Design Strategies for Overcoming Failures on Public Interactive Displays

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ABSTRACT
Public space is becoming increasingly augmented by public displays, bringing digital content into the real-world. Consequently, as public displays are a form of computing, they are prone to experiencing failure related to their hardware and software. In this paper, we investigate the types of failures that can arise on public interactive displays (PIDs) and how redundancy measures can be designed to ensure that a PID remains relevant even when a failure occurs. To gain an ecological understanding of failures, we focus on results that emerged from a field observation study and contextualise our findings within previous literature. From this, we contribute five design strategies for avoiding and mitigating the impact of these hardware and software failures. To assist designers and researchers of PIDs, we also present a failure matrix, which classifies failures along with suggestions on how they can be overcome. Our work specifically highlights the need for PIDs to become more adaptive and to include built-in redundancy measures, allowing them to at least partially recover from certain types of failures.

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

Author Keywords
Public Interactive Displays; Hardware and Software Failures; Redundancy.

INTRODUCTION
Public displays are becoming increasingly pervasive features within urban environments. Typically, the purpose of a public display is to show advertisements to people passing through busy areas, such as shopping centres, or to find information about a local neighbourhood or space. Due to advances in display technology, public displays range from TV-scale displays [1, 24, 21] to urban screens [23, 11] and large information displays [26], and often offer interactive features, such as touch or gestures.

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Over the years, research in the field of HCI has primarily focused on understanding how public interactive displays (PIDs) can attract attention, by making them playful [26, 18], responsive [27, 10], and ensuring the content is relevant [8, 20]. However, an area that has received little attention in research studies is the effect of errors ocurring in the display application, which is likely to deter people from further interaction due to short attention spans observed for public technologies [6]. Like other digital technologies, PIDs are prone to software crashes and complete system failures. In response to these public "failures" user groups have taken to uploading photos of affected displays to internet platforms[1], providing a comprehensive collection of failed public displays and an indication of the wide-spread occurrence of the problem. Replacing or repairing public displays when failures occur can become expensive, particularly when it is considered on a global scale [7].

Previous work by Kukka et al. [14] showed that providing the user with some information and reassurance about what went wrong can help them persevere through errors in a touch-based PID application. However, an alternative approach might be to consider the potential problems already in the design of PIDs by determining what redundancy measures could be put in place to minimise the impact of failures. Redundancy measures provide users with alternative ways of continuing their interaction rather than helping them to recover from failure. This approach implements the "escalator test" for public displays, which is based on the observation that escalators represent a technology that never fails as people can still use them as normal stairs in case the underlying electromechanical system breaks [25].

This paper presents a first step towards understanding how public displays can be designed with redundancy measures so specific hardware or software failures can be mitigated or overcome when they arise. We utilise the results that emerged from a systematic qualitative field observation of existing non-research PIDs throughout Sydney, Australia. The specific focus of this study is in the failures observed. From this, we provide five design strategies for avoiding or mitigating the impact of failures that can occur on PIDs. We also contribute the failure matrix, which is designed to help designers and researchers to identify different types of failures.

[1]Public Computer Errors on Flickr - https://www.flickr.com/groups/66835733@N00/

RELATED WORK

In the context of this paper, we define redundancies as additional functions built into the system to increase its reliability, such as duplicate components or procedures in response to errors or failure. Redundancy measures have long existed in computing; one common form of computing redundancy is an uninterruptible power supply (UPS) that switches the power supply to a battery or generator when a power failure is detected, enabling the connected computers to keep running without interruption.

Like all digital technologies, public displays can experience some form of failure, which can potentially cause significant or severe problems, particularly for people that rely on them. A complete failure of a certain component of a public display does not necessarily mean it is unusable. For instance, Fortin et al. [9] demonstrated that if interaction and feedback are still working in some form, users will still persist and use the system. During their study, their interactive media façade experienced a complete failure. This failure was overcome in a way, as the microphone interaction and sound feedback continued to work. Therefore, having a redundancy in place allows public displays to recover from failures and keep running until the problem causing the failure is resolved.

Public displays are usually deployed in public space, both indoors and outdoors, and are left running 24/7. However, this opens up public displays to challenges that can increase the rate of failures occurring. The first challenge is preventing hardware becoming overused and worn out. To tackle this, Davies et al. [7] suggest that the duty cycle of public displays to be altered in order to increase the lifespan of the hardware components and save energy. This could be in the form of running public displays only during peak usage periods, sleeping or powering off during off-peak periods. Cloud-based tools are already used in industry to monitor peak times and remotely manage public displays, such as Convergent FusionDX platform[2] and the SpinetiX Cockpit[3]. Depending on the use case, an alternative is to use mechanical low-resolution displays that only draw power when they need it [12].

A second challenge, relevant primarily to outdoor public displays, is making public displays usable and resilient to the changing conditions of the location in which they are situated. For outdoor displays in particular, one of the biggest challenges is withstanding different weather conditions [29, 17, 5].

This work sets out to understand what redundancies should be built into public displays in case they experience some form of failure. Therefore, we aim to formally understand the types of errors that can occur with public displays and how redundancy measures can be designed to overcome them.

STUDY DESIGN

This paper focuses on a subset of results from a larger field observation study on how people notice and interact with public displays in the city of Sydney, Australia [22]. The observation study was conducted as a manual field observation, where we only observed public displays and did not conduct interviews with people that walked past or interacted. This method was chosen for two reasons. First, to ensure ecological validity by avoiding any interruption to the space through our presence [2, 28]. Second, regulations imposed by our university's human research ethics committee meant that we were not able to approach people for conducting interviews (for example after they had interacted with the display). For each PID we recorded through photographs, sketches and notes how PID was set up, the content it displayed, the space it was situated in, and whether the PID had any immediately visible problems. Before each field observation session, we tested each PID to: (1) explore the interface; (2) test the features; and (3) interact under different conditions, such as in full sunlight and shaded areas. These tests and the subsequent observation of the PIDs in each location took place once in the morning (between 9am and 11am) and once in the afternoon (between 4pm and 6pm) to gain a better understanding of the space and its effect on the PIDs at different times.

While we did not specifically design the field observation study to find failures, we came across PIDs from two different PID networks that exhibited a surprising number of diverse failures related to their hardware, software, and interaction. The paper, therefore, focuses on PIDs from two different PID networks observed in that study, as they were the only networks with PIDs that exhibited some type of failure.

The PID networks we focused on are described below:

Outdoor PID network. The outdoor public display network consisted of over 40 public displays built into large booths that were deployed around Sydney city. The booths usually house a payphone and a touchscreen PID (Figure 1A) on one side, which in some cases was replaced by a static map (Figure 1B), and a large advertisement public display on the other. For the purpose of the study we focused on the observations of the PID only and we did not notice any problems with the other features of the booth, such as the advertisement display.

The *touchscreen PID* at first displayed an idle screen with the text "*Touch to activate*" and an animated hand performing a touching motion. After touching the screen, users were presented with a menu displaying the current time and date in the top left corner of the screen and four options to choose from displayed as tiles in the centre. The first option, allowed users to swipe through photos of the city's landmarks. In the second option, users were able to browse a map of the city and to search for a point of interest using the on-screen keyboard. The third option displayed the weather information for Sydney. The fourth option displayed a map and represented points of interest, such as landmarks and train stations, as icons that could be touched to view more information.

Although there were over 40 PIDs in the outdoor network, for this study we focused on three representatives chosen for their location which offered a mix of urban contexts: city wharf, business district, and Chinatown. In the city wharf location, the PID was situated in an open space next to a main outdoor thoroughfare, between a train station, ferry wharf,

[2] Convergent FusionDX - https://www.convergent.com/
[3] SpinetiX Cockpit - https://www.spinetix.com/products/cloud-services

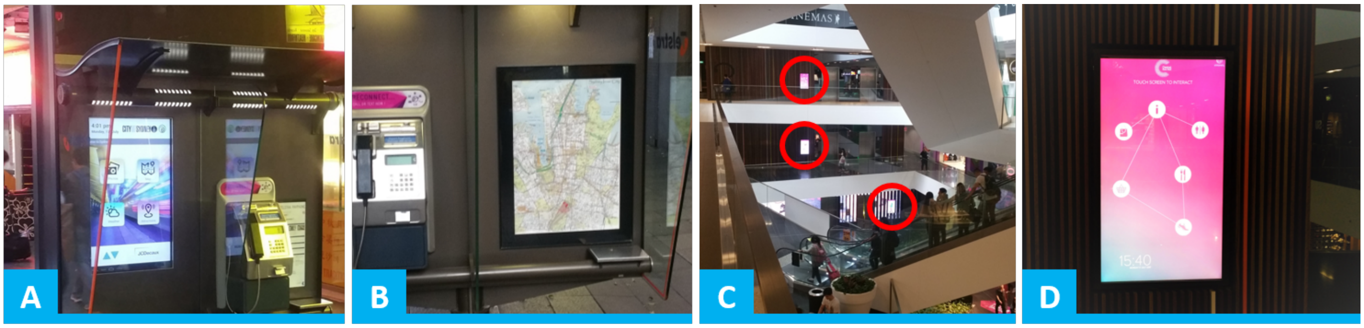

Figure 1. (A) an outdoor touchscreen PID contained in a large booth; (B) Some of the booths that the outdoor PID was contained in came with a static map instead of a PID; (C) Indoor PID network spanning across 3 floors of a shopping centre; and (D) Each PID contains wayfinding information for the shopping centre, allowing users to find shops and services on an interactive map;

and a major tourist attraction. The business district PID was also situated in an open space, nearby a train station and large company buildings. Finally, the Chinatown location differed from the others as the PID was nearby the entrance to Chinatown, situated in a closed and shaded area, due to the proximity of the buildings and trees.

Indoor PID network. The indoor PID network was located in a shopping centre in a very student-centric part of the city. The centre had four main floors accessible by escalators and elevators. Next to the elevator on three of the floors was a touchscreen PID (Figure 1C) that displayed advertisements while idle. When interacted with by touching the screen, it allowed the user to access wayfinding information relative to the businesses and services within the shopping centre (Figure 1D). The language of the interface could be changed by pressing the language button in the top right corner of the screen, which displayed 12 different languages that could be chosen.

FINDINGS AND DISCUSSION

In this section, the findings from our field observation and tests are discussed in terms of problems found with interactions, software, and hardware.

Hardware issues

The outdoor PID in the business district was switched off during both times when we conducted our observation. This may have been due to a hardware failure or the owner shutting it down [7]. The static map of the city included in some of these booths in lieu of a PID provided a possible redundancy, which we observed people on two occasions utilising.

Software issues

During one of our testing sessions with the indoor PIDs, we observed that some were displaying an update popup for the Windows operating system over the public interface (Figure 2A), urging the user to keep their system secure with the latest updates. Interacting with the popup caused the Windows start bar to be displayed, providing access to the operating system. We observed on another occasion that the PID on the second (main) floor was stuck on the Windows XP loading screen (Figure 2B).

The outdoor PIDs seemed to have problems with internet connectivity. When using the search function to find local attractions using the on-screen keyboard, the system would not return results or even suggestions, unless specific keywords were typed (Figure 2C). Commonly, these types of interfaces on the web, such as search engines, will recommend terms similar to the one typed if no results are returned. The system was also difficult to use due to the touchscreen's accuracy, often resulting in the wrong interface button being pressed as the touch registered was offset from the actual touch location.

In one of the outdoor PIDs that we tested, located near a train station and a local tourist attraction, we found that the weather app was not working, with it simply displaying a background colour and no information (Figure 2D), possibly due to a failed internet connection. No feedback was provided to let the user know that an error had occurred or that the PID was still loading.

Interaction issues

During our testing of the indoor PIDs, we uncovered an exploit with the touch interaction. Holding down a finger on the screen triggered a right click after 3 seconds, making the system display a Flash Player menu callout (Figure 2E). This could then be used to access the Flash Player context menu and change the quality settings of the interface. The callout also had the option to display the on-screen keyboard, which gave us the ability to access the Windows desktop through keyboard shortcuts.

This problem was not present on the outdoor PIDs, which had different problems with interaction. All of the outdoor PIDs were very slow to respond to touches and usually only displayed the main menu after tapping the idle screen multiple times. The on-screen menu buttons were difficult to interact with as the touchscreen sensitivity and accuracy was very low, often registering touches up to 20cm from where they happened. This also made searching for points of interest frustrating as using the on-screen keyboard was slow, with a noticeable 3-4 second lag before characters appeared on the screen, with a chance for the wrong characters to be registered due to the touchscreen's accuracy. The problem of touchscreen responsiveness was present in all of the outdoor PIDs in the network. However, some were noticeably less responsive than others, such as a PID that was located in an area that received

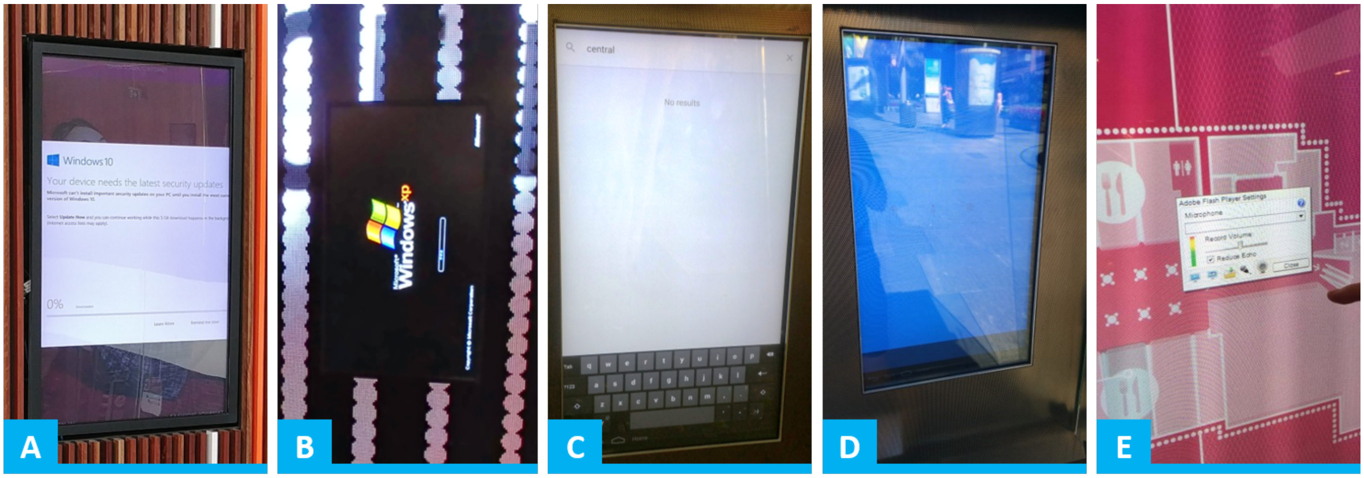

Figure 2. Problems with the PIDs: (A) Windows 10 update prompt popup; (B) Stuck on the Windows loading screen; (C) Searching provides no results or suggestions; (D) Features that are not working provide no feedback; and (E) Flash player popup window triggered by two fingers held down on the screen.

direct sunlight in the afternoon - making the PID virtually unusable.

DESIGN STRATEGIES

Ultimately, PIDs should be monitored remotely by PID providers to detect problems, which can then be fixed by sending a technician out. For instance, by identifying a sudden decrease in frequency of interaction in data logs may indicate that a problem may be occurring with the interaction or that the display is not working. However, even with such measures in place, it takes time for technicians to be sent out and to fix the issue. We therefore derive five design strategies from our field observations and tests of existing non-research PIDs as interim solutions to overcome failures.

Concealing errors. We noticed in our study that when PIDs encountered a problem, they did not give any acknowledgement that the problem had occurred. We suggest that PIDs should be adaptive to errors in that they either turn off a feature that is not working or automatically change into a limited functionality mode until the problem is addressed, similar to the "safe mode" feature on operating systems such as Windows and Mac OSX. For instance, in the case of no internet connectivity, a PID could just display an interactive map of the city or allow the user to scroll through photos until the problem has been resolved. This approach has also been described as failing "gracefully" [25], meaning that the application screen is replaced with content that is still relevant, concealing the error and/or providing users with access to alternative content.

Providing multiple input channels. Our observations and previous work suggest that failure of interaction can be influenced by weather, overuse, or vandalism [7, 29, 17]. Therefore, as a redundancy measure in the case of interaction failure, multiple interaction methods should be provided. This measure can also serve a dual purpose as it gives users more options to interact [30, 4]. Alternatively, the PID could also guide the user to another PID if there is one nearby.

Tweaking users' expectations. We observed that touchscreens, particularly in the outdoor PIDs, were generally unresponsive. Although, in some cases the issue was likely due to poor hardware design, there are opportunities to provide redundancy measures through design strategies. It is important to ensure that the interaction is working as expected since users would simply give up as they have no intrinsic attachment to the PID [14]. If the hardware fails, the application can respond by adapting its interface to tweak users' expectations. For example, if the accuracy or calibration of the touchscreen input is affected due to sunlight or hardware issues, the interface of the PID could respond by automatically increasing the size of buttons, making it easier for users to activate them. Another strategy is to provide physical buttons outside of the screen, similar to ATMs and parking meters, giving users an alternative option for providing input.

Providing a non-interactive fallback. When a PID encounters a problem where it cannot simply adapt its interface or turn features off, it should instead fall back to non-interactive content. For instance, when there is a complete failure of a PID's interaction method, such as a touchscreen that no longer even registers touches, then the PID system could simply display a non-interactive map of the area in which it is situated or cycle through information screens. This should also be combined with a physical label or sticker with contact details of the PID provider for users to report the problem.

Preventing unfettered access. The case of the indoor PIDs displaying prompts to update the operating system highlights the need for developers of these PIDs to ensure that the operating system is locked down and to schedule updates to happen outside of trading hours or in the background. If the system is not secure and can be easily exploited by users to gain unfettered access, there is a risk that the PID will be used to display inappropriate content. This was the case in Indonesia [15] and China [16], where pornographic videos were played on a public display, caused by hacking and negligence of the display providers respectively. Therefore, to reduce the chance of

Table 1. **The failure matrix, used to describe the types of failures occurring on PIDs.**

Failure Type		Component: Hardware	Component: Software	Component: Interaction
	Partial Failure	Non-critical failure of hardware component	Some software features stop working	Some interaction method functionality stops working
	Complete Failure	Critical hardware component completely fails	PID application crashes or freezes	All interaction method functionality stops working

users breaking into the system, it may be important to use non-consumer versions of operating systems that can be locked down to just certain tasks. Specialised Linux distributions exist that are designed for kiosk usage, such as JustBrowsing[4] and Webconverger [5]. However, locking a system down may have a negative impact on some types of PID deployments where the goal is to encourage user-led tinkering, gaming, or unexpected usage. This creates a challenging problem of ensuring there is a balance between a locked down system and one that allows for open usage or reappropriation by local communities [3]. This challenge can in some ways be paralleled with challenges experienced on desktop and mobile operating systems. For instance, Apple iOS is famous for being a "walled garden", where customisation is limited but the platform is very secure. Android on the other hand, is more customisable than iOS, but it comes at the cost of decreased security.

FAILURE MATRIX

The failure matrix (Table 1) emerged from drawing on both our observations made with PIDs in the wild and findings reported in previous literature. The matrix is presented to help identify failures and to assist in designing PIDs with redundancy measures in place for handling failures that might occur when the PID is deployed in the wild. We specifically describe the failures as two different types, partial and complete failure, in relation to the three components of a public display identified in the findings and discussion section: hardware, software, and interaction.

Partial failure

This type of failure is described as a component or feature that is not working as expected, but has not outright failed.

Hardware

A non-critical failure of a hardware component. For instance, the media façade presented in Fortin et al. [9] experienced a screen failure. However, the façade could still be interacted with and continued to deliver audible feedback.

Software

A software feature stops working. In the case of an outdoor PID that was observed, the weather feature was not loading the weather information. Despite this, the other apps on the PID were still functional.

Interaction

A partial failure of an interaction method causes it to become limited. For example, the touchscreen on the outdoor PIDs had low touch sensitivity resulting in poor accuracy. This problem was amplified in open spaces with direct sunlight exposure. Although users may persist through this [13], backup interaction methods, like external physical buttons on ATMs or adaptive interfaces [19], making elements larger when a failure is detected, could offer further redundancy measures to address this type of failure.

Complete failure

This type of failure is described as a critical component failing, rendering a PID non-functional.

Hardware

A complete hardware failure occurs when a critical hardware component, such as the screen itself, completely fails. We found this in one case during our observation study, where the screen of an outdoor PID was powered off. The static map that was used in place of the PID in some locations provides a redundancy measure for such extreme cases where the digital channel fails altogether. As display technology advances, electronic ink solutions could ensure that some content still remains visible on the display even when it is completely powered off.

Software

A complete software failure occurs when the PID software crashes or freezes. For instance, one of the indoor PIDs observed to never progress from the Windows operating system loading screen. Adding mechanisms to the software, such as a background application that monitors processes running on the computer driving the PID application, could help address this by automatically rebooting the system in case of such failures occurring.

Interaction

A complete failure of an interaction method on a PID refers to situations where the input mechanism allowing users to interact with the PID application completely stopped working. An example of such a case is a touchscreen not registering touches. Again, this could be overcome with alternative interactions or by simply displaying non-interactive content until the failure is resolved. Smartphone interaction could be provisioned as another form of redundancy measure to overcome this type of failure, enabling users to remotely interact with a PID application [20].

CONCLUSION

In this paper, we presented our initial insights that emerged from a field observation in relation to errors occurring in public interactive displays. Based on these insights we proposed the use of redundancy measures for allowing uninterrupted user interaction in the case of partial or complete failures. Through testing displays that were part of an indoor and an outdoor PID network, we identified three classes of issues: 1) failures associated with flawed application software design, 2) failures

[4]JustBrowsing - http://justbrowsing.info

[5]Webconverger - https://webconverger.com

associated with poor hardware (e.g. inappropriate touchscreen technology) or hardware failure (e.g. failed internet connectivity), and 3) failures linked to the location of the PID having an environmental impact such as sunlight affecting the PID's interaction mechanism. The PIDs observed in our study failed to respond to these errors, instead leaving it up to the user to resolve them, which in most cases is not possible in public interfaces, or for maintenance staff to attend to the failure, which can take time as errors may not be noticed or reported immediately. Through five design strategies we suggest that redundancy measures should be considered as part of the design of PID applications. Additionally, we contributed a failure matrix for identifying failures, which emerged from our observation and findings reported in previous literature. Although this study was limited to one city and two PID networks, the paper makes a broader contribution to HCI by introducing the concept of redundancy measures to public interfaces.

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