Can't Touch This: Rethinking Public Technology in a COVID-19 Era

Jennifer Pearson
Swansea University
Swansea, UK
j.pearson@swansea.ac.uk

Gavin Bailey
Swansea University
Swansea, UK
g.bailey@swansea.ac.uk

Simon Robinson
Swansea University
Swansea, UK
s.n.w.robinson@swansea.ac.uk

Matt Jones
Swansea University
Swansea, UK
matt.jones@swansea.ac.uk

Tom Owen
Swansea University
Swansea, UK
t.owen@swansea.ac.uk

Chi Zhang
Swansea University
Swansea, UK
chi.zhang@swansea.ac.uk

Thomas Reitmaier
Swansea University
Swansea, UK
thomas.reitmaier@swansea.ac.uk

Cameron Steer
Swansea University
Swansea, UK
c.d.steer@swansea.ac.uk

Anna Carter
Swansea University
Swansea, UK
a.r.l.carter@swansea.ac.uk

Deepak Ranjan Sahoo
Swansea University
Swansea, UK
d.r.sahoo@swansea.ac.uk

Dani Kalarikalayil Raju
Studio Hasi
Mumbai, India
daniel@studiohasi.com

ABSTRACT

What do pedestrian crossings, ATMs, elevators and ticket machines have in common? These are just a few of the ubiquitous yet essential elements of public-space infrastructure that rely on physical buttons or touchscreens; common interactions that, until recently, were considered perfectly safe to perform. This work investigates how we might integrate touchless technologies into public-space infrastructure in order to minimise physical interaction with shared devices in light of the ongoing COVID-19 pandemic. Drawing on an ethnographic exploration into how public utilities are being used, adapted or avoided, we developed and evaluated a suite of technology probes that can be either retrofitted into, or replace, these services. In-situ community deployments of our probes demonstrate strong uptake and provide insight into how hands-free technologies can be adapted and utilised for the public domain; and, in turn, used to inform the future of walk-up-and use public technologies.

CCS CONCEPTS

• **Human-centered computing** → **Field studies**; **Empirical studies in HCI**.

KEYWORDS

Public displays, field studies, prototyping/implementation.

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1 INTRODUCTION

Touch or tactile interaction is one of the most common technology interface techniques, and has long been perceived as a robust—and often the only—reliable method of communication between humans and machines. While many home, personal or mobile settings are beginning to support more "natural" interactions through speech (e.g., smart speakers), motion (e.g., Kinect) or facial recognition (e.g., face unlock), public-space interfaces are typically still reliant on input from more physical, touch-based sources. Take, for example, the extensive variety of common, essential public services such as elevators, ATMs or pedestrian crossings, which currently rely on physical components for use. From buttons and switches to dials and to touchscreens, the majority of walk-up-and-use technology installations require some sort of physical contact – contact which, until early 2020, was seen as a routine, reliable and perfectly acceptable method of interaction.

The touching of shared devices and resources can, however, provide easy routes for pathogens to spread. In the early days of the COVID-19 pandemic it was found that the SARS-CoV-2 virus can persist on surfaces for several days [9, 17, 64]. So, the once relatively unconscious actions of calling an elevator or typing a PIN have suddenly become far more perturbing, which has made many people rethink how—or even if—we should be interacting with such services going forward.

Figure 1: Disabled or modified interactive public technologies are commonplace in the new COVID-19 world. As we report in this paper, the potential risks and ongoing anxiety related to touching shared surfaces have, in many cases, resulted in user avoidance or provider adaption of such interfaces. While many of the examples shown here are perhaps merely inconvenient—for example, being unable to experience interactive exhibits, or having to use paper towels instead of a hand drier—others can pose accessibility or safety issues. For instance, replacing public technology with app-based alternatives negatively affects people without smartphones or those with low technological ability, while a refusal to accept cash disadvantages those without bank accounts. Further, many public-space technologies such as pedestrian crossings or ATMs provide vital services and therefore cannot simply be disabled in this manner.

There is no doubt that the COVID-19 pandemic has changed the way we behave, and in particular how we interact with people and objects, including these types of ubiquitous public utilities. While more recent research has nuanced early findings and shown that shared surface contact is rarely the cause of infection [14, 18], it has also been shown that much of the general public are still comforted by deep-cleaning [31, 39], with many so anxious that they entirely avoid touching objects in public spaces [6, 62]. In the new world of face masks and social distancing, it is understandable to feel on-edge about the potential for harm from germs left by others. This change in attitude puts into question whether the physical contact required to use shared interfaces is worth the risk. As a consequence, people may be attempting to adapt how they use these services, or making the choice to simply avoid them altogether.

Unfortunately, however, the majority of such public interfaces are not only very commonplace, but also often provide vital services, or safeguard against potential dangers. Consider the requirement in many places for a pedestrian to press a button to be able to stop traffic and safely cross a road; or, how a wheelchair user is regularly required to press various door and elevator buttons to navigate around a building. Clearly, then, there is a trade-off between the issues caused by adaptation or avoidance, and the risk of harm posed by usage patterns that were previously the norm.

This situation has created opportunities for the development of technologies that minimise touch and contact-driven interaction with shared devices [23, 37]. While advances in sensing and artificial intelligence have enabled consumer products that can respond to non-touch modalities, the underlying interaction paradigms have not been widely studied in public-facing settings (as opposed to specialised contexts such as operating theatres [35, 42] or with personal technologies in public spaces [47]). As a result, we do not know how usable, accessible, inclusive or effective these potential solutions are.

The goal of this research, then, is twofold. First, we aim to understand what impact the pandemic has had on pervasive touch-based technology, by identifying how organisations and individuals have dealt with these issues. Secondly, we create and deploy a suite of touchless interfaces and augmentations that can either be easily retrofitted onto or, if needed, replace entirely, existing public installations. As a result, this work provides a timely contribution to the potential safety of public-space utilities and interactions for the COVID-19 era (and indeed any subsequent outbreaks or pandemics), but further, highlights to the CHI community the opportunity to re-evaluate and shape the future of walk-up-and-use technology in the long-term.

We begin by discussing the results of an ethnographic evaluation in which we surveyed the current landscape of touch-based interactions with public services. Drawing on these insights, we go on to describe a set of touchless interaction probes we built and deployed in public settings. We conclude by discussing avenues for future exploration of this space.

2 BACKGROUND

Here we review the landscape of touch-free interactive technologies, looking at both generally-available and research systems, and their use in public spaces. We begin, though, by contextualising our research against the shift in behaviours caused by the pandemic.

One of the predominant modes of transmission of COVID-19 is thought to be exposure to respiratory droplets carrying the SARS-CoV-2 virus. While in-air transmission has been shown to be most common, contact with contaminated surfaces (and subsequent touching of eyes, nose or mouth) has also been identified as a risk [8, 66]. Even at the time of writing, 18 months after the initial worldwide spread of the disease in early 2020, there is still a lingering fear of touching things that others might have come into contact with. One 2021 UK-wide study found that 40 % of respondents strongly avoided touching things in public spaces because of a fear of the virus [62], while another US-based survey found that three in four commuters found deep-cleaning of public transit comforting [39].

Considering this continued underlying public anxiety, it is no surprise that significant attention is being paid to the cleanliness of shared environments, particularly in places such as restaurants, workplaces and shops. Most public-facing interactive services are designed for use without human assistance, however, and consequently the likelihood of regular sanitisation between uses is low. While some alterations have been made to mitigate this (e.g., increasing contactless payment limits), the majority of interactions still require touching of surfaces that are seldom cleaned. Concerningly, some of the current adaptations to such interfaces (e.g., app-based alternatives[1]) are inaccessible to less technologically advanced users, those without smartphones, or people with physical or other impairments.

2.1 Touchless technology in widespread use

Current touchless technologies in public environments are most commonly applied to support indirect or automatic interactions (e.g., self-opening doors, pressure-sensitive flooring, etc.), so rarely utilise natural user interfaces (NUIs), many of which are intrinsically touchless. More recently-developed hands-free NUIs such as conversational interfaces, gesture detection or facial recognition are becoming commonplace within private settings. While there has been relatively little desire or need from companies or researchers to incorporate such modalities into public spaces to date, we believe the integration of NUIs in these environments has potential to help reduce the spread of COVID-19 in the short term, but also provide opportunities to shape the direction of walk-up-and-use technology further in the future.

The commercial sector has been quick to respond to the pandemic with products offering modalities that re-frame previously-typical interactions. For example, computer vision and contactless payments are now being used to support touchless checkouts[2]. In a world responding to the challenge of working from home and hotdesking in the office, systems such as Backboard[3] demonstrate the potential for touchless interfaces using gestures for control.

Technologies such as SigmaHover[4] and Soli [32] are aimed at removing the need to interact with personal devices through touch alone, instead sensing hand and face positions to trigger interactive elements on a device. Similarly, devices such as the MicroBot Push[5]—a small actuator that can be attached to existing buttons to trigger them on-demand via an app—allow users to avoid touching a button themselves. In contrast to physical adaptions that provide touchless experiences, companies such as Ultraleap[6] are using mid-air haptics and gestures to support interaction and replace traditional physical controls. Finally, not all responses involve moving to a fully touchless experience – some have instead adapted existing options in response to health concerns. For example, the HappyOrNot[7] voting feedback system has been expanded to support alternative methods of interaction, such as allowing personal devices to interact with a platform in place of physical touch, while also providing antimicrobial buttons to lessen the risk from touching surfaces.

2.2 Touchless interaction in research

Health and medical researchers and practitioners have long known that touch can spread pathogens. While the added expense of developing touchless interactions may have slowed progress in other areas, the safety-critical nature of medical applications has meant that this area has often driven research into hands-free controls. For example, maintaining a sterile environment is imperative when manipulating digital images during surgical procedures, and touchless interaction methods have been proposed as a result [42]. While there have been workarounds over the years that use barrier-methods such as the inside of a surgical gown to interact with non-sterile peripherals [27], the field has moved quickly to consider gesture-based approaches such as capacitive flooring [25] or, more commonly, utilising affordable infrared sensors such as Leap Motion or Microsoft's Kinect [11, 35, 50, 51, 59] and implementing command-based speech systems [2, 16, 46].

Explorations into touchless interfaces often look beyond the way in which tasks are currently performed and instead rethink the possibilities that new methods of touchless interaction may open to users [43]. Recent examples from within the HCI field have explored the use of light [22], sonar [41] and radar [32] as methods of sensing touch on and around a device. Proxemic interactions [36] explore the sensing of attention, often on a larger screen, tracking both users' positions and the number of participants to introduce automatic interactions – such as stopping a video playing when attention is drawn away from the screen. Touchless techniques for interacting with wearable devices have also been explored to avoid the need for dual-handed methods of interaction [60].

2.3 Public-facing touchless interface research

Techniques such as gesture recognition have been used to support public displays [1, 24, 34], community engagement [19] and public-based game settings [49]. Gaze-based interfaces have been employed within public settings to interact with large displays [28, 29] and to infer attention while driving to determine points of interest [26]. Touchless interactions within a public setting have also been considered in a manner in which alternative body parts could be used to interact [58].

Further work that focuses on touchless in a stricter sense has explored supporting shared interactions on large media facades by using, for example, full-body gestures and on-screen avatars to support the interaction process [13], large-scale gestures and projected markers [20], or personal mobile devices in tandem with a larger display [3]. Public-facing deployments on smaller screens

[1]E.g., https://goplus.shell.com, https://smartshop.sainsburys.co.uk, etc.
[2]https://www.mashgin.com/products/touchless-checkout-system
[3]https://backboard.tv/
[4]https://sigmasense.com/technology/sigmahover/
[5]https://microbot.is/collections/best-selling-products/products/microbot-push
[6]https://www.ultraleap.com/company/news/blog/touchless-elevator/
[7]https://www.happy-or-not.com/en/smiley-terminal/

have also utilised gesture control to perform tasks such as query-and-answer [57], connecting users across different locations for moments of passive engagement [40] and supporting group-based interactions with a single display when working in a collaborative environment [5].

Turning to speech based interfaces, there exists a limited set of research that explores the use of voice based interfaces in public settings[4, 48, 56]. Concerns have previously been raised regarding privacy when using voice-activated personal assistants in a public setting due to the information that may be broadcast within hearing range of other individuals [10]. Research has also demonstrated that the COVID-19 pandemic has not impacted on the typical use of personal smart speaker devices within an individual's own home [12]. Studies of voice interfaces that serve as an information service in a public setting found that queries regarding device features accounted for 40 % of all questions, with simple fact-based questions accounting for 25 % of questions asked [33]. This suggests, then, that there is typically some level of learning that users of public voice systems may need to undertake in order to fully realise the potential of these devices. Placing speech systems within a public setting may require clearer instruction to users to both highlight the potential uses of the system and provide some form of guidance (beyond a device's typical appearance) to inform a user of the interactions possible with the device.

3 LANDSCAPE OF TOUCH INTERACTIONS AND ADAPTIONS: OBSERVATIONS, INTERVIEWS AND USAGE SURVEY

3.1 Device adaption study

In order to better inform the design of new and effective methods of public touchless interactions we conducted an ethnographic investigation in London, UK into the current landscape of such interfaces. As part of this review, we approached and held impromptu conversations with a range of providers and consumers of public-facing technology in order to better understand how and why they are currently being used, adapted or avoided. Over the course of the four-day evaluation we visited a variety of different public spaces including shops, museums, visitor attractions, restaurants, travel hubs, theatres, religious buildings, washrooms, sports centres, educational institutions, outdoor spaces, public transportation, hotels and government buildings. To help capture our observations, we created a simple mobile app to record instances where we saw public technology had clearly been adapted to change its original designed-in interaction. For each unique adapted device seen, we logged the type of location (e.g., street, transport hub, shop, etc.), the type of device (classified as vending machine, information display, control, communication or other) and the original interaction modality (e.g., physical control, touchscreen, etc.). We also categorised the type(s) of adaption that had been made to the device (e.g., replacement companion app, disabled or turned-off, sanitiser bottle close by, removal or replacement of cash payments etc.).

At the time of this study (June/July 2021) and of the others reported in this section, the UK was not under any formal "lockdown" restrictions. However, face masks were required in various social and transport environments, and government recommendations regarding regular testing and social distancing remained in place.

3.2 User adaption study

To complement the device adaption study, we also wanted to understand how *people* might be adapting or avoiding utilities in public settings. With this in mind, we conducted an additional focused study of the simplest yet perhaps most ubiquitous public interaction we could envisage: the pedestrian crossing button. Despite being safety-focused, crosswalk or pedestrian crossing buttons are the epitome of frequently-used, seldom-cleaned surfaces. They are also an example of a simple interface that can be adapted in many different ways to provide the same interaction result. For example, while some people might choose to use a tool (e.g., stick), barrier (e.g., glove) or alternative body part (e.g., elbow) to press the button in a more low- or no-contact manner, it is also possible to wait for (or ask) another pedestrian to press the button, or even take the risk of crossing the street without pressing the button at all.

We conducted an observational evaluation of a busy button-controlled crossing in central London for a total of 12 hours over a separate three-day period. As in the device adaption study, we logged our findings using a custom mobile app. For each person we saw using the crossing we recorded one of the following behaviours: press button with finger, press with knuckle, press with elbow, press with other body part, press with tool, wait for someone else to press, wait for traffic to disperse, give up and walk away, or any other behaviour. We also captured observed modifications to any the behaviour seen (if any): wearing a glove, using another barrier of some sort (e.g., a tissue), sanitising afterwards, or any other modifications.

3.3 Usage and behaviour survey

We conducted an online survey to better understand if and how the COVID-19 pandemic has caused people to change their behaviour with public touch-based technology. The survey was distributed through mailing lists, social networks and adverts on Twitter and Facebook. Recruitment focused primarily on the UK and participation was incentivised through a raffle of five £25 Amazon vouchers. In this paper we report on two questions that asked explicitly about behavioural changes caused by COVID-19. The first question was: *Compared to before the COVID-19 pandemic, are you presently less likely or more likely to use public touchscreen displays (e.g., ticket machines) or button-operated devices (e.g., pedestrian crossings)?*. Participants selected either "more likely", "about the same / no change" or "less likely". The follow-up question nuanced this by asking whether people had *changed* how they interact with such devices. Table 3 shows the full wording for the second question, and the four options participants were asked to respond to.

3.4 Results

3.4.1 Device adaption study. We observed and documented 88 unique instances of public-space technology adaptions, some of which are shown in Fig. 1. The majority of these were seen in museums, public spaces, shops and transport hubs. Table 1a shows the categories of devices and Table 1b the *original* interaction modalities of the adapted interfaces we recorded. The predominant type of interface adaptions we observed were made to vending machines, information displays and controls, while the most common modalities being adapted were physical controls and touchscreen displays.

Table 1: (a) Distribution of observations over the five categories of public-space interfaces in our device adaption study. (b) The categories of underlying (i.e., original, pre-adaption) interaction modalities observed. Contact-based interactions (e.g., buttons, touchscreens, etc.) were the most common. Only a small proportion (8 %) of interactions used audio-, gesture- or camera-driven interactions.

Device types observed	
Vending machine	31
Information display	28
Control	18
Other	10
Communication	1

(a)

Interaction modalities	
Physical control	47
Touchscreen	33
Audio / speech	5
Gesture	2
Face detection	1

(b)

The most commonly observed type of adaption we saw was simply to turn off or cover over a system to prevent use (27 of 88; 30 %). Twelve devices had been retrofitted with sanitiser bottle holders. During our impromptu interviews with employees we discovered that six of the 88 devices were now under regular (e.g., hourly, or after every observed use) cleaning schedules. It was common for interactive devices to be replaced with prompts to use personal mobile devices as an alternative. For instance, some tourist exhibits (e.g., audio guides) and restaurants (whose menus were previously touchscreen) covered interactive devices with a QR code that pointed to a companion app (12 of 88 observations). Similarly, many vending-type interfaces opted to replace coin mechanisms with contactless payment methods (11 observations). Interestingly, in all cases these observed adaptions were complete replacements for the current systems, which clearly has the potential to create to the sorts of accessibility and equity issues outlined above.

Many adapted interfaces included signage (20 instances) to describe the adaption, or indeed to apologise for it not being in service. We also saw three examples of signage attempting to nudge behaviour, asking people to avoid using the technology if at all possible, but not taking it out of service. The least-common method observed was a single occurrence of a physical control adaption, in this case a foot pedal add-on to replace a button interaction.

It is important to reiterate that in this study we were only capturing observations of technology that *had been adapted*, and that the vast majority of public utilities had no adaptions. However, our results clearly highlight the lack of suitable adjustments being made to public infrastructures to deal with the ongoing pandemic.

3.4.2 User adaption study. During our three-day pedestrian crossing study we made a total of 1211 observations. As Table 2 illustrates, the majority (700; 57.8 %) of people we observed managed to cross the road without ever pressing the button themselves, either by waiting for the traffic to die down (49.6 % of the time) or by waiting for other people to press it for them (8.2 % of the time). We did not see anyone abandoning their crossing attempt.

We observed people pressing the crossing button 511 times in total (42.2 % of all observations), with the majority opting to use their finger (437; 36.1 % of all observations, or 85.5 % of button press observations). The various other button press categories were far less common, as summarised in Table 2. In total, 59 people used part of their body other than their finger (e.g., knuckle, elbow, etc.), and 15 used some sort of tool. Tool interactions mainly involved using the edges of phones, bottles, cigarette packets or other small and easily accessible items. We also saw low levels of additional combined behaviours, such as wearing gloves, sanitising or using some sort of barrier between their body and the button. For example, people used bags, hats, coats and even face masks as ways to avoid their skin directly touching the crossing button.

Table 2: Overview of the results from our pedestrian crossing user adaption study. Lightly shaded rows show the behaviours we observed within the two key states of pressing or not pressing the button to stop traffic. Darker shaded rows indicate where we saw people combining behaviours within a category. For example, 15 of 437 people were seen using their finger to press the button, but also employing a barrier, such as a jacket sleeve, to avoid direct contact with their skin.

	Instances	%
Press button	511	42.2 %
├ With finger	437	36.1 %
+ Barrier	15	1.2 %
+ Sanitise afterwards	4	0.3 %
+ Glove	2	0.2 %
├ With knuckle	43	3.6 %
+ Barrier	1	0.1 %
├ With tool	15	1.2 %
├ With other body part	6	0.5 %
+ Barrier	4	0.3 %
— With elbow	10	0.8 %
Don't press button	700	57.8 %
├ Wait for a gap in traffic	601	49.6 %
├ Wait for another person to press	99	8.2 %
└ Decide not to cross	0	0 %

While this study has provided some evidence that many people are indeed avoiding or otherwise getting around having to touch such public utilities, a limitation of these results is that we do not have a baseline to compare to. That is, the behaviour we witnessed in this study could be typical of pre-COVID-19 pedestrian crossing button use, rather than a result of concerns relating to the pandemic. The usage and behaviour survey we conducted focused on this aspect in order to give further insight into people's perceived changes in attitude.

3.4.3 Usage and behaviour survey. We received 118 survey responses from a range of participant backgrounds. 42 % were female, 54 % were male, 3 % preferred not to say and 1 % preferred to self-identify. All were aged 18 and above. Most participants were either employed full time (65 %) or were full-time students (25 %). 78 % percent of participants reported that they were currently working or studying from home.

When asked about their likelihood of using public touch-based interfaces compared to before the COVID-19 pandemic, all participants responded that they were either less likely (56 %) or felt about

Table 3: Results from our survey question relating to behaviour change since the COVID-19 pandemic began. Respondents answered Yes or No to all four options.

Compared to before the COVID-19 pandemic, have you changed how you interact with public touch-screen displays (e.g., ticket machines) or devices with physical buttons (e.g., pedestrian crossings)?	Yes	No
Washed/sanitised hands before/after touching the button or touchscreen	73 %	27 %
Pressed button or touched screen with body-part other than finger (e.g., hip or elbow)	51 %	49 %
Pressed button or touched screen with key, stick, pen or similar implement	34 %	66 %
Opted against interacting with the device entirely	28 %	72 %

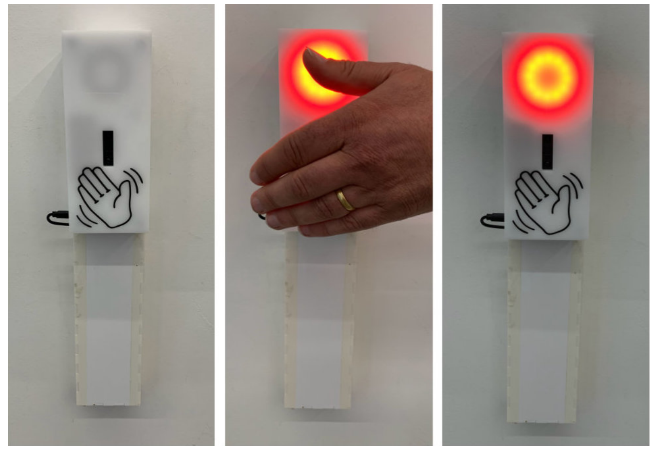

Figure 2: The single elevator button prototype. Using a simple proximity sensor, people can call the elevator by waving their hand over the icon (left and centre). LED lights pass through confirmation from the original underlying button to provide feedback that the interaction has worked (right).

the same (44 %), indicating a clear shift in behaviour away from touching public-space interfaces.

The second question gave participants options to classify their change in behaviour, as illustrated in Table 3. The majority of respondents said that they now sanitise their hands before/after touching such devices (73 %), with 28 % opting to avoid such interactions entirely. About half of the respondents (51 %) used a different body part in lieu of their finger, and 34 % chose to employ a tool instead. These findings align with previous studies [6, 31, 39, 62] that indicate, despite the low probability of infection through surface contact [14, 18], people are still wary about touching public surfaces, and many have gone to some effort to either adapt how they use them, or avoid them altogether.

4 RESPONSE

As we have seen from the investigations described above, since the COVID-19 pandemic began organisations have adapted or removed public-facing interfaces in the light of both government advice and public anxiety about touching shared surfaces. Clearly, the most common change that we saw in our device adaption study—simply removing or disabling an interface—is only an option for non-essential services, and is certainly not ideal. Many of the other adaptions we observed were either not fit-for-purpose or required additional accompanying equipment (such as a mobile app) or expertise that somewhat lessened the accessibility of their original simple interactions. Further, participants in our usage and behaviour survey showed a preference for avoiding touch interactions where possible, and we saw some evidence of this in context during our user adaption observations. Given both the lack of existing appropriate touchless interaction designs for public spaces, and the user preference for this modality, it is clear that there is an opportunity to develop more appropriate interaction designs for this environment.

The next step in our investigation, then, is to think creatively about how best we can build effective touch-free designs that can be either retrofitted onto or replace existing interactive public-space devices and technologies. In the remainder of this paper we document some of the possible directions that designers of public-space interfaces could take to reduce or remove the need for users to physically touch devices. We structure our exploration into probes of three separate areas of investigation. First, we present examples of retrofitting existing technology to provide touchless interaction without the need for any change in a device's operation. Next, we turn to the new infrastructures put in place specifically for the pandemic – are there ways to harness these for interactive purposes? Finally we look to the future by considering how various existing public-space technologies might be replaced with hands-free alternatives.

All of the probes detailed here were deployed between June and September 2021, under the same COVID-19-related restrictions and recommendations as described at the end of Section 3.1.

5 PROBE 1: RETROFITTING EXISTING TECHNOLOGY

We begin our exploration by augmenting two examples of existing public infrastructures with touchless interaction add-ons, and assessing the viability and usage of such hybrid devices. In the first example, our custom-made enclosures can be added to the existing interaction hardware without the need for any modification. In the second example, small modifications could be made to the existing device to allow our hardware to provide touchless interaction as an alternative to contact-based control.

5.1 Example one: touchless button pressing

We selected the common elevator call button as a starting point for this probe, which allowed us to investigate two scenarios: a single push-button (typically found only on the very top or very bottom floor of a building); or, two push-buttons (allowing both up and down travel on all floors). We created add-on hardware enclosures that registered a touch-free interaction and seamlessly transferred this directly to the underlying physical elevator button. This approach allowed us to test two types of interaction: a simple presence-based sensor (single button) or gestures to indicate the

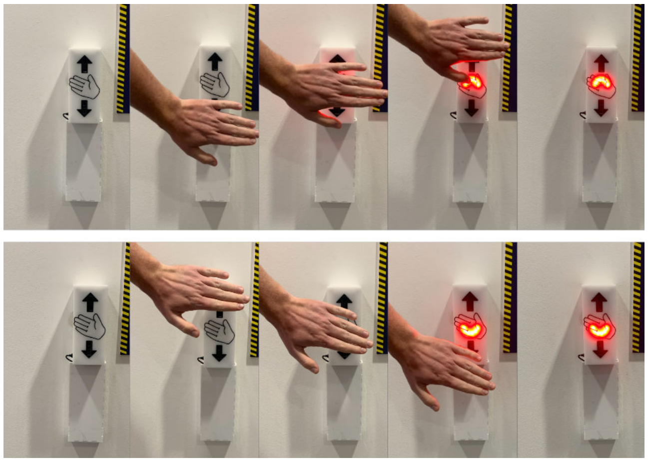

Figure 3: The double elevator button prototype. Top: the upwards swiping gesture used to trigger the up button. Bottom: the reversed gesture used to trigger the down button. An arc of LED lights provides feedback to the user as to which button has been pressed.

direction of travel (double button). Figures 2 and 3 illustrate the interaction for the single and double elevator buttons, respectively.

5.1.1 Deployment hardware. Both button-pusher enclosures are constructed using acrylic, designed to fit tightly over the existing elevator buttons and house the required components. Each device consists of one (single button version) or two (two button version) motors, infrared proximity sensors and photoresistors, in addition to a battery and an Arduino with a supporting printed circuit board to connect and control the components and record usage of the device. A cam is attached to each motor's shaft to make contact with the existing elevator buttons in place of the user's finger.

The proximity sensors are used to detect users' actions. For example, a single proximity sensor detects a hovered hand to activate the one-button pusher. The two-button pusher uses multiple proximity sensors to detect up or down gestures. As a fallback, and to allow us to track how people interacted with the device (i.e., when they touched instead of gesturing, or touched *and* gestured), each device's faceplate also acts as a button.

During normal use, the underlying physical elevator buttons light up to confirm that they have been activated. Our enclosures obstruct this feedback, so we added LEDs as an indicator to confirm interactions. Rather than simply lighting up when an interaction is triggered, we placed photoresistors above the existing buttons' lights, allowing our device to detect and pass through real button events. This also allowed us to account for buttons lighting up when no local user interaction occurs (e.g., when the elevator is arriving for someone to alight). We provided no instructions for the device other than simple icons printed on the front of the faceplate (see Figs. 2 and 3). Our assumption was that—just like the underlying buttons themselves—once learnt, usage would be easy to recall.

5.1.2 Pilot study. As a pilot, we installed our single button prototype over an elevator button in a university campus building for four 24-hour periods during a working week in mid-July 2021 to observe usage and help refine the designs for both devices. We logged the number of times a gesture was made and the number of physical presses of the device's faceplate. During several busy periods we also observed usage of the device from a distance.

Over the course of the four days, the automatic proximity sensor was activated 351 times, while the physical button was used 104 times, indicating that the device was mainly being used as intended. One unexpected observation on several occasions over the pilot period was that some users clearly mistook the device for an automatic hand sanitiser, and consequently put their hands underneath in an attempt to activate it. Our interpretation of this was that the pandemic has led people to expect such stations in most public areas, and potentially even socially conditioned some to associate hand icons with sanitisers. Consequently, we modified the two-button enclosure to include an additional proximity sensor at the bottom of the device to detect and log such interactions.

5.1.3 Deployment. We deployed one of each type of device on the ground (i.e., street level) and first floors of the same university campus building for eleven 24-hour periods during normal working weekdays between the end of July and the start of September 2021. The single button device was installed on the ground floor elevator panel, and the two-button prototype on the first floor. As with the pilot, we logged the number of times a gesture was made and the number of presses of the device's faceplate (in lieu of gesturing). Towards the end of the deployment, we also sent out a short anonymous survey to users of the building to gather feedback.

Over the course of the deployment the ground and first floor sensors were activated 869 and 368 times, respectively. The two-button device detected 172 "up" and 196 "down" gestures. The number of physical presses was similar for both versions: 229 for the ground floor (27 % of interactions) and 119 for the first floor (29 % of interactions), and there was no noticeable change in this type of usage over the course of the deployment. The sanitiser detector underneath the panel was triggered a total of 26 times.

The survey elicited 16 responses from people who had used the devices. Overall, 25 % of respondents admitted to physically pressing the devices due to initial confusion as to their purpose. Others mentioned they had noticed the iconography and realised the prototypes were touch-free modifications before using them. The survey asked participants how easy the devices were to learn to use, with responses of 8.2 and 7 out of 10 for the ground floor (one-button) and first floor (two-button) enclosures, respectively. Finally, to calibrate the responses with those in our earlier survey, we also asked the same question about likelihood of using public touch-based interfaces (see Section 3.3 for wording), to which all participants responded that they felt either less likely to do so (50 %) or about the same as before the pandemic (50 %).

5.1.4 Summary. Our retrofitted elevator buttons are a simple example of a quick, easy and cost-effective adaption to existing public-space technology. During our study a large number of people used the devices successfully with no training or instruction other than a simple icon and any previous experience of using lift buttons. We imagine such retrofitting can be expanded to include other simple button interactions such as pedestrian crossings, vending machines, doorbells or other similar devices with relatively little implementation and integration effort.

5.2 Example two: providing discreet feedback for touchless technology

In our elevator examples, while users lost the physical feedback of pressing a button, they still had confirmation of it being pressed via visual feedback from the LED indicators. In some cases, however, it would be inappropriate to provide such conspicuous feedback. Take, for instance, ATMs or credit card readers: these devices provide feedback that the user has pressed *a* button—typically via beeps and/or indicators in an entry field—but the only way to tell if the *correct* button was pressed is to either look at or feel the buttons as they are being touched. Should a standard touchless implementation (e.g., mid-air typing [67]) be retrofitted to such devices, users would lose this feedback and input errors would be more difficult to detect. Any non-touch visual augmentations would be unsuitable due to the privacy and security concerns of such situations.

In response to this challenge, we explored the use of mid-air haptic feedback for a standard 4×4 PIN pad commonly used in ATMs and card readers (see Fig. 4). Our approach used a Leap Motion infrared hand tracking device retrofitted adjacent to a PIN pad to detect button "presses" in mid-air, with an UltraHaptics ultrasound transducer array to create an invisible haptic keyboard and provide tactile feedback. In prior work, focused ultrasound has been used to conduct point localisation experiments for mid-air tactile feedback on the palm. Hoshi et al. initially explored a user's ability to localise a single feedback point at the centre of the palm by moving the point to that location from eight different directions [21]. Carter et al. investigated users' ability to recognise zero, one or two points as a two-point discrimination task with the points fixed in space [7]. Palovuori et al. [44] and Sand et al. [54] developed early prototypes to simulate tactile button presses, and Sand et al. further explored pressing multiple buttons with the palm using ultrasound feedback at the contact location [53]. Finally, Wilson et al. explored the ability to detect the location of a random point stimulation in a 5×5 grid on the palm [65].

Unlike these previous mid-air button approaches, and similar work that has provided feedback directly under a user's finger to confirm a press has taken place, we wanted to give extra positional feedback to allow users to confirm their PIN had been entered correctly. In our approach, users "press" the physical buttons of an ATM keypad in mid-air 10 to 20 cm above the surface. Simultaneously, a second virtual haptic keypad is imagined on the user's palm below the key entry points. When a user performs a keypress action with their finger, the corresponding position of the key is stimulated on their palm with focused ultrasound. In this approach, the user can imagine a virtual keypad on their hand which corresponds to the physical keypad in front of them (see Fig. 4) allowing confirmation of the correctness of their touchless key presses.

Figure 4: The proposed touchless keypad system for use in situations where private input is needed. The user holds their hand over the keypad in mid-air, where an infrared sensor tracks its movements. A grid of ultrasonic transducers aligned with the user's palm provides touch feedback in the same relative positions as the keypad buttons.

5.2.1 Experiment. We conducted a lab study based on the design of Wilson et al.'s on-point localisation experiment [65] to assess the viability of such an approach. Our goal was to determine the accuracy with which users are able to detect the correct numbers in the virtual mid-air grid on their palm. As such, we controlled the numbers that were selected programmatically rather than asking participants to "press" them in mid-air.

We asked participants to rest their hand on a box 15 cm above the UltraHaptics grid with their palm exposed through a 10 cm $\times$ 10 cm hole in its top side. After calibration and testing, participants began the main study which each consisted of 60 stimuli corresponding to the 13 keys typically present on a PIN pad: digits 0–9, Cancel, Clear and Enter, plus the two additional keys ⋆ and # that are sometimes used on other numeric keypads. Participants were first told the key they could assume they had "pressed", and then asked to report the key they thought they felt on their palm. We informed participants that in some cases there would be differences in the key they pressed versus the stimulation they felt. The system gave the correct stimulation half of the time and a different random stimulation the rest of the time. All 60 stimuli (2×15 keys $\times$ correct/erroneous stimulation) were given in a random order.

We invited 14 participants (7F, 7M, aged 22–34) to take part in the lab experiment in August 2021. The overall error rate across all keys when participants were given the correct stimulation was 13.7 %, whereas when users were given the incorrect stimulation the error rate was lower at 8.5 %. Overall, participants were more likely to detect stimuli correctly around the edges of the palm (in particular for the corner buttons 1, ⋆, Cancel and Enter), whereas buttons in the centre (5, 6 and 8) were the least accurate. We believe this could be due to the low tactile sensitivity in that region of the palm. Removing the number of stimuli that can be produced to make the grid smaller (i.e., outputting the numbers 0–9 only) could well improve this accuracy rating.

5.2.2 Summary. Our investigation into discreet touchless feedback has provided promising early results which could improve the privacy and security of public PIN entry devices. It could also provide haptic feedback for both input and output of information for visually impaired users in other situations.

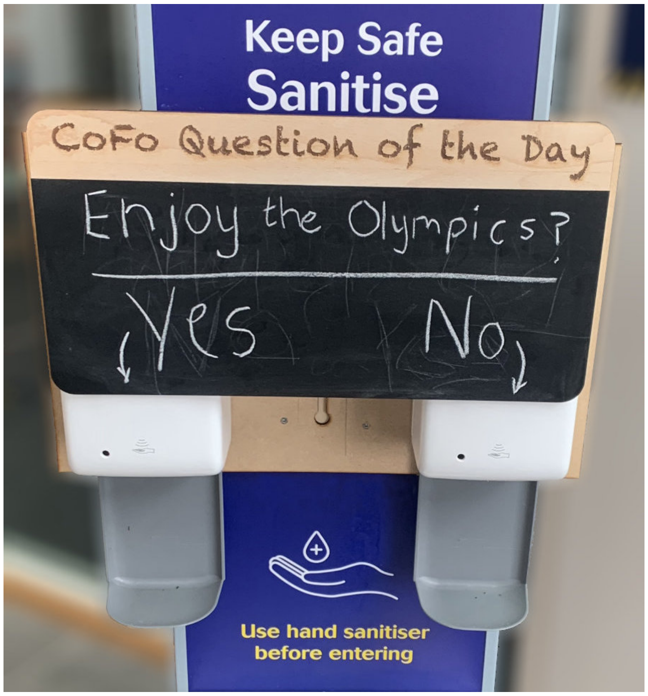

Figure 5: The SaniVoter Prototype. Entering a building, people are prompted to sanitise their hands. Our adapted version allows users to respond to a question via their choice of one of the two separate automatic hand sanitiser dispensers.

6 PROBE 2: ADAPTING NEW TECHNOLOGY FOR ADDITIONAL USES

Having observed a wide range of "new normal" behaviours around COVID-19 infrastructure (e.g., hand sanitisers, capacity indicators, temperature check points), we began thinking about how we could adapt some of these now ubiquitous and very frequently-used new devices for interaction. As a starting point, we focused on how they could be used to gather public opinion. Unattended public opinion gathering has previously been investigated by the HCI community, often using playful methods to entice participation (e.g., [15, 63]). As a baseline starting point, we opted for a simple voting system that facilitates binary decisions to be recorded in a touchless manner, similar to the work of Steinberger et al. [58]. With this in mind, we built a prototype with two automatic hand sanitiser stations connected to a simple Arduino controller that counts the number of times each one is used by monitoring the existing signal from the dispensers. Above this we mounted a chalkboard to provide details of the question and answer combinations. Users then select their response by simply placing their hand under the corresponding sanitiser dispenser (see Fig. 5).

6.1 Deployment

Our design—SaniVoter—was deployed in the foyer of a university campus building for a period of 12 weeks from June to September 2021, replacing the existing sanitiser station that had been put in place by the organisation. We periodically changed the question posed to users of the building and recorded the responses accordingly. Our focus in this study was simply to determine: (a) if visitors to the building used the device; and, (b) if any meaningful data could be gathered as a result. As the design is a binary input method, the majority of our questions involved a Yes or No response (for instance: "Are you happy?"). We also tried to encourage use by posing topical questions. For instance, the first two weeks of deployment were during the Euro 2020 football tournament, so our questions were simply: "Who will win the semi?" with options "England" and "Denmark"; and, "Who will win the final?" with response choices "Italy" and "England". During a week of particularly high temperatures we asked simply: "Hot?", whereas in the week following the Tokyo Olympics we asked: "Enjoy the Olympics?" (both with Yes or No as response options).

Over the course of the 12-week period (60 working days), we recorded 1180 interactions. Overall, the percentage of "left" versus "right" sanitiser usage was relatively even (56 % left versus 44 % right). However, if we look at individual questions, it is evident that each question has an overall winner, and the side that was chosen was distributed between the two stations (i.e., clearly caused by the choice of response). For example, 71 % of users predicted England would win the semi-finals of the Euro 2020 tournament, while 63 % thought the same team would win the final (choices from opposite sides of the device).

To assess if users were actually reading the question, as opposed to randomly selecting a dispenser each time, we asked the "Are you happy?" question three times (once in week three, and again in weeks six and eight), swapping the order of the answer dispensers each time. The average rating across the three iterations (451 interactions total) was 70 % happy versus 30 % unhappy (s.d. 0.24). A chi-squared test shows this result is not significant, strongly suggesting that users are actively reading the question and answering with the appropriate dispenser each time.

6.2 Summary

In this playful probe we sought to adapt new technology that has been installed explicitly due to the COVID-19 pandemic for the additional use of gathering contextual public feedback. Our results show that users engaged with the prototype, making decisions while performing the now-mainstream ritual of hand-sanitising.

7 PROBE 3: REPLACING EXISTING TECHNOLOGY WITH TOUCHLESS ALTERNATIVES

It is clear from our observations that people and organisations alike are modifying the way they interact with or deploy shared surfaces in the light of the COVID-19 pandemic. Further, though, there has been a recent call to arms (which some of this paper's authors contributed to) for interaction designers and HCI experts to adapt our research practises to prepare for the unlikely and unexpected [55], highlighting the unique and timely opportunity to completely rethink how public interactions can be performed. In this vein, we created two further prototypes that do just that. Both designs make use of touchless modalities not typically used in public infrastructures—computer vision and speech interaction—and cover a spectrum of inputs from the limited to the rich.

7.1 Example one: using computer vision

Inspired early on by the success of probe two, we also looked to reimagine how one might elicit opinion-based information using interaction paradigms not generally found in public infrastructures. An obvious starting point for this goal was to investigate how computer vision techniques might be utilised to gather simple emotions from passersby, taking inspiration from the feedback collection devices often seen in airports and other public spaces[7].

Our initial design was a simple "thumbs up" / "thumbs down" detector which, after some pilot user feedback, led to our final implementation: FaceVoter – a voting system that can detect smiles and frowns in order to elicit binary feedback from users (as shown in Fig. 6). Rather than selecting one of two physical options as in probe two, FaceVoter asks the user to smile to indicate a positive response, or frown to indicate a negative one. A similar concept by design agency Hirsch and Mann has previously been deployed to provide moments of playful intervention at pedestrian crossings by detecting facial expressions[8]. While this style of interaction provides moments of passive engagement, our system can be used to capture user opinions for feedback on experiences, in an approach more similar to that described by Tsujita and Rekimoto [61].

Our prototype's simple design was built around a facade of a face similar to that of an emoji, enclosed in a circular 3D-printed casing which housed an LED screen, camera and laptop. We used face- and landmark-detection algorithms to detect users who walked in front of the device, and a machine learning algorithm trained on Sagonas et al.'s dataset [52] to provide images with a range of expressions, backgrounds and lighting, aiding recognition in public outdoor areas with varying weather. The device logs the number of interactions; that is, each facial recognition attempt (multiple people standing in front of the device at the same time will result in a single recognition log) as well as the result (i.e., smile or frown).

7.1.1 Deployment. We deployed FaceVoter in an outdoor public space in Swansea city centre for a period of six days (approximately seven hours per day) in June and July 2021, with the same question being asked throughout ("Do you like the new bridge?"). A researcher stood close to the device and observed the response from the general public, at times prompting interested parties to interact with it. In addition, we interviewed 102 randomly-selected users to better understand their perceptions of such a device, as well as gathering their thoughts about touchless interactions in general.

Over the six days of deployment FaceVoter logged 545 interactions, of which 53 (10 %) were frowns, 357 (66 %) smiles and 135 (24 %) could not be recognised. It was clear via in-situ observations and interviews that the majority of the unrecognised interactions were caused by face coverings obscuring the user's mouth, while a small number were caused by people who glanced at the prototype long enough for it to detect their face, but walked away before recognition could take place. Disregarding these instances, the accuracy of the system at detecting smiles or frowns (as determined by observation) was approximately 80 %. During the observation sessions, our research team noted that passersby noticed the device (i.e., were visibly seen to look at it for more than just a glance) around 40 % of the time and chose to subsequently use it, unprompted, around 5 % of the time. Of the 545 total interactions, 187 were after prompts from a researcher.

[8]https://www.hirschandmann.com/portfolio_page/making-smiles-in-the-city/

Figure 6: The FaceVoter prototype. Approaching the device, a user's face is detected and the screen prompts them to answer Yes or No to a question by smiling or frowning.

Of the 102 users we interviewed (53M, 49F, 19 wearing masks), 28 had used the device more than once, with the predominant reasons for doing so being cited as either not having read the question in time to respond appropriately; or, their reaction not being recognised by the device. We asked the majority of our interviewees how they felt about facial technology, with 78 % responding positively, 15 % negatively, and the remaining 7 % being unsure. Many of the positive responses referred to the hands-free nature of the technology being a benefit for the COVID-19 situation, whereas the negative cited privacy concerns. Nearly 90 % of our interviewees said they had changed their behaviour with regards to touching public technology since the start of the pandemic. When asked about what sorts of technology they would like to see in replacement, both face- and speech-interaction were popular choices.

Finally, in order to ascertain if such an unusual device would be understood by the public in unattended contexts, before embarking on our interviews we asked several users what they thought the device was. Of those asked, 52 % correctly identified the device as a face-based voting system, 22 % thought it was a face-based technology of some form with an unknown purpose, 17 % suggested it was some sort of game, and 8 % had no idea.

7.1.2 Summary. Using facial recognition to detect expressions—in this case a smile or frown—worked well as a touchless and hands-free method of public space data-collection. Our FaceVoter prototype was well-used and positively received by the general public. While this sort of technology has previously been seen in public settings, it is not a common occurrence. We anticipate that if such

Figure 7: The SpeechBox prototype. Waving at the device triggers an audio prompt (via the speaker, top) to verbally ask a question. After an answer is provided, the user waves left or right to give feedback on the response's accuracy. LED strips at the bottom provide wave and status feedback.

technology became more mainstream the learning curve for use would continue to improve.

7.2 Example two: using speech interaction

As a final step in this work, we opted to completely rethink how public interfaces can be designed to incorporate new interaction paradigms for touchless control. One hands-free modality that has become increasingly widely used in personal spaces, but has to date had limited traction in public areas, is speech. Previous work in the area of public speech interaction has shown its viability in emergent user contexts [45, 48] from an accessibility perspective, providing users with low literacy or speakers of minority languages with information they might not otherwise have been able to access. As a result, these prior works are not entirely touch-free and do not focus on replacing standard touch-based modalities in the way we are keen to explore.

In this prototype, then, we chose to replace the common public information or internet kiosk that is commonly seen in shopping centres, hotels and visitor attractions, to provide touchless capabilities via speech interaction. Our hands-free public smart speaker prototype, SpeechBox (shown in Fig. 7) uses a Raspberry Pi, speaker, microphone, and 4G connectivity. It leverages the Google Assistant API[9] to recognise spoken language queries and provide audible answers. It also uses an electrical-field-based tracking and gesture controller to detect hand gesture input at ranges up to 20 cm.

[9]https://developers.google.com/assistant/sdk/reference/rpc

As public information systems typically require a physical button or screen press to initiate, we were concerned that some users might encounter confusion using the standard hands-free "wake words" associated with most home smart-speakers, so replaced this requirement with a more common modality. To access the system, then, users are instructed to wave their hand in front of the SpeechBox, which triggers a welcome message explaining the purpose of the system and asking them to speak a question into the microphone. The Google Assistant answer is then played back via the speaker, followed by another message asking if this answered their question. Users are then asked to provide feedback by waving to the right if the response did answer their question, or waving to the left if it did not. Animated LED strip lights are used to display visual feedback during this instruction and other wave gestures.

7.2.1 Deployment. We deployed the SpeechBox in Swansea's city centre shopping district for a period of 11 days in August and September 2021. On four of these days (19 hours total), we observed usage from a distance, while for the remainder we left it unattended. We automatically logged the number of uses of the system, wave-gesture feedback received and the answers provided. For privacy reasons we did not log any of the questions being asked or save any audio recordings. As an indication of whether the device was triggered without a question being asked, however, we did record the length of the input transcription. Transcripts with a length of zero either did not contain a question, or Google Assistant failed to recognise one (and in either case a response would not have been provided to the user).

Over the course of the deployment the prototype detected 123 initiation "wave" interactions, and subsequently successfully transcribed and sent 61 audio transcriptions to request answers from Google Assistant. Of these, just 26 produced meaningful answers (i.e., not "I don't know"). We received 30 ratings (using the wave interaction) for the 61 total questions, 12 of which were positive and 18 negative. Of the 26 answered questions we received 16 ratings, of which 9 were positive and 7 were negative.

During our four-day observation of the device in-situ, we noted around 32 % of passersby who looked at it directly actually tried to use it, and of those who tried, around 40 % were successful. We observed a range of behaviours while using the device that could have contributed to the low success rate, including people waving in the wrong place (e.g., too far away) or speaking at the wrong time (e.g., waiting too long to ask, triggering a timeout). We also noticed several people speaking their rating at the end of the process rather than using the wave gestures as requested.

7.2.2 Summary. The aim of this prototype was to explore the rich interactions of speech and gestures in a public setting to get an idea of how they might be received and used by a general audience. The results show a steep learning curve, with several users waving but not asking a question, and others unsuccessful at other stages.

Many of the transcribed questions did not produce answers by the system. Speech recognition can be troublesome at the best of times; and, as previous literature has demonstrated, public environments often have additional challenges to contend with [45]. However, investigating the accuracy of speech recognition in public spaces was not the purpose of this study. Rather, our goal was to discover how such interactions might be used to provide unattended services with little-to-no instruction.

This prototype has shown, then, that although some users found the device difficult to use, it did entice them to try and engage in a touchless manner, and even produced meaningful results in certain situations. Much like our earlier FaceVoter prototype, we imagine that if such devices were to become more integrated into public environments, the learning curve will flatten and uptake and successful interactions will increase as a result.

8 DISCUSSION AND CONCLUSION

Our investigations into post-COVID-19 shared technology use have provided strong evidence that the general public are anxious about touching shared surfaces, and as a result are either adapting the way they use public interfaces or, in the worst case, avoiding them altogether. Further, the current minimal adaptions made to public utilities by organisations in an attempt to protect from germs and relieve anxieties are fraught with accessibility or access issues. In our view, therefore, it is essential to investigate and develop touchless interactions for public technologies due to both their ubiquity and importance.

As a fast response to this challenge, we have focused on three areas of investigation: Retrofitting, Adapting and Replacing:

Retrofitting: An obvious starting point towards our end-goal of creating safer, touchless public utilities was to create add-ons that can be integrated into or around existing public-space devices. Our first example has shown how a mechanical approach combined with simple sensors can provide touchless button-pressing. Such retrofitted devices are cheap and simple to install and have proved to be discoverable and usable. Secondly, our investigations into discreet touchless feedback have shown that mid-air haptic sensations can be used to provide precise private feedback with reasonable success. These examples demonstrate how we can quickly and easily create additional technology to retrofit into existing infrastructure to provide both touchless input as well as discreet touchless output.

Adapting: In our second probe, we demonstrated how COVID-19-specific infrastructure can be harnessed for additional uses, in this case by leveraging hand-sanitiser stations to gather opinion-based public feedback. There are undoubtedly further opportunities in the plethora of new devices that have been installed throughout the pandemic.

Replacing: Finally, we looked to completely re-imagine walk-up-and-use utilities by incorporating less-common modalities not typically seen in the public sphere. The more natural user interfaces we selected can be used to replace touch-driven methods both in a limited way (i.e., detecting facial expressions using computer vision) as well as a richer manner (i.e., via speech interaction).

The world may slowly be emerging from the current pandemic situation, but as we have learnt, long-term effects and anxieties over pathogens left by others are still very much prevalent. Furthermore, while societies are still reeling from the aftermath of recent years, virologists and epidemiologists alike are not only warning about the inevitability of the next deadly virus outbreak, but are also busy planning ahead for it [30, 38]. Our proposal, then, is that we the HCI community should be following suit and preparing for such scenarios going forward.

There are of course limitations to the work described here. While we have proposed relatively cheap touch-free modifications to public space technologies, making these robust enough and reliably attachable to the diverse range of public-space devices could be challenging or costly in some cases. Our aim, however, is to outline a vision for the direction of further research into touchless public-space technology. The work described in this paper, then, not only presents a timely contribution towards alleviating the current anxiety around using shared interfaces, but also lays some of the groundwork for introducing new modalities and interactions into public spaces in preparation for future challenges.

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