MASTER‘S THESIS ASSIGNMENT

I. Personal and study details

Student's name: **Havranová Gabriela** Personal ID number: **485118**

Faculty / Institute: **Faculty of Electrical Engineering**

Department / Institute: **Department of Computer Graphics and Interaction**

Study program: **Open Informatics**

Specialisation: **Human-Computer Interaction**

II. Master’s thesis details

Master’s thesis title in English:

Dual-screen television

Master’s thesis title in Czech:

Televize s dvěma obrazovými výstupy

Guidelines:

Get familiar with dual-screen applications in the context of a household. Consider TV with a companion interaction screen (simulated with a tablet or a mobile phone) instead of the remote control. Design and implement a high-fidelity prototype of such a dual-screen television with functionalities such as a TV guide, content search, media playback, and photo viewer, controlled by an accompanying interaction screen that will not mimic the remote control buttons. Perform a usability study with a prototype to verify the design.

Bibliography / sources:

[1] Kuniavsky, M., Observing the user experience: a practitioner's guide to user research, Elsevier, 2003.
[2] Arnowitz J., M. Arent, and N. Berger, Effective Prototyping for Software Makers, Elsevier Science & Technology, 2007.
[3] Canziba E., Hands-On UX Design for Developers: Design, Prototype, and Implement Compelling User Experiences from Scratch, 2018.

Name and workplace of master’s thesis supervisor:

Ing. Ladislav Čmolík, Ph.D. Department of Computer Graphics and Interaction

Name and workplace of second master’s thesis supervisor or consultant:

Date of master’s thesis assignment: **04.02.2024** Deadline for master's thesis submission: **24.05.2024**

Assignment valid until: **21.09.2025**

Ing. Ladislav Čmolík, Ph.D. Supervisor’s signature	Head of department’s signature	prof. Mgr. Petr Páta, Ph.D. Dean’s signature

III. Assignment receipt

The student acknowledges that the master’s thesis is an individual work. The student must produce her thesis without the assistance of others, with the exception of provided consultations. Within the master’s thesis, the author must state the names of consultants and include a list of references.

Date of assignment receipt	Student’s signature

FACULTY
OF ELECTRICAL
ENGINEERING
CTU IN PRAGUE

Master's thesis

Dual-screen television

Bc. Gabriela Havranová

Department of Computer Graphics and Interaction
Supervisor: Ing. Ladislav Čmolík, Ph.D.

May 24, 2024

Acknowledgements

First of all, I would like to thank my supervisor Ing. Ladislav Čmolík, Ph.D. for his guidance and insightful inputs during creation of this thesis. I am also grateful for all the wonderful people I have in my life who supported me during the years at the university. Last but not least, I would like to thank all people who participated in user research and usability study for dedicating their free time to provide input necessary for creation of this thesis.

Declaration

I hereby declare that the presented thesis is my own work and that I have cited all sources of information in accordance with the Guideline for adhering to ethical principles when elaborating an academic final thesis.

I acknowledge that my thesis is subject to the rights and obligations stipulated by the Act No. 121/2000 Coll., the Copyright Act, as amended. In accordance with Article 46 (6) of the Act, I hereby grant a nonexclusive authorization (license) to utilize this thesis, including any and all computer programs incorporated therein or attached thereto and all corresponding documentation (hereinafter collectively referred to as the "Work"), to any and all persons that wish to utilize the Work. Such persons are entitled to use the Work in any way (including for-profit purposes) that does not detract from its value. This authorization is not limited in terms of time, location and quantity. However, all persons that makes use of the above license shall be obliged to grant a license at least in the same scope as defined above with respect to each and every work that is created (wholly or in part) based on the Work, by modifying the Work, by combining the Work with another work, by including the Work in a collection of works or by adapting the Work (including translation), and at the same time make available the source code of such work at least in a way and scope that are comparable to the way and scope in which the source code of the Work is made available.

In Prague on May 24, 2024 . . . . . .

Czech Technical University in Prague
Faculty of Electrical Engineering

Citation of this thesis

Havranová, Gabriela. *Dual-screen television.* Master's thesis. Czech Technical University in Prague, Faculty of Electrical Engineering, 2024.

Abstract

With the ever increasing usage of touchscreen devices, the potential for using these devices as controllers for television systems presents an intriguing opportunity for exploration. This thesis investigates the feasibility and user experience of using a touchscreen device as a television controller. User research involving 76 participants was performed to gather necessary data about needs, preferences and problems of television users. Based on the identified issues, a dual-screen television application prototype was created. This high-fidelity prototype was later evaluated through a usability study of 10 participants, who tested the prototype and provided feedback about their experience. The results indicate that using a touch device to control television may be a viable alternative to traditional button-based controllers, as it provides intuitive controlling interface, comfortable text input method and additional content complementary to main screen.

Keywords dual-screen interaction, touchscreen TV controller, interactive television

Abstrakt

So stále rastúcou popularitou používania dotykových zariadení sa poskytuje zaujímavá príležitosť na preskúmanie možností využitia takýchto zariadení v kontexte ovládania televízie. Táto práca skúma vhodnosť a používateľský zážitok z používania zariadenia s dotykovou obrazovkou namiesto televízneho ovládača. Uskutočneného používateľského prieskumu sa zúčastnilo 76 participantov, vďaka ktorým bolo možné získať potrebné údaje potrebách, preferenciách a problémoch ľudí používajúcich televízne zariadenia. Na základe zistených problémov bol vytvorený prototyp televíznej aplikácie s dvoma obrazovkami. Tento prototyp bol neskôr vyhodnotený prostredníctvom štúdie použiteľnosti s 10 účastníkmi, ktorí prototyp testovali a poskytli spätnú väzbu o svojich skúsenostiach. Výsledky štúdie naznačujú, že používanie dotykového zariadenia na ovládanie televízie môže byť vhodnou alternatívou k tradičným tlačidlovým ovládačom. Účastníci na prototype ocenili intuitívne ovládacie rozhranie, pohodlný spôsob zadávania textu a prítomnosť doplnkového obsahu dopĺňajúceho hlavnú obrazovku.

Kľúčové slová televízia s dvoma obrazovkami, dotykový televízny ovládač, interaktívna televízia

Contents

List of Figures

Introduction

Television technology has evolved rapidly, introducing novel ways to interact with and control our viewing experiences. As the usage of touchscreen devices continues to grow, the prospect of using a touch device as a controller for television presents an intriguing path worth exploring.

This thesis focuses on investigation of the feasibility and user experience of using a touchscreen device to control television sets. Aim is to determine what are the primary issues of television users regarding their controllers. The primary goal of this thesis is to create a high-fidelity prototype of television application with companion touch screen controller application which should address the main pain points of television users. Part of this assignment is to identify what actions and content should be presented on the companion controller, as it should not mimic the classical controller with buttons, but provide additional content adjusted to the visuals presented on the main television screen.

The following chapter *Analysis* provides an overview of existing television technologies and currently common usages of dual-screen interactions, setting the foundation for the research. At the beginning of chapter *User research* I will present an overview of user-centered design methodologies and various data collection techniques. Following this, I will detail the specific data collection method employed in my user research, along with the results and insights gained regarding user preferences, behaviors, and needs within the context of their current television usage. Next, the *Design of the solution* chapter outlines the concept and planning of the dual-screen interface, including the design principles and selected features to meet user functional and non-functional requirements. Possible content placement on the respective controller and television screens is discussed in the design as well. Fourth chapter describes the development of a functional prototype application, elaborating on the technical implementation and the integration of various functionalities such as browsing media, content search and media playback. The *User testing* chapter presents the results of usability studies performed with

the prototype, evaluating its effectiveness and user satisfaction. Finally, the Summary chapter concludes the findings, discusses the implications of the research, and suggests potential future work in the domain of dual-screen television applications.

Goals and subtasks

The primary goal of this thesis is to evaluate the viability of using a touchscreen controller, simulated by a smartphone or a tablet, to control a television. This involves exploring the potential and effectiveness of touchscreen interfaces as alternatives to traditional remote controls. Goal of this thesis can be subdivided into following subtasks:

Perform an analysis of existing solutions

Perform a research about currently used television technologies and relevant applications of dual-screen interfaces.

Understand user needs

Investigate how users currently interact with their televisions and identify any significant needs, preferences or features that a touchscreen controller could address.

Explore possible application designs

Define the various interaction techniques which a companion touch controller can provide and describe multiple ways how to split the content between the two screens. Discuss possible problems of the prototype, such as dividing the user's attention between two screens and create the design attempting to minimize the impact of identified problems.

Create a usable prototype

Develop a high-fidelity prototype of the application that allows for the testing of various interaction techniques. This prototype should be suitable for conducting user tests.

Conduct user testing

Design test scenarios and conduct usability testing with a selected number of users. Gather feedback and insights on the user experience and effectiveness of the touchscreen controller.

Evaluate testing results

Analyze the feedback and data collected from the user testing phase. Identify the strengths and weaknesses of the prototype and suggest possible enhancements and improvements based on the findings.

Chapter 1

Analysis

In this section, I will provide a comprehensive overview of the essential theoretical foundations, key terminology, and relevant technologies crucial for a thorough comprehension of the thesis topic. A detailed examination of television input methods will be undertaken, exploring both their advantages and limitations. Finally, an overview of existing dual-screen technologies and associated solutions will be presented.

1.1 Television set

Significant part of this thesis will be referring to the term "TV", but what it is, exactly? In this thesis, I will be using term television or shortly TV as a television set. A television set is an electronic device designed for the reception and presentation of television broadcasts or, alternatively, as a computer monitor [1]. It integrates a tuner for channel reception, a display for visual output, and built-in loudspeakers for audio reproduction.

1.2 Smart television

A Smart television (Smart TV) represents a fusion of traditional television sets with integrated internet access. This connection of technologies transforms TVs into multifunctional devices, offering users the ability to stream music and videos, browse the internet, and view photos. Smart TVs feature preloaded operating systems embedded in the firmware, granting access to a variety of apps and digital content. This stands in contrast to traditional televisions, which primarily serve as displays with limited vendor-specific customization. Applications on smart TVs can be preloaded, updated, or installed on demand through application stores, mirroring the integration model seen in modern smartphones [2].

The technology enabling smart TVs is not confined to television sets alone; it extends to external devices such as set-top boxes, Blu-ray players, game consoles, digital media players, smartphones, and other network-connected interactive devices. This broader ecosystem empowers users to discover and enjoy videos, movies, TV shows, photos, and additional content from the internet, cable or satellite TV channels, or local storage devices [3].

1.3 Smart TV operating systems

Television itself is not required to have any operating system in order to function. On the other hand, the operating system is one of the main things which make smart TV "smart". It enables the use of advanced features like installing apps, accessing the internet and others using user interface. In this section I will briefly mention a few most popular [4] TV operating systems as of 2024.

Android TV

Developed by Google, Android TV is an open-source platform widely used by various TV manufacturers. It offers a vast range of apps and services through the Google Play Store, and it is known for its user-friendly interface [5].

tvOS (Apple TV)

Exclusive to Apple TV devices, tvOS is Apple's operating system designed for television. It integrates seamlessly with the Apple ecosystem, providing access to the App Store, Apple Music, and other Apple services [6]. It is worth noting that tvOS does not actually operate on a TV, rather than AppleTV multimedia device, which I will describe later in this chapter in Section 1.5.

webOS (LG)

Developed by LG, webOS is an intuitive and user-friendly operating system used in LG smart TVs [7]. It features a unique card-based interface, offering smooth navigation and easy access to apps.

Tizen (Samsung)

Tizen is an open-source operating system developed by the Linux Foundation and primarily used by Samsung for its smart TVs. It supports a wide range of apps and services, and it's known for its fast performance [8].

Roku OS

Roku OS is used in Roku streaming devices as well as smart TVs from various manufacturers. It provides a straightforward and customizable interface, and

it's known for its extensive library of streaming channels. Roku is, according to their pages, the most popular streaming platform in the US. Similar to tvOS from Apple, Roku OS is mostly running on a dedicated streaming player which users need to buy [9]. However, there are some manufacturers offering television sets with built-in Roku receiver, e.g. TCL [10].

1.4 TV broadcast

The traditional and widely used method for accessing television channel is through terrestrial television, commonly referred to as over-the-air television (OTA). This broadcasting method involves the transmission of signals via radio waves from a terrestrial (Earth-based) transmitter belonging to a TV station to a TV receiver equipped with an antenna [11] [12].

It is a cost effective method, as it requires only a TV antenna, which is a one-time cost. No subscriptions are required. However, channels being broadcasted are depending on the area and may be limited.

1.5 External digital media players

External digital media players for TVs are devices that can be connected to a television set to enhance its multimedia capabilities. These devices typically provide access to a variety of online streaming services, local media playback, and other entertainment options. We'll describe capabilities of two most common.

1.5.1 Apple TV

Apple TV is a microconsole and digital media player created and sold by Apple Inc. Functioning as a compact network appliance, it transmits received media, comprising video and audio content, to a television or external display. The device offers diverse media services, encompassing streaming content, access to local media, sports journalism, and broadcasts [13].

Apple TV, however, does not replace TV providers and users still need to connect their pay TV or cable TV to watch live channels. Physical remote features a touch panel for navigation in the system using touch gestures and a few standard buttons, as "menu" or "back". Voice control is available as well using Apple's Siri.

1.5.2 Chromecast

Similarly to Apple TV, Chromecast is a small multimedia device created by Google. It is designed to be connected to most modern televisions, either via HDMI or USB-C connector, depending on the Chromecast version. Most

recent version – Chromecast 4, has a full Android 10 with Google TV interface, enabling users to download anything compatible. Chromecast device has its own bluetooth remote controller. Voice control using Google assistant is possible as well [14].

1.6 Television input methods

In this segment, I will explore various options for controlling the television. I will approach the descriptions mostly from an interaction standpoint, meaning that several of these input methods can be (and often is) integrated into a single device.

1.6.1 Remote control with physical buttons

A television controller typically consists of a handheld device that allows users to operate and navigate the functions of the television wireless. The remote control usually includes various buttons or features for controlling aspects such as power on/off, volume adjustment, channel selection, and menu navigation. Navigation in the menu is done by pushing arrow buttons on the circular pad. Functionality of these arrows can be contextual and can work not only for menu navigation but for switching the channels and/or volume control. Most prevalently, the remote communicates with the television through infrared signals. In that case, the remote control contains a rapidly flashing infrared light diode that transmits a message, which is detected by the TV [15].

On the other hand, equipping the remotes with bluetooth connectivity is gaining in popularity in recent years. There are multiple reasons for its use, bluetooth enables better signal transmission, pairability with multiple devices and better transmission range, to name a few. Moreover, bluetooth protocol enables the use of integrated voice control, which was not possible when using IR protocol [16].

The remote controller can feature a keyboard for text input, either partial like T9, or full QWERTY layout. If the remote does not feature an additional input method, writing text on the TV may be impractical, when users have to click on virtual letters using arrows and select button.

1.6.2 Voice control

With the rise of voice assistants like Google Assistant, Apple's Siri, Samsung's Bixby and others, using voice commands is another possibility of TV control and navigation. Voice controlling can provide additional features which can't be done with basic TV remote alone, like interpreting complex commands. For example, a user can say: "Recommend me a Quentin Tarantino movie", and the system can search within available streaming applications and suggest movies upon request. This input method, however, can come with some

drawbacks. For example, LG states [17] that their voice assistant works only when the TV is connected to the internet, which may be an issue in some locations. Furthermore, they claim that voice recognition may fail due to incorrect speech speed, pronunciation, intonation and ambient speed, which may be cumbersome while watching TV with friends and family. Lastly, the language support, or its recognition precision may be limited.

Voice control can be bound either to the TV only, in which case the user usually push a certain button on the remote controller to enable the speak recognition, or the TV can be controlled by standalone assistant, like Google Assistant [18] or Amazon's Alexa [19].

1.6.3 Virtual cursor

Some Smart TVs are expanding their remote controller functionalities by enabling them to act as a computer mouse by moving the remote control in the air, which consequently moves a virtual cursor on the screen, similarly to mouse cursor on the computer. This can be useful for internet browsing, however, might be unintuitive for elderly people or just a less technical population. As for disadvantages, LG states in their Magic Control manual [20] that "The Magic Remote depletes batteries faster than a normal remote due to the additional features." Another drawback may be lack of optimization for text input, as with virtual cursor users still have to click on virtual letters on TV screen one-by-one, which is time consuming.

1.6.4 Touchpad

As seen in Apple's TV or Samsung controllers, TV remote can be equipped with touch panel to expand its possibilities of navigation [21] [22]. Both (and possibly other) companies use the touch panel for touch gesture recognition to navigate in the television's user interface. Gestures are used similarly as in smartphone devices and are mostly consisting of swipes and clicks. Touch pads or panels on remotes may be used as regular buttons as well, which offers wider control options for diverse types of users. Panel can come in different shapes as seen on Figure 1.1, where on the left side is a Samsung remote with a rectangular touch panel. On the contrary, Apple chose a circular shape while adding recognition of another touch pattern on the outer circle of the joystick.

1.6.5 Keyboard and mouse

Another option to control the TV is direct connection of the wireless keyboard to TV. Using the remote control to search for shows or navigate websites can be tedious, requiring scrolling through each letter of the alphabet. This process can be even more frustrating when typing longer texts such as messages or using a smart TV's web browser. However, connecting a keyboard to your

Figure 1.1: TV remote controllers equipped with touch panels, Samsung Smart Touch Control (left) [23], Apple Siri remote (right) [24]

smart TV facilitates a more familiar and efficient typing experience, enabling you to input search commands, browse websites, and compose messages in a more familiar way, like on PC. However, having a full-sized keyboard in the living room may not be up to everyone's taste. Moreover, keyboard connection may not be supported by TV at all, or the manufacturer compatibility may be limited [25].

1.6.6 Smartphone controller apps

With use of Infra-red diode

Some smartphone manufacturers are adding a infra-red blaster to the phone's hardware configuration. The motivation is mostly to be able to control the TV using a smartphone app. Apps using built-in IR modules are usually mimicking the physical remote by showing the user set of virtual buttons. After clicking, the phone sends IR signals to the television receiver, controlling it.

Having a TV remote in the pocket has several advantages. It's not easily lost and can be rang up, it is possible to control multiple devices by a single controller and you do not have to think about the battery of the physical remote, since the user is charging their phone anyway. On the other hand, these apps are often limited to the non-exhaustive list of manufacturers and devices, in which case it can happen that some user's TV is simply not supported and

therefore they can not use the app controller altogether [26]. These built-in application often just mimic a physical controller with interface composed of buttons and navigation joystick in the middle with no additional functionalities, as seen on Figure 1.2.

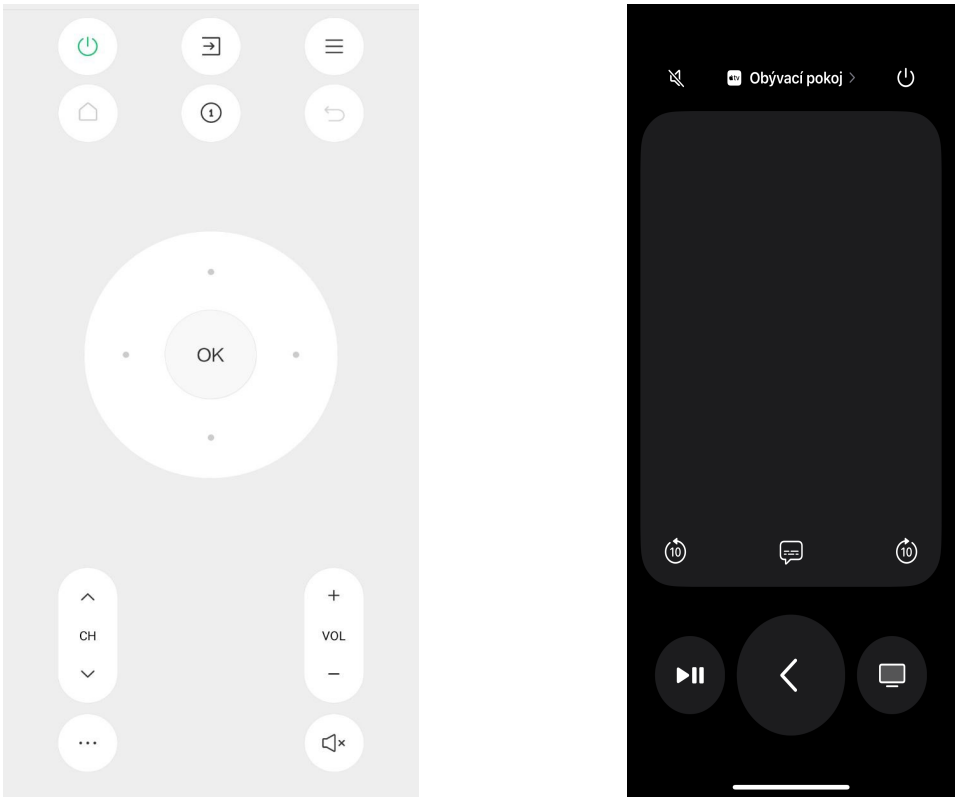

Figure 1.2: Interface of virtual controller in Mi Remote application on the left (screenshot taken on Xiaomi Redmi Note 8 Pro), interface of the Apple TV Remote on the right (screenshot taken on iPhone 14 by Tomáš Štefan)

Without use of Infra-red diode

Multiple TV manufacturers provide an option to use separate smartphone application as a virtual TV remote [27] [28] [29]. Infra-red diode is not required, as these applications use either bluetooth connection, or need the smartphone to be connected over wi-fi to the same network as the television. From the interface perspective, these applications basically mirror the physical controller functionalities, not utilizing the benefits of dynamic touchscreen. On the right side of Figure 1.2 is a screenshot of the Apple TV Remote application, which is pre-installed on iPhone smartphones. The application features very similar controls as its physical counterpart on Figure 1.1.

Other solutions

Around 2013, American company Vizio experimented with shipping their televisions with phone controllers. Specifically, Vizio introduced a series of televisions that came with an Android smartphone serving as a remote controller. This initiative was to push smart technology integration into their TVs, utilizing the capabilities of smartphones to enhance the user experience [30]. However, the project seems to be discontinued and I was not able to find reasons why it was not successful.

1.7 Dual-screen technologies

1.7.1 Miracast

Miracast is a wireless communication standard developed by the Wi-Fi Alliance that allows devices to mirror their screens to external displays such as TVs, projectors, and monitors. It works over Wi-Fi Direct, meaning it can establish a direct peer-to-peer connection without the need for an internet connection or router [31]. It may be used for various scenarios like streaming videos, sharing presentations, or simply mirroring smartphone screens to larger displays.

Despite its convenience, Miracast can have stability and latency issues, which can lead to image inconsistency between source device and target screen. This can be problematic for interactive applications like gaming. Miracast primarily only supports screen mirroring, meaning the screen content is duplicated rather than allowing multitasking [32].

1.7.2 Airplay

Another dual-screen technology intended for screen sharing from Apple devices. "AirPlay lets you share videos, photos, music, and more from Apple devices to your Apple TV, favorite speakers, and popular smart TVs" [33]. As opposed to Miracast, Airplay supports both screen mirroring and additional controls of mirrored contents such as controlling volume and video playback. However, its support outside the Apple ecosystem may be limited.

1.7.3 Air console

AirConsole is an online video game console that creates a new way to share multiplayer games. It enables users to play together on a shared screen using their smartphones as controllers, with a session code entry. Their catalog features over 180 games designed for its multi-screen setup. AirConsole's optimized games run locally on devices, eliminating the necessity for fast internet connection typically associated with game streaming [34].

From the context of this thesis, the concept of multiple interconnected screens with a single main display communicating with low latency is something that we aim for and may get inspiration from.

1.8 Analysis summary

In this chapter, I summarized all the relevant research regarding existing television technologies and dual-screen interactions. Although technologies similar to the proposition of this thesis already exist, I was not able to find a reference to a solution of television controller application, which would combine aspects of intuitive touch-based interface, comfortable text input methods, and complementary content presentation on a secondary device. This highlights the potential for innovation in creating a more integrated and user-friendly television controller application. The overview of existing technologies summarized here provide the basis for the design and development phases. However, in order to better understand user needs, a user research needs to be conducted, which I will outline in the following chapter.

Chapter 2

User research

In the beginning of this chapter, I will provide a general overview of user research, discussing the various methods available for conducting it, and highlighting its significance in the user-centered design process. Following this, I will provide details about the chosen approach I used to conduct user research. User research was performed to gather data required for creation of high-fidelity television controller application prototype.

2.1 What is user research?

User research involves studying target users, including their needs and challenges, to provide designers with insights for optimal [35] design outcomes. Utilizing a range of methods, user research uncovers issues, identifies design opportunities, and gathers essential information to perform the design process of a project effectively.

2.2 Purpose of user research

Without user research, people tend to project their own problems [36] and base designs on assumptions, which may be often incorrect. Taking the time to engage with real users and actually understand their problems is crucial for design of usable products. Performing the research is often the first step [36] of a UX design process, which involves not only collection of the data, but the cleaning, interpreting and other post processing, as well.

2.3 Systematic errors

Systematic errors, also called “biases” are different in nature from random errors. While random errors cause variations in observed values in both directions around the actual value, systematic errors push the observed values

in the same direction. As a result, they cause the observed mean to be either too high or too low.

We should try to eliminate or control biases during the experiment when biases are inevitable, and we need to isolate the impact of them from the main effect when analyzing the data. There are five [37] major sources of systematic error: measurement instruments, experimental procedures, participants, experimenter behavior and experimental environment. Since this section is just an overview of user research to give the reader needed context, a curious reader can find more details about user research biases in the cited book.

2.4 Sampling strategies

Random sampling

Random sampling consists of selecting participants from a pool with an equal chance for each person to be chosen. While this method is straightforward, it may not always be optimal for pre-qualification and ensuring inclusivity [38] because minority groups may be overlooked. It remains essential to ensure that the original sample adequately represents the broader population and includes minority groups.

With *simple random sampling*, we randomly choose first n participants from the whole pool. This approach is as random as possible, but it is not representative, as we might select too many people from certain groups and miss other people from minorities.

Systematic random sampling may be more viable, since we split the pool of people into groups that match a specific industry. Then, we choose randomly, but proportionally to the size of each group, which leads to more representative selection.

Non-random sampling

One of the non-random sampling methods is *quota sampling*. Using this method, respondents are chosen based on categories that match the study's requirements. With every extra quota, it may take longer to find suitable respondents [39], which adds costs and time to the quota sampling process.

Snowball sampling is another popular method [40] of sampling user research, where researchers usually start with a small number of initial contacts (seeds), who fit the research criteria and are invited to become participants within the research. The participants are then asked to recommend other contacts who fit the research criteria and who potentially might also be willing participants, who then recommend other potential participants, and so on. Sampling usually finishes once either a target sample size or saturation point has been reached.

Self-selection sampling is useful when we want to allow participants to choose to take part in research on their own [41]. It can be used with a wide range of research designs and research methods. For example, scientists that conduct experiments using human subjects may advertise the need for volunteers to take part in drug trials or research on physical activity. The key component is that research subjects volunteer to take part in the research on their own, they are not approached by the researcher directly.

2.5 Methodology

User research methods may be divided into two major groups.

Quantitative research

Quantitative research provides explanations that can be measured and communicated with numbers and statistics. While qualitative researchers might visit subjects in their homes or otherwise in the field, quantitative research is usually conducted in a controlled environment [37]. Instead of gaining insight or understanding into a subjective, context-dependent issue, the goal is instead to obtain objective information. Quantitative research can be used for hypothesis testing.

Qualitative research

Qualitative research differs from quantitative research in its objectives, techniques, and design. It aims to gain insights into phenomena, groups, or experiences that cannot be objectively measured or quantified with numbers. It is an exploratory form of research, providing an understanding of complex situations [37] and behaviors. Examples are interviews, focus group, case studies, and others. These methods are, usually, used for hypothesis forming instead of testing of already created hypothesis.

2.6 Conducted user research

Since the goal of this thesis already defines some structure of the thesis, I had chosen structured interview as suitable user research method, combining both closed-ended to gain statistical data and open-ended questions to find new insights from users. As a platform for the survey creation I chose Google forms [42], because of its simplicity and popularity [43] among users.

Survey was conducted in my native Slovak language, as it was intended to be shared locally, in the Czech and Slovak republic. Thus, results could be different if the survey respondents were international (e.g. many TV providers are local). Gathered raw data from the survey (in original Slovak language) can be found attached to this thesis in file *user_research_data.xlsx*. In this

section I will summarize insights I found interesting, and/or valuable for development of the final prototype.

2.7 Target group

This user research is directed towards a general adult population with a fundamental understanding of technology, including basic knowledge of concepts such as smart TVs and streaming services. This target group encompasses individuals who, while not necessarily considered highly technical, are comfortable with common digital technologies and possess a basic awareness of smart television features. A target user is watching, or using TV at least once a month.

Less technical-oriented people are not completely excluded, however, since the goal is to create multi-device prototype with usage of smartphone to control the TV. Therefore, it is possible that the prototype may not be too intuitive for elderly or people completely uninterested in technical gadgets.

2.8 Research questions

Following questions should be answered by the user research:

- What are users mostly using the TV for?
- What TV features users like?
- What TV features users dislike or miss?
- What part of TV users still watch TV broadcast?

2.9 Methodology

Structured interview

Choosing an online survey for user research, combining open-ended and closed-ended questions, offers both time efficiency and cost effectiveness. Participants can provide honest feedback anonymously in the comfort of their home, not freezing outside. The mix of question types allows for a comprehensive understanding, with closed-ended questions providing quantitative data and open-ended questions capturing qualitative insights. Conducting the interview online can be also considered as part of the screening process, as the respondents had to use some device connected to the internet, which implies basic technical literacy.

I reached the respondents in two ways, using Snowball technique when I sent the link to my friends and asked them to send it further to their friends

and parents. After that, I posted the questionnaire link to Facebook group "Letenska parta" which is a community online group for people living in a certain part of Prague. By posting it in a public group without any age constraints, I was able to get responses from a more diverse group of people, thus making the responses more representative.

Structure of the survey

Survey was split into multiple sections to better organize and categorize the nature of the questions contained in each section:

- Section A: Intro

  Initial section of the survey contained general questions about the participant's age group, whether they use television and if so, how often.

- Section B: TV usage

  In the case the respondent answered that they use TV, this section contained questions getting more insights to their behavior, watching patterns and user experience of watching TV and its controlling options.

- Section C: TV broadcast

  This section was dedicated to getting information about watching TV broadcast, specific functionalities of TV broadcast and providers of cable or satellite television.

- Section D: Not watching TV

  Respondents who do not use TV were asked in this section more details about the reasons not having or using the television.

- Section E: Space for feedback

  Final section for every path possible, this part of the survey was intended to give respondents space for feedback both to the TV and to the survey itself.

As I mentioned earlier, I used Google Forms platform to conduct this survey which allowed me to create conditional form traversal based on chosen answer. There were three possible paths to fill out the form from beginning to the submitting of the form, which is shown on Figure 2.1 in the form of UML diagram. If respondents stated in Section A that they watch TV less than once a month, they continued only with section D and E, as it would not make sense to ask people questions about television details if they do not use it. On the other hand, instead of just ending the survey right away, I tried to get as much information as possible, therefore the additional "Not watching TV" section was used, to gain some insight why people do not use TV and what could possibly motivate them to use it.

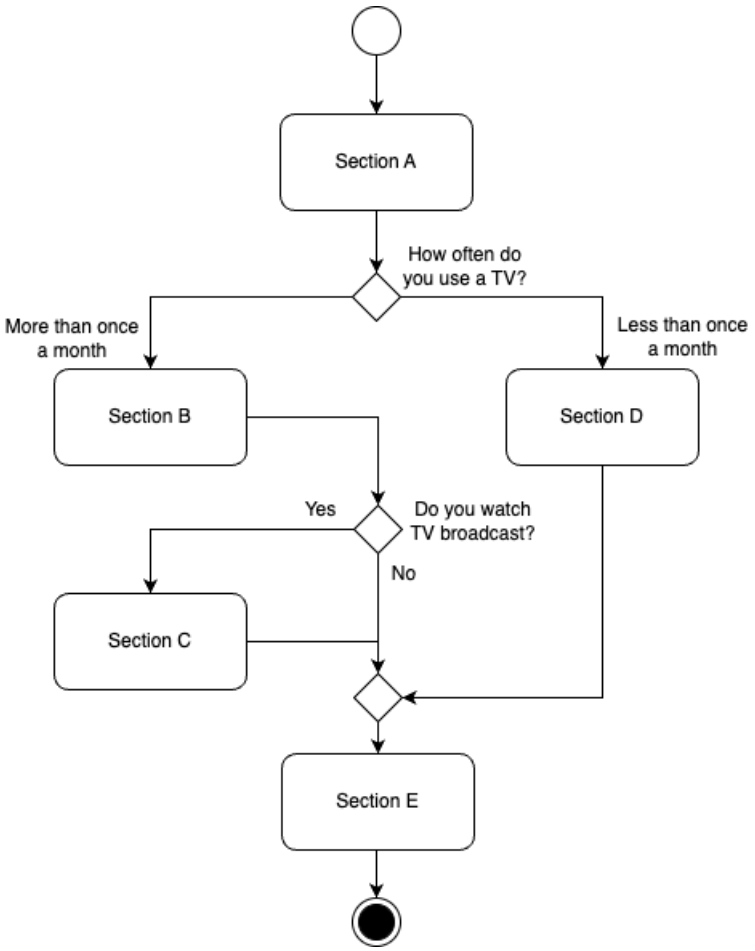

Figure 2.1: UML diagram of possible survey traversals

2.10 Response analysis

2.10.1 Data cleanup

Since multiple questions from the survey were open-ended or had an option to add their own response, data cleanup is necessary to enable further processing. I grouped the responses and removed outliers wherever applicable. Complete original responses (not translated) may be found in the Appendix of this thesis

2.10.2 Respondents

Total number of respondents in this user research was 76. Participants were all adults, mostly in productive years with only 3,9% people of 65 years of age and above as seen on Figure 2.2. In the context of this thesis, it is not an

issue, since the target users are people, which have at least basic technological literacy.

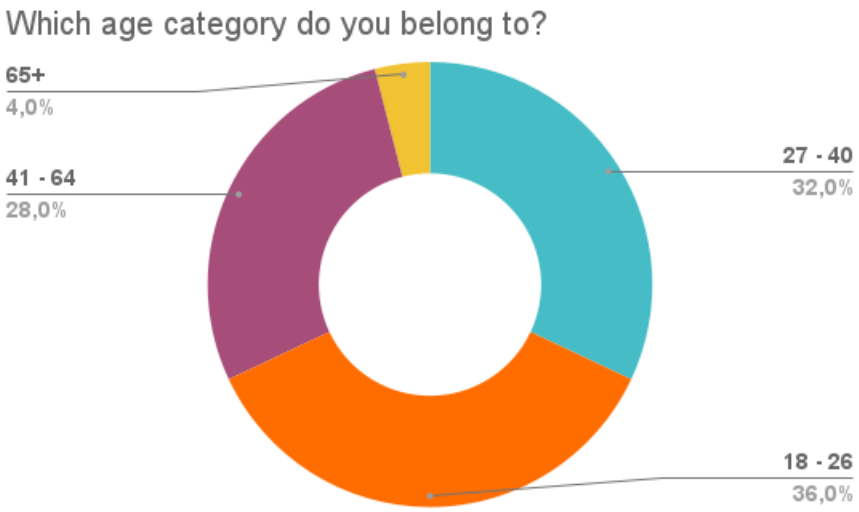

Figure 2.2: Age distribution of user research participants

2.11 Remarks and findings

Most respondents using TV are using it as it is primarily intended – for watching content, either TV broadcast or using streaming services. Minority of respondents stated playing games on consoles and content sharing as well. No additional patterns of TV usage was found in the responses.

Most popular television apps

One of the findings of this user research was that streaming apps are the most popular among television users. As seen on Figure 2.3, we can see that practically all the answers are either streaming apps, TV broadcast apps, or YouTube. Only two respondents mentioned Spotify, but that's another streaming app, just without the video.

Frequency of the TV usage

Among the respondents, 81% use TV at least a few times per month. Out of those, 69% of people are watching TV broadcast on a regular basis. While it is not possible to generalize these numbers to the whole population because of limited sample size and possible selection bias, we can deduce that still a large portion of TV users are actually watching TV broadcast and not everybody

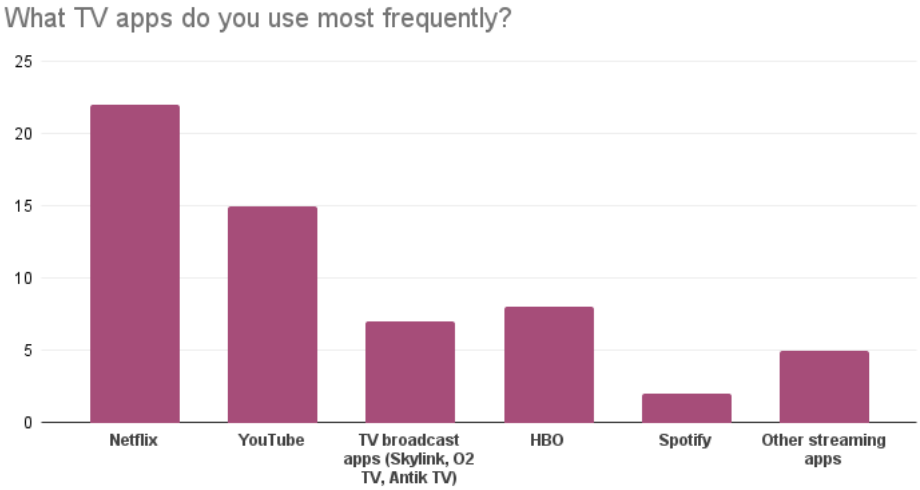

Figure 2.3: Most frequently used apps

switched to streaming applications only. Therefore, there is still a large target group of people who would benefit from improved controls and user experience of the television interface.

Used TV schedule sources

Based on this user research, the most common way to find out about TV schedule is using an EPG view directly on TV. Second most common source is the internet. Using physical newspapers as a TV program is seemingly on decline, as only one respondent chose this option as a used source.

Common issues

High response time and receiving insufficient feedback from controller cause that users often don't know if push of button was recognized by the TV. Searching for movie among apps is tricky and time-consuming.

Overall satisfaction with the text input methods is low. Only 4 respondents stated that they are fully satisfied with the text input method they are using, of which 2 people are using an external wireless keyboard and one is using voice control. On scale 1 to 5 (where 5 is full satisfaction), average satisfaction with the text input method of selecting each character on a virtual keyboard on screen was only 2.4 points.

Endorsed features

TV broadcast archive, pause and fast-forwarding were definitely the most endorsed features among respondents. Lots of advertisements and time flexibility are probably the main reasons why people tend to prefer watching TV shows and movies from archive rather than from regular broadcasts. Few respondents mentioned that they would appreciate an infinite archive and easier fast-forwarding, which can be tricky when the television is not responding to the controller very well.

More than half of respondents belonging to the TV users group are using the remote control either solely by touch, or at least the most used buttons without looking at the remote. This may be a disadvantage when having control panels on the smartphone which does not have physical buttons nor tactile bumps, and will have to be considered when designing the controller prototype.

Missing features

Most surprising (to me, personally) was to find multiple requests for picture-in-picture feature. Despite that this feature was not mentioned anywhere in the survey, 4 people mentioned it in free-text responses to the missing features, which I find to be a significant number out of 43 respondents watching TV broadcast.

Voice control was frequently mentioned as well, however, this feature is already available in a more recent TV models so it is up to users to get a TV model which supports voice control.

Other requested features were content sharing from various devices, child lock of settings, change of audio language in TV broadcast and easier text input.

One TV was (maybe) hurt

As a refreshing question to keep respondents focused when filling out the form (and of course to gain potentially valuable data), I asked respondents whether they've ever broken either controller or TV itself due to frustration from using it. As a detail to this question was the sub-question "What lead to this event?". Most of the responses were either empty, or simple "no". However, there was one response stating "slow internet connection". What exactly happened to this TV we will never know. Unfortunately, for the purpose of this thesis, there is hardly anything valuable I can do about slow network and there are plenty of other ways to vent frustration and manage anger.

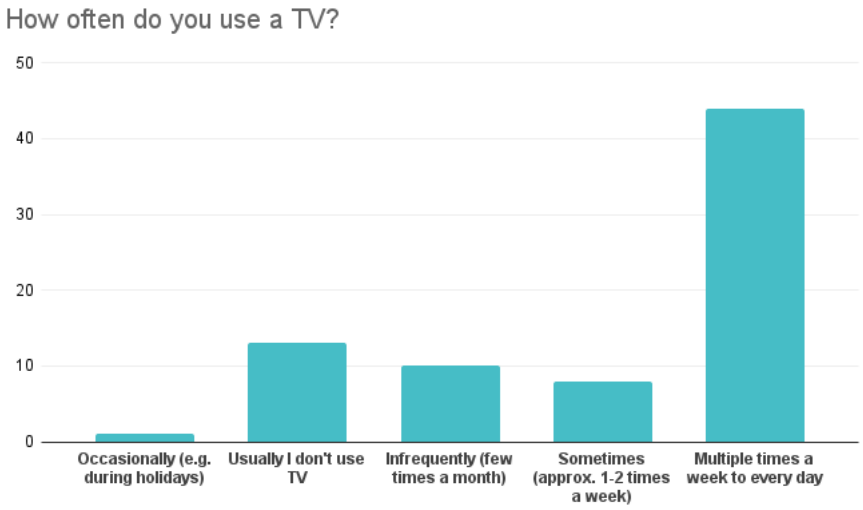

Figure 2.4: Average frequency of TV usage by respondents

2.12 User requirements

By summarizing the outputs from the conducted user research, following user requirements were identified:

- Comfortable and fast text input

  With the increasing integration of smart features within modern televisions, text input is essential for tasks such as search, browsing, and interacting with various applications. Making the text input method more simple and intuitive would enhance user engagement and satisfaction.

- Responsiveness and instant feedback of controller

  By using older remote controllers, users were often confused if the press of the button was recognized by the television receiver, which may lead to frustration. Thus, clear feedback from the controller to let the user know that the action was recognized is crucial when developing a new input method.

- Some version of picture-in-picture

  This feature enables users to view multiple content sources at once, facilitating multitasking and improving the viewing experience. Picture-in-picture functionality offers users greater flexibility and control over user's viewing preferences, which leads to greater satisfaction with the product.

2.13 Conclusion of user research

In conclusion, the performed user research on television usage and user experience has provided valuable insights into the needs and preferences of the users. Through a combination of open and closed-ended questions in the survey questionnaire, I had identified key user requirements that show the importance of prioritizing comfort, responsiveness, and multitasking capabilities in the development of television interfaces.

Considering the predetermined goal of this thesis, which was to create a dual screen television, the user research aimed to validate its viability and gather supplementary data. In this context, I would consider the research successful and the chosen method of online survey adequate. However, in the case of developing something new without any restrictions or guides, I would choose an in-person interview over the online survey.

Chapter 3

Design of the solution

In this chapter I would like to discuss possible interaction techniques and application design patterns for the implementation of a testable prototype of television application. Based on user-centered design principles [44], design should reflect on results of previously conducted user research and provide solutions to the identified user goals, requirements and pain points, summarized in the previous chapter.

3.1 Functional requirements

Main requirement for the prototype application is to support two interconnected devices, where one acts as the main television screen and the other serves as a touch screen controller for the main TV screen. The touch screen controller should seamlessly merge traditional remote control capabilities with an innovative feature that allows the display of additional interactive content. This application is intended to enhance the user experience and provide a comprehensive control interface.

In the first place, the prototype should be able to act as television remote control replacement. However, from this thesis' assignment, mimicking the buttons on the screen one-to-one should be avoided. Secondly, apart from the controlling actions, the application prototype should be able to show additional content related to the one on the screen, for example showing the description and rating of the currently playing movie.

As the text input was identified as the main pain point for the majority of questioned TV users in Section 2.11, this problem will be addressed in the implemented prototype and will provide full-sized QWERTY keyboard, enabling the users to type the text faster and more comfortable.

Based on the data from conducted user research, people usually do not like watching advertisements and they like to skip it if possible. However, fast-forwarding on many television devices currently requires holding down

a single button and waiting for the exact moment when to release it. This action can be definitely improved to be more comfortable and faster.

Another identified requirement is to create a picture-in-picture mechanism, meaning that users can perform actions on the controller without disrupting the currently running show.

3.2 Non-functional requirements

As the controller will be the only input device directly controlling the TV content, the primary non-functional requirement for this prototype is creating a real-time communication channel, so the response time of the screen is as little as possible, allowing for seamless and comfortable navigation through the application interface. On the other hand, the communication has to be reliable, so users can be ensured that every action that they performed was registered and acted upon, so handshake based protocol as TCP (Transmission Control Protocol) should be preferably used over UDP (User Datagram Protocol). Providing users instant feedback for their actions on both screens naturally solves the issue when users are not sure if a press of button was registered or not. Haptic feedback as device vibrations could be provided additionally, for more comfortable interaction experience.

3.3 Dual-screen content design approaches

There are multiple possibilities how to approach the dual-screen application architecture on the high level. When designing the prototype, I considered following combinations:

- **Main screen and controller show the exactly same content**

  Users should be able to fully control the application without looking at the main screen at all. In this case, the content is completely mirrored between the main screen and controller and any action performed within the screen (e.g. scrolling) is immediately reflected on the main screen. This can be viable in scenarios like browsing for a content with multiple people in the same room, when others want to see what the user controlling the TV is searching for.

- **Controller showing reduced, action-focused content**

  In this case, users should be able to perform actions just from looking at the controls on the phone, however, looking on the main screen to find additional information may be required. Action-focused content may be useful for quick actions or shortcuts, where the full description of the content on the main screen would not fit on the smaller companion device.

- **Controller showing complementary actions and/or information**

  Third case I considered is a scenario, when the controller shows complementary actions or information complementary to the content on the main screen. This content would be shown on the controller screen exclusively, meaning that the user would not find it on the main screen at all. This scenario can be used for example while playing some content on the main screen, the controller would show video playback controls, volume controls, additional information about the content like description, rating, duration and others. Possibility of browsing other content while already playing something on the main screen also falls in this scenario.

3.4 Design problems to tackle

3.4.1 Complexity of the user interface

Most significant challenge to address is the issue of users feeling disoriented or lost within the content. When using two screens at the same time, users may alternate their attention between multiple screens. This continuous back-and-forth movement, such as looking up and down between different display surfaces, can disrupt the user's workflow and concentration which would cause larger cognitive load. It is very important to split the information and actions in such a way that users would find most of the action or decision-based content on the controller screen so they are not forced to switch context too much. Solution should implement consistent visual cues and interactions across both screens to create a unified experience.

3.4.2 Responsiveness and synchronization

Ensuring that the actions performed on the controller device are instantly recognized and acted upon is critical for the usability of the prototype. This requires maintaining minimal latency in the communication between the devices, as described in the non-functional requirements section. To achieve this, the application should be designed using event-driven architecture to transmit only small amounts of data and therefore reducing the risk of lag and ensuring a seamless user experience.

3.4.3 Different controller screen ratio

Dimensions of the prototype controller, especially its aspect ratio, is different to the main screen configuration. This difference can affect the ergonomic comfort and usability of the device, as the interfaces which should be mirrored have to be resized to accommodate the controller's screen ratio. One potential solution could be limiting one of the screen's resolution, however, the less

than ideal look made me decide to just dynamically resize the content on the controller screen and test it this way.

3.4.4 Social aspect

Last but not least, there is a social aspect to watching TV. Many of the television users do not watch the TV alone, therefore, the application design has to consider that other people in the room should be able to see the important content as well, without awkwardly looking at the small device in someone else's hands.

3.5 Other application ideas

In addition to serving as a TV controller, touchscreen devices offer a versatile platform for a wide range of interactive applications. Expanding beyond traditional television controllers, these devices can enhance various aspects of entertainment, education, home automation, and social interaction. From interactive gaming and educational programs to smart home control and collaborative work sessions, the possibilities are limitless. In this section I will describe selected ideas I find interesting.

3.5.1 Image gallery application

This application serves as a comprehensive image gallery, allowing users to organize, view, and share their photos and videos with friends and family. The touchscreen device acts as a remote control, enabling users to browse through their gallery seamlessly while viewing the images on the TV screen and allowing them to pan and zoom the images directly using the controller. Additionally, the app could provide a feature like showing only selected photos on the main screen, to avoid showing unwanted content to others.

3.5.2 Interactive shows and quizzes

Educational programs app could provide users with a selection of quiz shows and interactive games similar to popular TV shows such as *Who Wants to Be a Millionaire?*. Users can test their knowledge across a variety of topics, compete with friends or family members, and earn virtual rewards for correct answers. The touchscreen device acts as a controller, allowing users to select answers, participate in challenges, and track their scores, while the TV screen displays the questions, visuals, and leaderboards. This could also be integrated directly into TV app, where during live quiz shows users can answer the questions, and for example even contribute with their answer when prompted for public opinion.

3.5.3 Role-playing and strategy games

Multi-screen television could be also applied in gaming, similarly to the existing Air console, mentioned in the first chapter *Analysis*. The touchscreen device would serve as a controller, providing intuitive touch-based controls for navigating the game world, managing resources and showing player-specific stats. Meanwhile, the TV screen would display the game environment, allowing players to immerse themselves in dynamic gameplay. This application, however, would probably require support of multiple controller devices. On the other hand, this can be solved by creating a controller app which could be downloaded and run on any smartphone, so other players would just use their own phone to play.

3.5.4 Live sport stats

Another great use of a companion screen could be for watching live sport events. Secondary controller screen could provide additional content about game analysis, player stats, predicted odds of winning and other game commentary. Additionally, it could feature interactive polls or social media integration, enhancing the viewing experience while watching live sports on the TV screen.

Chapter 4

TV application high-fidelity prototype

To test the concept of controlling a TV with another touch based device I need to first create a prototype of a TV application suitable for testing. In this chapter, I will describe the key features of the prototype application, high-level architecture, technologies used as well as I will provide reasoning behind the design of selected screens.

4.1 High-level idea of the prototype

This prototype should mimic a television operating system together with it's controller interface. User will be interacting with the controller only and the main TV screen will react to the actions that user is performing.

In an ideal case, the controller would be manufactured to suit the needs of the system, had ideal size and screen ratio, optimized battery life and other features. For the purposes of testing the prototype, I will just use my personal smartphone, Xiaomi Redmi Note 8 Pro. This is a lower-end class smartphone and was relatively cheap when bought (around 240 eur in 2020) so the processing power of the smartphone would be realistic to use and ship with the TV without doubling the television set price.

This prototype should allow users to perform the most fundamental activities when using the television: browsing available movies, finding more information about them, browsing through channels as well as filtering the content to enable faster and more convenient searching. Playing a video and direct interaction with a video slider for quick seeking will be added as well. Main highlight of this seeking feature will be a live preview of the current slider position, meaning that users will immediately see the frame of video they are fast-forwarding to, without having to wait multiple seconds as on traditional televisions with button controllers. Setting a reminder for upcom-

ing shows will be added as another nice-to-have feature, which emerged from user research. Most requested user feature was some kind of picture-in-picture feature, which will be implemented as a mirrored settings screen, where users can turn off the mirroring and the video playback would continue. This would allow other people continue watching the television without disruption while other person goes through settings. This possibility of browsing through another content while already playing something on the main screen could be extended to also browsing for another content, which I think users would appreciate the most, however, because of the tight time schedule I decided to not cover this in the prototype and keep this feature to settings only.

4.2 Key prototype features

To showcase and later test the possibility of direct interaction through companion touch screen controller device, following main features were implemented in this prototype:

- Playing a video with possibility to rewind the content, featuring a thumbnail of current frame
- Synchronous scrolling of larger lists, such as list of available shows and channels
- Text input synchronization, meaning that anything typed in the search bar on the controller device is also immediately visible on the main screen
- Search and filter based on the user's text input
- Setting a reminder for upcoming show

All aforementioned features will be described later in Section 4.7 in greater detail.

4.3 Chosen technologies

I chose to implement this prototype as browser application using TypeScript and React library [45] as it is a powerful tool to build front-end web applications with large community support and plenty of resources to learn from. Availability of learning materials was crucial for me, as I did not have any previous experience with building web applications. Backend part of the application is a JavaScript program running a WebSocket server intended for forwarding the messages from one device to the other. Aiming for the simplicity of the model, all the data and actions are processed directly on the front end and the WebSocket server is used only for message forwarding.

4.4 Application architecture

The architecture of the prototype application is composed of two instances of the same client application, running on two devices - one smaller controller device with touch screen and a larger screen device used as a television. These two application instances are communicating by creating a WebSocket connection between the server and each client. Server then simply forwards the messages from controller to the main screen, as shown on Figure 4.1. Even though WebSocket protocol allows two-way communication, it is not needed for the prototype so the server only listens for and forwards only messages from the controller.

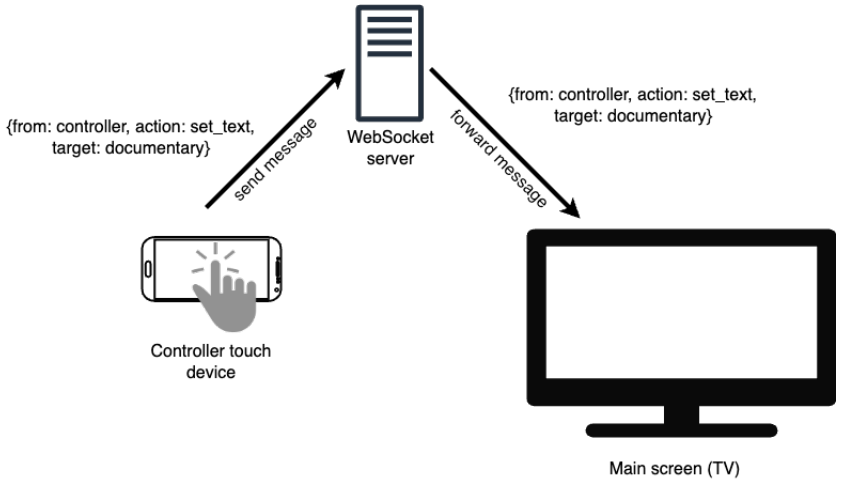

Figure 4.1: Diagram of app architecture and message forwarding from controller device to main screen

Regarding the architecture of the program itself, it is composed of React functional components, which can be easily reused and nested as needed, as shown on Figure 4.2. For clarity purposes, this code snippet shows reduced version of the actually used components. Both GoBackButton, used to navigate back in the app, and MenuButton, for showing the settings menu, are declared separately, but for the convenient import in another components and styling, I created third component, ControllerNavButtons, which returns both buttons at once, styling them correctly in the upper part of the screen with small margins from sides for appealing look. In most of the other components I am importing both of the buttons, but in certain screens the separate import of only the go-back button is still possible.

```
const MenuButton = () => {
    const sendMessage = () => { ... }

    return (
        <button
            onClick={() => {
                sendMessage();
                ...
            }}
        ></button>
    );
};

type ShouldSendMessageProp = { shouldSendMessage?: boolean };

const GoBackButton = ({ shouldSendMessage = true }:
                        ShouldSendMessageProp) => {
    const sendMessage = () => { ... }

    return (
        <button
        onClick={() => {
            if (shouldSendMessage) {
                sendMessage();
            }
            ...
        }}
        ></button>
    );
};

const ControllerNavButtons = ({ shouldSendMessage = true }:
                                ShouldSendMessageProp) => {
    return (
        <div className="controller-nav-buttons-center">
            <GoBackButton shouldSendMessage={shouldSendMessage} />
            <MenuButton />
        </div>
    );
};
```

Figure 4.2: Controller navigation buttons component

4.5 Real-time synchronization

Key non-functional requirement for this prototype is to have real-time synchronization of the content between the screens. The primary challenge is that the user views both screens side-by-side, making any synchronization delay highly noticeable which could possibly lead to user's dissatisfaction. Transmitting the entire screen content creates a large stream of data which puts a strain on the network and the application itself. Therefore, to achieve quick rendering and smooth user experience, each client application instance (both screen and controller) manages its own data and the messaging is based only on the event synchronization. Each message is a small JSON object, typically only a few hundred bytes, containing only the necessary data to update the screen client based on actions taken on the controller. Since all the devices are on the same local network, the communication is fast. This type of communication could be set up in the real eventual product as well, where the TV could act as the server itself.

4.5.1 Messaging system

As I find the messaging and synchronization of the screens the most technically interesting parts of the prototype, I would like to go into a bit more detail in this section. Code snippet of navigation buttons in Figure 4.2 indicates that each component handles their messages as needed. To enable sending messages, each component needs a reference to WebSocketProvider, however, to pass one global reference to each child component would be cumbersome. Therefore, I created a top-level component which allows the children components to create or re-use existing websocket connections.

```
// in main.tsx
ReactDOM.createRoot(document.getElementById("root") as HTMLElement)
                    .render(
    <React.StrictMode>
        <WebSocketProvider>
            <RouterProvider router={router} />
        </WebSocketProvider>
  </React.StrictMode>
);

// in any component which needs to send or receive messages
import { useWebSocket } from "./WebSocketContext";
const websocket = useWebSocket();
```

Figure 4.3: WebSocketProvider component encapsulating main RouterProvider component.

Simplicity of this approach is shown in Figure 4.3, where it shows the encapsulating the RouterProvider component by WebSocketProvider. Then, in any component which needs to send or receive messages, it is only needed to import the WebSocketContext module and initialize the WebSocket object, which already has methods *send()* and *onmessage()* defined.

Message itself is a simple JSON string, which contains all the information needed to perform a certain action. Each message contained the sender, which is a sanity check that the received message is not from the screen client but only from the controller.

```
{
    "sender": "controller",
    "action": "navigate",
    "target": "/screen/menuSettings"
}
```

Figure 4.4: Example of JSON message for navigating to another component.

Next field is *action*, which, as the name suggests, defines action to perform on the receiving screen. Examples of values are navigate, navigate back, scroll or set text. Lastly, there are action arguments. In the example message in Figure 4.4 there is argument *target* for action *navigate* with value representing target url, where the screen client should navigate to.

On the other hand, the screen client instance has to be able to listen to the messages, parse them and make actions accordingly. For this purpose, I am using React *useEffect()* hooks, where I can register WebSocket listeners. Figure 4.5 shows an example hook I used in SearchBar component, which listens to two types of action, setting text to search bar, and navigating back from the current page. This way, I am able to synchronously set the text in the search bar on the main screen, when the user is typing the input on the controller.

4.6 Distinguishing the client type

While it is certainly possible to implement the controller application separately from the screen application, I find it easier to work with only a single website. This allows me to reuse existing code even further, as I do not have to re-implement the screens where the content is the same on both screens. Therefore, I decided to implement this prototype as separate instances of the same client application. Despite the benefits of this architecture model, it brought a minor problem, which is how to distinguish between the clients. I solved this problem using initial screen, called LandingPage component, which shows two simple buttons, one for screen, one for controller. During the setup before the user testing session, I simply click on the button on each device

```
useEffect(() => {
    if (ws?.OPEN && is_screen) {
        ws.onmessage = (event) => {
            const message = JSON.parse(event.data);

            if ("action" in message &&
                message.action == "set_text" &&
                "value" in message) {
                  setInputText(message.value);
            }

            else if ("action" in message &&
                     message.action == "nav_back") {
                  nav(-1);
            }
      };
    }
});
```

Figure 4.5: Example of React hook listener for WebSocket messages.

respectively. This button then sends an initial message to the server, and the server then generates a unique client id and saves the reference to clients – screen and controller respectively. Now, the server knows which id belongs to the screen client and is able to forward the messages from the controller.

Clients themselves need to know the type of device they are running on in order to render the content correctly. To avoid drilling the client type parameter to each child component, I used React Router for this and simply prepended each URL location with device type. As an example, in Figure 4.4 can be seen such a target URL, which starts with *"/screen/"* string, meaning that the receiver of the message is the screen device. Then, inside any component, I am able to retrieve the current URL address, extract the information about the device type and render output accordingly.

4.7 Final prototype design

In the design phase, I considered numerous ideas to enhance the prototype. However, incorporating all these ideas would be impractical and inefficient for the current stage of development. Therefore, I prioritized key features that demonstrate the interaction techniques essential for this thesis. To achieve this, I implemented a set of components covering text input, direct interaction with content, mirrored screens, and screens with differing content. While these aspects are primarily technical, they are designed in the screens to be

semantically intuitive for users, ensuring they can be tested seamlessly in later scenarios.

In this section I am using screenshots from the application running in a browser on my personal laptop for simplicity purposes. However, as mentioned in the design section, the controller client is intended to run on a smaller touch screen device (smartphone). User testing will be performed as intended – using a dedicated controller device.

4.7.1 Video playback

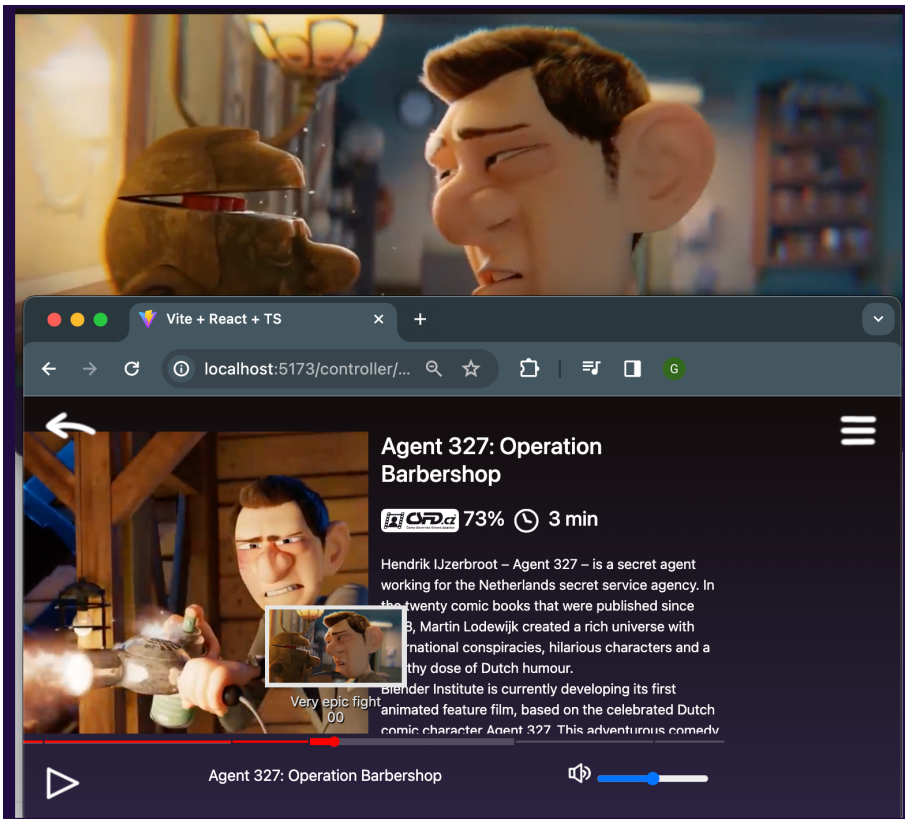

Figure 4.6: Video playback screens, the main screen on the top part of the picture features a video player, the bottom shows the controller screen.

In my opinion the most interesting part of the prototype is the video playback. It is one of the scenarios where the screens are intended to completely differ visually, but keeping the same context. Main TV screen is very simple, it shows just the video content itself, nothing else. Controller part is more sophisticated and features both controlling and informative elements for the users to interact with. On the first sight, most noticeable is the video poster and its name, in this case *Agent 327: Operation Barbershop* [46]. Beneath

can users find the shows' rating, length and description. One of drawbacks of the traditional controller is inconvenient rewinding of the video, where users often have to hold a button for multiple seconds. This can be avoided by creating a video slider that allows users to directly interact with the video and comfortably skip to the part of the video, which they are interested in. Used video slider also features a thumbnail preview of the video at the current timestamp, so the users do not even have to look at the main screen to be able to rewind the video. Provider of the video (either a streaming service or cable TV provider) could also implement timestamps in the video slider so the users can see individual named parts of the video, as shown on Figure 4.6.

Naturally, the controller also provides a play/pause button and volume control slider for easy control of the video playback.

4.7.2 List of shows and movies

Next important use case to cover by the prototype is to have the possibility of browsing the content, when the user does not exactly know what they would like to watch. I was aiming for simplicity and clarity when creating a component with a list of shows and movies, so users can easily browse through the content. This component is (apart from navigation buttons) mirrored exactly, meaning that the content does not differ between the controller client and main screen client.

Two main challenges arose in developing this component. The first was ensuring scrolling synchronization on both screens, which I addressed in a previous section by using WebSocket messages. The second challenge was dealing with differing screen resolutions and aspect ratios. Initially, I tried to make use of absolute changes in the y-axis when a user scrolled, sending these changes to the screen and adjusting them to fit the larger screen. However, this approach often caused the screens to display different vertical levels of the page. Then, I realized that any absolute positioning is practically useless and I have to recompute the scrolling action relative to the vertical size of the entire page rendered on the device. This way, achieved seamless synchronization of the scrolling component between the two screens so the user always sees exactly the same part of the page on both devices.

From the design perspective, the list of movies and shows is minimalistic to not overstimulate the user with tons of information. On the other hand, I tried to provide enough data about the show, so the user does not have to click on every single movie which they want to learn more about. Each movie shows its thumbnail image, title, short description and genres, as seen on Figure 4.7.

After selecting a movie, users can also gain insight about the movie's rating from preferred rating sites, its duration and the streaming services or eventually TV broadcast stations which are broadcasting this show in the near future. The idea behind this screen is to provide the user information about

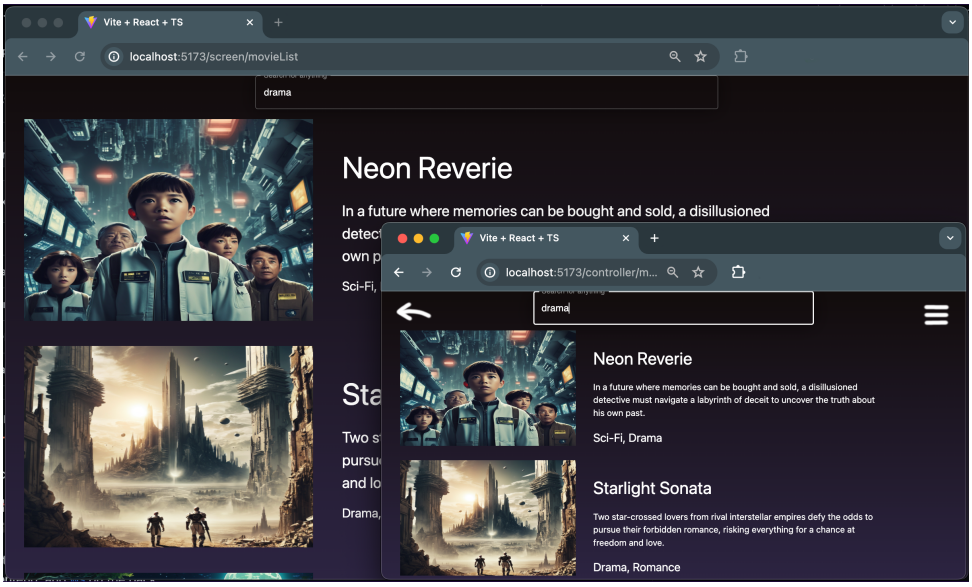

Figure 4.7: Screenshot of movie list rendered on screen client (larger in background) and controller client (smaller in foreground)

virtually any movie (e.g. existing in an open movie database [47]) and gather the information about its availability in the application, based on already connected streaming services and/or availability of connected cable TV.

4.7.3 Searching and filtering the shows

With an always growing database of movies and shows to watch, or just simply having too many TV channels to choose, searching for something specific can get really frustrating for the users without filtering and searching features. Furthermore, the searching should be as comfortable as possible, enhancing the current user experience where users often have to click with their controller on each letter they want to type in. Therefore, the prototype provides a full-text search in all of the shows, movies and channels in the database. Searching is possible also by tags, which are assigned to each title or channel to filter them by category or genre. In the case multiple people are watching a TV in the same room, the search bar text input is synchronized with the main screen as well, to enable other users to see the input and filtered results, too. Mirroring of the text input to the main TV screen is also visible in the top part of Figure 4.7. For even more comfortable use, I added a quick filter buttons to the list of channels, which allow users to filter the channels by selected tags. Ideally, in the final application, the tags could contain the user's most favorite genres, or customized lists of channels. An example of filtering can be seen on Figure 4.9.

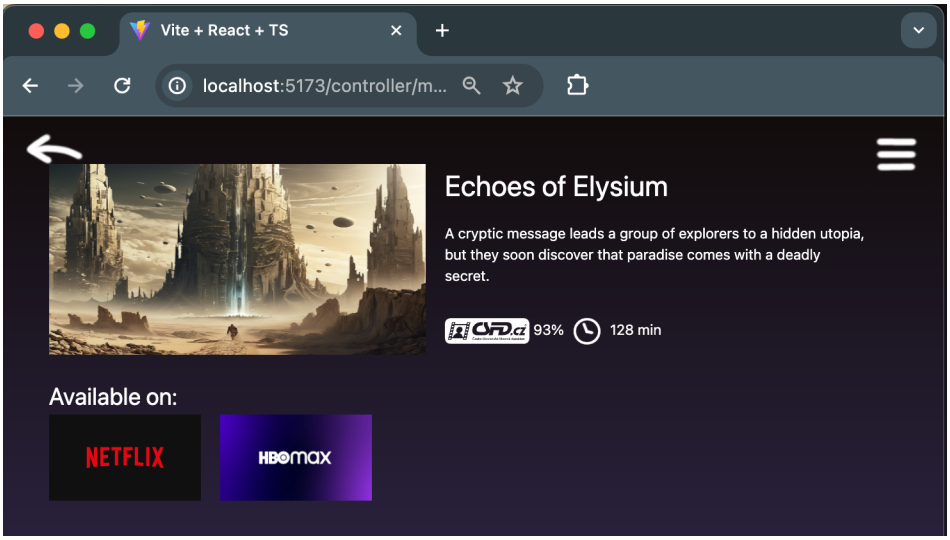

Figure 4.8: Screenshot of controller screen showing movie details and its availability on streaming platforms

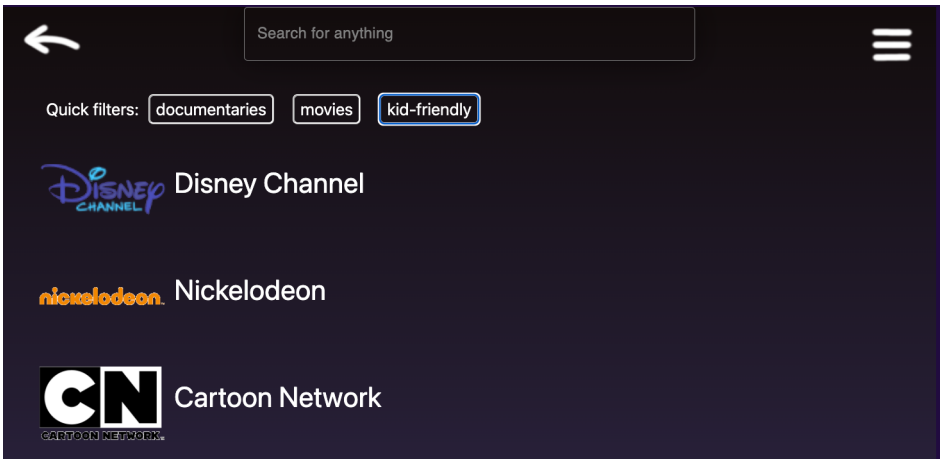

Figure 4.9: Screenshot of controller screen showing filtered results of channels targeted for children audience.

4.7.4 Ease of access, reminders

Lastly, the fact that the controller device has a touchscreen which can serve any content can be used for creating quick actions for the user. Ideally, the application would learn the user's favorite shows and also provide a mechanism to mark selected shows as favorite which would allow it to create a home screen with quick actions to play some of the favorite shows as promptly as possible.

In this prototype, this functionality was imitated by selecting a few shows

and creating shortcuts to them on the initial screen of the TV application. The initial screen is one of the few screens where the content between the controller and the main TV differs, as the controller screen is intended to be more action-based while the main screen is more informative. However, most information is already provided on the controller. This distinction was made to test whether users can understand the content provided to them if screens slightly differ. Additionally, in the real application, only the exact shows to play or set reminders for would change, while the actions themselves would remain the same, making it easier to navigate after multiple uses. This feature is mainly intended for expert users who watch TV regularly, allowing the algorithm to provide very precise recommendations so the user can play their favorite content with just two clicks.

Initial screen also features the possibility to set the reminder for an upcoming favorite show which is starting in the near future, so if the user plays something else while waiting, they will not miss the start of the show. In this prototype, reminder was only mocked and after clicking on of the *Set Reminder: ...* buttons as seen on Figure 4.10, an alert box was created with information that the reminder for the show was successfully set.

4.7.5 Video recordings and source code

I created a set of short videos corresponding to usability testing scenarios (described in upcoming chapter) to showcase functionalities of the developed prototype. Videos are available as attachments to this thesis. Application can be also built from sources according to instructions provided in *readme.md* file.

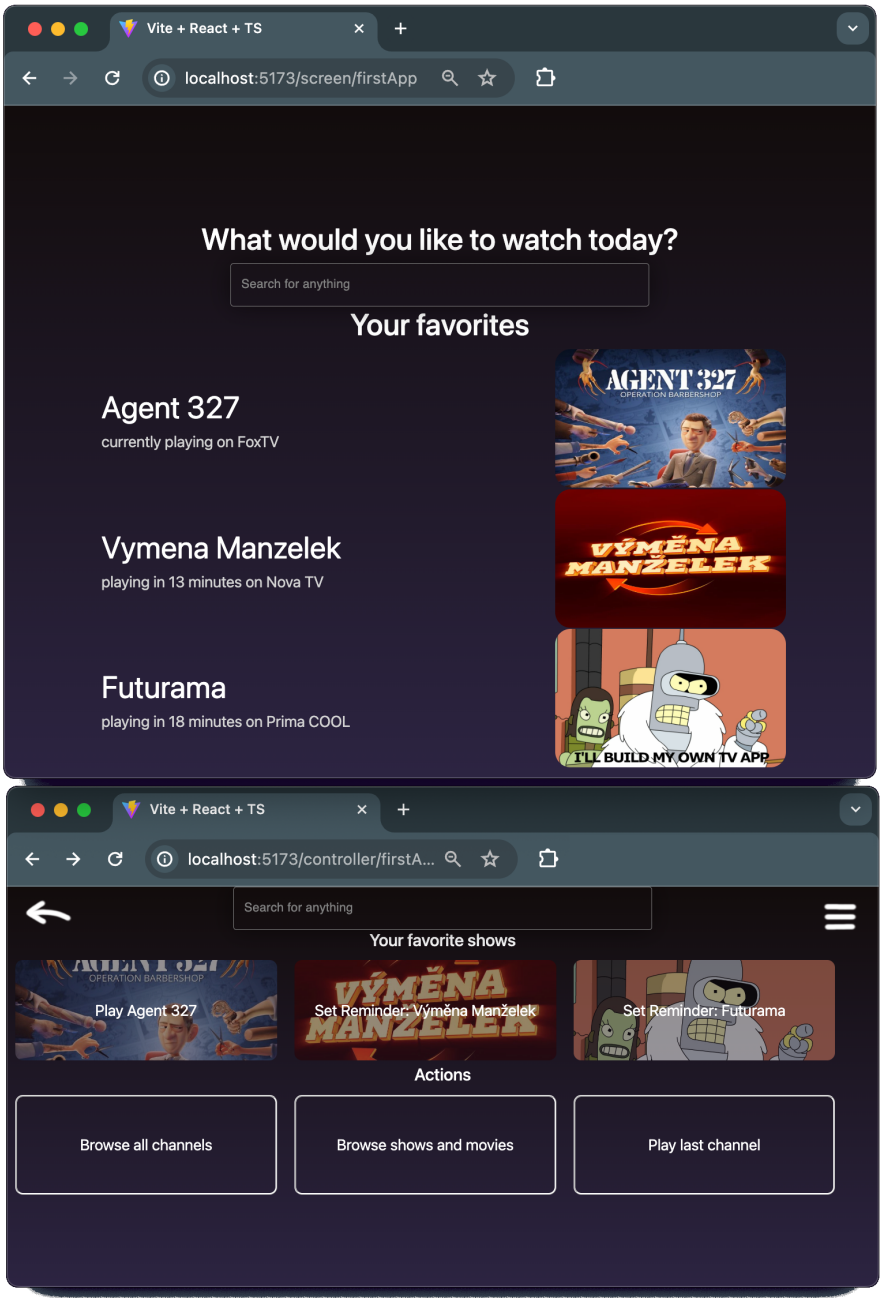

Figure 4.10: Initial screen of TV application with quick actions and reminders. Top screenshot is from the main TV screen instance, bottom one is from the controller client instance.

Chapter 5

Usability testing

User testing, also known as usability testing, is a key component of user-centered design (UCD) [44]. It involves observing real users as they interact with a product or prototype to identify usability issues, gather feedback, and understand how well the product meets their needs and expectations.

The primary goal of this usability testing is to uncover any problems or obstacles users may encounter when using the prototype application, verify feasibility of the prototype and identify problematic parts which would need to be redesigned. While usability testing in UCD is often an iterative process of testing and adjusting the prototype according to feedback, the main focus of this thesis is verification, whether the model of controlling the TV with another touch screen device is viable or not. Therefore, I will perform only the initial round of testing, evaluate the results and suggest eventual prototype enhancements.

5.1 Usability testing method

There are multiple methods of user testing [48] to choose from, each offering unique insights into user behavior and product usability. Moderated usability testing involves a moderator guiding participants through tasks, either in-person or remotely, allowing for real-time observation and interaction. Unmoderated usability testing lets users complete tasks independently in their own environment, providing real-world data through remote testing tools. A/B testing compares two versions of a product to determine which one better meets user needs based on metrics like task completion and satisfaction. Surveys and questionnaires complement these methods by gathering user feedback on their experiences, satisfaction, and suggestions for improvements. Each of these methods provides valuable data that can inform iterative design improvements and enhance overall user experience.

I chose to use in-person moderated usability testing, as I find it the most valuable for the purpose of this thesis. This way, I am able to watch the par-

ticipants how they perform the actions by myself and see if their answers in the concluding interview performed after testing are coherent with my observations made during the testing.

5.2 Respondents and sampling method

The goal was to verify feasibility of the prototype with 10 participants, which was met. I did not have any other specific quota set, however, I aimed to reach people from various age groups and professional backgrounds to keep the group of respondents diverse. Participation in the user study was voluntary, without compensation, however, I offered each participant snacks and drinks during the testing. I used the snowball sampling method [40] to find the respondents willing to participate in the user study for free, starting with a group of three friends and colleagues, who then recommended their other peers and parents. Only requirement for the participants was to be a regular TV user, so they would be able to compare the prototype to their current television usage experience.

5.3 Testing setup

For the test to be performed, I needed only one larger screen to imitate the television, my personal smartphone, which I used as a controller and a stable network connection. On the smartphone, I used the Fully Kiosk Browser application [49], which allowed me to set the prototype application to full-screen mode, disabling all other system UI elements. Moreover, I set the system keyboard to be the smallest size possible, to not take up too much screen space, as it might have caused problems.

I performed the usability study at two places, first one was at my home where I initially tested the prototype with three friends. As I did not want to invite strangers to my house, I had to set up a testing space somewhere else, with the access to the additional screen, reliable internet connection and relatively quiet and private, so the participants can feel relaxed and recordings from the testing are clear. Therefore, I asked at my work if I can use one of the meeting rooms for testing and I am grateful that I was allowed to perform the testing there. Additionally, I was recording each session to have additional materials for evaluation. Instead of recording just the screens, I set up the camera so the frame contained both screens and participants' profile, allowing me to see at which screen they are currently looking.

5.4 Briefing

Briefing before usability testing is an important step where participants are informed about the testing process, its purpose, and what is expected of them.

This ensures that participants are comfortable, understand the context, and can provide meaningful feedback. During the briefing, I introduced the prototype, explained what the testing is about and emphasized that it is the prototype that is being tested, not the participant. I also encouraged the participants to not be afraid to criticize the parts they do not like or are confusing, or just take the time they need to perform an action, there is no time pressure. I asked the participants to be more aware of *how* do they perform certain actions, rather than assessing the looks of the user interface, which in its prototype state is, naturally, not perfect. Even though I spent an unhealthy amount of time aligning the buttons to satisfy my perfectionism, CSS is not my friend, apparently.

Participants were also ensured that all the data I gather is confidential and all the recordings from the testing are solely for my own use and will be deleted after testing evaluation. Last, but not least, participants were asked to think aloud and share their thoughts during the usability testing to better understand their actions.

5.5 Testing scenarios

In designing the testing scenarios for the TV app prototype, the primary objective is to guide users through the most crucial functionalities and interface designs. Each scenario simulates realistic use-cases that an average user would encounter during their interaction with the app. By using tasks which are reflecting everyday TV viewing habits, we aim to simulate an environment where participants can engage authentically with the prototype, offering insights into its usability, intuitiveness, and overall effectiveness. Through this approach, gathered feedback from the users should be more authentic to their experience of using a touch device as a TV controller.

1. Open the TV app and describe what you see on the screen and what actions you can perform.

2. Your most favorite show "Výměna manželek" is playing in 13 minutes and you definitely don't want to miss any drama. Set up a reminder for the start of the show.

3. While you're waiting, you do not want to sit in silence and your other favorite show, "Agent 327" is already playing. Play the show.

4. You're not very interested today for the intro of the show and you want to just skip to the main fight scene. How would you find that?

5. The scene is too quiet, how would you adjust the volume?

6. You want to access device settings, how would you do that?

7. While you're searching for a setting, your friend next to you wants to continue watching TV, how would you stop sharing the settings menu?
8. You changed your mind about watching "Výměna manželek" and you want to put on some documentary instead. How can you find documentary channels?
9. Your kid is really bored from the documentaries and wants to watch Cartoon Network. How would you find that?
10. You remembered that your friend was talking all day about a movie "Silent Symphony" that you definitely have to watch. How would you find information about the movie?
11. What information does the screen provide about the movie?
12. That movie seems too serious for your mood at the moment and you'd like to watch something more cheerful at the moment. How would you find some adventure movies?

5.6 Performing of the tests

After the initial briefing with each participant, we could start with testing scenarios. As mentioned in *Usability testing method* section, I chose to use a moderated usability testing method, therefore I was present during the testing, right next to the participant. I started each session with a short introduction to set the right mood and told the participants that they just arrived from work and they would like to watch something good on television. They are provided with a touch screen device from the television manufacturer, which is the only source of input for the TV, there is no other controller. Then, I instructed the participant with the tasks, which I read slowly, one by one, and repeated if needed. I did not provide participants with the printed instructions, so they would not be distracted with reading them and rather explained what was needed myself. This allowed me to ask additional questions, mainly if the participant seemed lost, I asked how they understood the content or actions available. On the other hand, I tried to interfere with their actions as little as possible, so the results of the testing would be authentic and reflective of real user behavior. Each testing session was recorded on camera, providing me additional resources to learn about user behaviors and actions which I missed during the testing.

5.7 Concluding interview

I decided to make wrap-up interview in form of semi-structured dialogue with guiding questions, as I am able to get more details from the respondents about

their experience. Following questions were used as a interview guidance:

1. Which tasks confused you?
2. Remember how you were looking up the movie or genre name. How would you rate the experience of typing the text input to the search bar? Compare it to the input method you've used the last time you were searching for something on your TV.
3. How intuitive did you find controlling the TV with the other screen which is changing?
4. How often did you have to look up from the controller to the main screen to find additional info about the content which was presented to you?
5. How effective would you say the controller was, when performing the tasks? How do you compare the speed of actions made to the regular physical controller?
6. How would you rate the feedback of your actions made on the controller? Were you sure they were recognized?
7. What interaction mechanic or interface did you like?
8. What surprised you?
9. If you could change anything on the app, what would it be? What would you add or remove?
10. Would you use a similar touch device if it was available for your TV? Explain why.

Summarized and interpreted answers from the concluding interviews can be found in part C of the *Appendix*.

5.7.1 Debriefing

After the interview questions, each participant was given a space to engage in a post-test debriefing session. This session allowed participants to share any additional feedback they wished to offer, whether it was related to the prototype itself or their overall experience of the testing session. Participants were encouraged to express their thoughts, concerns, and suggestions openly, which was a valuable extension of the testing process, allowing for deeper insights into user experiences beyond the interview questions.

5.8 Evaluation

The last section of this chapter, and probably the most important one is dedicated to evaluation of usability testing results.

5.8.1 Course of the usability testing sessions

Testing sessions went generally smooth, without any major issues. From the technical point of view, I had two issues. The first was to set up the network communication using public wi-fi, which was not possible, because the network was set up in the way that devices do not see each other. I had to improvise and fortunately, connecting the notebook to the hotspot shared from the smartphone worked. Second minor hiccup was that during the first testing session, the participant was only interacting with the controller (as was supposed to), but my laptop went to sleep, disrupting the testing session. Setting the sleep schedule was an easy fix for the issue and did not affect other testing sessions anymore.

Participants were great and all of them were using the thinking aloud method, however, some of them admitted they were a bit nervous, mostly ones I did not personally know. During the first few sessions I was nervous as well, as I was not sure whether everything will work and I felt self-conscious about the prototype, as I concentrated on its imperfections rather than the whole work. However, after about the third session I started to feel more comfortable and encouraged, when I saw that the feedback was generally positive. Each session took about 30 to 40 minutes, from initial briefing, testing itself and concluding interview, which usually took most of the time, but really varied from person to person, depending on how communicative the participant was.

5.8.2 Positive aspects of the prototype

From the interaction point of view, the concept of controlling the television with another touchscreen device was appealing, more or less, to all of the participants, which is actually surprising to me. I expected more doubts and questioning responses, however, most of the participants seemed to dislike their current controllers so much that any improvement to the user experience would be probably endorsed.

User experience

Main concern when designing this prototype was that user workflow and concentration would be disrupted because of alternating the attention between two screens. This was only the first few seconds, when the participants looked up and down to learn what was happening and after a short while, each of the participants concentrated mainly on the controller screen. Subjective rating of the experience was also rated positive, and many respondents stated

that controlling the TV felt natural and intuitive, as it was very similar to controlling just another smartphone application.

Responsiveness of the application was rated as very good, as all the user actions had instant feedback. Participants appreciated the seamless synchronization of the screens, mostly noticeable when scrolling the lists of movies or channels. Controller prototype was also stated as more effective than the traditional controller, as users had to perform less actions to get to the content they wanted. Having the full keyboard available, it was more comfortable to type the text than using buttons on the controller, however, few respondents would still prefer voice input and keep the keyboard as an alternative in noisy environments, when the voice recognition is not as effective.

One participant endorsed an use case for the prototype, that they can use it remotely from the other room at home, e.g. bathroom, to choose the content they would like to watch later, which is something I did not expect, but I can see the potential.

User interface

First and most significant hit among the participants was the video rewind screen. Having the ability to directly control the video playback on the screen in the user's hands was very comfortable and intuitive for most of the participants, as they are already used to this mechanic on their smartphones. Moreover, having the instant preview of the current frame of the video was a very endorsed feature. About half of the participants also appreciated having additional information about the movie or show currently playing on the controller.

Participants also liked the idea of interconnecting multiple streaming services, so they could get content recommendations from various platforms at once, not having to open each of them separately. Searching in the TV broadcast was appreciated as well, however, many of the participants do not have cable television anymore and use mostly streaming platforms.

5.8.3 Negative aspects of the prototype

Despite the many positive aspects of the prototype, it is not without its shortcomings. Biggest issue during the testing was the system keyboard, which was taking up half of the screen space. Additionally, as the controller screen content was dynamically sized, when the keyboard popped up, it shrunk all the content on the screen which was not aesthetic, nor even functional. The keyboard was also difficult to hide as it did not have a dedicated system button for the action, and participants had to click somewhere else on the screen to hide the keyboard, which was not pleasant. This was more of a problem of the used device to test the prototype on, that application itself, but there is

valuable knowledge that it is important to design the keyboard carefully, to make the user experience plausible.

Another issue was the lack of initial tutorial. While for most of the participants, which grew with technologies it felt natural to use the controller application, for others, mostly people later in their productive years it was a completely new concept to grasp and it took them a while to adjust and comprehend how the devices work. I am yet unsure, if this is supposed to be part of the process, to learn by yourself, or provide a tutorial but risking getting biased feedback.

Application design was not perfect either. While the idea of browsing another content on the controller while still watching something else on the main screen was a very endorsed, the practical implementation of settings menu where the participant could turn off the mirroring was not working very well. I was experimenting with animations in React using react-spring library [50] and while aiming for a modern feel and look, it ended up taking me almost three days to make it work and in the end the animation was not smooth and even menu option highlight did not work very well. Retrospectively, I should have just stick with a regular scrolling menu, which would look better and be generally more reliable, in the limited time I had for development of the prototype.

Initial television application screen had mixed responses as well. While some of the testing participants liked the quick access to favorite content, many of them did not understand the purpose of the screen, or just simply misread the captions on the reminder buttons. Visibility of the captions was limited as I had used image an background on the buttons. My idea was to better connect the button with the action regarding a certain show, however, even with using only half-opaque images, actions were not clear to everybody. By the participants, it would be best to design the initial screen to be customizable, allowing the users to put their own preferred actions to the quick panel.

From the practical point of view, multiple participants were worried about the eventual battery life of such a device, together with its durability, as the touch screens are more prone to breakage than classic controllers.

Last but not least, the UI design itself was not perfect. Even though I tried to aim for a modern look, it was visible that the application is in its prototype state, buttons and other components were not perfectly aligned which respondents noticed. This highlights the fact that even with great practical ideas, visual application appeal is still very important.

5.9 Conclusion of usability testing

Despite the drawbacks of the prototype, usability testing proved its viability and yielded promising results, meaning that using a touch screen device for

controlling a television is a path definitely worth exploring further. In this chapter I summarized both strong sides and weaknesses of the prototype, which can be insightful start for follow-up research in the field of dual-screen television solutions. Even though more iterations of usability studies would be needed to get the application design right, participants of the performed user study expressed sympathetic attitude towards the touch screen controller idea, as it was comfortable to use and generally more effective than using their current controller. As previously mentioned, summarized answers from the concluding interviews can be found in part C of the *Appendix*.

Chapter 6

Conclusion

This master's thesis aimed to answer the question, whether the idea of using a touch screen device to control a television is a viable approach. In the beginning, I created a theoretical research about the currently used technologies relevant to dual-screen television topic. The analysis provided a solid foundation for understanding the principles and provided best practices that I could use as a guide during the design and development of the prototype.

As the needs of real-world users are very important when creating a prototype, the next phase was focused on conducting comprehensive user research. 76 participants contributed by filling out information about their watching habits, preferences and problems. This research highlighted the specific needs and expectations of potential users, highlighting the necessity for an intuitive and responsive television controller with a comfortable text input method.

Based on the results of the user testing, I summarized both functional and non-functional requirements and described possible design of the application prototype, considering multiple approaches of splitting the content between two screens. I also discussed alternative application ideas, where the dual-screen television might be beneficial for the users. Following-up on the prototype design, I created a high-fidelity prototype of a television application with a companion application for a touchscreen controller device.

To answer the main question, the primary goal was to perform a prototype usability study with 10 participants, to evaluate the effectiveness and usability of the prototype. Participants interacted with the application according to created scenarios, performing a series of tasks designed to test key functionalities and verifying viability of the interaction technique. Their feedback was important in identifying both strengths and areas for improvement.

By evaluating the results of the usability study I was finally able to answer the question: Is dual-screen television usable? Short answer is, probably yes. The prototype had generally positive feedback from the usability testing, with users appreciating the comfortable text input method, modern feel, intuitive interface, responsive feedback and additional content complementing the main

screen. On the other hand, several areas for improvement were identified, including the need for a customizable quick access menu, reducing distractions from the dynamic controller screen, and enhancing the durability of the touchscreen device. Another key outcome is that while for many people is using smartphones more natural than using a button controller, it is not the case for everybody, mainly a bit older people, who do not find the controlling method as intuitive. On the positive side, fears that having two screens to control would be too distracting did not come true and usability testing participants were mostly concentrated on the controller screen in their hands. Therefore, I assume that the choice to put the most important and action-based content to the controller and more passive content to the main screen was correct.

Performed usability testing yielded promising results. However, further research might be needed, as the prototype implemented only a subset of real-world TV application functionalities and testing was performed on relatively small sample size to draw any ultimate conclusions. I personally think that dual-screen television technologies is a path worth exploring further. As a follow-up research I would recommend exploring how such touchscreen-based controllers could be integrated with existing television operating systems and how individual application vendors could implement their own companion controller interfaces.

Bibliography

1. UNIVERSITY OF MINNESOTA. *The Evolution of Television* [online]. [visited on 2023-12-29]. Available from: https://open.lib.umn.edu/mediaandculture/chapter/9-1-the-evolution-of-television/.
2. TCL. *The Evolution of TVs: What is a Smart TV?* [online]. [visited on 2023-12-29]. Available from: https://www.tcl.com/au/en/blog/android-tv-vs-smart-tvs1.
3. ROBERT SHELDON. *What is smart TV?* [online]. [visited on 2023-12-30]. Available from: https://www.techtarget.com/whatis/definition/smart-TV.
4. ESAT DEDEZADE. *Best smart TV OS 2024: which TV platform is best for you?* [online]. [visited on 2024-01-01]. Available from: https://www.stuff.tv/features/best-smart-tv-os/.
5. M. BIZZACO, S. COHEN, D. MALCOLM. *What is Android TV? Google's smart TV platform fully explained* [online]. [visited on 2024-01-01]. Available from: https://www.digitaltrends.com/home-theater/what-is-android-tv/.
6. DANIEL NATIONS. *Apple TV: What It Is and How It Works* [online]. [visited on 2024-01-02]. Available from: https://www.lifewire.com/what-is-apple-tv-1994193.
7. LG ELECTRONICS. *What is webOS™?* [online]. [visited on 2024-01-03]. Available from: https://www.lg.com/us/business/learning-center/what-is-webOS.
8. THE LINUX FOUNDATION. *Introduction to Tizen* [online]. [visited on 2024-01-02]. Available from: https://docs.tizen.org/platform/what-is-tizen/overview.
9. ROKU, INC. *What is Roku* [online]. [visited on 2024-01-02]. Available from: https://www.roku.com/what-is-roku/roku-os.

10. ROKU, INC. *TCL Roku TV models* [online]. [visited on 2024-01-02]. Available from: https://www.roku.com/products/finder/roku-tv/tcl.

11. DAVID E. FISHER ET AL. *television* [online]. [visited on 2024-01-05]. Available from: https://www.britannica.com/technology/television-technology.

12. ROGER MANVELL ET AL. *broadcasting* [online]. [visited on 2024-01-05]. Available from: https://www.britannica.com/technology/broadcasting.

13. ELI BLUMENTHAL. *Apple TV 4K (2022) Review* [online]. [visited on 2024-01-06]. Available from: https://www.cnet.com/tech/home-entertainment/apple-tv-4k-2022-review-excellent-streaming-but-still-too-expensive/.

14. ROBERT SHELDON. *Chromecast* [online]. [visited on 2024-04-27]. Available from: https://www.techtarget.com/whatis/definition/Chromecast.

15. DUNCAN WILSON. *How does a remote control work the TV?* [online]. [visited on 2024-01-05]. Available from: https://www.ucl.ac.uk/culture-online/case-studies/2022/sep/how-does-remote-control-work-tv.

16. TELINK. *Why TV Remotes Need Connectivity Protocols Like Bluetooth® LE and RF4CE* [online]. [visited on 2024-01-05]. Available from: https://www.telink-semi.com/tv-remotes-protocols-ble-rf4ce/.

17. LG ELECTRONICS. *Magic Remote Control manual* [online]. [visited on 2024-01-06]. Available from: https://eguide.lgappstv.com/manual/gb/12018_2.html.

18. GOOGLE. *Set up and use the Google Assistant on your Android TV* [online]. [visited on 2024-01-05]. Available from: https://support.google.com/androidtv/answer/9440564?hl=en.

19. HELLOTECH. *How to Control Your TV with Alexa* [online]. [visited on 2024-01-05]. Available from: https://www.hellotech.com/guide/for/how-to-control-tv-with-alexa.

20. LG ELECTRONICS. *OWNER'S MANUAL Magic Remote* [online]. [visited on 2024-01-05]. Available from: https://www.lg.com/us/support/products/documents/AN-MR500%20owner%20manual.pdf.

21. APPLE INC. *Apple TV Remote* [online]. [visited on 2024-01-05]. Available from: https://support.apple.com/kb/SP887.

22. SAMSUNG. *Walk around of Samsung F Series SMART Touch Remote Control* [online]. [visited on 2024-01-05]. Available from: https://www.samsung.com/in/support/tv-audio-video/walk-around-of-samsung-f-series-smart-touch-remote-control/.

23. VIDEO AUDIO TELEVISION. *Samsung AA59-00761A (Smart Touch Control)* [online]. [visited on 2024-01-20]. Available from: https://www.vat-remote.com.ua/product/originalnyj-pult-samsung-aa59-00761a-dlya-televizora-smart-touch-control/.

24. APPLE INC. *Siri Remote* [online]. [visited on 2024-01-21]. Available from: https://www.apple.com/shop/product/MNC73AM/A/siri-remote.

25. AUTHORJONAH MATTHES. *How to Connect a Keyboard to a Smart TV* [online]. [visited on 2024-01-07]. Available from: https://thehometheaterdiy.com/how-to-connect-a-keyboard-to-a-smart-tv/.

26. MATTHEW LYNCH. *Why is an IR blaster still useful on phones?* [online]. [visited on 2024-01-07]. Available from: https://www.thetechedvocate.org/why-is-an-ir-blaster-still-useful-on-phones/.

27. SAMSUNG. *Remote For Samsung Smart TV* [online]. [visited on 2024-05-20]. Available from: https://play.google.com/store/apps/details?id=com.samsung.android.oneconnect.

28. LG ELECTRONICS. *Smart TV Remote Apps for LG Smart TVs* [online]. [visited on 2024-05-20]. Available from: https://www.lg.com/us/experience-tvs/remote-apps.

29. APPLE INC. *Control Apple TV with iOS or iPadOS Control Centre* [online]. [visited on 2024-05-20]. Available from: https://support.apple.com/cs-cz/guide/tv/atvb701cadc1/tvos.

30. EDGAR ALVAREZ. *Vizio begins shipping 2013 M-Series Smart TVs* [online]. [visited on 2024-04-12]. Available from: https://www.engadget.com/2013-05-28-vizio-m-series-smart-tvs-shipping.html.

31. WIFI ALLIANCE. *Miracast* [online]. [visited on 2024-04-14]. Available from: https://www.wi-fi.org/discover-wi-fi/miracast.

32. CODRUT NEAGU. *What is Miracast, and how do you use it?* [online]. [visited on 2024-04-14]. Available from: https://www.digitalcitizen.life/simple-questions-what-miracast-and-how-do-you-use-it/.

33. APPLE INC. *AirPlay* [online]. [visited on 2024-04-14]. Available from: https://www.apple.com/airplay/.

34. N-DREAM AG. *Your screen is the console, your phone is the controller* [online]. [visited on 2024-01-21]. Available from: https://corp.airconsole.com/.

35. TECHNOLOGY TRANSFORMATION SERVICES. *User Research Basics* [online]. [visited on 2024-02-18]. Available from: https://www.usability.gov/what-and-why/user-research.html.

36. INTERACTION DESIGN FOUNDATION. *What is User Research?* [online]. [visited on 2024-02-18]. Available from: https://www.interaction-design.org/literature/topics/user-research.

37. LAZAR, JONATHAN AND FENG, JINJUAN HEIDI AND HOCHHEISER, HARRY. *Research Methods in Human Computer Interaction*. Introduction to HCI research. 1st Edition. Elsevier, 2017. ISBN 978-0470723371.

38. PEOPLE FOR RESEARCH. *Data sampling collection types and when to use them* [online]. [visited on 2024-03-03]. Available from: https://bootcamp.uxdesign.cc/getting-geeky-data-sampling-collection-types-and-when-to-use-them-13fa71d513ea.

39. PARVATHI VIJAYAMOHAN. *Quota Sampling 101: Definition, Methods and Examples* [online]. [visited on 2024-03-03]. Available from: https://surveysparrow.com/blog/quota-sampling/#section1.

40. CHARLIE PARKER, SAM SCOTT, ALISTAIR GEDDES. Snowball Sampling. 2019. Available from DOI: https://doi.org/10.4135/9781526421036831710.

41. ANTHONY B. MASTERS. *Self-selection bias and social research* [online]. [visited on 2024-03-01]. Available from: https://anthonybmasters.medium.com/self-selection-bias-and-social-research-516df8be01b3.

42. GOOGLE. *Google Forms* [online]. [visited on 2024-01-21]. Available from: https://www.google.com/forms/about/.

43. 6SENSE. *Market Share of Google Forms* [online]. [visited on 2024-01-21]. Available from: https://6sense.com/tech/survey/google-forms-market-share.

44. INTERACTION DESIGN FOUNDATION - IXDF. *What is User Centered Design (UCD)?* [online]. [visited on 2024-05-12]. Available from: https://www.interaction-design.org/literature/topics/user-centered-design.

45. META OPEN SOURCE. *React The library for web and native user interfaces* [online]. [visited on 2024-05-08]. Available from: https://react.dev/.

46. BLENDER FOUNDATION. *Agent 327* [online]. [visited on 2024-04-28]. Available from: https://studio.blender.org/films/agent-327/.

47. BRIAN FRITZ. *OMDb API - The Open Movie Database* [online]. [visited on 2024-04-28]. Available from: https://www.omdbapi.com/.

48. DARIA KRASOVSKAYA. *Types of Usability Testing* [online]. [visited on 2024-05-13]. Available from: https://www.uxtweak.com/usability-testing/types/.

49. FULLY FACTORY GMBH. *Fully Kiosk Solutions* [online]. [visited on 2024-04-30]. Available from: https://www.fully-kiosk.com/.

50. REACT SPRING DEVELOPERS. *react-spring* [online]. [visited on 2024-05-10]. Available from: https://www.react-spring.dev/.

Appendix A

Acronyms

TV Television (Television set)

OTA TV Over-the-air television

Hi-Fi High-fidelity

OS Operating system

PC Personal computer

IR Infra red

UI User interface

UX User experience

UML Unified Modeling Language

EPG Electronic Program Guide

PIP Picture-in-picture

TCP Transmission control protocol

UDP User datagram protocol

JSON JavaScript Object Notation

URL Uniform Resource Locator

Appendix B

Contents of attachments

- `react_app.zip` ..... implementation sources
- `latex_src.zip` ..... the directory of LaTeX source codes of the thesis
- `README.md` ..... instructions how to setup the application
- `public_assets_pt1-3.zip` ..... Prototype assets
- `video1.mp4 - video7.mp4` ..... Videos exhibiting functionalities of the prototype

Appendix C

User testing interviews

Participant 1, age category: 20 - 29

1. Which tasks did you find confusing?

   Respondent found setting the reminder confusing, as they initially thought that the buttons for favorite movie actions are part of the buttons below.

2. Regarding searching for movie or genre names, how was your experience with typing into the search bar? How does it compare to your last TV search?

   Since the respondent typically uses a regular controller with physical buttons at home, they found typing on the keyboard much more comfortable than selecting letters on screen.

3. How intuitive did you find controlling the TV with the additional changing screen?

   Controlling the TV with the changing screen was much more intuitive than using a regular controller with buttons, according to the respondent. They mentioned finding it confusing to use a regular controller at their parents' house. They also appreciated how comfortable it was to rewind videos without having to hold down a button for an extended period, with instant previews on the screen.

4. How often did you need to look up from the controller to the main screen for additional information?

   Almost never, as all the necessary information was provided on the controller itself.

5. How effective was the controller for performing tasks? How does it compare to a regular physical controller in terms of speed?

The respondent noted that the tested controller was more effective than the regular one they're used to. They found rewinding to be faster and text input to be more comfortable.

6. How would you rate the feedback provided by the controller for your actions?

   The feedback was good, every action had instant feedback.

7. Was there any specific interaction mechanic or interface that you liked?

   While nothing stood out specifically, the respondent liked the concept as a whole.

8. What surprised you during the testing?

   The respondent expressed surprise that the system actually worked (respondent laughed hard on this).

9. If you could change anything in the app, what would it be? Is there anything you'd like to add or remove?

   They suggested adding buttons for fast-forwarding or rewinding by 5-10 seconds, similar to Netflix, for quick navigation. Additionally, they would like to have the ability to set some programs as favorites for quick access.

10. Would you use a similar touch device if it were available for your TV?

    Absolutely, as the respondent often finds using a regular controller cumbersome and prefers the app-like interface they enjoyed during the testing.

Participant 2, age category: 30 - 39

1. Which tasks did you find confusing?

   The participant did not notice the volume control at first. However, after asking where they would expect it, I didn't get any exact response.

2. Regarding searching for movie or genre names, how was your experience with typing into the search bar? How does it compare to your last TV search?

   At home, the participant typically controls the TV by clicking or using voice commands. They found typing on the keyboard much more reliable and comfortable than using the regular TV remote.

3. How intuitive did you find controlling the TV with the additional changing screen?

The participant found controlling the TV with the touch screen certainly better than using the regular controller. They particularly liked that the video player component with direct interaction.

4. How often did you need to look up from the controller to the main screen for additional information?

   The participant found it a bit unusual to look up from the controller to the main screen and wasn't always sure if there was different content. However, they primarily made decisions based on the phone.

5. How effective was the controller for performing tasks? How does it compare to a regular physical controller in terms of speed?

   The efficiency was definitely higher than with the regular controller. The participant appreciated the ease of searching the content and the idea of interconnecting streaming services with regular TV broadcast which they still like to watch. It was definitely better to directly look up channels than remembering channel number or scrolling through an endless list of channels.

6. How would you rate the feedback provided by the controller for your actions?

   The participant found the feedback to be great, as they were confident that their actions were recognized. However, they mentioned that the keyboard could be better. On the other hand, this is more of an issue of the smartphone model on which the prototype was tested rather than the prototype itself.

7. Was there any specific interaction mechanic or interface that you liked?

   The participant appreciated the basic menu's speed, particularly for searching movies, as the response was instant.

8. What surprised you during the testing?

   The participant found the reminder functionality interesting and stated that they would probably use it.

9. If you could change anything in the app, what would it be? Is there anything you'd like to add or remove?

   The participant suggested adding quick choices to channels or series for convenience.

10. Would you use a similar touch device if it were available for your TV?

    The participant would use a similar touch device instead of a physical controller, however, they would be a bit worried about battery life of such device, which could be annoying if it had to be charged too often.

Participant 3, age category: 20 - 29

1. Which tasks did you find confusing?

   Participant found a bit confusing the visibility of the video slider element when streaming the movie, they didn't notice it at first, but they liked the captions of video parts.

2. Regarding searching for movie or genre names, how was your experience with typing into the search bar? How does it compare to your last TV search?

   They definitely liked touch controller more than pressing buttons and in practice he liked it even more than voice control which they usually use because it often doesn't recognize the input very well. Also for shorter inputs, it takes too long to recognize it for the voice controller as opposed to quickly typing it on screen.

3. How intuitive did you find controlling the TV with the additional changing screen?

   It came to them intuitively, even for those quick actions that he first understood in a different way.

4. How often did you need to look up from the controller to the main screen for additional information?

   Not as often as they had expected, as they got most of the information from the controller and there were rather passive things on the main screen.

5. How effective was the controller for performing tasks? How does it compare to a regular physical controller in terms of speed?

   Respondent found it more effective for searching for content, but in the case of cable TV, when they have only around 8 channels, he finds it too much and the regular controller is more straightforward.

6. How would you rate the feedback provided by the controller for your actions?

   Touch screen controller had great feedback, but they didn't have a problem with the regular button controller either.

7. Was there any specific interaction mechanic or interface that you liked?

   They liked rewinding the video directly with visible preview and also how the scrolling was synchronous when browsing for channels and movies.

8. What surprised you during the testing?

   No surprises.

9. If you could change anything in the app, what would it be? Is there anything you'd like to add or remove?

   They would like to have a combination of voice input and a controller like this for quick actions.

10. Would you use a similar touch device if it were available for your TV?

    Respondent would definitely use it until the voice control is improved and they would probably prefer it over voice control for browsing of the content and quick actions, as the direct interaction is much faster. They would prefer a voice assistant for more complex commands such as "Find me a video from youtuber X where he talks about topic Y" or for switching songs when they're in the kitchen.

Participant 4, age category: 30 - 39

1. Which tasks did confuse you?

   Respondent struggled with distinguishing between setting a reminder and playing a movie. They read "play" on the first button so they automatically assumed that the rest of the buttons meant "play" as well.

2. Remember how you were looking up the movie or genre name. How would you rate the experience of typing the text input to the search bar? Compare it to the input method you've used the last time you were searching for something on your TV.

   Typing on the keyboard felt more natural compared to using voice input. However, respondent had a great point about accessibility, that people with visual impairments might struggle with small letters on the keyboard, their mom likes to use the voice assistant at home as she does not need glasses for that.

3. How intuitive did you find the TV controlling with the another screen which is changing?

   The controlling felt intuitive since their focus was on the controller. However, they stated that the screen might be distracting when watching content on the main screen so they would like some raise-to-wake functionality which would automatically dim the controller when not in use.

4. How often did you have to look up from the controller to the main screen to find additional info about the content which was presented to you?

   Not much, as the controller held their attention until they found the desired movie.

5. How effective would you say the controller was when performing the tasks? How do you compare the speed of actions made to the regular physical controller?

   The controller's actions were probably faster than a regular physical controller, which often requires numerous clicks to find desired content.

6. How would you rate the feedback of your actions made on the controller? Were you sure they were recognized?

   The feedback was instant and sufficient, respondent was sure that actions were recognized.

7. What interaction mechanic or interface did you like?

   They appreciated the natural interaction mechanics and lag-free synchronization, especially the instant video preview feature which they miss on Apple TV.

8. What surprised you?

   They were surprised by how natural the controller felt and how easy was it to use without needing to explain.

9. If you could change anything on the app, what would it be? What would you add or remove?

   They would remove reminders as they wouldn't use them. Respondent would expect adaptation to user behavior and preferences for favorite content and actions through multiple linked streaming services.

10. Would you use a similar touch device if it was available for your TV? Explain why.

    Yes, they would use a similar touch device for their TV. However, respondent stated a drawback that touch device like this would definitely break when thrown against the wall (as professional as I wanted to look, I could not hold my laughter after this). But realistically, they often just throw a blanket off the couch and the controller falls on the floor so they would be afraid that this one would not survive the impact.

Participant 5, age category: 30 - 39

1. Which tasks did confuse you?

   When searching for a movie or a channel, they would expect searching only within the tag if it's turned on, not global searching which cancels the tag filtering.

2. Remember how you were looking up the movie or genre name. How would you rate the experience of typing the text input to the search bar? Compare it to the input method you've used the last time you were searching for something on your TV.

   They would prefer to have a vertical controller as it feels weird to hold it horizontally: "How can I hold a pizza in the other hand?" They feel that the voice input does not always work, and clicking with the cursor is slow, so the respondent liked the keyboard input very much.

3. How intuitive did you find the TV controlling with the another screen which is changing?

   They thought it was fine, they just didn't focus on the main screen, which didn't matter in the end because they had all the information from the controller.

4. How often did you have to look up from the controller to the main screen to find additional info about the content which was presented to you?

   Almost never but in the beginning the respondent felt a bit lost in the content, which changed after few minutes.

5. How effective would you say the controller was when performing the tasks? How do you compare the speed of actions made to the regular physical controller?

   Certainly faster than clicking with a controller, response time was good enough.

6. How would you rate the feedback of your actions made on the controller? Were you sure they were recognized?

   They were sure of individual actions and the feedback was instant so no problem there.

7. What interaction mechanic or interface did you like?

   Greater scrolling granularity and accuracy compared to buttons, they liked the video preview very much.

8. What surprised you?

   Reminders, respondent said that they would love this feature on their current device.

9. If you could change anything on the app, what would it be? What would you add or remove?

   Having the choice between vertical versus horizontal alignment and they would add some kind of ongoing notification on the display about upcoming reminder.

10. Would you use a similar touch device if it was available for your TV? Explain why.

    Entering text was much better and even the direct interaction was smoother. Respondent liked the mirroring of content when browsing movies and shows so they could argue with their spouse about what to watch, so yes, they would definitely use it.

Participant 6, age category: 50 - 64

1. Which tasks did confuse you?

   When searching for the fight scene in Agent 327, they couldn't find the exact scene at first, because they were only clicking at the video slider and not dragging it, which did not show the thumbnail of the video and description of video part.

2. Remember how you were looking up the movie or genre name. How would you rate the experience of typing the text input to the search bar? Compare it to the input method you've used the last time you were searching for something on your TV.

   Respondent liked the input method better than clicking with the controller, however, they don't usually type much text as they don't use any streaming services on TV, only the regular TV broadcast.

3. How intuitive did you find the TV controlling with the another screen which is changing?

   It took the respondent a bit of adjusting which I personally agree, they seemed a bit lost and did not know where to look, whether on the controller or the screen. However, after a while they got more comfortable and realized that they can mostly ignore the main screen and concentrate on the actions on the controller.

4. How often did you have to look up from the controller to the main screen to find additional info about the content which was presented to you?

   Quite a lot at the beginning but as already mentioned, respondent then mostly concentrated on the controller and was not much looking on the main screen.

5. How effective would you say the controller was, when performing the tasks? How do you compare the speed of actions made to the regular physical controller?

   Probably a bit more effective, they are not using streaming services but browsing through the channels was faster than using their controller at home.

6. How would you rate the feedback of your actions made on the controller? Were you sure they were recognized?

   Feedback was good, actions were clear.

7. What interaction mechanic or interface did you like?

   Having movie description directly in the TV, respondent would like that in their TV broadcast.

8. What surprised you?

   Synchronous scrolling, when the list of channels on the controller was the same as on the main screen.

9. If you could change anything on the app, what would it be? What would you add or remove?

   They would like to have some quick access to their favorite channels.

10. Would you use a similar touch device if it was available for your TV? Explain why.

    Respondent would not be completely against the usage of the controller but would not change at the moment. Even though the app seems "nice", they find it a bit complicated for their use case and they are worried about the battery life that they would need to charge it too often. On the other hand, they liked that the screen would be visible also in the dark, , which they sometimes have problems with.

Participant 7, age category: 30 - 39

1. Which tasks did confuse you?

   Respondent tried to search for the movie name in the channel list, which they didn't notice that it's separate from movie list but they noticed the difference themselves after a short while and navigated to the other list after.

2. Remember how you were looking up the movie or genre name. How would you rate the experience of typing the text input to the search bar? Compare it to the input method you've used the last time you were searching for something on your TV.

   They quite already like text input by voice on their current TV but sometimes it does not recognize the input very well, mostly when it's too noisy in their living room so in that case they would like this full keyboard more.

3. How intuitive did you find the TV controlling with the another screen which is changing?

   Controller interface was intuitive enough, apart from the searching problem they didn't have issues with understanding of other components. The controller app felt natural to use.

4. How often did you have to look up from the controller to the main screen to find additional info about the content which was presented to you?

   Not too much, they basically ignored the main screen until a video was playing there.

5. How effective would you say the controller was, when performing the tasks? How do you compare the speed of actions made to the regular physical controller?

   Very effective, they liked how quickly the actions can be done as opposed to just clicking with regular controller.

6. How would you rate the feedback of your actions made on the controller? Were you sure they were recognized?

   Feedback was good, no issues.

7. What interaction mechanic or interface did you like?

   Respondent mostly liked the video fast-forwarding with the instant thumbnail preview. Also they like the idea of mirroring content, they often just turn on something and meanwhile search for something else they want to actually watch. This is just simulated in the prototype by mirroring the settings menu but I explained the idea behind it to the respondent and they would really appreciate something like that.

8. What surprised you?

   Fast response time of the controller, everything felt instant.

9. If you could change anything on the app, what would it be? What would you add or remove?

   As already mentioned, the respondent would mostly appreciate the browsing content while playing something else on the main screen.

10. Would you use a similar touch device if it was available for your TV? Explain why.

    Respondent would probably use such device as they liked how it works when browsing for a new content, but they would still want to keep the voice assistant as well for the tasks when they know exactly what to watch, because it's even easier and faster for them to use.

Participant 8, age category: 20 - 29

1. Which tasks did confuse you?

   Respondent was confused about playing the favorite show Agent 327, that it's streaming in the TV at the moment and they can rewind the show as well. While many TV providers allow the show to be stopped and played from beginning, it's true that the streaming cannot be usually fast-forwarded to the end, or past some point which was already streamed.

2. Remember how you were looking up the movie or genre name. How would you rate the experience of typing the text input to the search bar? Compare it to the input method you've used the last time you were searching for something on your TV.

   Respondent only uses the regular button controller so having the full keyboard was much more comfortable for them, even though in the prototype the keyboard is difficult to hide after typing the text, but that's more of a technicality of the prototype rather than design.

3. How intuitive did you find the TV controlling with the another screen which is changing?

   Controller was easy to use, it was showing mostly the same content as the main screen so it was not difficult to navigate through.

4. How often did you have to look up from the controller to the main screen to find additional info about the content which was presented to you?

   Respondent was checking both screens at first but after a while when they noticed they're almost the same, the focus remained on the controller.

5. How effective would you say the controller was, when performing the tasks? How do you compare the speed of actions made to the regular physical controller?

   Definitely more effective than regular controller, mostly using the quick actions to play the last channel or some favorite show.

6. How would you rate the feedback of your actions made on the controller? Were you sure they were recognized?

   Feedback was good, it was nice that they didn't have to point the controller in the direction of the TV.

7. What interaction mechanic or interface did you like?

   They liked the idea of having large movie database available in the TV to browse through and directly have links to streaming services where

the movie is available. Respondent is annoyed by having three separate streaming service accounts and browsing through them separately.

8. What surprised you?

   Reminders for the TV shows, respondent didn't know that it's already available from some TV providers in their app interface.

9. If you could change anything on the app, what would it be? What would you add or remove?

   They would add multi-device support, the respondent would like it more if the controller was not separate but it was downloadable app for anyone in household to download so they could browse the content separately.

10. Would you use a similar touch device if it was available for your TV? Explain why.

    Yes, respondent would definitely use app or device like this over their regular controller as it felt more comfortable for them to use.

Participant 9, age category: 40 - 49

1. Which tasks did confuse you? Participant initially thought that they are supposed to hold the controller aimed to the television. I did not comment that at first as I thought they just hold a smartphone in a specific way, but after the first task it was obvious that they were trying to aim at the television with the controller. After explaining to the participant that it is not needed, they admitted it is much more comfortable to use it normally as a smartphone.

2. Remember how you were looking up the movie or genre name. How would you rate the experience of typing the text input to the search bar? Compare it to the input method you've used the last time you were searching for something on your TV.

   Respondent found typing on the touchscreen keyboard much more comfortable over using their current TV remote. However, they would prefer a bigger keyboard, as the one provided was small for their fingers to use comfortably.

3. How intuitive did you find the TV controlling with the another screen which is changing?

   They found the controller interface fairly intuitive, though they suggested a tutorial might be helpful for new users. Other than the initial confusion, the touchscreen controller felt intuitive and responsive.

4. How often did you have to look up from the controller to the main screen to find additional info about the content which was presented to you?

   Respondent occasionally looked up at the main screen to verify what was happening at first, but after a while they mainly focused on the controller screen once they got used to it.

5. How effective would you say the controller was, when performing the tasks? How do you compare the speed of actions made to the regular physical controller?

   They found the touchscreen controller to be more effective and faster for navigating menus and performing tasks compared to a physical remote. Actions felt more direct and immediate with touch input.

6. How would you rate the feedback of your actions made on the controller? Were you sure they were recognized?

   Feedback was clear and immediate, no issues there.

7. What interaction mechanic or interface did you like?

   Even though the menu carousel was a bit laggy, participant liked the possibility to continue watching content while setting something in the menu. I explained the possibility to extend the model to be able to browse for content while watching something else and participant was very enthusiastic about the idea, as his wife hates when he takes too long to choose something to watch and nothing is on TV meanwhile.

8. What surprised you?

   As already mentioned, participant was initially surprised that the controller does not use infra red diode and they does not have to point the controller in the direction of the television receiver. They were generally surprised by the whole concept of controlling the TV with a smartphone.

9. If you could change anything on the app, what would it be? What would you add or remove?

   Respondent would add option to record the broadcasting, as they are not able to record all the channels, just selected ones. They also mentioned the need for clearer instructions or a brief tutorial for new users.

10. Would you use a similar touch device if it was available for your TV? Explain why.

    Respondent liked the modern feel of the touchscreen interface and they would use it for browsing the content, though they would still appreciate having a traditional remote as a backup.

Participant 10, age category: 30 - 39

1. Which tasks did confuse you?

   Respondent was very quick to get their hands on the prototype and learned to navigate fast. Single point of confusion were the reminders, where they did not notice the white text on image background, which I agree, was not the best choice even though the opacity of the image was lowered.

2. Remember how you were looking up the movie or genre name. How would you rate the experience of typing the text input to the search bar? Compare it to the input method you've used the last time you were searching for something on your TV.

   Typing on the touchscreen keyboard was much faster and more accurate than using virtual cursor they have available on their current controller. They appreciated the ease of typing, although they mentioned that a voice input option would be a nice addition, as they like to use it when they are alone (respondent mentioned that they do not like to use voice commands when having other people around as it feels weird for them).

3. How intuitive did you find the TV controlling with the another screen which is changing?

   They found the touch screen controller intuitive, as the most actions were on the touchscreen and main screen provided mostly background content.

4. How often did you have to look up from the controller to the main screen to find additional info about the content which was presented to you?

   Not often. Participant mostly used the controller screen for navigation and only looked up at the main screen to see that selected content Agent 327 was actually playing and video was correctly fast-forwarding.

5. How effective would you say the controller was when performing the tasks? How do you compare the speed of actions made to the regular physical controller?

   The touchscreen controller was very effective and they appreciated how tasks could be completed with fewer steps than on their own television.

6. How would you rate the feedback of your actions made on the controller? Were you sure they were recognized?

   Participant felt confident that their actions were being recognized and executed without delay.

7. What interaction mechanic or interface did you like?

   Participant particularly enjoyed the ability to quickly scroll through a list of channels or movies with a swipe gesture. They also liked the thumbnail previews when fast-forwarding through content.

8. What surprised you?

   They were surprised by how responsive and fluid the controller was. The seamless interaction between the controller and the main screen was comfortable to use.

9. If you could change anything on the app, what would it be? What would you add or remove?

   They would add an option to customize the layout of the initial controller screen, allowing users to prioritize their most-used features, not only favorite shows or channels.

10. Would you use a similar touch device if it was available for your TV? Explain why.

    Yes, the respondent would use such as it felt more enjoyable. They also mentioned it could be perfect for choosing the content to watch while sitting on the toilet as it is connected through the wifi, which was amusing to hear.