Feedback Mechanisms for Smart Systems

Bachelor's Thesis of

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I declare that I have developed and written the enclosed thesis completely by myself, and have not used sources or means without declaration in the text.
PLACE, DATE

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(Jan Bauer)

Acknowledgements

After being informed, by KIT's Erasmus coordinator, about the possibility to write the Bachelor Thesis during an exchange semester, I was immediately convinced to take this opportunity and applied for the University of Zurich. As soon as I got accepted, I started to search for open thesis positions. Unfortunately, after having found a suitable thesis, I had to realize that the professors, pursuing research in the respective area at KIT, wanted me to write the Bachelor Thesis directly at their institute and not abroad. In consequence, the conclusion to cancel the exchange semester, before it even started, seemed inevitable. Luckily, it did not turn out that way in the end. At this point, I want to thank Professor Koziolek, Professor Glinz and my supervisor Professor Seyff, for offering me a Bachelor Thesis about "Feedback Mechanisms for Smart Systems". I am very thankful for this opportunity. Special thanks belongs to Professor Seyff and my co-supervisor Melanie Stade, who actively supported me during the whole time, by contributing their expertise, discussing next steps and giving motivating feedback. It was a pretty busy and sometimes stressful time and I learned a lot about the topic as well as scientific work. Therefore, I am very happy and proud to finish this work and hopefully continue with my master's degree at the University of Zurich.

Abstract

The Internet of Things is on the rise and with it, the importance of so-called smart systems is surging. Formerly independent systems, of any size, gradually transform into their smart and connected successors. Cars, homes and even cities are advancing to their smarter equivalents. This revolution takes place regardless of the physical system size. Through these new technological capabilities, advanced interactions between human and technology become conceivable. Use cases like refrigerators that independently reorder food if necessary, or intelligent thermostats that constantly adapt the temperature to the user's preference have already become reality. Increasingly complex human-to-machine interaction, in combination with self-deciding smart systems, require extensive feedback. It is the responsibility of the developers to ensure that the system response to external stimuli meets the users expectations. This is hard to achieve a priori. Therefore, it is crucial to involve the user during the entire product life cycle via suitable feedback mechanisms.

In order to assess the current state of feedback mechanisms for smart systems, a market analysis and a literature research were carried out. The results show that commercial solutions mainly rely on traditional online push mechanisms. Scientific literature, on the other hand, also presents more advanced concepts that are tailored to specific use cases. Some described solutions allow users to augment their feedback with various types of media while others can attach automatically recorded information like bug reports. Smart systems, especially in the smart home sector, feature language as their primary mean of interacting with the user. It is shown that the possibilities emerging from voice user interfaces in regard to feedback have not been sufficiently investigated.

Users tend to favor integrated feedback mechanisms and no integrated tool could be identified, which enables the user to conversationally give voice feedback. Therefore such a system was prototypically implemented, based on Amazon's Alexa voice assistant. In a small study, it could be shown that the developed solution also achieved good results regarding usability, effectiveness, efficiency, and satisfaction among the study participants.

Zusammenfassung

Das Internet der Dinge ist auf dem Vormarsch und mit ihm steigt auch die Bedeutung sogenannter intelligenter Systeme. Ehemals eigenständige Systeme gehen allmählich in ihre intelligenten und vernetzten Nachfolger über. Autos, Häuser und sogar Städte werden smart und vernetzt. Diese Revolution vollzieht sich unabhängig von der physischen Größe des Systems. Diese neuen technologischen Fähigkeiten, die auf der Vernetzheit und Intelligenz dieser Systeme beruhen, machen noch fortgeschrittenere Interaktionen zwischen Mensch und Maschine denkbar. Kühlschränke, die Lebensmittel bei Bedarf selbständig nachbestellen, oder intelligente Thermostate, welche die Temperatur ständig an die Vorlieben der Bewohner anpassen, sind bereits zur Realität geworden. Zunehmend komplexe Mensch-Maschine-Interaktion, in Kombination mit selbstentscheidenden intelligenten Systemen, erfordern ein immer umfassendes Verständnis der Bedürfnisse der Benutzer. Die Entwickler müssen sicherstellen, dass das Verhalten des Systems den Erwartungen der Benutzer gerecht wird. Benutzer-Feedback ist hierfür von sehr hoher Bedeutung.

Um aktuellen Stand der Industrie und Forschung im Bereich der Feedback Mechanismen für intelligente Systeme zu beurteilen, wurde zuerst eine Marktanalyse und eine Literaturrecherche durchgeführt. Das Ergebnis zeigt, dass kommerzielle Lösungen hauptsächlich auf traditionellen Online-Push-Ansätzen basieren. In der Literatur hingegen werden auch fortgeschrittenere Konzepte behandelt, die auf bestimmte Anwendungsfälle zugeschnitten sind. Manche Tools erlauben es dem Benutzer ihr Feedback zum Beispiel mit Screenshots zu erweitern können, während andere Tools automatisch Fehlerberichte anhängen können. Intelligente Systeme, insbesondere im Smart-Home-Bereich, werden vom Benutzer hauptsächlich über Sprache gesteuert. Die Möglichkeiten, die sich daraus im Bezug auf Feedback ergeben, werden von der Industrie nicht ausreichend genutzt und in der Literatur nicht ausreichend behandelt.

Benutzer bevorzugen in der Regel integrierte Feedback Mechanismen, jedoch konnte kein integriertes Tool identifiziert werden, das dem Benutzer die Möglichkeit gibt, in einem Dialog mit seinem Sprachassistenten Feedback zu geben. Zu Testzwecken wurde ein solches System, basierend auf Amazons Sprachassistent Alexa, prototypisch umgesetzt. In einer kleinen Studie konnte gezeigt werden, dass dieser Prototyp auch gute Resultate bezüglich seiner Benutzbarkeit, Effektivität, Effizient und Zufriedenheit von den Studienteilnehmern erhielt.

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1. Introduction

1.1. Context

Smart systems are on the rise and they are steadily becoming more important and prevalent [16]. All smart systems, from smart cars over smart grids to smart homes, distinguish themselves from their less smart predecessors through a form of built-in intelligence and adaptability. This thesis investigates feedback mechanisms for this type of systems. Smart systems are characterised by incorporating "functions of sensing, actuation and control into a single device" [20]. These capabilities enable innovative interaction between human and machine. Smart objects can be taught to react to the user´s presence, movements or even gestures and vocal commands [3]. New interaction schemes, like the use of speech and hand gestures, provide an attractive alternative to traditional user interfaces [11].

1.2. Problem Description

Despite the increased complexity, the system design and behavior must match the needs of heterogeneous users. This cannot be achieved solely through an a priori process. Feedback can be a valuable source of information and opinions provided by customers and users. Research has shown that incorporating feedback into the whole product lifecycle can lead to a system, that is better tailored to the users' needs [30]. Therefore, it is beneficial to put effective means for user feedback into place. The extent of given feedback can range from general feedback, e.g., concerning how well the general system design is tailored to the users' needs, to very specific feedback, e.g., about a specific system reaction in a certain situation. However, the research carried out so far shows that feedback mechanisms have not yet been sufficiently researched in the context of smart systems [24]. From the research and the industrial perspective, this motivates for investigations on how users could be supported to provide appropriate feedback in the given context. A key challenge for providing such feedback means in the smart system context might be to understand and consider the needs of smart system users for communicating their feedback.

1.3. Thesis Goal

The goal of this thesis is the creation of innovative feedback mechanisms, that are tailored to a specific context within the domain of smart systems. Already existing feedback mechanisms for software-intensive systems in general and smart systems in particular are assessed and the users' needs regarding those mechanisms will be examined. The overall aim of the developed feedback mechanisms is to enable smart system users to effectively and efficiently give feedback regarding their smart devices. The individual research objectives of the thesis are defined as follows.

- **Assess the current state of the art of feedback mechanisms for smart devices.**
  In a first step, it should be researched what concepts and tools exist in science and industry that enable users to give feedback regarding smart devices. A literature and market analysis is carried out in order to identify existing feedback mechanisms and to examine their advantages and disadvantages.

- **Develop a concept for an innovative feedback mechanism for the smart device context.**
  Based on the insights gained from the state of the art analysis, several concepts for feedback mechanisms for smart devices shall be sketched and weighed against each other. The most promising of these is supposed to be selected and further refined.

- **Prototypically implement a novel feedback mechanism for smart devices.**
  Based on the selected and refined concept, a prototype is supposed to be developed, that can be evaluated with users. The implemented solution is intended to support a large number of devices within the ecosystem, but should also be implementable for various smart device ecosystems.

- **Evaluate the prototypically implemented feedback mechanisms with users.**
  The prototype should be evaluated with test users, to see how well it enables smart device users to give feedback. It should be assessed in terms of usability, effectiveness, efficiency, and satisfaction.

1.4. Thesis Outline

At first, a state of the art analysis of already existing concepts and mechanisms for feedback in the context of smart systems is carried out. This assessment includes an overview of existing technologies, identified through a market analysis, and concepts found in scientific literature. The strengths and weaknesses of the identified concepts are assessed in the subsequent step in regard to the users' preferences for giving feedback. The assessment of existing feedback mechanisms leads to the creation of three innovative conceptual solutions. After weighing them against each other the concept for a conversational feedback mechanism is considered to be the most promising one. This concept was prototypically implemented for Amazon's smart home ecosystem. In a final step, a user study, with potential users, was conducted to assess the users' opinion of the implemented solution. In order to enable the reader to better understand the topic, the central terms are explained at first. Although, there are a lot of different definitions of smart devices, smart systems, and IoT, it was tried to select the most common definition.

1.5. Central Concepts, Entities and Defintions

1.5.1. Internet of Things

The Internet of Things (IoT) can be seen as one of the key enabling factors of smart systems. It provides the required communication infrastructure that enables individual systems to communicate with each other and to function as a whole. From a practical point of view, the IoT can be seen as a communication platform that connects everyday objects, comprising electronics, software, and sensors, to the Internet. These devices collect information and exchange them via the network [13]. The term "Internet of Things" was coined in 1999 by Kevin Ashton from MIT's AutoID lab. This was before anything, except computers, was connected to the Internet. The term originated from the insight that the majority of the available data in the network was put in by humans. Because this approach is limited by the time and accuracy of humans, computers should gather data autonomously through sensors and distribute the data over the network [5]. Many standardization institutes (ETSI, ITU, IEEE, NIST, OASIS, W3C) offer modern definitions, for this already over 20 years old concept, and a very good and respected one comes from the IETF.

> **"The Internet of Things is the network of physical objects or things embedded with electronics, software, sensors, and connectivity to enable objects to exchange data with the manufacturer, operator and/or other connected devices."** - Internet Engineering Task Force [59]

The IoT can be viewed as the underlying communication platform that smart systems use for data exchange. IoT devices are expected to spread rapidly over the coming years and reach a number of 20 billion internet-connected devices by 2020 [15].

1.5.2. Smart systems

The concept of a smart system is very abstract. A system is generally known to be a combination of individual components that work together, in order to achieve a common goal or function [14]. The prefix "smart" signals that the system carries some form of embedded intelligence. This can be characterized by "incorporating functions of sensing, actuation, and control in order to monitor and analyze a situation" [65]. The system takes decisions based on gathered data and the sensed context and reacts in a predictive manner, by performing appropriate actions [65]. Since the concept of a smart system is very general and based on the interconnection and intelligent cooperation of individual components, it can refer to a large number of specific systems. Such are smart cars, smart grids, smart cities, smart homes and many more. Hereby, the physical system size is not of great importance. Smart systems are expected to play an important role in many industries. For example, In healthcare they are expected to advance more personalized health systems like continuous vital signs monitoring [62]. Smart systems within the city could improve the lives of its inhabitants by offering useful services and providing data to its citizen.

1.5.3. Smart cities

Smart cities can be seen as a very complex manifestation of a smart system. According to Nam and Pardo, the term smart city refers to a fuzzy concept with various available definitions. To be able to define the concept of a smart city in respect to the taken perspective, they define the three most important dimensions as "technology, people and institutions" [28]. Harrison. et al. technically define the term smart city to denote an "instrumented, interconnected an intelligent city" [18]. "Instrumented" refers to the collection of data from various sensing devices incorporated into the city. The attribute "interconnected" reflects the exchange of available data among the various city services. "Intelligent" means that this data is analyzed, processed and visualized in order to make better-informed decisions [18]. Caragliu, DelBo, and Nijkamp provide a socially more inclusive definition of smart cities: "We believe a city to be smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance" [10]. This emphasizes a smart city, to be much more than a set of technical arrangements. The imaginable interaction patterns within a smart city are manifold, but not explored far enough let alone fully available today [35]. Because of these two issues, smart cities are a difficult research object. Therefore, it was decided to focus on smaller and more common types of smart systems - namely smart homes and smart devices.

1.5.4. Smart homes

The main focus is placed on smart devices in the smart home context. A smart home can be understood as living space equipped with smart devices, that are installed for improving the overall quality of life. According to a 2017 study commissioned by the European Commission, smart homes are expected to have three major impacts - "Improving safety and security", "Saving Energy", "Providing greater convenience, comfort and wellness" for their inhabitants. The integration of new technologies, with complex interactions, into our immediate living environment have introduced new challenges. This certainly holds true for smart homes, where one key determining factor is the smooth integration of different devices into one seamlessly working ecosystem. [33].

1.5.5. Smart devices

Smart devices are software-intensive systems, comprising software and hardware components, that operate autonomously to a certain extent and are interconnected with other systems and devices for information exchange and interaction. They are characterized by providing a certain level of automation and programmability, but they also have the capability of dealing with a level of uncertainty in their environment [21]. The main focus of this work is placed on smart home devices for end consumers. Therefore, smart devices in industry are not actively taken into consideration. The focus on smart home devices for end consumers results from a higher market penetration and easier accessibility.

2. State of the Art Analysis

Many future smart systems will offer the user the opportunity to solely interact with the system through voice control. Well-known control mechanisms such as buttons or screens could become completely optional or even obsolete. Smart cars already allow the user to control certain features of the car - like starting the navigation for example - through verbal commands [7]. Scenarios in which the user only tells the car his desired destination and is then driven to this destination by the autopilot, are becoming conceivable for the future [64]. Smart homes are becoming more and more real. Today, for example, it is already possible to turn on and off every connected lamp by saying a single sentence. Applications in which the smart home independently takes decisions, based on the analysis of collected data, are also on the rise. A smart home could, for example, switch off the heating as soon as the resident leaves and switch it back on 30 minutes before the expected return [58]. These increasingly complex interaction schemes require validation. The system's conclusion must be compared and match the user's expectations. User feedback gathered via advanced feedback mechanisms can support this.

2.1. Feedback regarding smart systems

It is important to understand the reasons why feedback can be considered extremely important for the development, operation, and improvement of smart systems. The following section shows some of these reasons. Furthermore, existing feedback mechanisms will be made more tangible by introducing the reader to the most important dimensions for the classification of such mechanisms. According to Almaliki, Ncube, and Raian, "Users' feedback is vital to improve software quality and it provides developers with a rich knowledge on how software meets users' requirements in practice" [2]. The received feedback can provide insights about features, that are being requested, and about errors and their context. Therefore, feedback can guide a system's adaptation and evolution [32]. This does not only hold true for software but also for hardware/software systems like smart devices and even more complex ecosystems. Examining existing feedback mechanisms can help identify proven concepts and areas for further research.

2.1.1. Dimensions for classifying feedback mechanisms

Since classifying feedback and feedback mechanisms makes them more tangible, it also allows to, later on, select certain types for further investigation. Therefore, the most important dimensions for classifying feedback and feedback mechanisms are introduced [26]. A feedback mechanism can be understood as a specifically designed solution or concept that allows the user to provide feedback. While feedback mechanisms can only be classified with regard to the acquisition process, feedback can be classified with regard to its acquisition and content.

Users of smart systems nowadays have a variety of channels at their disposal to express their opinion. They can publish their opinion in social networks, forums, and app stores, contact customer support via email, ticket system and live chat. Or express feedback through contact forms and surveys. Feedback mechanisms, that are embedded in the companies software or hardware, enable for in situ provision. The **feedback channel** can be seen as the communicative mean through which feedback was received or acquired. Important feedback channels for smart systems, according to Stade et al. are shown in table 2.1 [40].

Table 2.1.: Important feedback channels for the smart device context.

F1: Hotline/ Phone	**F8:** Social network
F2: Email	**F9:** (Online) Survey
F3: Feedback/ Contact form	**F10:** (Live) Chat
F4: Ticket system	**F11:** *Meeting at fairs*
F5: Embedded feedback tool	**F12:** *Company's meeting at the customer site*
F6: Forum	**F13:** Ecosystem spanning channel
F7: App store	

These channels can either be based on digital **online** technologies (e.g. Email, Contact form, App store) or make use of traditional **offline** communication (e.g. Offline survey, face to face interviews). Some feedback mechanisms (e.g Surveys) may even exist as online and offline versions [29]. Since smart systems are digital technologies, they are inherently linked to Internet technology. The focus is placed on digitally supported strategies. Therefore, offline feedback channels like '*Meeting at fairs*' (F11) or '*Company meetings at the customer site*' (F12) were excluded, due to their minor importance in the smart system context. The available communication channels are either intended (**explicit**) for feedback acquisition (Surveys, Reviews) or unintentionally used (**implicit**) to express one's opinion (e.g. Social Media). Hereby, the feedback loop can either be triggered by the user (**push**) or the feedback recipient actively seeks to acquire it (**pull**)

[25]. The mechanism to pull feedback can get triggered either time-based or event-based. Classic examples of pull feedback are questionnaires, surveys, and interviews. Customer service hotlines and online chats are representatives of push feedback. Feedback can be obtained in different ways. On the one hand, prospective customers could be asked to fill out a questionnaire regarding a product or service. This represents a very **structured** appraisal following a well-defined process model. On the other hand, feedback is also communicated in **unstructured** everyday interactions [34].

The key artifact of feedback is still its **content**. The **source** for this valuable content can be every stakeholder, ranging from employees over sellers to users. It is important to consider that different stakeholders may have different needs for giving feedback [34]. The communication can be **ex post** or **ex ante**. This means that the providing instance either refers to events from the past, like observed system behaviour (**feed backward**), or to possible future happenings, like desired system capabilities and intended behaviour (**feed forward**) [34]. Usually feedback addresses a certain aspect of a system. The user maybe encountered an error that he would like to resolve, or he wants to propose new desired functionality. The **type of feedback** signals the addressed aspects. Some important types of feedback for software intensive systems were identified from literature [17]. It would be really hard to order the feedback types according to their importance, therefore it is easier to focus on listing those that are relevant for smart systems.

Table 2.2.: Important feedback types for the smart device context.

FT-1:	Bug reports	**FT-4:**	Praise and criticism
FT-2:	Feature requests	**FT-5:**	Reviews
FT-3:	Questions	**FT-6:**	User experience feedback

Many feedback mechanisms allow the user to extend their textual content with different types of **supported media**, like graphics, audio recordings, video, and hyperlinks [26]. These artifacts are part of the feedback's content. The most important classification is based on whether the feedback is positive or negative. The **sentiment** of feedback can be a simple indicator of how satisfied a customer is with the product or service [1].

2.2. Market analysis

In a first step, the current state of the art regarding feedback mechanisms for smart devices is to be ascertained. In order to, assess existing smart devices with regard to the feedback mechanisms they offer to the customer, a market analysis was carried out. The analysis focused on such devices, that are integrated into a broader framework, that enables the device to fetch information and be controlled according to a users commands or preferences. This framework is called smart home ecosystem [33].

2.2.1. Available and considered smart home ecosystems

The idea behind a smart home ecosystem, is to control a variety of smart devices from one solution. The integrated devices can potentially come from many different manufacturers and also use different protocols (Z-Wave, ZigBee, WiFi, Bluetooth). The smart home ecosystem must offer well defined interfaces that a smart device can use. Interoperability and communication between devices from different manufacturers using various protocols is a typical characteristic.

The focus is placed on smart home devices that are aimed at end-users and controllable via at least one voice assistant. Due to the fact that a strong emphasis is placed on voice feedback, smart home ecosystems that include an Intelligent Virtual Assistant (IVA) were favoured, over ones that are lacking this entity. As shown in table 2.3, the largest smart home ecosystems all include a voice assistant.

Table 2.3.: List of important smart home ecosystems.

	Ecosystem	Voice Assistant
1	Amazon's smart home ecosystem	Alexa
2	Google's smart home ecosystem	Google Assistant
3	Apple's smart home ecosystem	Siri
4	Samsungs's smart home ecosystem	Bixby
5	Xiaomi's smart home ecosystem	XiaoAI
6	Facebook's smart home ecosystem	Facebook Assistant
7	Microsoft's smart home ecosystem	Cortana

Online market research has shown that Apple's, Google's and Amazon's smart home ecosystems together dominate the smart home market with a combined market share of over 90% [52], and almost every smart home device is compatible with at least one of those. For the three selected smart home ecosystems, it was examined which feedback mechanisms were implemented that can be used to provide feedback regarding incorporated devices.

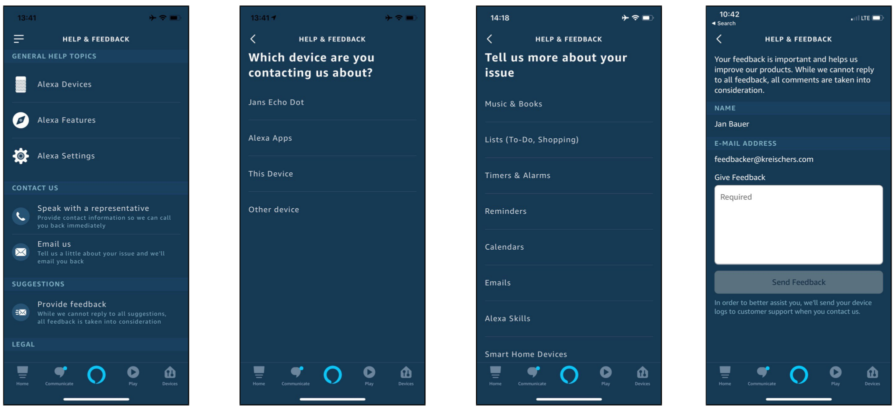
2.2.1.1. Amazon's smart home ecosystem

Amazon's ecosystem is built around it's digital voice assistant, called Alexa [45]. The company announced to have sold over 100 million devices, with Alexa on board and to be compatible with over 28,000 smart home devices [53]. The ecosystem offers extensions - the so-called "skills". These skills can be created by third-party developers and are meant to extend Alexa's functionality. Over 100,000 skills in total are already available to its users [49]. These numbers and a market share of over 50% in the smart speaker market prove that Amazon is a dominant player in the smart home market [51]. Amazon's smart home ecosystem allows the user to control almost every aspect of their connected homes through Alexa. Using compatible devices, the lights can be dimmed and switched on and off, the entrance door can be remotely unlocked. These actions can all be completed just by telling Alexa to do so. Although, Alexa has access to a lot of useful information about a device, such as context and firmware versions, it is not possible for a user to leverage this. Inquiries like "**How to provide feedback?**" or "**I would like to provide feedback**" are either not understood or answered by showing a list of not helpful web results.

Table 2.4.: Feedback channels supported by Amazon's smart home ecosystem.

	F1	F2	F3	F5	F6	F7	F8	F9	F10	F13
Feedback channel availablity	✓	✓	✓	✔	O	✓	✓	X	✓	X

✔= explicitly advertised, ✓= available, X = unavailable, O = non-identifiable



(a) (b) (c) (d)

Figure 2.1.: Trying to provide feedback through the Amazon Alexa app.

However, Amazon offers an integrated solution in their smart home app that allows users to give detailed feedback regarding their devices. At first, the user asked to select one of his connected devices. Afterwards, he then selects one aspect of the device he wants to address (e.g device and hardware, new feature request, accessibility). In the end, he is presented with a simple feedback form. Amazon points out that they may automatically collect diagnostic information and receive it together with the feedback.

2.2.1.2. Google's smart home ecosystem

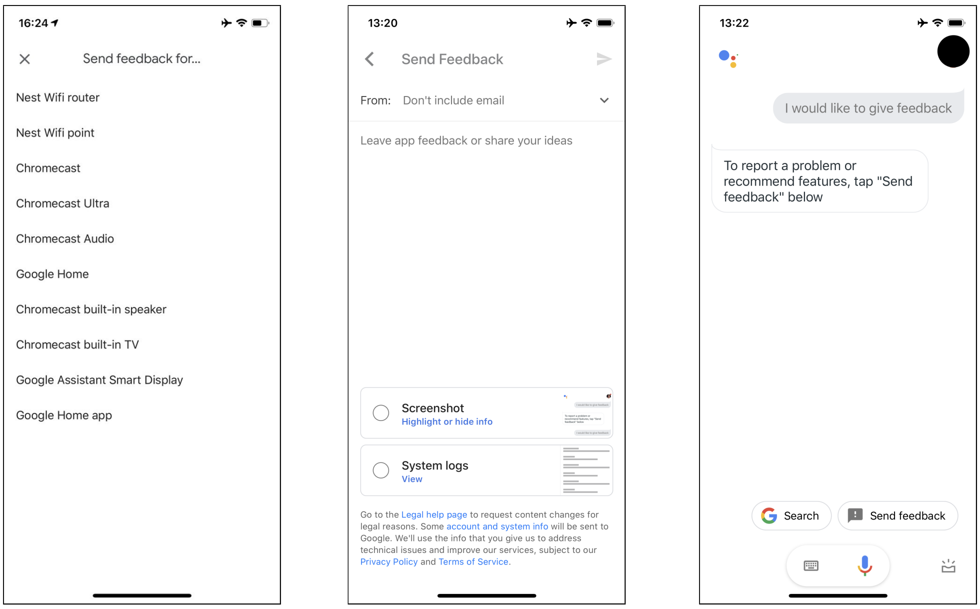
Google's smart home ecosystem is called Google Home [56]. It is also considered to be one of the largest ones, based on the market share amongst all smart home ecosystems. According to Google, there are over 10.000 Google Home compatible devices available [56]. The system comprises multiple elements like a voice assistant called Google Assistant with its associated SDK [55] as well as a smartphone app that can be used to control incorporated smart devices [57].

Table 2.5.: Feedback channels supported by Google's smart home ecosystem.

	F1	F2	F3	F5	F6	F7	F8	F9	F10	F13
Feedback channel availablity	✓	O	✓	**✓**	✓	✓	✓	X	X	X

✓ = explicitly advertised, ✓ = available, X = unavailable, O = non-identifiable

The user is able to communicate with Google Assistant through the eponymous smartphone app. He can either enter his requests as text or formulate the request in natural language. The inquiries are answered by Google Assistant with text and voice output. The user can ask **"How to give feedback?"** or state **"I would like to provide feedback"**. Google Assistant answers this inquiry by redirecting the user to a feedback form. It was necessary to provide the feedback in written form. Screenshots and systems logs can be used to augment the provided information. A way to give feedback within the Google Assistant app via voice recording could not be identified. In the end, the receipt is confirmed with the message **"Thank you for your feedback"**.



(a) Google Home App. (b) Shared Feedback Form. (c) Google Assistant App.

Figure 2.2.: Providing feedback within Google's ecosystem.

2.2.1.3. Apple's smart home ecosystem

Apple's smart home ecosystem is build around its digital voice assistant called Siri [48] and their so called HomeKit [47] framework. This framework enables third party developers to integrate their devices into Apple's smart home ecosystem, allowing the user interact with them from within the ecosystem. Every integrated device can be controlled via the so-called "Home" app or by giving voice commands to Siri. About one hundred manufacturers produce devices that integrate with Apple's HomeKit. This number is significantly lower than the number of manufacturers producing compatible devices for the other two ecosystems [46]. Nevertheless it is still a very important player in the smart home market with over 500 million Siri enabled devices [50] and an estimated global market share of 12% in the smart speaker market [52]. The following table 2.6 shows an overview of feedback channels that were identified in Apple's smart home ecosystem.

Table 2.6.: Feedback channels supported by Apple's smart home ecosystem.

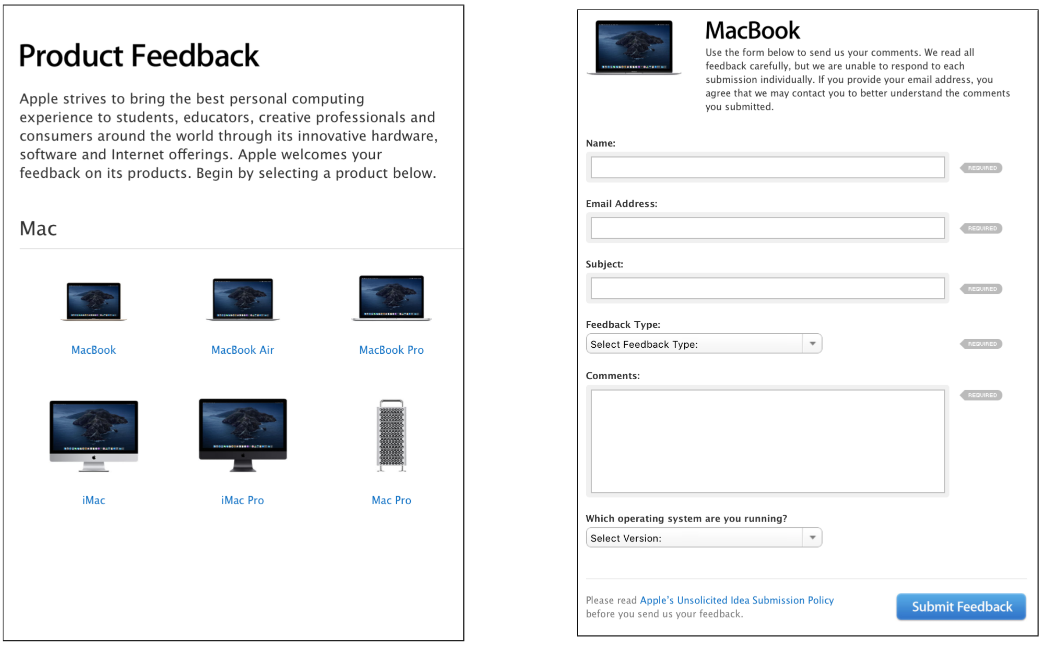
	F1	F2	F3	F5	F6	F7	F8	F9	F10	F13
Feedback channel availablity	✓	✓	✔	x	✓	x	✓	x	✓	x

✔= explicitly advertised, ✓= available, X = unavailable, O = non-identifiable

It was tried to provide in-app feedback from within Apple's Home App. This app represents Apple's control center for the smart home inhabitant. It enables the user to control all of his smart home devices via one central interface. For example, the user can control the music in the living room, or lower the blinds in the bedroom. However, he can neither give feedback on individual devices nor the ecosystem, from within this app.

Apple's voice assistant offers the user with the option to control connected smart devices, by giving vocal commands. Intents like **"Play some music please"** and **"What movies are playing near me?"** are understood and answered with ease. However, questions like **"How to provide feedback?"** or statements like **"I would like to provide feedback"** are not understood and hence do not lead to a desirable outcome. Siri does not give a very helpful answer to these requests. The attempt to submit a bug report or a feature request via this channel also remained unsuccessful. Since no possibility was ascertainable, how to give feedback by conversing with Siri, this possibility is regarded as not present.

The only explicitly advertised feedback channel is on Apple's website. To enable the user to provide feedback regarding a products or services, Apple created a three-stage feedback architecture. At first, the user visits Apple's feedback website and selects the concerned device. Afterwards, a more specific aspect has to be selected that the feedback will be about. This leads to the presentation of a feedback form that is tailored to the specifics of the selected device.



(a) (b)

Figure 2.3.: Apple's online feedback architecture.

Some general information like **name**, **email address** and **subject** always have to be provided in order to inform the company about the inquirer and enable them to get in contact if needed. Depending on the previous selection some device specific information has to be provided. This ranges from specifying the exact operating system version and model number to information about paired devices. The last step is that the user selects the type of feedback he wants to provide (bug report, feature request, compatibility issue) and enters the feedback in free text form. The clear separation of devices and the structured process provide orientation to the user. Therefore, unusable feedback due to missing important information is less likely. Feedback is augmented with a lot of necessary background information. That helps the company to effectively process the submitted information. The same process is also used in Apple's 'Feedback Assistant' app on iOS and macOS. Here, the user is also given the opportunity to view the status of his feedback and the responses received. However, it is only possible to give feedback regarding compatible third-party non Apple products.

In summary, one can say that Apple's feedback architecture is limited, because only one channel and mechanism is explicitly advertised. One the other hand, it as a very focused architecture, that clearly separates between feedback and support channels. Furthermore, it supports the user by offering a clear and supportive process. Although, the necessary infrastructure exists, in-app and voice feedback mechanisms are neglected.

2.2.2. Available and considered smart home devices

After having a detailed look at smart home ecosystems, the focus is now on individual third-party devices. According to market analysis conducted by GfK [54] and McKinsey [60], the market for smart home devices can be separated into five broad categories. Devices for **Smart Security and Safety**, **Smart Health**, **Smart Entertainment**, **Smart Utilities Management** and **Smart Appliances**. Four devices, with high market penetration, were considered for each category. Overall, 20 devices were researched for their incorporated feedback mechanisms. The research included inspecting the manufacturer's website, social media presence, device manuals, and the device's smartphone app. Figure 2.4 consolidates the results, by displaying the total number of times a certain feedback channel was identified for the 20 chosen devices. To effectively give feedback, the user must know what means of communication he should use to provide feedback. Therefore, figure 2.4 shows whether a channel is explicitly advertised by the manufacturer for feedback acquisition, or whether it can only be used implicitly. The y-axis shows how often a certain feedback channel was identified, while the used color indicates its explicitness.

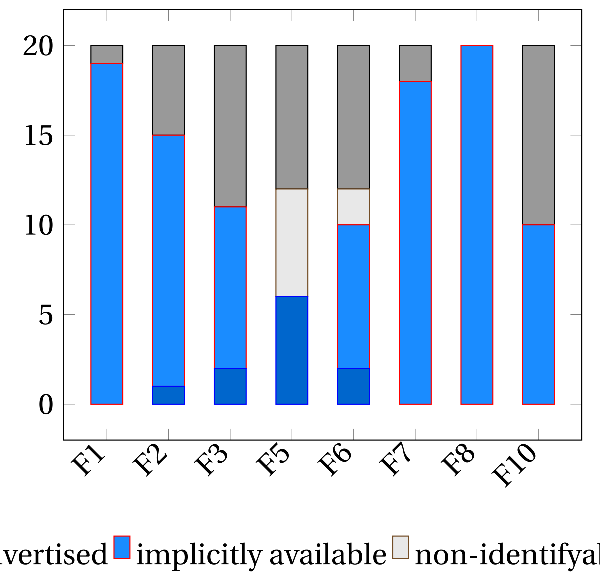


Figure 2.4.: Consolidated feedback channel availability.

Table 2.7 shows the results in greater detail. The five embedded feedback options that could be identified should be briefly described. Onelink, for example, allows to contact the customer service via voice-call or email from within their app (*1). Google lets the user record an audio message when they want to provide feedback (*2, *5). TCL and Amazon enable the user to provide feedback within their smartphone apps (*3, *4). The communication is text-based and can be augmented with a screenshot. In summary, one can say that many traditional channels, like email, hotline, app store and social media, are implicitly available for feedback provision. However, figure 2.4 proves that many manufactures do not explicitly advertise their offered feedback channels. Furthermore, the possibilities that emerge from voice controlled devices are not yet fully used for feedback acquisition.

Table 2.7.: Detailed feedback channel availability.

	E1	E2	E3	F1	F2	F3	F5	F6	F7	F8	F9	F10
Security and Safety												
Smart smoke detectors												
Onelink Safe & Sound	✓	✓	✓	✓	✓	x	**✓***1	x	✓	✓	x	x
Nest Protect	x	✓	x	✓	x	x	**✓***2	✓	✓	✓	x	✓
Smart Access Systems												
Nuki Smart Lock	✓	✓	✓	✓	✓	✓	x	o	✓	✓	x	x
August Smart Lock	✓	✓	✓	✓	✓	x	x	x	✓	✓	x	✓
Smart Appliances												
Robot Vacuum Cleaner												
iRobot Roomba	✓	✓	x	✓	✓	x	x	x	✓	✓	x	✓
Xiaomi Roborock	✓	✓	x	✓	✓	x	o	x	✓	✓	x	✓
Smart Microwave/ Oven												
Amazon Smart Oven	✓	o	o	✓	✓	x	**✓***3	✓	✓	✓	x	x
June Smart Oven	x	x	x	✓	**✓**	✓	o	x	✓	✓	x	✓
Smart Entertainment												
Smart TV												
Samsung LED TV	x	x	x	✓	✓	✓	x	✓	✓	✓	x	✓
TCL Smart LED TV	x	x	x	✓	✓	✓	**✓***4	x	✓	✓	x	x
Smart Set-TopBox												
Google Chromecast	o	✓	o	✓	✓	✓	**✓***5	✓	✓	✓	x	x
Apple TV	o	o	✓	✓	x	**✓**	✓	✓	x	✓	x	x
Smart Utilities Management												
Smart Thermostats												
Nest Thermostat	✓	✓	x	x	x	✓	x	✓	✓	✓	x	✓
Ecobee Thermostat	✓	✓	✓	✓	✓	✓	o	o	✓	✓	x	x
Smart Lighting												
Philips Hue	✓	✓	✓	✓	✓	x	o	x	✓	✓	x	x
IKEA Smart Lights	✓	✓	✓	✓	x	✓	o	x	✓	✓	x	x
Smart Health Devices												
Smart Fitness and Activity Tracker												
Apple Watch	x	x	✓	✓	x	**✓**	x	✓	x	✓	x	✓
Xiaomi Mi Band	x	x	x	✓	✓	x	o	✓	✓	✓	x	✓
Smart Scale												
Withings WiFi Scale	x	x	✓	✓	✓	✓	x	**✓**	✓	✓	x	x
Fitbit Aria	x	x	x	✓	✓	x	x	**✓**	✓	✓	x	✓

✓= explicitly advertised, ✓= available, X = unavailable, O = non-identifiable
E1, E2, E3 indicate the compatiblity with Amazon's, Google's
and Apple's smart home ecosystem

2.3. Literature research

To complete the state of the art analysis, a literature research regarding feedback mechanisms for smart systems was carried out. The focus was placed on the smart home and smart device context. The relevant literature that could be identified focuses on feedback regarding software-intensive systems. Specific literature dedicated exclusively to the broad topic of feedback on smart systems could not be identified. Since smart systems can be viewed as software-intensive systems, which often have characteristics of self-adaptive software systems, this literature is also relevant. Overall, six different approaches are considered.

Seyff, Ollmann, and Bortenschlager describe a mobile feedback approach, that enables users to document individual feedback on mobile platforms and apps, in situ. The concept emerges from the observation that "individual user feedback on mobile platforms and apps is hard to obtain" [38]. This also holds true for smart systems. The key idea that **AppEcho** introduces, is to allow users to take screenshots or photos of the system they want to give feedback to. The screenshot can be augmented by adding textual annotations and audio recordings. It is considered innovative to represent feedback as a combination of textual, visual and auditive elements. Another interesting concept is the **cross-app Android feedback tool**, developed by Jan Gubler. It is an app-based online solution, similar to AppEcho, that enables users to provide feedback regarding apps installed on their smartphone. Multiple types of feedback (Ideas, praise, criticism) are explicitly supported. Given feedback comprises a text-based description and an optional image. The feedback loop is completed by a star rating and the choice of whether the feedback should be publicly visible to other users or only visible to the developers. The tool supports both push and pull feedback. The **ConTexter** Feebdack System allows the user to give feedback regarding predefined entities that are geographically spread out. Such entities can be all objects of interest, like ticket machines and escalators for example. To give feedback, the user, first of all, is presented with a list of entities on his mobile device. The presented entities are the ones that match the user's semi-automatically identified context. This context detection is done using the GPS and WiFi capabilities of the user's mobile phone. The user selects the relevant entity and gives feedback, by providing a text-based description that can be extended by attaching optional videos, images or audio recordings [43]. The approach is interesting for this work because it considers geographically distributed systems and takes into account the context of the user. These two characteristics can also be relevant in the broader context of smart systems.

The **iRequire** concept, developed by Seyff, Ollmann, and Bortenschlager, is a mobile requirements engineering solution that enables the user to blog his requirements in situ. A flexible four-step procedure guides the user, but still allows to skip any of the proposed steps. At first, a photo capturing the most important contextual information is supposed to be provided. A text-based description or audio recording can then be used to describe the specific needs within the context. In a third, step the user is supposed to explain the underlying rationale and how the desired outcome could be achieved. Finally, the supplied information can be reviewed and submitted [37]. The concept is interesting because it allows the user to blog feedback, and it is semi-flexible and supports multiple types of media. Feedback can be hard to understand and interpret when it is unstructured or lacking important contextual information. The **FAME** approach combines user feedback and monitoring data, by using an Ontology, to support a continuous requirements elicitation process. Many different types of media (text, audio, video) can be used for providing feedback. Furthermore, star ratings and emoticons can also be used [31]. The **In-situ everywhere** approach developed by Hess et al. allows the user to give feedback, utilizing multiple input devices. In situ feedback that was gathered on one device can be further edited on another device. For example, a screenshot can be taken on the phone but the textual annotations are then done on a laptop for example. The feedback comprises text, photo, and audio recordings. Futhermore the possiblity for the developer to contact the feedback provider, in case of questions, is included. The innovative aspect of this approach is that feedback acquisition can be started on one device and finished on another one [19]. Table 2.8 briefly summarizes the concepts considered approaches.

Table 2.8.: Summary of scientific feedback mechanism concepts.

	Feedback regarding	**supported media types**	**Interesting features**
App Echo	Apps, Mobile platforms	Audio recordings, Textual descriptions, Annotated screenshots	Documents application context and feedback.
Cross-app Android feedback tool	Apps	Screenshots, Textual descriptions	Anonymous feedback, View public feedback from other users
ConTexter Feebdack System	Geographical deployed objects	Photos & Videos, Audio recordings, Textual descriptions	Pre-defined geographical entities are displayed based on the users context, Support for different types of feedback
iRequire	Surrounding objects	Screenshots, Audio recordings, Textual descriptions	Blogging needs in-situ, Supportive semi-flexible elicitation process
FAME	Software systems	Textual descriptions, Annotated screenshots	Combining user feedback with monitoring data
In-situ everywhere	Multimedia Information Systems	Audio recordings, Textual descriptions, Annotated screenshots	Multiple devices can be used together for the feedback acquisition

2.4. Conclusion

Numerous conclusions can be drawn from the state of the art analysis. Usually, the bigger the company, the more mature the provided feedback architecture. The large smart home ecosystem providers all offer a feedback mechanism, at least enabling users to provide feedback regarding their products, but not necessarily regarding ecosystem compatible third-party products. There is still a lot of room for improvement regarding the feedback architectures of the examined smart home ecosystems. Apple disregards in situ feedback by forcing the user to search for a feedback form on their website. Google's feedback architecture could be expanded by allowing to provide feedback regarding all compatible devices. Amazon, as the only company allowing to give feedback regarding compatible third-party devices (by selecting **'other device'** during the feedback process), is still lacking the opportunity of giving feedback via the voice assistant. Although, users primarily communicate verbally with their voice assistant to interact with smart devices, it is not possible for them to provide feedback in the same way.

Smaller companies, like manufactures of a single smart device, usually do not have a very sophisticated feedback architecture. They tend to focus on traditional feedback channels like email, feedback forms, and app stores. However, these means are subject to many restrictions. Feedback gained from application stores, for example, is often "useful, but not detailed enough" [38]. Some companies even neglect user feedback by not providing explicit feedback channels at all. A feedback mechanism that allows giving feedback on all devices, integrated in the ecosystem, is more consistent and convenient for the user. Furthermore, developers could rely on feedback received from the ecosystem and had more time and information to develop and improve their smart devices.

Scientific literature knows many advanced concepts when it comes to feedback on software-intensive systems. These can be a good example for the smart system context. However, the literature mainly deals with voice feedback mainly in form of allowing the user to give feedback by recording an audio message. It's one way of enabling voice feedback, but not a very advanced one. It has also been noticed that the advanced scientific concepts need to be further disseminated in practice and industry.

3. Conceptual Solution for a Conversational Feedback Mechanism

The next step was to develop an innovative feedback mechanism, based on the insights gained from the state of the art analysis. It was shown in the previous step, that the industry focus is still on traditional feedback channels and the user has to adapt to a different feedback mechanism for almost every device. Furthermore, a conversational voice mechanism, that allows the users to provide feedback by having a conversation with their voice assistant, does not exist for smart devices yet. In a first step, users' feedback channel preferences regarding smart devices were assessed. The three most promising ways to give feedback in the smart device context were identified and evaluated against each other. The approach in which the user has a conversation with his voice assistant to give feedback was perceived as the most innovative and further refined.

3.1. Assessment of users feedback mechanism preferences

According to an empirical study conducted by Almaliki, Ncube, and Ali, users prefer mechanisms that do not interrupt their current work and let them provide feedback in situ [3]. Furthermore, easy, fast and well-integrated mechanisms are favored [36]. These findings almost certainly apply to the smart device context. The question of why certain feedback mechanisms, such as voice feedback or ecosystem spanning feedback mechanisms are not fully developed or not existent yet, need to be addressed. This is done to check whether the users perceive such options as compelling or not.

To assess user preferences regarding feedback mechanisms for smart devices a small series of tests with individuals, mainly drawn as a convenience sample from the author's circle of acquaintances, were conducted. Overall, 17 individuals participated. The subject of investigation are the advantages and disadvantages of used feedback mechanisms as well as their frequency of use. The participants were asked what feedback channels they are using and which channels they would prefer to use. It was also asked, if being able to provide feedback by having a conversation with a voice assistant would be interesting to them.

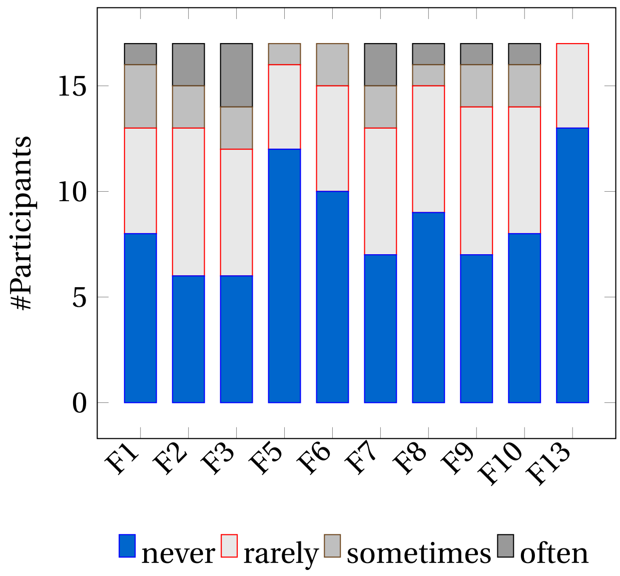


Figure 3.1.: Feedback channel usage.

Figure 3.1 consolidates the numbers regarding the question "How frequently do you use this channel to provide feedback?". It can be seen that the most frequently used channels are email and feedback forms. Typically these channels do not allow for in situ feedback acquisition. The least frequently used ones are embedded and ecosystem feedback channels. However, these are considered to be the most promising candidates for feedback acquisition in the smart device context.

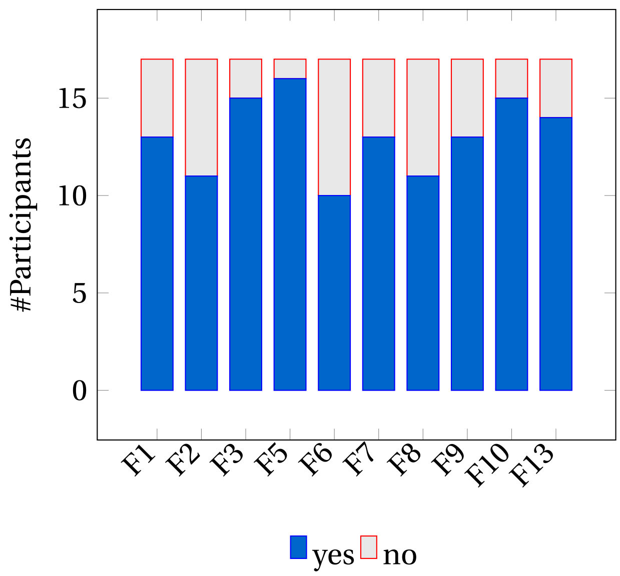


Figure 3.2.: Feedback channel preferences.

Figure 3.2 outlines the replies received regarding the question "Would you like to use this channel for giving feedback?". The participants were allowed to answer with yes and no and they seemed to favor embedded and ecosystem feedback mechanisms. Furthermore, 12 out of 17 people liked the idea of in situ feedback acquisition through a voice assistant. For these two channels the biggest discrepancy between usage habits and usage preferences can be observed. This makes it possible to carry out further investigations of these concepts in accordance with user preferences. Since smart device users are an in-homogeneous group with potentially varying needs for feedback acquisition, the design process of feedback mechanisms for this domain can be supported by persona based design.

3.2. Persona-based method for adaptive feedback acquisition

The design of feedback mechanism concepts, in such a novel domain, can be supported and improved by using persona-based design. Personas as a concept, are part of Human–Computer Interaction (HCI) [44] and they can be understood as a "Hypothetical archetype" [12] of prospective end users. They incorporate a precise description of a user's characteristics with goals they want to accomplish [44].

> **"User models, or personas, are fictional, detailed, archetypal characters that represent distinct groupings of behaviors, goals, and motivations observed and identified during the Research phase"** - Calde, Goodwin, and Reimann

Therefore, personas can be seen as a helpful design tool for the design and evaluation of feedback mechanisms. Although, the usefulness and the process of creating personas is questioned, due to its subjectiveness, they are primarily considered and used as a supporting design tool [42]. Since personas contain many details and are easy to understand, they can simplify the communication between stakeholders of different backgrounds. Almaliki emphasizes the importance of feedback for achieving consensus between requirements and implementation. According to him the preferences of users for giving feedback are diverse but very important.

> "**Knowing the user is the most relevant factor so that a product usability or service can be achieved**" - Aquino Junior and Filgueiras

Ignoring users' preferences or offering a poorly designed feedback experience can harm the quality of collected feedback. To deal with the high diversity in users' preferences for feedback acquisition, he suggests to use an adaptive feedback acquisition mechanisms that is supported by personas. Almaliki, Ncube, and Raian's designed seven personas for the context of feedback acquisition. This set of personas was extended to even better match personas in the smart system context. To maintain compatibility with the existing personas, it was decided to decorate the personas with the same attributes. Persona one emerged from personal experience while persona two is based on interviews conducted with five smart device users. Persona three is based on data collected during Stade, Baikenova, and Seyff's exploratory interview study.

3.2.1. Incentive seeking persona

Table 3.1.: Incentive seeking persona.

Sara

"If a company asks me to give feedback regarding their product, I would be happy to be rewarded for providing it."

- **Age**: 22
- **Gender**: Female
- **Job**: Student
- **Family status**: Single
- **Character**: Open-minded, self-focused

Goals

- Views giving feedback as a chance to be able to use improved products and services in the future.
- Wants to be rewarded for helping to improve products and services.

Frustrations

- Needs to be actively incentivised to provide feedback.
- Has the feeling that usually the company is benefiting more from her given feedback than she does.

Biography

- Is in the middle of her higher education and is quite familiar with new technologies.
- Has relatively little income and limited unallocated time.

Personality

Analytic vs. Creative

Proactive vs. Reactive

Conservative vs. Liberal

Motivations

Getting rewarded

Helping others

Seeing improvements

Channels

Social network

Online Survey

Email

Giving feedback requires at least a certain amount of time. From the user´s perspective, giving feedback can be seen to be an effort to a certain extent. Usually, the user provides his feedback voluntarily. Therefore, users and especially the ones that resemble the incentive seeker, expect to be somehow rewarded [2]. Possible rewards can range from getting an improved product or service over social recognition to monetary incentives (lottery, giveaway). As long as there is such an incentive the incentive seeker is eager to provide feedback through various channels and means. The lack of suitable incentives can quickly reduce the willingness to invest time and effort for giving feedback. Although, it is hard to tell how many people giving feedback are incentive seekers, many companies consider types of incentive seeking personas [6]. This persona is similar to Almaliki's incentive seeking persona but has been given additional attributes.

3.2.2. Sceptical and privacy-aware persona

Table 3.2.: Sceptical and privacy aware persona.

Matthew

"My feedback will not be taken seriously anyway, so I am not wasting my time."

- **Age**: 53
- **Gender**: Male
- **Job**: Engineer
- **Family status**: Married
- **Character**: Critical, disillusioned, stubborn

Goals

- Wants to see that errors are fixed and improvements are made following his feedback.
- Wants to be recognized for his contribution.

Frustrations

- Has the feelings that companies don't take his feedback seriuos enough.
- Wants to get updated about improvements.

Biography

- Studied product design and has deep technical knowledge.
- Works at a big technology company on new products.

Personality

Analytic vs. Creative

Proactive vs. Reactive

Conservative vs. Liberal

Motivations

Getting rewarded

Helping others

Seeing improvements

Channels

Hotline/ Phone

Live Chat

Forum

Persona two can be understood as a negative or critical persona. Negative personas can be defined to explicitly clarify for whom you do not design [8]. In this case, the persona was created to make the problems of users more tangible and therefore better addressable. It is very important for users to have the feeling that their feedback is acknowledged and appreciated [41]. Persona two represents the semi-fictional rendition of a user that used to give feedback but got discouraged over time because the receiver of the feedback did not act accordingly. Furthermore, the persona is highly aware to privacy because he grew up in a time where digital communication and sensing devices were not omnipresent. He likes to know what data is collected and how this data is used.

3.2.3. Cooperative non-tech savvy persona

Table 3.3.: Cooperative non-tech savvy persona.

Frank

"Giving feedback can be very hard and obscure. I wish there was an easier solution."

- **Age**: 28
- **Gender**: Male
- **Job**: Architect
- **Family status**: In a relationship
- **Character**: Social, Cooperative

Goals

- Likes to help by giving feedback because the feedback he receives at work also helps him.
- Wants to use technological gadgets as tools without looking at the internals.

Frustrations

- Has the feelings that companies don't take his feedback seriuos enough
- Wants to get updated about improvements.

Biography

- Studied product design and has deep technical knowledge.
- Works at a big technology company on new products.

Personality

Analytic vs. Creative

Proactive vs. Reactive

Conservative vs. Liberal

Motivations

Getting rewarded

Helping others

Seeing improvements

Channels

Hotline/ Phone

Live Chat

Forum

Persona three is based on data collected during Stade, Baikenova, and Seyff's exploratory interview study, conducted with "smart home inhabitants" [39, p.3]. Their work suggests that there are many people that would like to give feedback, but they are getting discouraged by a lack of supporting tools. Persona three is supposed to reflect this dilemma. Study participants stated to be more willing to give feedback on smart home technologies than on traditional software products. However, the frequency of feedback given regarding traditional software was much higher amongst the study participants. Feedback on smart devices was rarely given by the study participants. It is a contradiction that the actual frequency decreases with seemingly higher willingness [39, p.5]. This phenomenon is explained by the author for two reasons. Firstly, a lack of supporting feedback opportunities or a lack of knowledge about the existence of certain feedback mechanisms.

3.3. Potential concepts for feedback within smart home ecosystems

Three promising conceptual solutions for feedback mechanisms regarding smart devices, integrated into an ecosystem, were identified. Specific restrictions, that smart devices impose on the concept, were taken into consideration. Each smart device can be controlled by the user in different ways. Some devices are controlled via an integrated display (e.g Amazon Echo Show, Nest Learning Thermostat), others offer dedicated apps (August Smart Lock, Nuki Smart Lock). Some devices even offer the possibility to be fully controlled via the ecosystem, they are integrated in (e.g Philips Hue). Although the interaction possibilities for different devices are manifold, the conceptual solutions are supposed to work for a large number of different devices.

The market analysis identified standalone smart devices, that were not compatible with any smart home ecosystem and also some that were compatible with all three considered ecosystems. Therefore, the second aspect to consider is that every smart device can be compatible with an arbitrary number of smart home ecosystems. Each ecosystem features its own ways of interacting with the connected devices. Without loss of generality in regard to feedback mechanisms, the focus of this work is placed on smart devices that are voice controllable through a voice assistant. This focus enables us to examine concepts that make use of this language assistant. However, the possibility to look at concepts that do not depend on the voice assistant assistant remains. This allows to design concepts that can work for a large number of devices.

3.3.1. Ecosystem feedback mechanism

One promising concept is that the ecosystem provider could already include a standard feedback mechanism that enables users to give feedback regarding all their incorporated smart devices. Therefore, this mechanism should work for devices that are developed by the ecosystem provider as well as compatible third party devices. Such a concept is promising for feedback in smart home ecosystems since the user only has to get used to one way of giving feedback regarding all his connected devices. A simple and easy solution, based on this idea, could even increase the frequency of given feedback after the user has become familiar. Furthermore, third party manufacturers could rely on the ecosystem as their main source of feedback and they don't need to develop their own feedback architecture. This allows them to spend more time on the development of their smart devices, while still being able to receive high-quality user feedback. Such a mechanism could be implemented as a feedback section within the ecosystem's website or app. Such solutions already exist on the market to a limited extent (for example within the Amazon Alexa app) and are used productively.

3.3.2. Overlay feedback mechanism

Another fundamentally different concept for feedback acquisition for smart devices, is a so-called overlay feedback mechanism, that is provided as a service by a third-party. Such mechanisms do neither depend on specific device interfaces nor the ecosystem's capabilities at all. An example of such a mechanism would be a platform where smart device manufacturers can register their devices to gather feedback, similar to the ConTexter feedback system [43]. For every device type, specific feedback forms would be created. The availability could be communicated to the user in various ways, for example by affixing a QR code to the product, packaging or manual. Scanning this QR code would present user with a questionnaire or feedback form tailored to his device type. This means, that the user can give feedback regarding smart devices that are integrated into different smart home ecosystems. Such solutions already exist on the market [63]. The biggest advantage of this concept is that feedback regarding devices that are included into arbitrarily many ecosystem can be given. Furthermore, the device to which feedback is to be given does not have to be adapted to support the concept. Because every device can be registered here, no matter if it has the communicative interfaces for a certain ecosystem. The concept can also be used for devices that do not have their own communication channel outside their ecosystem (e.g. Philips Hue). The user can get used to a single feedback mechanism and use it for different devices and ecosystems. The disadvantage of this solution is that the level of integration with the device and ecosystem is rather low due to the desired cross compatibility . However, such a feedback mechanism is also subject to compatibility issues, because before feedback can device manufacturer and the feedback service provider have to work together in order to inform the user and provide the necessary feedback forms. Overall, this is an existing and proven concept.

3.3.3. Conversational feedback mechanism

The idea for this concept emerged from observing human face-to-face feedback. These natural language conversations revolve around a set of elements that feedback is supposed to be given on. The communication flow is open and revolves around the aspects to be discussed [61]. As shown, during the state of the art analysis, this type of feedback has not yet been sufficiently investigated, especially with regard to smart systems. The idea is to give users the opportunity to conduct a feedback dialog with their voice assistant regarding a smart device, similar to how they would give feedback to another person. Such a feedback mechanisms, leverages the possibilities that a smart home ecosystem, including a voice assistant, is offering.

3.3.4. Comparison

The decision which of the three concepts should be further pursued, in order to be implemented, as a prototype is based on an assessment regarding the **Perceived Innovativeness**, **Level of Integration** with the ecosystem, the **Implementability**, the **Expected Ease of Use** and the concept's **Cross-Ecosystem Compatibility**. The last dimension describes how easily the concept can be used to support smart devices from different ecosystems or ones that are compatible with no smart home ecosystem. The individual dimensions have been formulated in a way that higher values can be regarded as better.

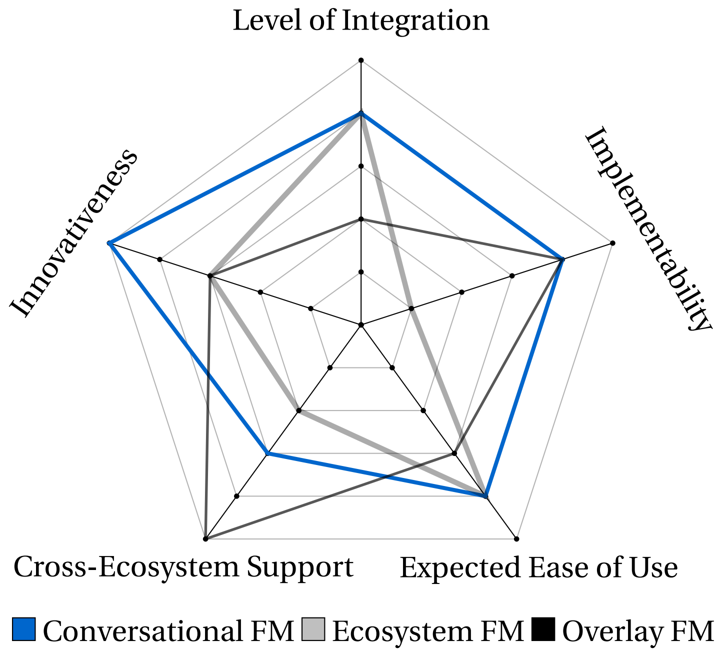


Figure 3.3.: Comparison of promising feedback mechanism concepts for smart devices.

Figure 3.3 shows how the individual feedback concepts compare to each other. The overlay concept reaches the lowest level of integration with the ecosystem, due to it's independence from specific device APIs and focus on cross ecosystem support. The three concepts are expected to reach a similar ease of use. However, the conversational feedback approach surpasses the ecosystem approach in every dimension, since it can be viewed as a super set of the later. The conversational feedback mechanism is classified as the most innovative, as no such concept could be identified in the smart home market so far. Although, some assessment participants either expressed preferences for a different approach or expressed privacy concerns regarding voice feedback, the concept still covers the largest area in the diagram. Therefore, it can be expected to be the most promising approach.

3.4. Refining the conversational feedback mechanism

It was decided to pursue and further refine the concept for a conversational feedback mechanism. Before the concept could be implemented as a prototype, it had to be assessed how such a process would optimally look like. Since, the idea emerged from observations how people give feedback to each other, an almost ideal feedback mechanism for a voice-controlled device would be similar to having a conversation with another human about the device. This means, that the user should be able to just state his feedback and the other side should understand these statements and respond appropriately. It would be conceivable that developers, wanting to collect user feedback, delegate the dialog with the user entirely to the voice assistant, after defining which information should be elicited. Information that the user has already provided would be analyzed and influence the further flow of communication. Sentiment analysis could be applied for example to analyze how positive or negative the user's feedback is, in order to start the following reply with an appropriate beginning, like "*I am glad to hear that ..*" or "*This is sad to hear ..*". After the necessary information has been recorded, it could be decided to request optional information. This would result in a very flexible, almost natural communication flow, similar to table 3.4. At the end of the dialogue, all required information would have been communicated. Like shown in figure 3.4, the complexity of the elicitation process is hidden inside one black box state. Although, this can be considered to be an almost ideal solution, a completely free feedback dialog seems not yet technically feasible.

Table 3.4.: Example of a free feedback dialog.

Frank:	Hey Alexa, my Philips Hue Light is not working anymore. Can you help me?
Alexa	This is sad to hear. I just looked at the error report and there seems to be a problem with the software. I would send this to the developers so they can resolve the issue?
Frank	Yes, please.
Alexa	Alright. We will contact you as soon as we worked out a solution.

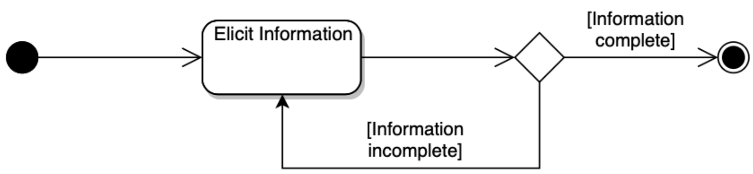


Figure 3.4.: Unstructured feedback process.

3.4.1. Feedback Process

Since an absolutely dynamic feedback dialog is currently not yet feasible, a concept supported by a more structured elicitation process is favored (Figure 3.5). The user starts the dialog with his voice assistant with the intention of giving feedback on one of his smart devices. The voice assistant recognizes this intention and first tries to identify the device that is referred to. If it could not be identified, the user could be presented with a list of his connected devices from which he can select the relevant one. There are several options for the next step. On the one hand, the user could be directly asked for his feedback and then the important information could be recorded step by step. Hereby, the type of feedback heavily influences what information is considered important. A bug report, for example, depends on completely different information than a feature request. The type of feedback that the user has given could be determined automatically with machine learning. However, a lot of training data would be needed for this. Alternatively, the user could be just asked what type of feedback he wants to provide. This should be done directly after selecting a device. In a subsequent step, the required information is recorded by asking specific questions, depending on the chosen type of feedback. For example, a description, the context, steps to reproduce and the criticality are elicited for a bug report. The process is completed by asking the user about their contact preferences. The feedback can either be submitted anonymously, or the email address and name can automatically be attached to the feedback, to enable the developers to contact the user. The concept may be reminiscent of automated telephone hotlines, where some information is also elicited automatically, before speaking to an actual human. However, the described concept is integrated with an ecosystem and allows for in situ feedback acquisition. This does not hold true for telephone hotlines.

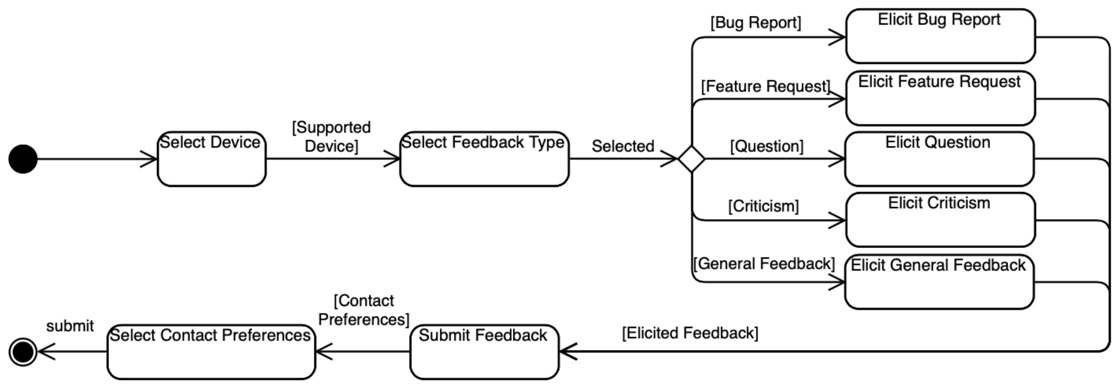


Figure 3.5.: Structured feedback process.

The voice assistant knows all integrated devices, can communicate with them and control them. This means that that the status of integrated devices is well known. For developers, it would be very helpful if the ecosystem could automatically collect information from the device that the user gave feedback on. If an error is reported, for example, an error report or stack trace could be automatically collected. If new functionality is suggested, the current device configuration could be added. The automatic collection of information still has to respect the users' privacy. Therefore, the information collected should be communicated transparently and the user should also be able to reject an automatic collection.

The feedback process comprises mandatory steps, where indispensable information is acquired, and optional ones, that elicit useful but expendable information. The intention of a user to skip a step during the feedback acquisition is supposed to be recognized and transferred into action, if possible. If the user tries to skip any optional step, the process should simply continue with the next step, and acknowledge this action with a suitable message, like "*Okay, lets skip this one*" (Figure 3.6). If the step is mandatory, the process will remain in its current state and inform the user accordingly.

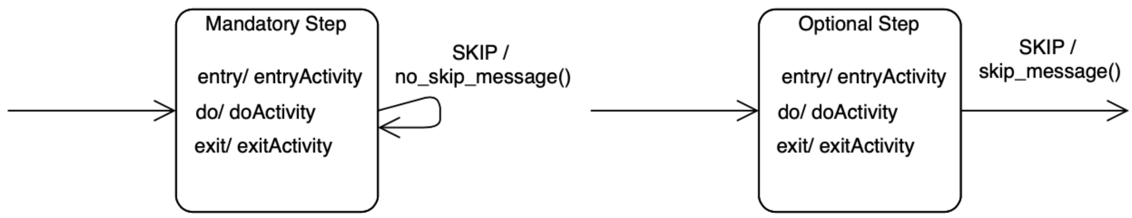


Figure 3.6.: Skipping an optional step in the feedback process.

It is also considered ideal, if the user can ask for help in every step and is then presented with a helpful and supportive answer by the voice assistant. If he asks for help when selecting the device he wants to talk about, his devices could all be listed. Furthermore, users giving feedback should be able to end the feedback acquisition at every step of the process, by just saying "*stop*" (Figure 3.7). Only a goodbye message should be issued before the feedback process ends. Although, these state transitions have been left out in figure 3.5, to increase the readability, they are still implicitly existing.

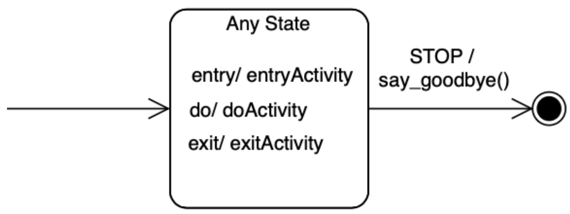


Figure 3.7.: Stopping the feedback process.

Many features, that can be observed in feedback mechanisms for software-intensive systems, are less useful or more tricky to implement in the context of voice based feedback acquisition. Many feedback mechanisms that were identified during the state of the art analysis, offer the users the possibility to extend their feedback with screenshots, images or video recordings. Some allow to view publicly posted feedback from other users. The unsuitability of these two features is intended to illustrate that voice assisted feedback sometimes has to support completely different requirements than traditional approaches.

3.4.2. Supported Feedback Types

Although, it is theoretically possible to identify and support an almost exhaustive number of feedback types, the focus is placed on the most important ones for the smart device context. These were derived from literature regarding feedback for software intensive systems [17]. Every feedback must contain descriptive content and the providing instance's contact preferences. The inclusion of further information is based on the given type of feedback. The concept supports the five most important types of feedback that could be identified for the smart device context.

1. Bug report: Errors occur particularly frequently with smart devices due to their complex usage patterns. To report an error, a user can submit a bug report. The user describes the error and the context in which it occurred. Optionally, steps are described how the reproduce the respective error and the errors criticality is assessed by the user. If possible, a stack trace, gained from the device, is attached.

2. Feature request: The preferences and wishes of users regarding new functionality can be a driving factor in the evolution of a system. Therefore is should be possible for the user to submit feature requests. This comprises a description and the context in which the feature would be helpful. Good feature requests usually address a specific problem by proposing a prospective solution. Therefore, a description of the problem and the solution are also elicited.

3. Question: No matter how smart a device might become, some aspect will always be unclear to the user and questions can arise. Therefore, the concept enables the users to submit their questions. Received questions can provide insights into which aspects of the system are not intuitive. Feedback of this type includes the question and an assessment of the question's importance.

4. Praise and Criticism: This type of feedback is given by the user to express his opinion about a device. This can range from negative corrective comments about past behaviour to affirmations of successful behaviour that should be continued in the future. It comprises a descriptive content and a star rating of how satisfied the user is overall with the device.

5. General Feedback: Since the type of feedback is potentially not always known to the user, general feedback can be given in this case. This is focused on just letting users share their feedback and does not require any further information.

Although the focus is currently on the five most important types of feedback, it is possible to extend the support in the future, as further specific types of feedback are identified. In addition to the supported types of feedback, another important aspect to consider is how the feedback process is initiated.

3.4.3. Initiation of the feedback loop

In order that a user can actively use a feedback channel, he must be aware of its existence. This also holds true for an integrated feedback mechanism using verbal communication. According to a survey conducted with potential users most of them would try to use a traditional feedback mechanisms, if they wanted to provide feedback regarding a device being integrated into a smart home ecosystem. Only one of the subjects considered trying to use the voice assistant, to provide feedback on connected devices, as a first option. This discrepancy resulted from a lack of knowledge about the existence of this possibility. One way to address this issue, would be that the voice assistant pulls feedback. The users might be asked periodically by the voice assistant if they have feedback regarding a device. This process could be triggered time or event based. Another option is to inform the user, at the beginning or during the product life cycle, about this innovative way of giving feedback and how it can be used to push feedback. It is important to communicate how to initiate the feedback loop. Ways to inform the user include attaching transparent and removable stickers to the product or its packaging. A section in the manual describing the feedback process could augment this.

Figure 3.8.: Sticker informing about voice assistant feedback.

Another good point in time is the setup process as every device has to go through it at least once. A prompt mentioning "*You can use Alexa to give feedback regarding your product*" can be displayed. Technically more advanced means are time- and event-based invocations of the feedback loop. Certain events, like the detection of a flickering light bulb, could be used to trigger the feedback process. The voice assistant can also ask for feedback after fixed time intervals, such as 100 hours of use or once a month. Context-sensitive methods that permanently analyze whether the user is verbalising his thoughts and opinion about a certain product and thereby activate the feedback loop are also conceivable. However, these carry deeper privacy concerns.

The effectiveness of the individual means to inform the user was not examined. In further analysis, the willingness of users to provide feedback could be compared based on the initiation type of the feedback loop. However, the knowledge about the existence of a conversational feedback mechanism significantly increases the possibility to make use of it. Nevertheless, a non-negligible percentage of users have privacy concerns regarding voice assistants. These have to be taken seriously and clarified.

3.4.4. Tackling privacy concerns

During semi-structured interviews, that were conducted with five possible smart home inhabitants, many data protection and privacy concerns regarding voice assistants with "continuously listening microphones" [23] were expressed. These concerns coincide with those of the sceptical and privacy aware persona. According to a vignette study, conducted by Naeini et al. that included 1007 participants, people prefer data collection in public over private spaces [27]. Smart devices reach far into one of our most private spaces - our homes. Therefore, smart home technologies are perceived as a potentially big threat to privacy [22]. Although, in-depth investigation of privacy aspects of smart home technologies and smart devices are not focus of this work, end users' concerns about this issue must be addressed in conceptual and implemented solutions. Some privacy concerns of the user can be resolved relatively easy. For example, there are users who do not want voice recordings of their feedback to be saved. The user makes this assumption because he does not know, that his feedback is converted into text and only the textual representation of his feedback is saved. A viable option to address privacy concerns was already identified during the state of the art analysis. The feedback tool simply allows the user to sent his feedback anonymously. An additional data protection declaration, including information about what data is collected and what it is used for, can further reduce privacy concerns.

Table 3.5 contains a classification of the concept regarding the most important dimensions for classifying feedback mechanisms. The concept is explicitly meant for feedback acquisition and makes use of online technologies, like the ecosystem's voice assistant. It allows users to push and developers to pull feedback regarding a device. Hereby, the acquisition can be based on an unstructured, semi-structured or structured process. The user is supported in giving multiple different types of feedback. This can be done using audio recordings or transcribed audio.

Table 3.5.: Classification of the conversational feedback concept.

Dimension	**Classification**
Online vs Offline	Online
Availability	Explicit
Feedback Process	Structured, semi-structured or unstructured
Feedback Loop Trigger	push, pull (time and event based)
Supported Media	Audio, Transcribed Audio
Supported Feedback Types	Multiple
Feedback Channel	Voice Assistant, Ecosystem

The next step is to convert the presented concept into a prototype. The process and outcome is described in the next chapter.

4. Prototype of a Conversational Feedback Mechanism

The sketched concept got implemented as a prototype, in order to be able to evaluate it with potential end users. It was decided to use Amazon's ecosystem to develop the voice user interface, because it offers the most advanced API. However, a conversational feedback mechanism could also be implemented using other voice assistants. The fact that Alexa can be used to control devices, implies that Alexa is aware of a user's integrated devices and can communicate with them. The concept involves asking the user regarding which of his devices he wants to give feedback. Unfortunately, no smart home ecosystem allows third-party developers to access a user's list of connected devices. This also limits the ability to automatically collect status information, bug reports or stack traces from a smart device. The concept therefore shows how an ideal conversational feedback mechanism could look like, while the developed prototype has to cope with the technical constraints of the ecosystem. Ecosystem providers could either open their APIs to enable the implementation of more advanced feedback mechanisms or they can implement it themselves. The restricted access to data currently has to be considered for the concept implementation. Overall the prototype consists of three parts. The Feedback Skill is the voice user interface that can be used to give feedback regarding a device. The Feedback Server receives this feedback. The Feedback Client on the other hand is used by developers to view the received feedback.

In order to give a brief overview of how the prototype compares to the concept, it was also classified in Table 4.1. In comparison to the concept (Table 3.5), it can be seen that the prototype features a structured feedback process and only allows for push feedback acquisition. This is because Amazon does not allow Alexa to query the user for information.

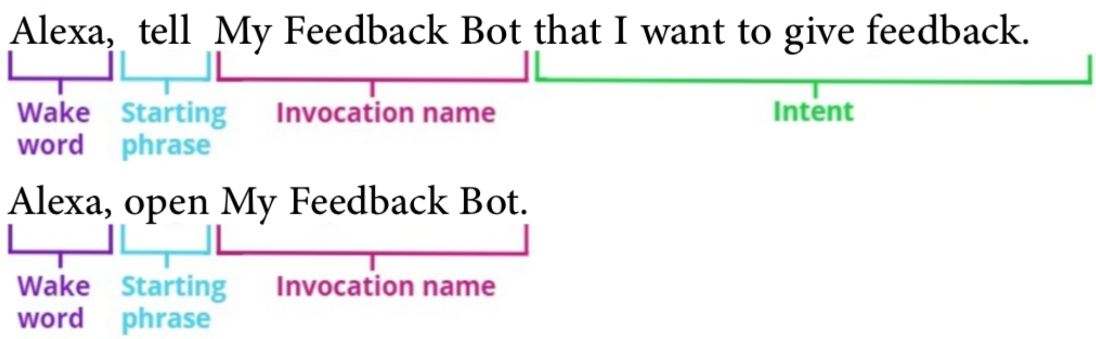
Table 4.1.: Classification of the conversational feedback prototype.

Dimension	**Classification**
Online vs Offline	Online
Availability	Explicit
Feedback Process	Structured
Feedback Loop Trigger	Push
Supported Media	Transcribed Audio
Supported Feedback Types	Multiple
Feedback Channel	Voice Assistant, Ecosystem

4.1. Feedback Skill

Somehow, Alexa has to be taught to have a feedback dialog with the user. For this purpose, the possibility to extend Alexa's functionality, with an extension, was used. These extensions, called skills, for Alexa are the equivalent of apps to smartphones. The way a skill is started (Table 4.2) is pre-defined by Amazon. After the user has activated the skill within the Alexa Skill Shop, it can be started by saying "*Alexa, open My Feedback Bot*" or "*Alexa, tell My Feedback Bot that I want to give feedback*". **My Feedback Bot** was chosen as the skill's invocation name because it was still unique, integrates well into the invocation sentence and reveals enough information about the skill's purpose.

Table 4.2.: Alexa Skill Invocation.



Schema	**Description**
Wake word	The wake word starts the conversation and wakes Alexa from the idle state.
Starting phrase	The starting phrase comprises one or more given words. It is either possible to start the skill with "start", "open", "load" without directly specifying an intent or by using "tell" and immediately stating an intent.
Invocation name	Is the name that uniquely identifies the skill.
Intent	An intent is as an action to be triggered, based on user utterances. Since every user speaks differently, the same intent can be triggered by many different utterances.

At the beginning, the user is greeted with a selection of possible actions to take (Figure 4.1). Either a certain type of feedback (Bug report, feature request, question, criticism, general feedback) can be given or it can be checked whether there are answers to already given feedback. A sample feedback dialog is shown in table 4.3. An intent can comprise multiple slots that can be elicited during the intent. The name of the product to which feedback is given would be one slot. A slot can be viewed as a variable that is assigned a value, during an intent's dialog.

Table 4.3.: Sample feedback dialog.

Frank:	"*Alexa, open My Feedback Bot.*"
Alexa	"Hey, I am your feedback bot. With me you can give feedback on your most popular smart devices. You can report errors, suggest new functionality, ask questions or share your criticism with me. I'll make sure that your feedback ends up in the right place. What would you like to do?"
Frank	"*I want to give general feedback.*"
Alexa	"Your opinion is very important to us. Please tell me the name of the Alexa compatible device you want to talk about."
Frank	"*Regarding my Amazon Echo Dot.*"
Alexa	"Okay, I am listening. You can share your feedback with me now."
Frank	"*I am super happy with my Amazon Echo Dot. Thank you very much for developing it!*"
Alexa	"Do you allow the developers to contact you in case of questions regarding your feedback. If yes your name and email address will be attached, otherwise your transcribed feedback will be sent anonymously?"
Frank	*"Yes."*
Alexa	"Thank you very much, your feedback got submitted."

After hearing Alexa's welcome message, that contains various options that the user can select from, some users were still not sure how to select a certain option. Therefore, the various options are also displayed as a list, on devices with a screen.

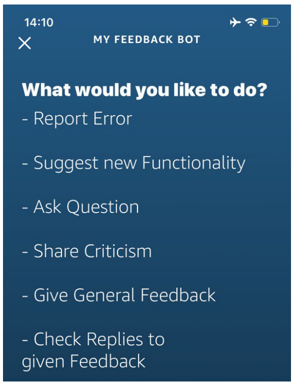


Figure 4.1.: List of possible actions within the Alexa skill.

A very important question, when creating an Alexa skill, is how to design the communication flow for the dialog with the user. Firstly, the information that must be recorded for each action (Section 3.4.2) is defined. For example, for a **bug report** this is the referenced **device**, the user's **description** and **context** of the problem as well as optional **steps to reproduce** and the user's **contact preferences**. The whole feedback process consists of a cascade of intents by the user. Therefore, the elicitation of this information must be appropriately distributed across intents. Two dominant approaches were tried out for the distribution. On the one hand, a one to one mapping between slots and intents was tried. This means creating an intent for every information that needs to be elicited. For example an **ElicitContextIntent** to record a feedback's **context**. Individual intents would be chained to achieve the final user interaction. The advantage of this approach is that the user always has the possibility to ask for help, to stop or to try to skip the current step.

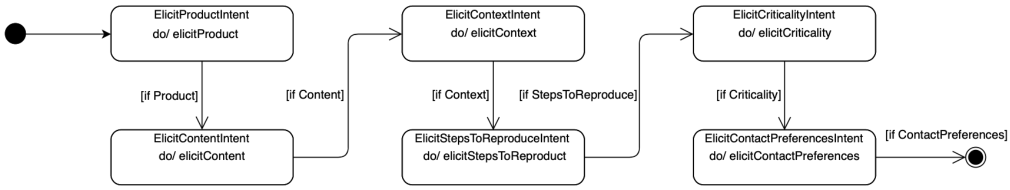


Figure 4.2.: Chain of intents together forming the Elicit Bug Report Action.

The problem with this approach is that every intent has to start with a certain predefined utterance. The answer to the question "*What is your feedback?*" would have to start with a certain phrase, from a self-defined list of utterances, like "*My feedback is ..*", for example. Everything after the introductory phrase would count towards the respective slot value. It is not possible to omit this introductory utterance and if the user does not use any of the predefined phrases, his intention is not understood. Therefore it was decided to create a separate intent for each type of feedback, i.e. a **BugReportIntent**, **FeatureRequestIntent** etc. This structure is easily expandable. To add a new type of feedback, such as feedback regarding the user experience, only a new intent with the associated slots and utterances to trigger the intent, has to be added. This approach uses Alexa's dialog management, where you define all slots for an intent and sample questions whose answer can be used to fill these slots. For these sample questions, options are given how the user could answer them. However, it is not absolutely necessary to use an introductory phrase here. After the user's contact preferences have been recorded, the elicitation process is complete and the recorded information is sent to the feedback server. This is described in the following section.

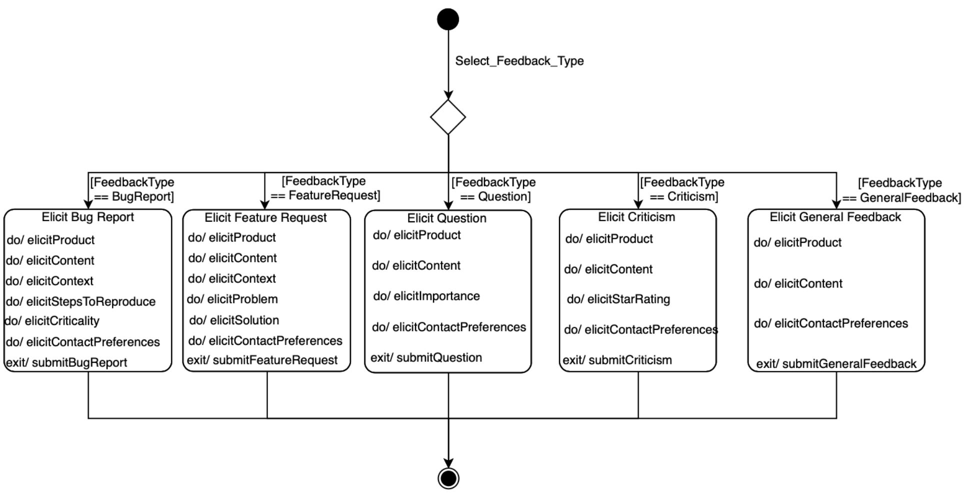


Figure 4.3.: Chain of intents forming the feedback process.

4.2. Feedback Server

Since it should be able to display acquired feedback to the developers at a later point in time, a feedback server capable of acting as a broker between the developer and the user interface, was added. The feedback server comprises a simple API, that receives user feedback elicited by Alexa. Feedback, that complies with the defined relational scheme, is then stored in a relational database. The interface that can be used by developers to view received feedback, queries and receives the data from the same API.

4.2.1. Database

The acquired feedback is persisted in a relational database. Hereby, a simple relational schema with five tables is applied (Figure 4.4). The central element is the **Feedback** table which consolidates all information regarding a feedback entity. To avoid redundancy, the **Feedbacker**, **Companies**, **Products** and **FeedbackTypes** table have been added. The **Feedbacker** table stores information, like name and email address, about the providing person. Feedback always refers to one specific product, manufactured by a specific company. Information about the object to which the feedback relates, like product and company name, is stored in the separate **Companies** and **Products** table, because for one product multiple feedback entities can exist. The different available feedback types are kept in the eponymous **FeedbackTypes** table and each feedback has a specific type.

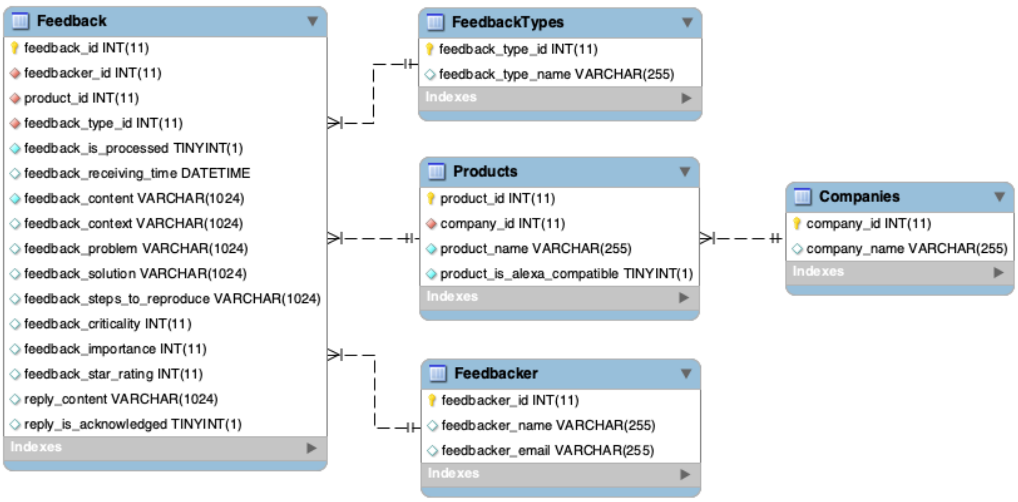


Figure 4.4.: Database schema.

Every feedback, no matter what type, contains a description, a providing subject (user) and referenced object (product) as well as contact preferences. Therefore, it would also be possible to create a separate table for each feedback type, which will then refer to the feedback table for the shared properties. It was deliberately decided against because of the greater complexity and the fact that it is not possible to quickly decide which type a feedback entity has. The chosen schema, leads to the circumstance that many attributes contain no value for a specific feedback entity.

4.2.2. API

A simple REST API was developed in order to receive data from the client interface and deliver feedback entities to the developer interface. All non secure http requests, received on port 80, are redirected to use https on port 443. For this, an SSL certificate was obtained from LetsEncrypt. The API was made available at **api.myfeedbackbot.com**. Requested data is returned in JSON format.

Table 4.4.: Feedback server API.

Method	**Route**	**Description**
POST	/feedback	Submit new feedback.
GET	/feedback	Returns all received feedback entities.
GET	/feedback/:feedback_id	Returns feedback entity with specified id.
GET	/feedback/:feedback_id/reply	Returns the reply for a specific feedback entity.
PATCH	/feedback/:feedback_id/reply	Submit reply for a specific feedback entity, identified by id.
PATCH	/feedback/:feedback_id/process	Changes the feedback status to processed.
DEL	/feedback/:feedback_id	Deletes the feedback entity with the specified id.
GET	/products	Returns all available product entities.
GET	/product/:product_id	Returns the product entity with the specified id.
GET	/product/:product_id/feedback	Returns all received feedback regarding a specific product.
POST	/feedbacker	Create new user.
GET	/feedbacker/:feedbacker_id/replies	Returns all unacknowledged replies for a user.

4.3. Feedback Client

In order to make it possible to display the received feedback, a web interface was developed. It is based on Angular and Node.js and is hosted on Amazon EC2. It was made available at www.myfeedbackbot.com, using NGINX reverse proxy for the API and Client. The application comprises four different views. One view lists all currently supported products (4.7a) while another one list all received feedback (4.7b). These are intended to provide an overview and to give the feedback recipient the opportunity to select an entity for more detailed inspection. The products page (4.5) lists all feedback received regarding a certain product. Different types of feedback are arranged one above the other in columns. Only the time of receipt, content and processing status are displayed, to provide a quick overview about a feedback. The feedback detail view (Figure 4.6) displays all information of a received feedback. Furthermore it allows the developer to delete useless feedback, mark it as processed, and reply to it. The reply is a simple text message that the user request to listen to

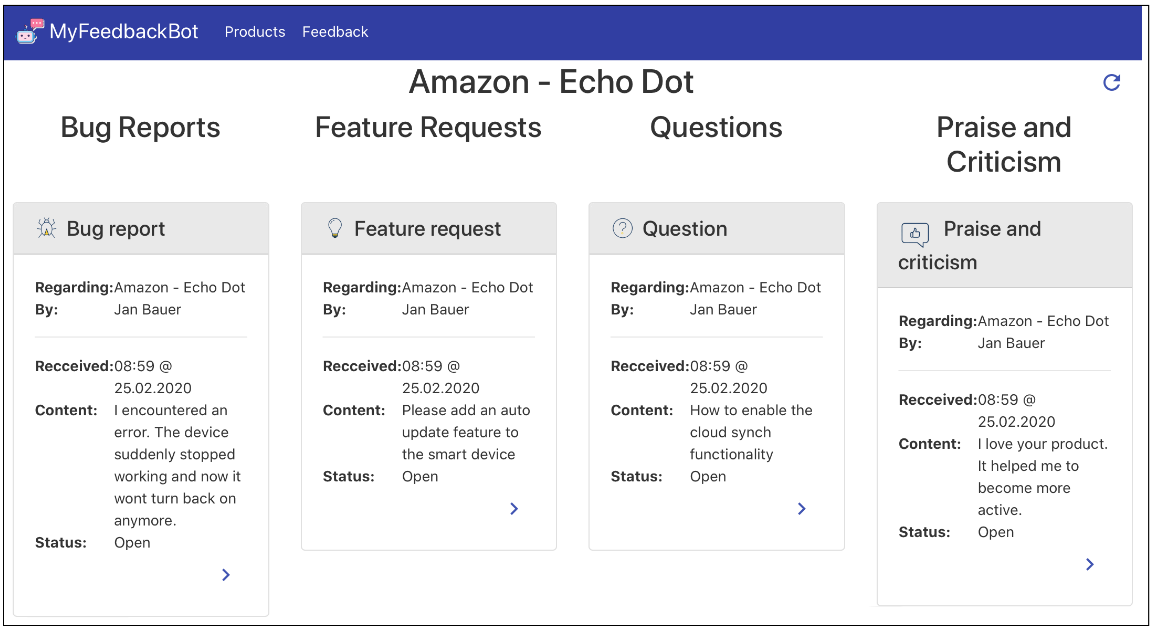


Figure 4.5.: Page informing about feedback received regarding a specific product.

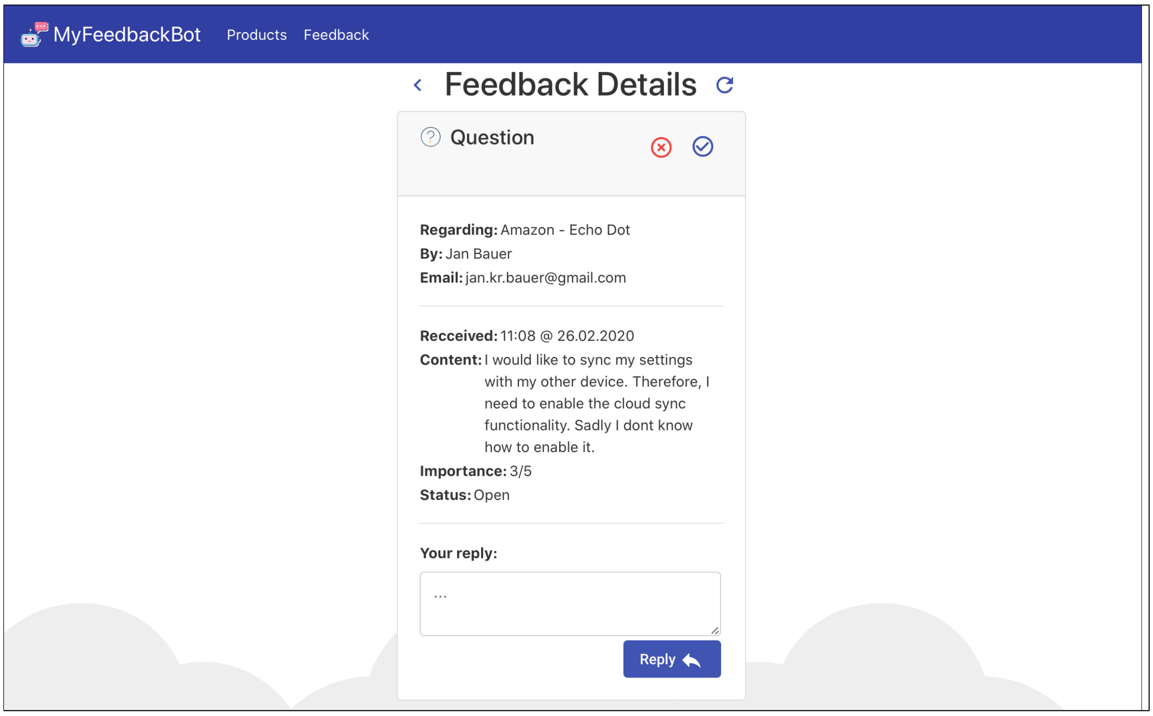
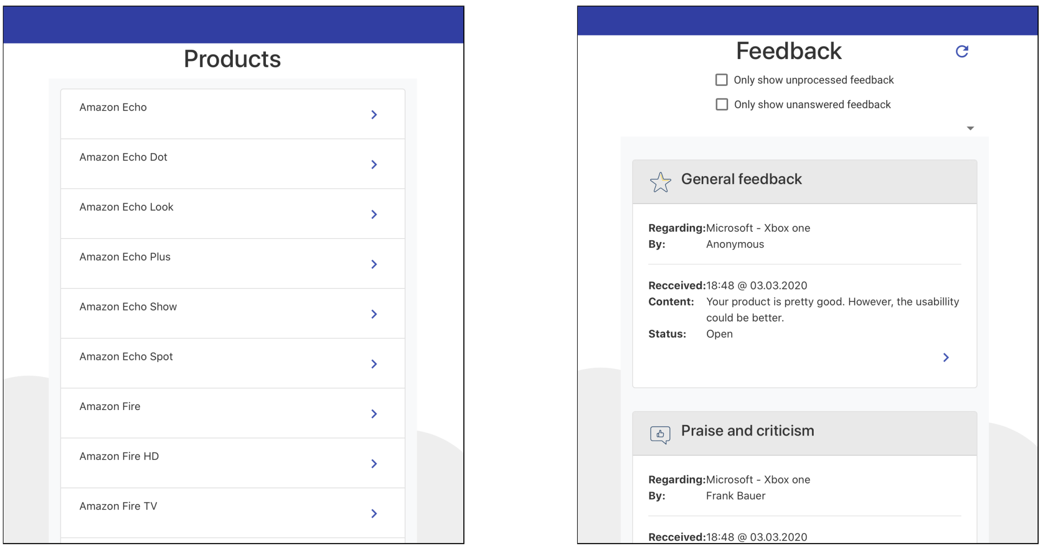


Figure 4.6.: Detail view of individual feedback.



(a) List of products.

(b) List of feedback.

Figure 4.7.: Products and feedback page.

5. Evaluation

The prototype was tested with potential users in order to identify eventual problems and opportunities for improvement. The evaluation includes an assessment of the prototype regarding effectiveness, efficiency and satisfaction. The data was collected between 23 February 2020 and 06 March 2020. A total of 17 people took part in the assessment, which resulted in several new insights. A third of the people was selected as a convenience sample from the circle of acquaintances of the author. Around a third are randomly interviewed persons and the rest were attendees of a conference in Zurich on "Robots as Support for Elderly". At first, the participants were informed about the concept behind the prototype. Afterwards they were asked to use the developed prototype to give feedback regarding a self-chosen smart device. In the end, they were asked to fill out a questionnaire, that contained questions to elicit demographic information, a system usability scale as well as specific questions regarding the prototype. It contained multiple open questions and statements to be rated on a Likert scale. A rating of one expresses strong rejection and five signals strong agreement to the statement. Like shown in Figure 5.1, the participants came from different age groups, but the group of 16 - 25 year old was slightly over-represented. This can be explained by the fact that the use of voice assistants is also more common in this age group.

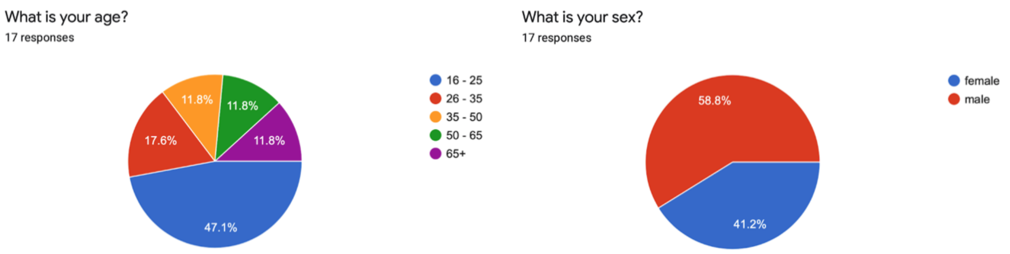


Figure 5.1.: Sex and age distribution of the study participants.

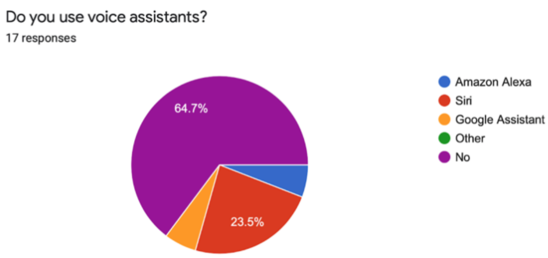


Figure 5.2.: Voice assistant usage.

Although, only around a third of the participants (Figure 5.2) are actively using voice assistants, it could be shown that the concept and prototype also appeals to non-users. All participants expressed that they never used a feedback mechanism based on the idea of having a feedback dialog with a voice assistant. This coincides with the observation that users rated the prototype as very innovative ($\mu_{inno.} = 4,4118$, $\sigma_{inno.} = 0,6183$). The participants liked the idea of being able to give feedback in situ and not having to search online for the right communicative mean. It was positively mentioned, that it is not necessary to learn a lot before being able to use the tool and that they were mostly understood correctly and the feedback was correctly transcribed. It turned out that one person, suffering from visual impairment, liked the tool because it enables to give feedback without depending your vision. Visually impaired people are often particularly dependent on working processes.
The participants also uncovered numerous opportunities for improvement. So far, there is no support for multiple languages. Three German native-speakers expressed the wish to be able give feedback in German. This wish can probably be generalized to the statement that users would like to use their language of choice for interacting. One participant also expressed the wish to be contacted by phone instead of just via email. This could definitely be implemented. Two times it was said that after listening to a list of options to select from, it was still not clear what could be selected. It was proposed to show the list of options also on screen, if the device Alexa is used on is capable of doing so. During a test in a noisy environment, it was also found that the received transcriptions contained many errors and were not really usable. On the one hand, there is not much that can be done in this regard since the speech processing is provided by Amazon and it is also to be expected that the results achieved in noisy environments will be worse. Several participants also commented that they will not use voice assistants due to privacy concerns. These concerns are similar to those of the privacy aware persona. Overall, the participants rated their level of privacy awareness pretty high ($\mu_{priv} = 3,7647$, $\sigma_{priv} = 1,0914$). A feedback mechanism, requiring a voice assistant, will therefore not be optimal for very privacy aware users or at least be subject to privacy concerns. However, it can be assumed that people who already use a voice assistant have already considered the possible implications for their privacy and have no higher privacy concerns regarding such a mechanism. The possibility of being able to anonymously give feedback was considered positive, but it will not always be possible to give anonymous feedback, especially if a user wants to receive an answer. It was already pointed out in the persona based design section that users' willingness to give feedback could be low and it therefore would potentially be difficult to encourage them to give feedback. The willingness to give feedback to companies is only in the lower middle range ($\mu_{wgf} = 2,588$, $\sigma_{wgf} = 1,1213$) and the participants only gave feedback around one time per year to a company (($\mu_{wgf} = 1,1471$, $\sigma_{wgf} = 1,3201$). Both these values could still be increased. How this could be achieved would require further research. The participants also mentioned that always being asked to confirm what they just said is tiring. This is done to be sure that Alexa understood them correctly. This practice could also be discontinued. Furthermore, the tool is only available for one language assistant right now. However, it would be possible to implement it for other voice assistants, offering the right SDKs, as well.

In order to assess the prototype based on quantitative data, a System Usability Scale was part of the survey. The average of the received ratings is shown in table 5.1. The System Usablity Score can be calculated from the collected data by subtracting one from the mean of each odd numbered question and subtracting the mean of every other question from five. The sum of these interim values is calculated and multiplied by 2.5. The calculation of the SUS score yields 77.5. This is a good but not yet perfect value.

Table 5.1.: Summary of the System Usability Scale.

	Mean (μ)	Standard Deviation (σ)
I think I would like to use the shown feedback mechanism frequently.	2,9412	1,3906
I found the shown way of giving feedback unnecessarily complex.	1,8235	1,0744
I thought the feedback mechanism was easy to use.	4,0588	1,1440
I think that I would need the support of a technical person to be able to use this feedback mechanism	1,4118	0,6183
I found the feedback mechanism to be well integrated with the Alexa ecosystem.	4,5294	0,7174
I thought there was too much inconsistency in this feedback mechanism.	1,7647	0,8313
I would imagine that most people would learn to use this way of giving feedback very quickly.	4,2941	0,6860
I found the feedback mechanism very cumbersome to use.	2	1
I felt very confident using the feedback mechanism.	3,7059	0,9196
I needed to learn a lot of things before I could use the feedback mechanism.	1,5294	0,7998

It was also how users would rate the shown tool in terms of effectiveness (Did you achieve want you wanted to achieve?), efficiency (How well did you achieve what you wanted to achieve?) and satisfaction. The average rating for effectiveness ($\mu_{efe} = 4,2941$, $\sigma_{efe} = 0,58787$), efficiency ($\mu_{efi} = 3,7059$, $\sigma_{efi} = 0,8489$) and satisfaction ($\mu_{sat} = 3,82353$, $\sigma_{sat} = 0,9510$) also signal a positive outcome.

6. Discussion

6.1. Thesis Goals Revisited

The achievement of the research goals should be assessed retrospectively. One activity that was defined at the beginning but was not carried out explicitly was a workshop with experts. This workshop was intended to prioritize the list of developed concepts and select the most promising one for implementation. Initially four main research goals were defined.

- **Assessment of the current state of feedback mechanisms for smart systems.**
  It was shown that even novel smart systems, like smart devices, mostly rely on traditional feedback mechanisms. The large smart home ecosystem providers offer their customers somewhat more advanced mechanisms, but it is not possible to express feedback by sharing it with the voice assistant. Since language is seen as a main form of interaction with smart systems, this is considered a major disadvantage. Concepts from scientific literature have not yet been sufficiently put into practice.

- **Development of an innovative feedback mechanism concept for the smart device context.**
  Several concepts for feedback mechanisms in the smart home context were developed and weighted against each other. The concept that was considered the most innovative was further refined. The other two concepts can be further elaborated in the future. Different versions of the conversational feedback concept were tried, until a satisfactory solution has been reached.

- **Prototypical implementation of a novel feedback mechanism for smart devices.**
  The developed concept was implemented for Amazon's ecosystem. It allows the user to give feedback on compatible devices by having a conversation with Alexa. Available data (name, email address, telephone number) is extracted from the ecosystem and extends the given feedback.

- **Evaluation of the prototypically implemented feedback mechanisms.**
  The user study that was carried out showed that the developed prototype reaches good results in terms of usability, efficiency, effectiveness and satisfaction. The prototype is perceived as innovative by the test users. Therefore, it would be reasonable to invest further effort in the concept and its implementation.

6.2. Threats to Validity

Every scientific work is subject to several uncertainties. First of all, the reasons why large smart home ecosystems do not support voice feedback at all are not well enough known. The providers potentially carried out investigations into this possibility and noticed that users prefer to use other feedback mechanisms instead. However, this contrasts with the fact that each ecosystem seems to implement a different feedback architecture. In addition, it is considered critical that the scientific literature apparently focuses on software-intensive systems such as apps and software, and that research findings from this area can only be partially transfered to the smart systems context. The users' feedback channel preferences were assessed based on a small sample size drawn as a convenience sample from the personal circle of acquaintances. Therefore it is difficult to draw general conclusions from the collected data. So far it was shown that the prototype is well received by test users. It would be interesting to compare different implemented feedback mechanisms in a larger study against each other to see which one is preferred by the participants and due to what reasons. Furthermore, it could also be examined how to give developers the opportunity to design a custom feedback process for their device within the built framework.

6.3. Future Work

The positive feedback received from test users and the lack of research in this field leaves many opportunities for further investigations. To extend the state of the art analysis, it would be interesting to investigate why no company has yet integrated such a feedback mechanism into their ecosystem. There is a strong competition between these ecosystems and high quality user feedback can certainly fuel development and differentiation. Furthermore, all technical prerequisites seem to be met by the ecosystem providers to implement advanced feedback mechanisms. To understand their reasons could also help transfer advanced feedback concepts from research into practice. The preferences of smart device developers with regard to user feedback have not been sufficiently investigated. Therefore, little is known about these preferences. For example, it is probably interesting for developers to define what data the voice assistant should elicit when feedback regarding a certain device is given. However, this should still take place within the framework, so that the user only has to use one voice interface. The exact process for such a conversational feedback mechanism has also not yet been conclusively investigated. In future work, the feedback process could be made more adaptive in order to make the communication flow more dynamic. So there is still a lot work to be done in this research area.

Acronyms

API Application Programming Interface.

HCI Human–Computer Interaction.

IoT Internet of Things.

IVA Intelligent Virtual Assistant.

REST Representational State Transfer.

SDK Software development kit.

Glossary

a priori relating to or denoting reasoning or knowledge which proceeds from theoretical deduction rather than from observation or experience.

ex ante in regard to an event from the past.

ex post in regard to a prospective event from the future.

in situ In the original place instead of being moved to another place. In regard to feedback this means that the user can give feedback regarding a problem in the situation it happend and not only retrospective..

Ontology An ontology encompasses a representation, formal naming and definition of the categories, properties and relations between the concepts, data and entities that substantiate one, many or all domains of discourse.

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A. Appendix

Logged in Gitlab users can request access to the code, for the Feedback Skill, Feedback Server and Feedback Client, using the following three links.
https://gitlab.com/exeeds/myfeedbackbot_skill
https://gitlab.com/exeeds/myfeedbackbot_server
https://gitlab.com/exeeds/myfeedbackbot_client