present there. Furthermore, *F*6 who were having guests over during the study used the *PostBits* to remotely update the *PostBit* in the visitors bedroom with some interesting places to see around the area. Family member said, "I have some visitors, so when they wake up they have messages such as 'Thing 1 to see in area: Botanic Garden'" (Fig. 10c). She also revealed that usually family members wake up earlier than visitors and leave to work. Therefore, *directed posting* gave them a chance to post-information relevant to visitors, at a location visible to them without intruding their space or disturbing them. *Spatially directed remote postings* made

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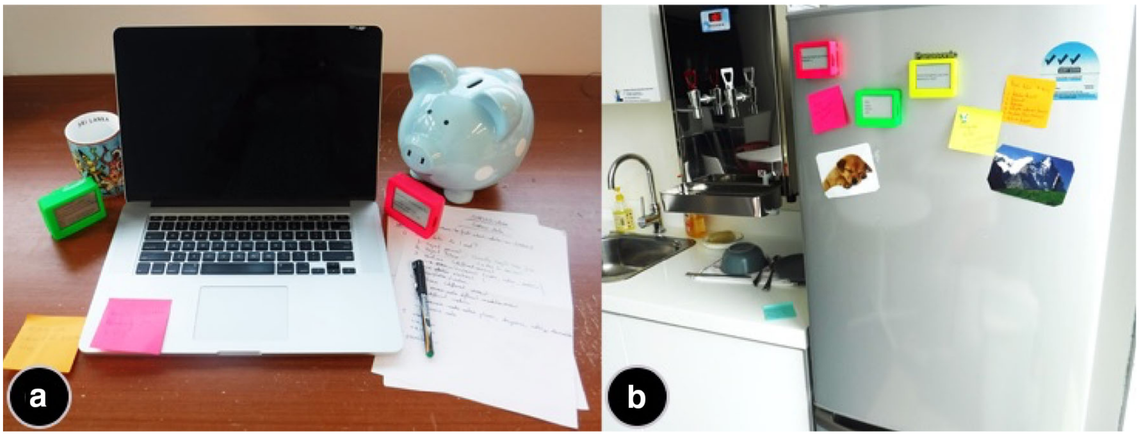

Fig. 9 Shared use of *PostBits* between family members and reconfiguring the *PostBits* based on location

Fig. 10 Prime sites for placement of *PostBits*—**a** dining area/living room, **b** study, **c** bedroom and **d** kitchen

it easier for the users to interact and change content on *PostBits* according to circumstances but still retain the critical and valuable cues that location provided.

6.2 Active in situ communication

PostBits enabled *Active* in situ *communication*: sharing and updating information on a display situated at home. This information helps not only the user who posted it but also the other members of the family. For example, participant from *F*2 shared that he always left a *PostBit* at his study room. According to him, "…over the course of the day when meetings change, I just change the text on my *PostBit* immediately from the office instead of having to write a sticky note (after reaching home)". His wife shared, "When I am not sure whether my husband is coming for dinner or why he is late, I sometimes check his PostBits". This was particularly novel as the content was used to infer about the

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user's presence, absence and predict their arrival. Since she knew that the content was more likely to be updated, there was also a certain element of trust that she as a user placed on this content. Another participant from *F*5 shared that, "With lists, I found it really convenient to delete things off the shopping list once I purchased it". This particular *PostBit* was attached on the kitchen refrigerator and helped the decision-making process of the family member at location (wife) to decide whether she needs to go out shopping and if so what she needs to buy. In this regard, updating content on the *PostBits* placed at a designated "public" location enabled situation awareness.

6.3 Spatially filtered information feeds

The fact that the *PostBits* connected to an information feed (weather, tweets, news) can be attached to a specific location has been used as a filtered information feed to that location. We identified this as spatially filtered information feeds. For example, one of the users from *F*6 allocated two *PostBits* for Twitter feed. While one *PostBit* carried the feed of his mentor and was placed on his study desk, the other was from a sportsman he is a fan of and was placed in the living room. He said, "I follow my mentor 'X's' tweets closely. He inspires me. It is really cool to have this auto-update feature, now I can always see the latest tweets". He liked to see his mentor's tweets while he studied (context), but not the sportsman's tweets. However, in the living room, he preferred to get away from work and just focus on the entertainment. Another user from *F*4 used two *PostBits* to monitor the ongoing election updates from the two parties involved. He chose to place both *PostBits* in the living room where they also had the television that displayed news related to the election. With these usage patterns, we can infer that there is a filtering of information feeds using location (context) as the key.

6.3.1 Novelty effects

Our study highlighted how *PostBits* are used in home settings for a period of 1 week to communicate a variety of content. We observed novel patterns and strategies during this period. In addition, with an aim to understand how this usage changed over longer periods, we conducted an extended study with *F*6 for 3 weeks. We found that with increased time, the users got more familiar with the device and were able to assign content with ease through the Web interface. In addition, they reported to be able to use *PostBits* as a learning tool with more ease. We observed that the participants assigned learning content to each *PostBit* and placed them in the same "prime" sites (kitchen, bedroom, living room). One of the interesting patterns that emerged was the fact that some *PostBits* were switched OFF after they placed important information such as an image that they did not want to be changed. We plan to run an extended study with more families to understand how current usage patterns would change over time and if newer strategies would emerge.

6.3.2 Direct manipulation of content

One user from *F*1 shared, "When making a quick list of things to buy or leaving notes for someone, it is intuitive to reach for pen and paper. Or anything to write with. Having a stylus will be really a good addition". This suggests that users tended to use the medium that was most convenient at a given point in time, especially for sharing quick messages. This was affirmed by other users who also shared that they sometimes find it "handy" or more intuitive to jot down a quick message on a piece of paper. These observations emphasize the need for incorporating a mechanism for direct input into the *PostBits* such as being able to write on the *PostBits* screen itself.

6.3.3 PostBits in other contexts

In order to observe how *PostBits* are used in other contexts such as shared workspaces, we have initiated a preliminary study at a research laboratory setting consisting of 3 individuals. We observed that *PostBits* were used to communicate ideas between people such as leaving notes/reminders for others and updating progress on joint tasks. The users reported that they found this quite different from sticky notes only when there was a change to be updated, and they were away from their desk. However, the users also felt the need to have a more interactive/scroll function on the screen as they felt that the screen space was too small to leave certain long messages. The *PostBits* were not moved around much during the study as the 3 users divided the *PostBits* among themselves. Since the weather in the area was unpleasant during the study, the users also reported to have found the auto-update of weather function useful. The users in fact felt that the low notification level was good as it did not interfere with their work, and they could glance at the message when they felt the need to. However, they also shared that if the notification can be controlled by the user, it would be useful in some contexts. In addition they felt that it would be beneficial to know whether the intended recipient had seen the message and acted on it.

7 Design implications

Further design opportunities of *PostBits*-like systems can be discussed with a taxonomy of ambient information systems [23]. This includes four design dimensions:

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7.1 Notification level

The degree to which system alerts is meant to interrupt a user. With *PostBits*, we kept the notification level to a minimum where the user does not get any indication about content changes. This meant that there were no beeps or vibrations to notify users of any update. During our interviews with users from home and work settings, only a couple of users indicated the preference for obvious notification. Therefore, when designing similar systems, the absence of a notification mechanism can be argued as both a limitation and a feature, as some users preferred *PostBits* as a non-disturbing communication method. However, in future designs, implementing an optional notification mechanism would be worth considering.

7.2 Information capacity

Number of discrete information elements the system can display. User feedback and study observations indicate that cloud-based information feeds were largely placed in contextual locations and potently utilized in the domestic environment. Accordingly, providing an open platform to integrate a wide range of cloud-based feeds rather than using a fixed set of information feeds will further enhance this feature.

7.3 Representational fidelity

How the information is encoded into the representation medium of the display. Compared to other features, image content was less utilized by the users. This may be due to the relatively small and monochrome display of the *PostBits*. However, supporting rich image content with a larger, colour display would result in trade-off in terms of power consumption and portability. Even though a conclusive point cannot be made in this regard, the ability to display rich image content in such systems does not appear as a key requirement.

7.4 Aesthetic emphasis

How visually pleasing an object is when placed in the environment. All the users found *PostBits* to be aesthetically pleasing and resembling sticky notes. We believe that this was one of the reasons why they found it easy to integrate *PostBits* in their daily lives and architectural space. *PostBits* were placed on various locations at home, and one *PostBit* was broken as it had dropped on the floor. As such, we identified the need to create good attaching/supporting mechanisms. However, this needs to be done without making the design cumbersome. We found this as a key design consideration that would facilitate fluid integration of the system with the physical context of the home.

8 Conclusion

In this paper, we present a pervasive platform, *PostBits*, to investigate how users would integrate digital information on the cloud onto contextual physical locations in their homes. Implementation of the *PostBits* was robust and energy efficient to be operated for an entire week without recharging. The *PostBits* could be assigned with *user inputs* (text, list and images) that need to be manually updated or *information feeds* (weather, twitter and news) that get auto-updated. We gave *PostBits* to 6 families where each family used the system for a period of 1 week. We found that the usage of *PostBits* were similar to traditional media as users placed contextually relevant information on them. The study also revealed unique usage patterns and advantages of *PostBits* in comparison with traditional media, namely *spatially directed remote posting*, *active* in situ *communications* and *spatially filtered information feeds*. We also conducted a long-term study with one family and explored the use of *PostBits* across office and workspace contexts through a preliminary study. Our findings and observations motivate us to continue user studies over longer periods of time in home and office settings. We believe *PostBits*-like system would provide an intuitive way to connect digital information on the cloud with the physical information in our living spaces.

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