How security constraints impact usability: the development of an IoT control device.

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Figure 1: An overview of the 'Genie' user interface.

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Abstract
In this paper we investigate how to integrate new functionality into an existing IoT home healthcare platform that has restrictive security and budgetary constraints. Focusing on the tablet based IoT control device, the 'Genie', based on usage data from a long-term trial and an expert evaluation we identified issues with security codes and multiple navigational steps. To address these issues, we developed a secondary physical device that focused on the key interaction activities (Pause and Delete) – the 'Tangenie'. A feasibility interview study with 6 participants showed that while 'Tangenie' and its physical form address 'Genie's' limitations, the design does not match the participants' mental model. This highlights issues with adoption of novel solutions that go beyond apps.

Author Keywords
IoT; Control Device; Tangible; Security; Usability.

CSS Concepts
• **Human-centered computing; Human computer interaction (HCI)**; *Haptic devices*; User studies;

Introduction
While prior work has focused on the feasibility of IoT systems, most recent academic and commercial

Figure 2: The pause and delete functions for the current control device, the “Genie”.

research has begun to explore tailored IoT control devices to interact with IoT platforms. IoT control devices range from chat bots [5,6,7], web apps [6], smartphone apps [8,10] to tangible devices [9,13] and voice-based apps [14]. These control devices support a wide range of control functionalities, such as managing individual rooms, the whole house [8], scheduling of activities based on physical location, and accessing these activities remotely [8,10]. However, it remains unclear how home-based IoT devices could be designed to support people’s individual preferences, including their sense of control and security. In this paper, we investigate the design space of IoT control devices and provide two contributions: (1) a quantitative analysis and expert-based evaluation of a digital IoT control device; and the (2) implementation, design and evaluation of a tangible IoT control device. Our findings demonstrate the importance of not only security and usability considerations but also people’s individual preferences to control their IoT systems.

Reviewing the current IoT control device

As part of our IoT platform [11] development, we created a control device in a form of a tablet with a custom application called the ‘Genie’. This application displays wearable battery levels and several control options, as well as contact details for the research group. Control options included deleting the last 1hr, 6hrs or 24hrs of data and pausing the system for 1hr, the ‘rest of the day’ (ROD) or ‘forever’ (Figure 2). This pause functionality enables household participants living with the IoT platform to alter the system status (Recording/Not recording). Participants are encouraged to pause the system when visitors arrive, or at any other time they wish to do so. During deployments the ‘Genie’ was typically placed flat in the household’s hallway.

Security was a high priority. The ‘Genie’ was initially designed with dual purposes: show participants’ data and present the control functionality. Because of this constraint, a simple visual pattern lock was implemented. The possibility of security flaws ruled out the participants using their own devices at this stage, due to the diversity of age, operating systems and manufactures of those products. Additionally, any device that needed to access the internet to operate was also ruled out such as IoT voice systems, for example Amazon Alexa. This was due to the platform being a closed system with no access to the internet other than a limited-capacity, unreliable and often slow 2G/3G system monitoring connection via a secure gateway (a custom APN - Access Point Name).

To understand any issues or how we could improve the ‘Genie’ we completed three tasks: 1) the analysis of data that had been gathered during deployment; 2) an exploration of potential user experience (UX) changes that could improve usage; and 3) understanding the IoT platforms constrains.

Task 1: Analysis of deployment

Quantitative data was collected about the `Genie' during a deployment of 35 households (lasting 3-17 months). This data showed that 20 households (57% of the cohort) used the ‘Genie’ to pause. 1hr pause dominated (53% of uses across all homes), followed by `ROD' (34%) and ‘forever’ (12%). Of households actively using the pause functionality, 16 used two or more options, predominantly 1h and `ROD'. 14 households used each option fewer than 10x (figure

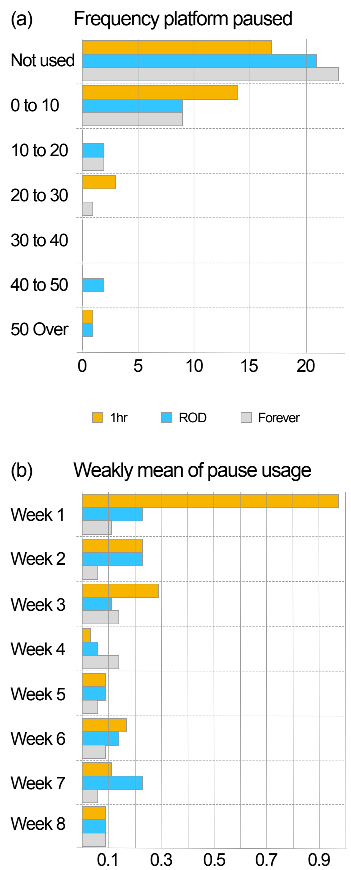

Figure 3: (a) The frequency of households using the 'Genie' to pause during the deployment duration. (b) Households weakly mean usage of the pause functionality.

3a). Mean usage of the pause functionality diminished over time, showing a rapid decline after the first few weeks for the 1h pause (figure 3b); the `ROD' and `forever' functionality displays this trend less clearly, likely due to a lower usage baseline.

'Genie' status statistics show mean 54.3% uptime across the cohort (s=29%). While this number may seem to correlate well with the proportion of the cohort making active use of the pause functionality, uptime cannot be predicted from Genie usage (R^2=0.07, $p<0.05$).

Task 2: Reviewing the 'Genie' UX
In order to understand why the 'Genie' usage may have been so low during the deployments, we conducted an expert-based evaluation [12] with a UX designer who used the 'Genie' tablet to compete multiple task-based user journeys. Through this evaluation we identified 5 key areas that needed improvement: (1) Reducing the steps taken to access the control functionality. (Access the tablet via a pin code or pattern lock, then select either delete or pause and finally complete the required pause or delete function); (2) Improve the current limited delete and pause functionality; (3) Add feedback for pause so that participants are aware of when the platform will be 'recording'; (4) Make the placement of the 'Genie' within the home more visible and (5) Remove buttons that had no implemented functionality (message and show household data).

Task 3: Platform constraints
To understand what changes were possible with the 'Genie' we needed to understand our IoT platform's technical constraints. As well as those mentioned earlier, we identified 3 key areas: security, cost, and the time it would take to implement the technical solution. As the IoT platform is part of a research project, cost and availability of components needed to be considered. This ruled out using multiple tablets as access points within each home. Additionally, any iteration on the current 'Genie' had to limit the UI design to minimal backend changes, as there was limited capacity to roll-out modifications to IoT home gateways following installation.

Design of the 'Tangenie'

Taking into account the requirements gathered from the three tasks that reviewed the current version of the 'Genie', we conceptualized a new solution that could improve the participants experience when interacting with the IoT platform.

Expanding the functionality:
We discovered through the quantitative data that the households used all three pause functions, however, the 1hr functionality was the most popular. To include this feedback and that of the UX review, we increased the hour pauses, enabling 1hr through to 8hrs (figure 4a). From the UX review we additionally added feedback for the pause so that participants would be aware when the platform would again be operational; this was done through the 'Rotary Dial' turning automatically back, counting down time left (figure 4b).

Accessibility:
As the IoT platform has been developed with healthcare in mind, we need to be mindful of accessibility for all interactions. This included making sure that participants with conditions that effect hands such of arthritis or mobility issues have been considered. Therefore, we developed the concept of multiple access

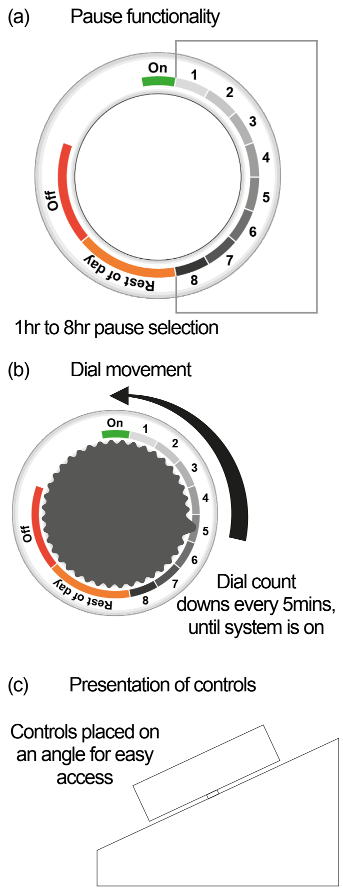

Figure 4: The pause and delete UI for the current control device.

points (e.g. upstairs and downstairs). These access points would need to work in sync and reflect the same pause status. As stated within the constraints defined, the cost involved in using multiple 'Genie' tablets was too high and we were unable to create an app for the participants smartphones due to system security. Consequently, a tangible device, the 'Tangenie' was designed (figure 4).

Increasing household engagement:
Based on pausing usage data, engagement with the 'Genie" was lower than expected and trailed off over time. Additionally, control devices were often switched off between uses, suggesting that an energy-efficient always-online control panel may be desirable. Using this feedback, we focused on the recommendations of the UX review by firstly reducing the steps needed to access the delete and pause functionality. As there is still a future intention of adding participant data to the 'Genie' for participant and clinician review, the requirement of a locking screen was still valid. Current security recommendations suggest that a PIN is a better choice than the visual pattern lock previously used, as these are susceptible to 'smudge attacks' - oily fingerprint residue is used to identify the pattern drawn [3]; this is particularly successful on devices with little subsequent app usage after each unlock [4]. We made the decision to transfer the delete and pause functionality to a secondary device. Focusing on this secondary device, we wanted to improve the engagement and altered how it was placed within the home, making it a tangible situated display (figure 4c)

Proof-of-concept prototype

To understand if such an access point as the 'Tangenie' could be implemented within the platform we created a proof-of-concept for the 'Rotary Dial' which would control the pausing of the IoT platform.

The 'Rotary Dial' functionality used a N20 micro speed reduction motor mini gear box with 1000 RPM (Revelations per min). A 10k Ohm Rotary POT (Potentiometer) that is positioned on top of the N20 motor, coupled to the shaft with a tiny 3D printed C-shaped coat. A Collect Type Knob was then attached as a base for the 3D printer dial (Figure 5).

We used an ADC (Analog-to-Digital Converter) ADS1x15, 16 Byte development board module to interpret in real time the value of resistances for the POT. The ADC then passes this information to the Raspberry Pi 3B+ which reads the digital signal. Mapping the value from different resistance to various degrees on the POT. We then connected the N20 motor to the TB6612 1.2A DC/Stepper motor driver breakout board which is being controlled via the Raspberry Pi. Enabling us to control the speed of the N20 motor and it's on/off state. This is based on the change of the resistance value of the POT.

Integrating with the IoT platform
To integrate the 'Rotary Dial' into the IoT platform, we made use of the same RESTful interface used by the 'Genie' app to set and retrieve system state information. Since the 'Tangenie' concept allowed for a greater range of pause values, we made a single update to the API enabling arbitrary legal values to be set (e.g. any integer number of hours). This allowed for additional hourly pauses to be implemented.

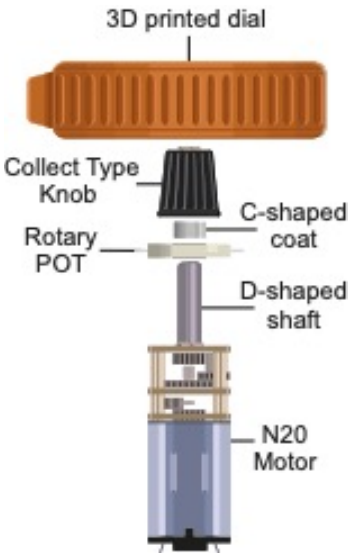

Figure 5: The breakdown of the 'Rotary Dial' construction.

Evaluation of 'Tangenie'

Our next step was to apprehend how the 'Tangenie' concept would be perceived by participants.

Methodology

The usability study was completed with 6 participants (3 female, 3 male) aged between 25 and 54. The participants were invited to a one-to-one session within the university. All worked full time and lived in a multi-residential household. All owned a laptop/desktop and mobile phone. 5 owned a TV, 4 a tablet PC, with 2 a smart watch. 4 participants had commercial IoT systems, with 2 controlling their lighting or heating and 3 owning a Google home or Amazon Alexa.

The evaluation had three steps. First, so the participants understood the context, we presented the IoT platform using storyboards and answered any questions that the participants had. Second, using a semi-structured interview method we asked the participants what would they use if they could choose how to control the IoT platform? Third, we presented two physical models (figure 6) of the 'Tangenie', asked the participants to interact with them (pausing and deleting) and conducted a semi-structured interview to gain feedback. All sessions were audio-recorded, transcribed and coded using iterative thematic analysis.

Physical Models

We used models to present two different versions of the 'Tangenie': one with delete buttons and one without (figure 6); each sized to fit the proof-of-concept hardware and created using standard laser cutting techniques. To present a more tactile feel, we added a rotary switch and tactile push buttons.

Results: No constraints IoT control device

After presenting the storyboards we asked the participants, without informing them of the platform's constraints, what they desired from an IoT control device. This highlighted two areas: the way of interacting and what features the control device should have.

USER INTERACTION

The participants highlighted four types of user interaction: Smartphone, Voice, Tangible switch and Remote-control. All but one participant discussed the usage of a smartphone with the creation of a custom app. For example, P2 preferred having access via the smartphone: *"Yeah I feel that a phone would be easiest, definitely got it on you"*. Two participants discussed the voice technology Amazon Alexa, with P5 highlighting the benefits they have seen for the older generation. For the tangible switch, two participants requested a switch per room, as P3 put it *"where you would have a light switch to turn on and off".* P3&4 discussed a remote-control, with P4 stating *"I think if it's the camera it would be useful to have a remote or something ".*

FEATURES

Participants discussed four types of features: Control of the sensors, Setting times, Showing status and Remote access. Five participants asked to control the sensors, individually, as a group (room), and as all in the home. Three participants requested the ability to set times for when the sensors where on/off, highlighting night and day activities as P2 put it, *"ignore certain sensors during the weekends".* Five participants asked about highlighting the system status, so they knew if an individual sensor is on/off or if the batteries need

Figure 6: The two physical models used during the 'Tangenie' review session.

changing. For remote access, two participants discussed being able to control the platform from anywhere and P5 highlighting that they could use the platforms data to look in on their parents.

Results: 'Tangenie' feedback
Our next step was to inform the participants of the platform's constraints and introduce the 'Tangenie' concept via two physical models. We the asked the participant what their opinions were.

The Delete buttons had varying responses from participants. P5&6 did not understand why that functionally was needed, with P6 asking "*What was the reasoning for being able to delete that person's data especially if it's being used for medical purposes?"* Four participants thought it was a nice option to have in case they had visitors. Whereas P1&P2 had issues with the defined timings and execution of the buttons. P2 highlighting that it would be easy to delete data *"by accidentally poking it"*.

Three participants commented positively on the countdown of the dial with P6 stating *"I can tell straight away it's acting like a thermostat, in the classic turn down system.*" Two participants stated that they liked the multiple access points with P1 calling them *"The main hub plus companions".* P4&P6 liked the way in which the dials synced automatically. P2 was less enthusiastic with the multiple versions stating, *"I feel better having one, just because then it is all in one place".*

As a final task, we asked the participants want features they would want to include in the 'Tangenie". Five participants stated that they would want to include a screen of some sort. P6 commenting that *"I think adding in a digital screen maybe would be like my* number one". Three participants wanted a display for data, e.g. P4 stated they wanted to *"see the data on the screen"*. Two participants wanted the display to be interactive so that they had more control over the sensors. P2 asked for the display so that they could get feedback on the pause functionality highlighting, that it would be nice to *"if there was a screen saying this will recommence at 10:35 tonight".*

Conclusion and future work

In this paper we presented an iterative development of a control device for an already implemented IoT platform. We have shown how the constraints of the platform shaped the limited 'Tangenie' concept. However, the design did not seem to match the participants' mental model and their expectation of using a screen and an app. This highlights issues with adoption of novel solutions, which future work should investigate further. Our study had limitations, as the prototypes were not tested and only discussed to explore feasibility. Therefore, the next step will be to implement this and incorporate feedback into the 'Tangenie'. Next, we intend to investigate the creation of a smartphone app that would be installed on a device provided as part of the project and would act as a remote-control. Finally, we intend to deploy all three systems ('Genie', 'Tangenie' and the remote-control) in a comparative field-based qualitative study in order to better understand the usage patterns and requirements of participants when controlling IoT platforms.

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