Designing Smart Home Controls for Elderly

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ABSTRACT

Technology is evolving by the day and with it the devices to control it. Sophisticated systems, like Smart Homes, are currently controlled in most cases via a smartphone app. While this may be acceptable for younger and middle-aged people, elders, however, have trouble keeping up with new devices and might not want to use a smartphone. Most modern-day control schemes like touch screens and menus are regarded as too complicated. However, Smart Homes provide many opportunities to reduce the every-day burden on elderly and people with special needs. Providing elderly people easy access to advanced and helpful technology via familiar interface types immensely improves their quality of life.

We propose a Smart Home control designed especially for use by elderly. Our contribution ranges from evaluating existing systems to designing and building the Smart Home control for elderly based on their special requirements. Moreover, we involve elderly in the design process and evaluate the proposed prototype in a qualitative study with 10 elderly users. The results conclude that being presented with the scenario to already own the required Smart Home technology, the participants were quick to accept the cube as user friendlier when compared to smartphone controls or touchscreen controls in general.

CCS CONCEPTS

• **Hardware** → *Haptic devices*; *Analysis and design of emerging devices and systems*; • **Human-centered computing** → **Ubiquitous and mobile computing theory, concepts and paradigms**; **Accessibility design and evaluation methods**.

KEYWORDS

Tangible Objects, Accessibility, Smart Home

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Figure 1: Non-functional mock-up of cube remote control concept

1 INTRODUCTION

Currently, there are many efforts to increase the quality of life of elderly by supporting their activities of daily living by the use of digital solutions. These solutions range form assistive applications outdoors, to the technology equipped Smart Environment at home. Especially elderly which have difficulty moving, and are mostly restricted to their homes can profit from Smart Home technology. Having the opportunity to reduce the distance a user has to walk to achieve a certain goal within their house – like switching on the lights or operating the window blinds – is a huge burden for those that aren't as mobile anymore.

Many endeavours exist to improve technology usability, and to design it in an inclusive manner. While these efforts can be experienced while accessing the web, or through user interface adjustments for smartphones for special impairments, there are no direct efforts to adjust Smart Home controls to the usage of elderly.

Our contribution closes this gap. We present a Smart Home control designed especially with the needs of elderly people in mind. The goal is to enable elderly to profit from the quality of life improvements by easily controlling their Smart Home. By analyzing currently existing Smart Home controls, we design and build functional and non-functional prototypes, which are operated by control schemes already familiar to the elderly, like rotating a certain handle, just like one would on a heater.

2 RELATED WORK

Smart Homes are mostly controlled via apps on a smartphone, laptop or tablet. They give their inhabitants the possibility to control it, independent of their location, provided an internet connection is available. The ability to set rules for the Smart Home to act upon is desired as well as the possibility to control settings on the fly [11].

In contrast to the Smart Home control via apps, speech and gesture recognition are viable input modalities. However, they have limited use as yet. Using speech control as single input modality is not really desired, due to the possibly of the Smart Home to interpret words as commands, that are not meant as such. Additionally, misunderstandings and confirmations by the system possibly add a delay to the desired outcome after a command is issued. Therefore, most controls are bundled in a centralized form such as the apps that were already mentioned and/or a terminal inside the house.

Another form of the centralized controls is occupied by Smart Objects. These are used in addition to a terminal or in standalone manner. Examples of such objects are Nuimo control[1], SPIN remote[2], and Nanoleaf remote[3]. These are available on the market and have been specifically designed to full-fill the role of controlling the Smart Home. The Nanoleaf remote is a 12-sided tangible, which is designed for the purpose of controlling the corresponding Aurora ambient lightning. Each side can be configured to execute a specific command. It has the drawback that it serves a very narrow purpose, although it it is compatible with the Apple HomeKit, it is not a general purpose controller. The SPIN remote and the Nuimo control are rotation-based and correspondingly touch-based Smart Home remotes. They are a good example of possible control schemes. The SPIN remote provides no real indication on which controls are possible, and the Nuimo control uses a touch display, which is not desired in the context of elderly users. In addition, Tangible Objects such as the Surface Dial by Microsoft[4], can be used to extend input possibilities while working with screens.

3D printed Tangible Objects are new approaches for interaction controls. They are mostly used as on-screen controls [8, 15]. The input is created by placing the objects on the surface of the screen, the screen being able to differentiate the objects. Furthermore, interaction through these objects is possible by touching them and deforming them, such as squeezing and bending [17]. An additional possibility of interaction is by tilting the objects. These trigger the controls by a moving liquid in a specifically designed interior pathway [16]. While tilting an object filled with water might be a suitable form of input, adding an additional mean of input, that is not immediately recognized by elderly, adds another layer of complexity, which is not desired.

To specify, what the benefits and drawbacks of current remote control solutions are, we considered existing principles and standards of product design. There are many works on design principles and user experience design in the area of HCI interaction design [1, 2, 9, 10, 18, 20]. Mostly they focus on designing user interfaces on screens of PCs or mobile phones. While Höök et al. present interactions designed to interact in an affective way with mobile applications [7], Cowley et al. design interactions for a multiplayer serious games [4]. These interactions are extended by tangible interaction principles applied on controlling the ambient environment, as Ross et al. are proposing [14]. On a meta-level Cockton et al. present six meta-principles for interaction design [3]. Finally, we focus on two different guidelines for the design process: Seven Fundamental Principles of Design by Don Norman [13], and Usability Heuristics for User Interface Design from Nielsen Group[5] based on work by Molich and Nielsen [12]. These works present basic design principles which relate to designing objects and lay the basis for user interface design. Additionally, as a third category of design guidelines, we consider the design requirements given by the context in which the remote control will be used. The use-case has elderly people with restricted mobility as target group.

The first set of principles are extracted from the revised edition of Don Norman's popular book 'The Design of Everyday Things' [13]. These seven principles are *Discoverability, Feedback, Conceptual model, Affordances, Signifiers, Mappings and Constraints*. A good conceptual model leads to good understanding and feeling of control, and is closely related to discoverability and signifiers. The according affordances and constraints are needed to create effective mappings between controls and intended actions supported by corresponding feedback.

Even though the second set of principles focuses more on the design of digital user interfaces, some of them apply to physical remotes. These principles, as well as other similar principles can also be found in the design principle collection[6]. We decided to go with the following ones from the Norman Nielsen Group, as we believed them to be the most encompassing guidelines: *visibility of system status; match between system and the real world; user control and freedom; consistency and standards; error prevention; recognition rather than recall; flexibility and efficiency of use; aesthetic and minimalist design; help users recognize, diagnose, and recover from errors; help and documentation.*

While the principles listed above are the result of careful consideration of human behavior, wants and needs, we contribute design requirements we find appropriate in the context of designing Smart Home controls for elderly:

(1) **Ease of use** Input modalities should be simple and easily recognized;
(2) **Easy to handle** Product should have a reasonable size - not too small for elderly to handle, not too large to be unwieldy;
(3) **No required knowledge of the controlled devices internal workings** Product comes configured with the most common use-cases - or professional setup is provided;
(4) **Not bound to a specific area** Users should be able to use the product from all places inside the house, they usually would want to use it from;
(5) **Immediate feedback** Product provides the user with information that their input did indeed change something;

[1] https://www.senic.com/en/nuimo-control
[2] http://www.spinremote.com/
[3] https://us-shop.nanoleaf.me/products/nanoleaf-remote
[4] https://www.microsoft.com/en-us/p/surface-dial/
[5] https://www.nngroup.com/articles/ten-usability-heuristics/
[6] https://principles.design/

(6) **General purpose** Product should be able to work with many different devices within it's scope and not end up as one of many remote controls;
(7) **Privacy** Product should not listen to the user's every action, like speech and gesture recognition do, which could give elderly an uncomfortable feeling of being monitored;

3 EVALUATION OF DESIGN PRINCIPLES

In the following we will go over the design principles listed in Section 2 and analyze which design principles have been adhered to or violated in several remote control families and actual examples. An overview of our findings is presented in Table 1.

Now that we rated existing remote control families based on design principles, we will take a look at what is missing or superfluous in the context of remote controls.

For some of the design principles (flexibility and efficiency of use, help users recover from errors, help and documentation) we were not able to give a concrete rating. This is due to the fact that these principles apply more to the operated devices than the remote control which is operating it. Therefore, we will not see them as necessary principles for the design process and are not mentioned in the overview. Since *Immediate feedback* is mostly covered by the principle *Feedback*, *Immediate feedback* is considered void, and be dropped from the list. We will instead use *Feedback*.

Comparing *Aesthetic and minimalist design* with *Discoverability*, we can see that the ratings are almost inversed. High discoverability usually requires the presence of something that can be perceived as a part that can be operated. Providing high discoverability while maintaining many functions (*Affordances*) leads to a crowded device that is the opposite of minimalistic. Since the fluid intelligence of people declines with age [5], it is important that users are able to recognize (*Discoverability, Ease of use*) and understand (*Conceptual model, Signifiers, Mappings, Match between system and world, Recognition rather than recall*) the functions provided by the remote while not making it too crowded (*Aesthetic and minimalist design*). Fluid intelligence describes a person's ability to learn new things and adapt to changes. The older a person gets, the more they rely on crystallized intelligence – their experiences – as their fluid intelligence declines. Confronting elderly people with new technologies should capitalize on this crystallized intelligence and require the least amount of fluid intelligence possible. Thus, our goal is to create a remote control with good *Discoverability* that is as minimalistic as possible and balance it with a sufficient amount of possible actions.

The principles *Help users recognize, diagnose and recover from errors* should primarily be addressed by the controlled device and only be of secondary concern of the remote control.

Concluding, we state the most important principles, which need to be satisfied. These are *Discoverability, Conceptual model, Affordances, Signifiers, Mappings, Match between system and world, Recognition rather than recall, Aesthetic and minimalist design,* and *Ease of use*. The other remaining principles will not be dismissed in our further evaluation, but we found these eight have the highest priority for us.

4 DESIGN OF REMOTE CONTROL FOR ELDERLY

There are multiple dimensions of designing to consider when designing a remote control for elderly people. While selecting these, the use-case described in the introduction, has to be considered. Aging persons live in a Smart Home. Due to their mobility impairments they wish to control their Smart Home remotely. While keeping this in mind, we consider tangible vs. intangible interface design, the choice of affordances, shape and size considerations, and finally the input modalities. We weigh each of the options and discuss the choices according to the degree they satisfy the design principles identified and prioritized in Section 3.

4.1 Tangible vs. intangible design

One of the more basic questions when designing a new control interface is whether it should be intangible (e.g. a touch screen), semi-tangible (traditional WIMP user interface) or fully tangible. Currently there are many Smart Home control interfaces, which are either realized as smart phone or desktop app. People that are well accustomed to these devices should have no problem using these, but the elderly have difficulties adjusting to new technologies. Despite them being willing to adopt new technologies there are multiple obstacles like the increasing impairment of visual or motor functions [6]. Interface items on desktop and mobile apps tend to grow smaller as their complexity increases, which further hinders adoption by the elderly. Using tangible user interfaces introduces a haptic element to a user interface. Compared to graphical user interfaces, tangible user interfaces have proven to be favored by people when presented with both. This was the case even though the tangible user interface was perceived as inferior and performance didn't differ significantly [21]. Elderly in particular have been shown to accept and adopt tangible user interfaces more readily due a high perceived ease of use and learning [19]. Due to these reasons, we use tangible user interfaces as our starting point.

4.2 Functionality selection

Most devices in a household are manually operated via a tangible interface. These interfaces come in different forms and shapes, like light switches mounted on a wall, TV controls on a remote or the pulley mechanism of window blinds. We have grown accustomed to these interfaces and the movements required to operate them. To create a tangible Smart Home controller that borrows from these experiences, we gathered in Table 2 common actions one might want to perform at home. All discussed actions assume a tangible interface.

The most frequent actions performed while operating the tangible interfaces at home are rotating and pressing. Toggling the power for any kind of device – including but not limited to: lights, radio, TV, stereo, ceiling fan, toaster – is normally done via a switch-off button on or near the device. Pressing buttons or operating any kind of switch has become an everyday occurrence. Another action one often perform is rotating. Whenever one wants to change a setting that has several possible values on a discrete or continuous scale, one tends to use some kind of rotation-based input. Be it operating a heater or regulating the volume or frequency of a radio, they follow the same principle. Clockwise rotation usually causes an increase

Table 1: Satisfaction degree of the collected Design Principles, rated per families of remote controls. Rating ranges from "★" - when not satisfied - to "★★★★★" - when totally satisfied. "-" shows that no relevant rating could be given. The column "Smart Phone" was rated with the best possible scenario in mind.

Design principles	Analog remote	Digital remote	Smart-phone	Speech	Gestures	Surface gestures	Nanoleaf	SPIN	Nuimo
Don Norman									
Discoverability	★★★	★★★★	★★★★	★	★	★	★★★★	★★	★★★
Feedback	★★	★★★	★★★	★★★	★	★	★★★★★	★★★★★	★★★★★
Conceptual model	★★★	★★★	★★★★★	★★★	★★★	★★★	★★★	★	★★★
Affordances	★★★	★★★★	★★★★	★★★★★	★★★★★	★★★★★	★★★	★★★★	★★★
Signifiers	★★★	★★★	★★★★	★	★	★	★★	★★	★★
Mappings	★★★	★★★	★★★★	★	★★	★	★★	★★★	★★★★
Constraints	★★★★	★★★★	★★★★	★	★	★	★★★	★★★	★★★★
Norman Nielsen Group									
Visibility of system status	★	★★★	★★★★★	★★	★	★	★★★★	★★★★★	★★★★
Match between system and world	★★★	★★★	★★★★	★	★★	★	★★	★★★	★★★★
User control and freedom	★★★★	★★★★	★★★	★★★★	★★★★	★★★★	★★★★	★★★★	★★★★
Consistency and standards	★★★	★★★★	-	★★★	★★★	★★★	★★★★★	★★★★	★★★★★
Error prevention	★	★	★★★★★	★★★★	★★★	★★★	★★★★★	★★★★	★★★★
Recognition rather than recall	★★★	★★★	★★	★★★	★	★	★	★	★★★
Aesthetic and minimalist design	★★	★★	★★★	★★★★★	★★★★★	★★★★★	★★★★	★★★★★	★★★★★
Additions for elderly users									
Ease of use	★★★★★	★★★★	★★★	★	★	★	★★★★	★★	★★★
Easy to handle	★★★★	★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★	★★★★★	★★★★★
No required knowledge	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★
No specific area	★★★★	★★★★	★★★★★	★★★	★★★	★★★	★★★★★	★★★★	★★★★
General purpose	★	★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★	★★★★★	★★
Privacy	★★★★★	★★★★★	★★★	★	★	★★★★★	★★★★★	★★★★★	★★★★★

Table 2: Possible tangible interactions a user might want to perform in their house. Each goal is associated to a movement that the user has to perform to reach their goal.

Goal	Movement	Shape
adjust temperature	rotate	cylinder round/rectangular
toggle on/off	press	switch/button
toggle music	press	round/rectangular, button
change volume	rotate	circular, surface/cylinder
dim lights	rotate	cylinder
(un-) lock	rotate	cylinder/key
open/close blinds	pull	band

in whatever setting it is connected to while counter-clockwise rotation causes a decrease. However, in which direction one turns a key to lock or unlock a door, depends on which side of the door one is. But if one looks at a lockable drawer, one can see that one has to turn the key clockwise to lock and counter-clockwise to unlock.

Even though other examples, like flushing the toilet or operating a faucet, are usually not cases in which the user might want to use a remote control for it, they still make use of the same principles of operation.

To give users a familiar feeling and a sense of mastery of the remote, we capitalize on the types of operations that were already learned while interacting with the devices themselves. To make the user aware of the similarity to the familiar device, a shape that is closely connected to it should be used (e.g. a round shape to connect it to the action of rotating).

We show possible use-cases for a Smart Home remote in Table 3. Controlling the temperature, lights, TV, or the stereo, are all common occurrences that one either already has a remote for, or one has to move to personally. Toggling an alarm system, or checking up on security cameras is less common and should not be part of a remote that is used on a daily basis. However, if a door lock system is in place, it may be a desired function, especially if the user would have to take the stairs to lock the front door every day. Opening and closing window blinds is also a desired functionality. Keeping out blinding light while watching TV or taking a nap on the couch should be common enough to warrant integration into the remote. Household appliances, like an oven or a washing machine, aren't prominent candidates for remote control either, as (un-)loading them requires the proximity of the user anyway.

Table 3: Possible Smart Home devices and status of desirability of operating it remotely.

Device	Desired to control remotely
Thermostat	✓
Lights	✓
TV	✓
Stereo	✓
Alarm system	×
Security camera	×
Door locks	✓
Window blinds	✓
Oven	×
Washing machine	×

4.3 Shape design considerations

Choosing a suitable size and shape for the Smart Home remote control is the next logical step. Akin to a remote, it should be portable and not fixed to the environment. Looking at the tangible interfaces we evaluated, we have: the analog remote, the Nanoleaf remote, the SPIN remote and the Nuimo remote.

A traditional analog remote is prone to cluttering as complexity increases (contradicting *Aesthetic and minimalist design*) which leads to less or more concise *Signifiers*. Its use is also fixed to one device. Having multiple devices leads to having multiple remotes than can easily be confused with one another.

The Nanoleaf remote is a promising candidate but has several weaknesses that makes it undesirable for use with elderly people. Even though it's easy to use and readily provides a conceptual model due to its shape, it lacks meaningful *Signifiers*. This requires memorization of all settings and commands which is not feasible in our context (*Recognition rather than recall*). Its use is also limited to Nanoleaf Aurora or Apple HomeKit compatible devices (*General purpose*). Its resemblance to a dice reinforces the idea of its sides having different meaning but neither dice nor spheres are normally connected to a rotating movement when interacting with them.

The SPIN remote takes care of that by allowing to be freely programmed. It also supports multiple kinds of signals like infrared, Bluetooth and Wi-Fi, making it an excellent device for *General purpose*. But same as the Nanoleaf remote it lacks *Signifiers*. Its arbitrary shape does not contribute to forming a *Conceptual model* of it when it is first encountered. Not being able to understand what the SPIN remote is used for or how to use it creates frustration and quickly leads to the abandonment of the device. However, its round, conical shape leads to an understanding that it can be rotated, if a correct *Conceptual model* is created.

To create a tangible interface for elderly people, we need a device that is easy to use and provides its user a good idea on how it is used without first consulting a lengthy manual or other people. It also requires signifiers that help recognizing possible commands and input modalities.

As first of the two shapes we consider after intense discussions, the cube is a shape that everyone is familiar with. It is the same shape as a dice, showing information on each of its sides. While it lowers the amount of possibly available commands to six, it would solve the problems the SPIN remote has. Each side can provide signifiers that clearly state the input modality and the operated device. Depending on how many different commands are used in general, other polyhedrons like a octahedron (8 sides) are also a possibility. An exception would be a tetrahedron or other pyramid shapes as they provide no clarity about which side is currently the important one. However, according to Table 3, six sides should be enough to cover desired functions.

Another shape that would be possible, is a flat cylinder, like the Nuimo remote. The round shape of the Nuimo device invites the user to rotate it, which would create a good conceptual model for the main input modality. A problem would be the choice of the controlled device. As it only has two sides, using the same approach as with the cube would limit it to a maximum of two possible commands. A touch display, as it is used by the Nuimo remote, enables device switching and additional inputs but may find less acceptance from elderly users. Section 5.2 shows how this basic shape is finally adjusted to offer multiple command possibilities.

4.4 Select input modalities

As already outlined in Section 4.2, rotation is a very common way to interact with devices. The shapes of a cube and a cylinder, discussed in Section 4.3, allow for rotation in multiple ways. Cube and cylinder can be rotated as a whole, like the Nanoleaf remote, or provide a separate ring like the Nuimo remote. Turning the object itself might hinder providing adequate *Feedback* via a display, as it would turn with the object and no longer be legible. Keeping the display stationary would be preferred. A cube can be turned onto a different face which could be used to select a device. This is not possible with the cylinder which needs an additional way to cycle through devices as the Nuimo remote provides with its touchscreen. This can be achieved by providing multiple rings as part of the cylinder, a ring for each device. Multiple rings lead to a taller cylinder than using just one.

Pushing and pulling rings along their rotational axis could be another possible way to create inputs, provided its existence is made obvious enough via signifiers. As this input modality has precedence in reverse gear selection of cars by some manufacturers, this may be intuitive for some people, but not for everyone.

5 CONCEPT

Resulting from our previous comparison and discussion of possible designs, we propose two concepts, described in Sections 5.1 and 5.2. These are subsequently evaluated in a survey in Section 6.

5.1 Cube concept

Extracted from the shape design consideration, the cube is the basis of our first concept, see Figure 2. Each of the six sides represents one device. Each side has a revolving ring as a form of input. Inside the ring, signifiers for possible commands will be shown. A possible implementation would be an e-paper display. This way, the currently selected command can be highlighted using either backlighting or changes on the display while still providing visibility of all other sides. The display also functions as a two-part button (top and bottom separated) to allow input by pressing.

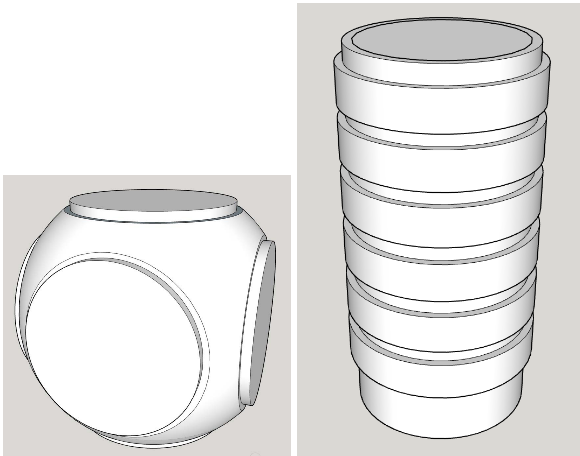

Figure 2: 3D sketch of cube (left) and cylinder(right) shaped remote concept.

After choosing a device, the user can issue a command by either rotating the topmost ring or by pressing down on the middle part. Pressing will produce a change in a binary setting, like on/off or start/stop. Rotating will change a value that is part of a scale, like volume, brightness or the position of blinds on the windows. Possible commands will be shown on the display. To further facilitate a conceptual model that also encompasses rotation of the rings, the cubes edges and corners are rounded so that it resembles a cube cut from a sphere. Feedback is handled via vibration and changes on the display.

To enable widespread use and customizability, the cube should be able to communicate with the APIs of the most common Smart Home systems. For power-supply, we suggest an internal battery that can be charged via an inductive charging station. This avoids the need of a power inlet on the cube.

A familiar shape together with unambiguous *Signifiers* provides good *Discoverability* and *Mappings*. The user might want to turn the whole cube instead of the topmost ring, which slightly hurts the defined *Conceptual model*. If the display rotating with the cube and the lack of feedback is enough to correct the user, remains to be seen during testing. Feedback is given to ensure the user that the given input was indeed registered, which is important when controlling devices that are out of sight. Due to the shape of the cube, it only allows for six different controls, but it was shown that six would be enough to accommodate the most accepted Smart Home devices by elderly, see Table 3. Moreover, the user is able to quickly determine the chosen command type by looking at the top side of the cube.

5.2 Cylinder concept

As second output from our discussion on the desired shape, we consider a cylinder with several rings, see Figure 2. Each ring corresponds to a single device. For input, rings can be rotated – just like with the cube – as well as pushed down and pulled up a bit – to replace the button functionality of the screen. Feedback is given by an e-paper display on the top of the cylinder and vibration.

Due to its shape, rotating the rings as a way of generating input should come naturally. Pushing and pulling should be indicated via signifiers and mapped to actions that translate well into up and down movements. The cylinder could be constructed of several, stackable modules. Each module would consist of a slice of the cylinder, containing one of its rings. This way, rings could be added or removed, depending on the user's preferences.

Compared to the cube concept, the cylinder does not provide a "turn to select your device" functionality and exchanges it with a more stationary experience. It features only a single display on top that changes depending on what ring is currently in use. This leads to a slight change in discoverability of the current system status. Instead of rotating a cube to the desired display to check on the current status, the user has to at least touch the corresponding ring to get the desired information. A button functionality, as with the cube, is still a possible alternative. Which type of interaction is preferred, is subject to experimentation with the target group.

The modularity of the cylinder concept has the advantage that adding or removing rings is possible in case the number of desired functions turns out to be higher or lower than expected. However, meaningful signifiers and the push/pull input each take up a bit of space. This way, the cylinder may end up very tall, which is undesirable. Reducing the width of the rings takes away needed space for signifiers. Without them, users have to rely on memory to recall each rings function. Exact measurements for both, the cylinder and the cube, are subject to the executed survey.

5.3 Notable trade-offs between the two concepts

Equivalent to Table 1, Table 4 shows the rating performed by the authors of the different design principles for the cube and the cylinder. While both concepts share similarities, there are several aspects in which one ranks higher than the other, while sacrificing ranks in another aspect of the related design principles:

Conceptual model/Not bound to a specific area: The conceptual model created by the cube may be worse than the cylinder one. While the concept of a dice is familiar to most people, using a remote in the shape of one is not. However, the cylinder is bigger when accounting for the need of space for signifiers and is not as easy to carry around.

Discoverability/Visibility of system status: The cylinder only has one display and can therefore only display information about one connected system at a time. To access the status of another device, turning or touching of the corresponding ring is required. This requires the user to direct their gaze to the rings, identify the correct one, and look back to the display. The cube only has to be rotated to the relevant face.

Flexibility and efficiency of use: While not a primary concern and hard to judge when it comes to remotes, the cylinder has the benefit of possible modularity. Rings could be modules, which could be added, removed, and stacked as desired.

6 SURVEY WITH MOCK-UP PROTOTYPES

To determine which of the two concepts should be developed further, we conducted a survey. Possible users should interact with mock-ups of both concepts and voice their opinion about them. This

Table 4: Satisfaction degree of the collected Design Principles by cube and cylinder concept. Rating ranges from "★" - when not satisfied - to "★★★★★" - when totally satisfied.

Design principles	Cube	Cylinder
Don Norman		
Discoverability	★★★★	★★★★
Feedback	★★★★★	★★★★★
Conceptual model	★★★★	★★★★
Affordances	★★★★	★★★★
Signifiers	★★★★★	★★★★ (★)
Mappings	★★★★	★★★★
Constraints	★★★★	★★★★
Norman Nielsen Group		
Visibility of system status	★★★★	★★★★
Match between system and world	★★★★	★★★★
User control and freedom	★★★★	★★★★
Consistency and standards	★★★★★	★★★★★
Error prevention	★★★★	★★★★
Recognition rather than recall	★★★★★	★★★★ (★)
Aesthetic and minimalist design	★★★★★	★★★★★
Additions for elderly users		
Ease of use	★★★★★	★★★★★
Easy to handle	★★★★★	★★★★★
No required knowledge	★★★★★	★★★★★
No specific area	★★★	★★★
General purpose	★★★	★★★
Privacy	★★★★★	★★★★★

way, we also hope to gain some insight into what elderly people actually think of as important in the context of remote controls. While consulting design principles goes a long way in creating a good product, getting actual feedback and proposals for improvements is very important as well. As we wanted the participants to answer as freely as possible, we decided to opt for a qualitative survey, where they were not bound by strict answering guidelines.

6.1 Mock-up creation

To test our concept on some possible users, we created two non-functional mock-ups.

The cube mock-up, see Figure 1, was created from foam, which was spray-painted to reduce crumbling. The sides consisted of revolvable discs of the same material, each fixed with a nail. Graphics of a possible UI were glued to each side. The whole cube has a diameter of 9.3 cm with the discs being 5.5 cm in diameter and a thickness of 0.75 cm.

The cylinder mock-up consists of a closed plastic tube, with revolvable plastic rings around its body. Possible UI graphics were glued on top and on the rings, see Figure 3.

Both mock-ups were designed to have the same use cases to enable a better comparison. The six provided use cases were: changing the temperature, operating the TV, manipulating the blinds, locking the front door, switching the lights, and operating the stereo. The

Figure 3: Non-functional mock-up of the cylinder concept.

cylinder has a height of 14.1 cm with a diameter of 8.3 cm. The rings have a diameter of 8.9 cm.

6.2 Choosing the right labels

Choosing good labels for our mock-ups is important, because without any real functionality, the participants have to rely on visuals and verbal explanation to experience the mock-up. Based on meeting the design principles of *Signifiers*, *Recognition rather than recall* and *Aestetic and minimalist design*, we decided that text-less labels that consisted mostly of icons would explain the intended function better than text could. Figures 4 and 5 show the chosen labels. The icons were taken from the website vecteezy[7] and flaticon[8] which host freely available icons. The idea was to choose icons that were as simple as possible, while being easily recognizable. The orientation of the icons – in conjunction with arrows, if present – should be a clue as in which direction the user has to turn the input for a desired result.

6.3 Survey execution

Ten people participated in the survey (6 female, 4 male). The subjects' age ranged between 62 and 81, with a mean of 74,4 and a median of 75. These participants were recruited from family, neighbors and friends. They participated on a voluntary basis and received no material compensation.

Subjects were surveyed in pairs and each session was recorded with an audio recording device after getting consent from the participants. Each pair was given an introduction about Smart Home and its possible uses. They were then confronted with an imaginary scenario of them already having a house or apartment outfitted with Smart Home technology and were asked how they think, a

[7]https://www.vecteezy.com
[8]https://www.flaticon.com

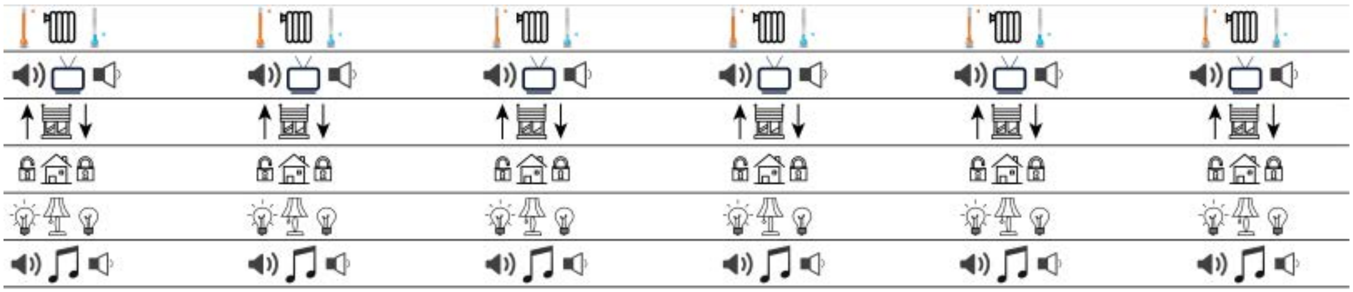

Figure 4: Labels that were glued on the rings of the cylinder mock-up. The temperature label in the cube label Figure (without arrows and thermometer symbols) was used for the top.

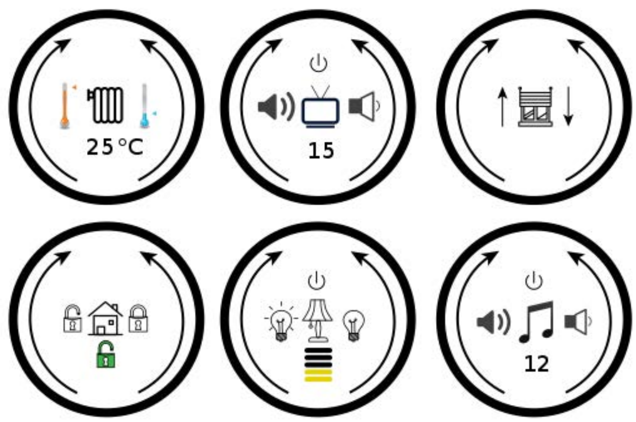

Figure 5: Labels that were glued on the sides of the cube mock-up.

good controller for it could look like. Participants were encouraged to talk to each other and discuss the topic.

After the participants had exhausted their ideas, they were presented with one of the two mock-ups. Without further input they were asked to explore the mock-up and guess it's functions. The allotted time for this part was not fixed, as to get as much feedback as possible. After the participants finished their exploration, the intended use-cases for the mock-up were explained. Participants were then asked about what they do or don't like about the presented mock-up, and if it was missing something. After exhausting all opinions and ideas, the process was repeated for the other mock-up.

To control for sequential effects, three of the five pairs were given the cube first, while the other two pairs got the cylinder first.

After seeing both mock-ups, participants were asked which one they liked best, and if they would use it as a Smart Home remote or if they preferred something else entirely. Sessions lasted about 40 to 60 minutes.

6.4 Survey results

The initial questioning about the preferred control scheme resulted in discussions about standard remotes and smartphones as these are what the participants were used to or at least familiar with. Privacy and security against outside intervention was voiced in two of the five sessions as a primary concern.

Seven of the ten participants preferred the cube model over the cylinder one, see Figure 6. Five of six preferred the cube when it was shown first, while two of four preferred the cylinder model when it was showed second.

Subjects began comparing the two models as soon as they were presented the second one. This behavior was consistent over all five pairs. The degree of preference varied between outright dismissing the cylinder, and switching preference towards the cube after learning more about it. They liked the fact, that not all information and options are shown at the same time. The possibility to accidentally turn multiple rings on the cylinder was also mention as a drawback.

Most participants were looking for arrows indicating the intended turn direction of the rings. The provided symbols were not indicative enough. Two participants also searched for a marked "zero" position. However, after additional clarification on the model's intended workings, a "zero" position wasn't a necessity for these participants after all.

A desire for markings was voiced, to indicate the scaling of the current option (e.g. a visible indication for much a ring has to be turned to increase the temperature by a certain amount and not having to discover this via exploration).

Two subjects with background in electrical engineering voiced concerns about cost, and warnings and repairs in case of possible malfunctions.

The amount and type of functions, as discussed in Section 4.2, were regarded as sufficient and fitting. Usage for oven and washing machine was dismissed by the subjects without mention by the experimenter.

The size of the cube was regarded as very fitting. It was mentioned that it should not be smaller under any circumstance, due to readability.

However, almost all participants were skeptical about actually acquiring Smart Home technology to use such a remote. When posed with the question whether they would use it if they already had access to a house or apartment with Smart Home technology, all answered with a decisive "yes".

7 BUILDING THE FUNCTIONAL PROTOTYPE

According to the participant's opinions, we decided to choose the cube version for further refinement.

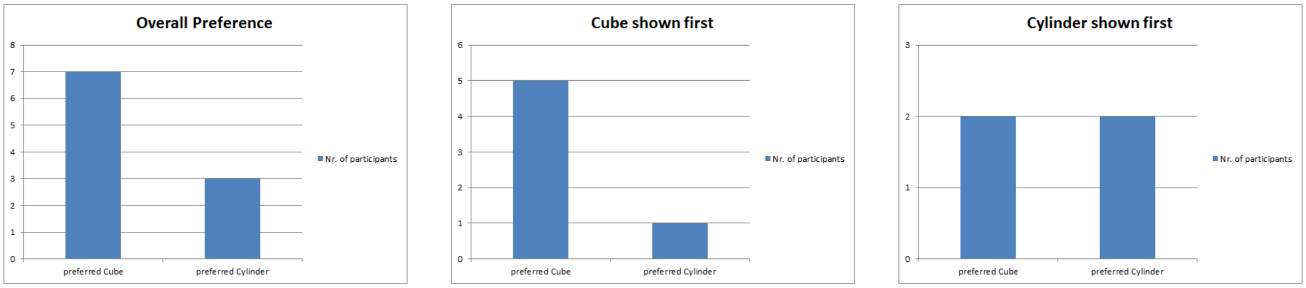

Figure 6: Preferred concept: by number of participants (left); cube concept shown first (middle); cylinder concept shown first (right).

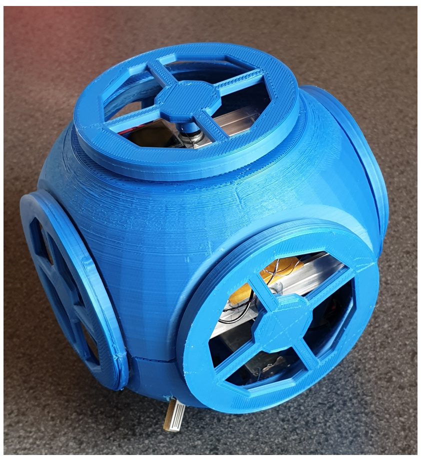

Figure 7: Final prototype with rotating rings, a small screen on one side and a USB connection on the bottom.

We created a minimal working prototype, see Figure 7, to showcase how the finished product could look like in practice. The size was slightly increased to comfortably fit-in the hardware. Its diameter increased to 9.7 cm, while the wheel's diameter increased to 6.5 cm. The wheel's thickness decreased to 0.5 cm. The casing is made of two pieces and the six wheels were printed with a 3D-printer. The required 3D models were created with the concept sketch as base. The additional indicators, that were desired by the participants were added.

All design principles, that were previously discussed, are still valid. As privacy was considered an important point by participants, it should play a deciding role, when choosing which communication protocols to use later on.

For simplicity's sake, several intended features were only implemented in a reduced fashion. Power is supplied via a standard USB type B plug. We use an ESP32 micro controller as it was readily available. The idea of a display completely covering each side of the cube was dropped for one small OLED display. An accelerometer was used to determine the side currently facing up, while only the option of this side can be manipulated via the rings. Inputs from other sides are ignored. The display is temporarily disabled while it is not facing up.

Direct manipulation is done via six rotary encoders – one for each side. The intended revolvable rings were replaced by wheels that allow sight into the prototype, to see the display mounted inside. The encoders have discrete states that snap into place to add a haptic component. The prototype itself provides no functionality besides a counter, that can be in- or decremented with the currently active wheel.

The software was written in C using the espressiv ESP-IDE. The communication between the accelerometer and the display occures via I2C.

To reduce power usage, the orientation of the prototype is updated only every 100 ms. This interval is small enough to handle normal operation while still feeling fluid.

The initial development took place on a breadboard to easily change connections on the fly. The transition to the final version – and with it the lack of space inside the casing – saw an increase in tight wire management which proved to be a challenge on its own.

8 SURVEY WITH FUNCTIONAL PROTOTYPE

To evaluate the cube prototype, a second survey was organized. The goal was to see if the participants agreed with the improvements and if they liked the way the prototype can be operated. The participants in the second survey where the same as in the first one, which contributed their input on the two presented concepts. This approach was chosen due to their familiarity with the topic and the two mock-ups, enabling a comparison between their feedback and the created prototype. The participants were put into the same five groups to facilitate discussions. Again, they participated on a voluntary basis and received no material compensation.

8.1 Survey Execution

After a quick verbal refresher, the prototype was presented to the participants. They got a short briefing on the capabilities of the prototype and were encouraged to pick it up, play around with it and think aloud.

Questions given by the experimenter included:

- "What do you think about the size?"
- "What do you think about the discrete states of the wheel?"
- "What do you think about the markings?"

Ideas given by the participants were also incorporated in later sessions. Sessions lasted about 20 to 30 minutes.

8.2 Survey results

In general, the feedback was positive throughout all groups. All participants liked the increase in size and commented on it being easier to handle. The discrete states, in conjunction with the markings, were received very positively. Three of five groups even desired more resistance when rotating to make the haptic component even more noticeable.

In four sessions, it was noticeable that the participants were very slow and timid when rotating a wheel.

One participant brought up the idea of changing the wheel into an octagonal shape (or similar) to avoid slipping. This was brought up by the experimenter in all subsequent sessions but the feedback was more on the negative side. Most participants were okay with the circular shape as-is or preferred a simple, rough surface.

Also mentioned was the idea of adding another layer of functionality to the wheels by pulling them and making them snap into a new position. This way, additional devices could be supported, depending on the current position of the wheels.

9 CONCLUSION AND OUTLOOK

In this work, we proposed a new type of tangible user interface for Smart Homes, intended for use by the elderly. We collected and evaluated multiple design principles in addition to formulating our own, to aid us in the creation of two mock-up concepts – a cube-like model and a cylinder. We then built two mock-ups out of foam, plastic and paper and evaluated them via a qualitative survey with 10 elderly people.

The cube version is the most desired one, even though the participants were still unsure whether they would want to actually outfit their own home with smart technology to make use of it. Being presented with the scenario to already own the required Smart Home technology, the participants were quick to accept the cube as user friendlier when compared to smartphone controls or touchscreen controls in general.

Building on the feedback received, we created a functional prototype using the preferred cube shape. During the building process several adjustments suggested in the previous survey were incorporated.

The final evaluation of the functional cube prototype with the same participants, was met by positive resonance and also yielded some more ideas for improvement like an additional layer of input or an angled shape instead of a ring to rotate.

Several improvements can be made to the current prototype. The use of an internal battery and inductive charging eliminate the need for cable management. Using an e-paper display, as previously suggested, can reduce energy consumption and creates a more pleasant viewing experience in darker environments. Also, using an actual ring around the display instead of a complete wheel as input makes the display itself keep the direction, not rotate.

In our opinion, the pull functionality that was mentioned by the participants in the second survey may prove too much in terms of complexity. This kind of functionality is not directly apparent and may interfere with the intended ease of use when consulting the design principles.

By making the display part of an exchangeable cover, some degree of modularity could be achieved. For this, each cover could be outfitted with an NFC chip that would indicate the part's functionality (e.g. changing temperature). Readers inside the cube would then register the chosen covers. This would enable the user to customize the provided functionalities, or simply the layout of their cube. This way, additional devices could be supported, while keeping the amount of controlled devices at the same level at any point in time.

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