D5.5 – Anticipated social implications for networked data aggregation following privacy by design approach

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Executive Summary

This report provides an overview of the societal and ethical implications of data processing and aggregation with a specific focus on using radio frequency (RF) range electromagnetic (EM) waves for gesture recognition. Machine learning expands the potential of RF holography, allowing for the recognition of “fine gestures” (picture making a “checkmark” with one’s pointer finger). Such a tool has the potential for accidental and opportunistic sensing. Point clouds created for gesture recognition might contain biometric data related to how a specific individual moves. Furthermore, point clouds could be retrained to decipher information beyond gestures such as breath and heartrate. Detection over a long period of time could be used to see changes in individual behavior, such as if someone is growing sluggish or developing a tremor.

In this report we examine the nuances of the technological advancements of the Aalto University team within the HOLDEN project specifically in the context of Smart TVs. Smart TVs are the third innovation being explored by Adant for potential commercial development. Section 1 introduces Aalto’s innovations, implementation options and the use case of Smart TVs. Section 2 delves into ethical considerations following the framework introduced by Twente researchers in HOLDEN. These include responsible data processing, bias avoidance, power relations, exclusion and privacy intrusion. Section 3 specifies technological considerations and design requirements using Value Sensitive Design. Finally, the conclusion summarizes the main findings of the report.

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Abbreviations

Abbreviation	Description
HOLDEN	Ethical Holography of Dense Wireless Networks
AALTO	Aalto University
RF	Radio Frequency
ML	Machine Learning
AI	Artificial Intelligence
ESM	Ethics Status Monitor
VSD	Value Sensitive Design
WP	Work Package
TET	Technological Environmentality Theory
TMT	Technological Mediation Theory
ATGT	Active Technological Gaze Theory

1. Introduction

1.1. Overview

The European Innovation Council funded HOLDEN (Ethical Holography of Dense Wireless Networks) Project consists of three technical radio frequency (RF) innovations. This report details the third of these innovations, fine motor detection through RF "chirping." Chirping in the context of this project will be explained shortly in the following section under "1.2 Description of the Technology." Chirping is a more precise method than using ambient Wi-Fi waves for point cloud creation and is being utilized by Aalto University in Finland for gesture recognition and palliative care monitoring. Adant plans to adopt this technology for Smart TVs.

The first and second innovations were analyzed in D3.4 (Privacy and Ethical Constraints in Static Environments) [1] and D4.4 (Privacy and Ethical Constraints in Dynamic Environments) [2], respectively. As expected, some ethical concerns overlap between innovations. This report (D5.5) is intended to focus on networked data aggregation and machine learning, which are both already addressed in D4.4 [2, pp. 18–19]. Therefore, this report will concentrate on the networked data aggregation and machine learning aspects necessary for Smart TVs.

Gesture recognition and palliative care analysis, as with activity recognition in dynamic environments, is reliant on machine learning to make sense of the data. This report focuses on machine learning in the privatized business to consumer context of Smart TV as opposed to the healthcare context explored in D4.4 [2, pp. 7–8]. Additionally, this report considers the network effects of global deployment of Smart TVs and what information would be inferable from widespread usage. Finally, it addresses 'accidental' or 'opportunistic' sensing, how to responsibly process data, and making the system design transparent to users, which are also detailed in the HOLDEN Ethics Status Monitor [3, pp. 27–29]. Technical details from this report were confirmed through two interviews with partners from Aalto University and Adant on 28 August 2025 and 7 October 2025.

1.2. Description of the Technology

The third HOLDEN innovation, under development by Aalto researchers, sends out electromagnetic chirps of increasing frequency (higher than that of Wi-Fi) from antennae (See Figure 1). These chirps reflect off of objects in the environment at the speed of light and are reabsorbed by receivers. Since the start and end points are known and the speed of light is constant, the distance from emitted chirps to various points in the surrounding environment can be calculated. These points form a snapshot point cloud. Multiple point clouds are made in rapid succession to make a three-dimensional "movie" of points, which is then trained with supervised learning to link point cloud series to specific gestures. The training and test data are primarily collected from researchers and students in a lab environment.

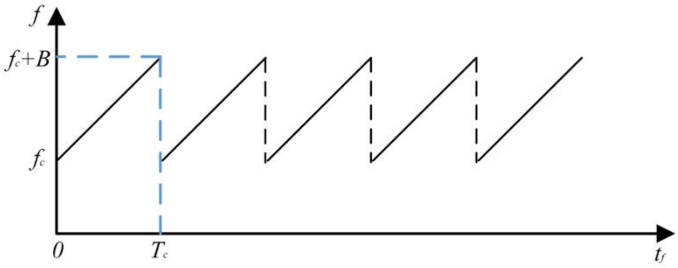

Figure 1: Chirping Schematic

Aalto has developed both general off-body gesture recognition and *fine* gesture recognition, which works from 1-1.5 meters distance with the device up to a 45˚ angle from the user (See Figure 2). A fine gesture is a limited movement, such as making a checkmark with an index finger, whereas a more general gesture might be swiping an arm sideways. The technology needed to operate fine gesture recognition is about the size of a €1 coin, including the antennae, receivers and initial computation. Powering the device requires more space and gesture recognition and obfuscation are currently done on a PC. However, powering the device might require more space. As outlined in D3.4, the location of the sensors makes a difference in its effectiveness [1, p. 16]. Aalto is exploring testing gesture and activity recognition in a 7 by 4-meter area with five sensors affixed to the ceiling. The idea is that aerial data collection will make it easier for gestures to be recognized from all angles without obfuscation.

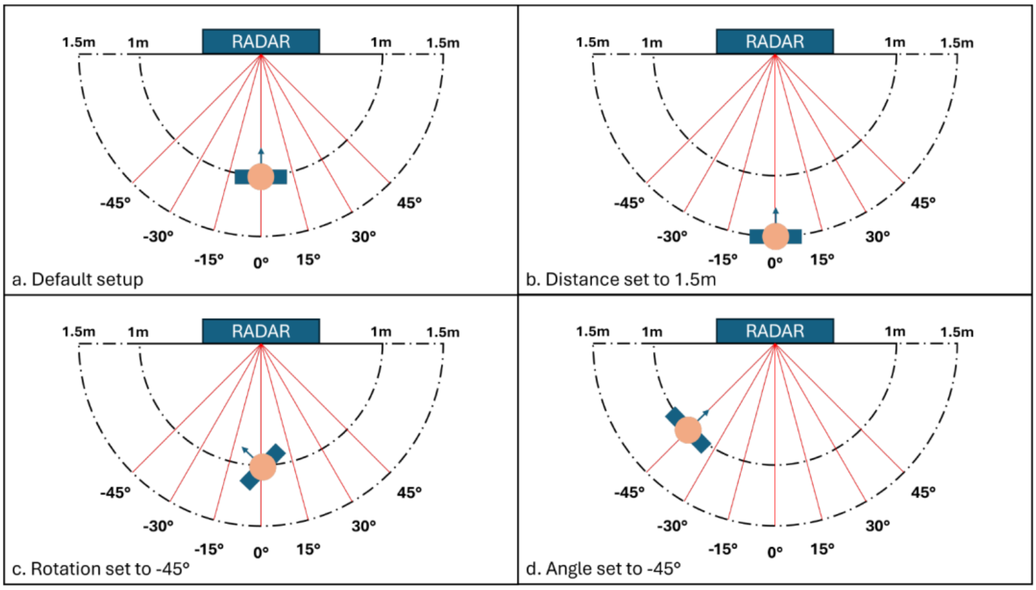

Figure 2: Current Fine Gesture Recognition Confinements

Aalto has discovered that the point cloud series created from the chirps contains biometric information. Using machine learning, it is possible to associate certain movement patterns to specific individuals. Aalto is reverse engineering a machine learning system to obfuscate personally identifying information while maintaining gesture data. Essentially, the point cloud data runs through an algorithm that adds noise to obfuscate personally identifiable information, while keeping the data necessary for gesture recognition. This technique can lower personal identification accuracy from 100% to 40%. Unfortunately, the model cannot hide all personally identifiable features. Furthermore, it is possible that outliers will remain identifiable even post-processing, for example, someone with a strong hand tremor.

In addition to off-body systems, Aalto is devising a body wearable that can recognize gestures and may use muscle movement under the skin to identify movement patterns. Such a device could also detect the pulse through veins. Aalto is also researching systems that can tell temperature – when the body is warmer the amplitude of the electromagnetic wave reflection increases. It must be noted that other factors besides temperature can increase the amplitude of the reflected wave, so it is important for data to not be misinterpreted. Currently the temperature measurement system can only work maximum 20 cm from the person.

Lastly, Aalto is working with IRLab in Prague, Czech Republic to explore options for RF holography in palliative care as a part of the WP9 hop on project of HOLDEN. Palliative care is the central focus of all WP9 deliverables, which are led by researchers in philosophy and ethics. Therefore, we exclude the palliative care case in this report as it is covered extensively in WP9. Furthermore, the use case of elderly care was covered in D4.4, which shares some overlap with the palliative care use case.

1.3. Smart TV

Adant is currently exploring the potential of Innovation III for Smart TVs. The application is in the pre-prototype phase and far from being market ready. The USA company, Texas Instruments, is also developing Smart TV sensor technology using RF electromagnetic waves, describing features such as 5+ person detection, vital sign measurement for breath rate and sleep monitoring, gesture recognition, human vs. non-human classification (to mitigate false detection) all with under 2mW power consumption [4].

D6.1 describes a potential HOLDEN Smart TV application in detail [5, pp. 45–51]. This report contains a brief summary of the information from that deliverable. The Smart TV is described as being able to recognize individual household members and offer personalized settings based on who is watching by, for example, adjusting the volume or brightness settings. The Smart TV would also offer hands free interaction for business, gaming, fitness and TV control.

Using the RF technology, it would be possible for the Smart TV to have automatic turn on and shut-off, sleep tracking, limited sign language recognition, posture detection, virtual meetings with whiteboarding, and immersive interactive gaming. There is also a potential to employ adaptive learning so that the technology can interpret new gestures and information. It is worth noting that some of these steps would require layers of machine learning processing. For example, sign language recognition requires that first each sign is recognized, then those signs would (most likely) be translated to text, to be then interpreted by a separate search function or large language model for the following application. Without transparency, it might not be evident where in the process a communication error occurs. It's also important to be aware that more than 130 sign languages are used worldwide, many of which evolved independently from one another [6, p. 6]. In addition to Aalto-specific innovations, the Smart TV will have common TV features such as child controls, personalization, and viewing history.

Televisions have a central role in many modern living spaces including homes, hotels and rental apartments. Additionally, TVs and monitors have a growing prevalence in offices and public environments such as museums, stores and kiosks. A Smart TV therefore has the potential to track incidental information about users including guests, tenants, renters, employees, and shoppers, depending on the environment. Smart TVs offer surveillance opportunities both for the software operator and the owners of the TV to observe, control and police what users watch and how they use the system.

As the Smart TV will have the capability to monitor behaviors outside of the system itself, whether intentionally or incidentally, and the capability to offer personalized experiences, there is a concern for coercion and lack of autonomy reinforced by the owners of the device, the device manufacturer and third-party services. Opportunistic surveillance could be used for nudging [7]. Based on user behavior typically not associated with what a TV can comprehend, the system could train the user by, for example, recommending certain shows or pushing specific ads based on the daily emotional profile of a user. This daily emotional profile could be constructed based on months of movement detection in association with how the TV is used by an individual user.

Moreover, with a network of TVs linked into one consumer system, the provider and database owner might have access to more information and insights from aggregated data, ranging from what shows people are most likely to fall asleep watching by region, to living room usage habits, to profiles such as whether individuals are introverted or extroverted depending on how frequently they are out or have guests over. This grants the producers of the technology increased power relative to those who purchase the device, especially if the aggregated data insights are only used for company gain, leaving the data producers in the dark. While many are already accustomed to surveillance capitalism [8] through social media and other online platforms, there is perhaps a new risk when the data gathered are from sensors in the built environment of one's own home. Amazon's Alexa encourages users to make purchases (a feature which can be shut off), but most of those recommendations are based off of the user's account profile. Shared autonomy between a user and smart "things" in their home is both a growing risk and feature of smart automated environments. The Mediation Theories in Section 2.1 of this report demonstrate how differently or effectively Smart TV may mediate human experience. The following subsection explores implementation options that can be fine-tuned to change the ethical and social implications of the technology.

1.4. Implementation Options

As demonstrated in D3.4 [1, pp. 15–17] and D4.4 [2, pp. 17–19], certain design choices may fundamentally change the constraints and possibilities of the technology under development by Aalto. The following list contains some of these options and some questions, which point to alternative implementation options for Smart TVs. The list is based on the interviews undertaken to prepare the report and the corresponding sections from previous reports. Understanding the difference between these implementation options is helpful to make an informed decision about choosing one particular alternative to realize specific values as will be more thoroughly described in Section 3.1 Value Sensitive Design.

1. Sensor position
    a. Placing from above makes it easier for gestures to be recognized from all angles without obfuscation. However, most people face the TV while watching, it may be preferable to only accurately manage gestures within a defined range.
    b. The angles of the antennae can affect the point of cloud accuracy.
2. Sensor amount
    a. More sensors make it easier to validate data.
    b. More sensors also make it challenging to avoid being sensed.
3. EM Wave Frequency and Power

a. Higher frequency allows for more precision.
b. Lower frequency can go more easily through walls.
c. More power gives off stronger signals
d. More power increases wave exposure when close to the element.

4. Algorithm
    a. Training Data (amount, diversity of participants)
    b. Training Environment
    c. Can the users train the system on specific gestures?
    d. Supervised versus Reinforcement Learning (Can new gestures be added?)
    e. How does the algorithm handle uncertainty?
5. Data Processing
    a. Option to obfuscate personally identifiable data before applying it to the algorithm
    b. Is the processing done locally or on the cloud?
6. Storage
    a. How long is data stored?
    b. Where is the data stored?
    c. Is the data shared?
7. System Turn On/Shut Off
    a. Is the system always on?
    b. What initiates the system to turn on?
8. Control
    a. Can the user change the settings?
    b. Can the user access the data?
9. Transparency
    a. Is it clear that the system is on?
    b. Is it clear what the system does?

In the following section we will explore the anticipated social and ethical implications of this RF application to have a better sense of necessary design requirements.

2. Ethical Considerations

The University of Twente has developed and is following a mixed methods approach to understand and reveal the ethical challenges presented with radio-frequency holography (See Figure 3). This approach is thoroughly outlined in the HOLDEN Ethics Status Monitor (ESM) [3, pp. 19–20]. Guidance Ethics is a stakeholder first method of addressing and designing a new technology that is more practical than theoretical [9]. Techno-moral scenarios is a purely theoretical approach, imagining a new developing technology in society and the potential affects it might have in various contexts [10]. Mediation theories [11], [12], [13] acknowledge that technologies fundamentally change how humans interact with and adapt to the world and consider how an emerging technology might reshape perception and the human experience. Lastly, Value Sensitive Design (VSD) takes findings from these domains, in addition to legal requirements and moral values, to construct design requirements for each technology [14], [15]. VSD is addressed in "Section 3: Technical Considerations and Design Recommendations."

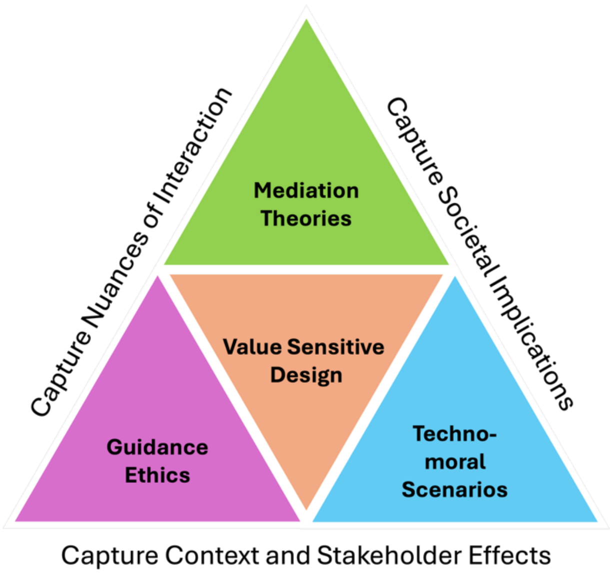

Figure 3: HOLDEN Approach to Addressing Ethical and Social Implications of RF Sensing

2.1. Mediation Theories

Mediations theories are concerned with how technologies shape phenomena (or experience). The main mediation theories included in the HOLDEN project are Technical Mediation Theory (TMT) [13], Technological Environmentality Theory (TET) [12], and Active Technological Gaze Theory (ATGT) [11]. Deliverable 2.3 engages with how Smart TVs may mediate perception.

ATGT points to Smart TVs giving people the sense of being watched, particularly in public or semi-public environments. Although the home environment has the potential to expose more *personal* information than a public environment, there might be a greater sense of control having the device in one's own purview. Similar to a Google Home or an Alexa, there may be the feeling that a user can shut it off any time they want, and that the device is increasing their autonomy by making life simpler for them, as opposed to nudging their behavior and gathering data for a large enterprise. Contrastingly, in an office, store, or hotel room, the user may lack the authority, or even the option, to remove the device. The user may even have less trust in the owner of the device (e.g., the office, grocery store, etc.) than the company that creates and sells it, which would make the gaze more active in a public or semi-public environment. The sense of having external gaze on one's behavior might limit personal autonomy and sense of freedom to behave naturally in a space. Thus, whereas the presence of a security camera can raise concerns about one's physical movements in a particular space being monitored, the presence of a Smart TV can raise additional concerns about one's biometric data being monitored (e.g., the discovery of potential health issues being used against an employee due to fears of higher insurance costs for the company).

TET shows that certain reactionary automations might reshape the environment. If the TV automatically shuts off when people leave the room or adjust volume and brightness for individual user profiles, then each household member may have a different experience of the environment specifically adapted to them. This might make the system fairer on an individual level, but also distance users from an objective united sense of the interface and the environment. There is also a question of whose settings "win" in a shared interaction scenario.

TMT describes the ways that technologies mediate human-world relations. In a private context users may employ the technology to better understand themselves such as their posture and sleep. This would be a "hermeneutic relation" [16, p. 80] from human to Smart TV to world because the Smart TV would mediate how users *interpret* the world and even themselves. In a public or semi-public environment, Smart TV data might be used to make conclusions about the populations who use or pass by the device such as hotel guests, employees, and shoppers. Creating truths from Smart TV data might create an incomplete picture that individuals are biased to believe because the data exists. For example, it could be that someone sleeps worse in front of the TV and that their sleep data is not representative of their natural sleeping habits. Additionally, the Smart TV might create a sense of "extension" of the human form that a normal TV does not offer due to gesture recognition [17, pp. 26–31]. This perhaps could make users feel more connected to the system and that the system "understands" them, despite the interaction being no deeper than a couple sensors and a machine learning algorithm.

2.2. Guidance Ethics

The Guidance Ethics is a positively driven, bottom-up approach to ethics first innovation developed by Peter-Paul Verbeek and ECP | Platform for the Information Society [9]. The idea is that the stakeholders know their needs and concerns. These needs and insights can push positive technological development. This method can be contrasted to more pessimistic approaches that might slow down or call for the complete dismissal of a potentially helpful innovation. It is essential however to get the correct stakeholders into the room for guidance ethics to work as an approach, as it may not be possible for a non-expert to empathize with or understand the needs of all users. This is why we pair guidance ethics in this project with other approaches to fill in potential blind spots.

Although Smart TVs were not fully flushed out as a possible innovation in the initial HOLDEN Guidance Ethics workshop in 2023, "Behavior Monitoring and Recognition" was chosen as a possible use of the technology, as were "Gaming" and "Embedded Art Systems." This section contains the results from "Behavioral Monitoring and Recognition," which was ranked 7th on average with two groups (Group 2 and 4) ranking it quite highly as a desired context of RF holography (See Figure 4). Both groups that ranked it highly explored the innovation further, brainstorming how they would determine proper use of the technology.

#	Use Cases (Contexts)	Group 1	Group 2	Group 3	Group 4	Median Ranking	Average Ranking
1	Built in Safety Measures for Working Environments	3	2	12	6	4.5	5.75
2	Automation (Heating Ventilation)	6	7	5	1	5.5	4.75
3	Ability to live at home longer for those aging or with disabilities	1	5	11	8	6.5	6.25
4	Crowd Monitoring (Festivals, events)	5	8	9	4	6.5	6.5
5	Long-term Health Monitoring	2	4	13	9	6.5	7
6	Indoor Navigation	7	9	2	11	8	7.25
7	Behavior Monitoring and Recognition	13	1	15	3	8	8
8	More advanced Smart Home Functionalities	9	10	8	7	8.5	8.5
9	Intrusion Detection	15	12	3	5	8.5	8.75
10	Facility Management and Monitoring	11	17	7	2	9	9.25
11	Gaming	17	6	4	12	9	9.75
12	Human Recognition for Robotics and AI	12	3	17	10	11	10.5
13	Baby Monitoring	8	16	6	15	11.5	11.25
14	Democratic Engagement through Global Gestures	4	14	10	17	12	11.25
15	Ubiquitous Surveillance for Law Enforcement	10	11	16	14	12.5	12.75
16	Embedded Art Systems	14	15	1	13	13.5	10.75
17	Ubiquitous Transparency (Like Police Body Cams)	16	13	14	16	15	14.75

Figure 4: Context Ranking from 2023 Guidance Ethics Workshop

Both groups envisioned different uses for Behavior Monitoring and Recognition. Group 2 considered "proper uses" as security tech (airport, festivals, sport), crowd control (especially in panic and crisis scenarios), facility management, border control, and refugee monitoring, which are not Smart TV functions but align more closely to the first innovation being explored in HOLDEN of person/object detection. Group 4 thought that proper use would be for knowledge collection such as academic research. Although neither group was considering behavior monitoring and recognition in an entertainment context, potentially helpful insights from the workshop can still be found.

Each group considered possible benefits and risks of the technology. Cited benefits included that the system would be invisible and non-intrusive, which would mean that people would not know they are being watched and therefore act more naturally. Additionally, the system does not depend on light, so it can be used in the night or less preferable lighting. It also may react to potentially harmful situations. In the context of a smart TV these findings might mean that the TV system could appear magical as there is no visible camera processing movement, yet feedback from gestures and behavior. However, for a smart TV it is doubtful that this would lead to more natural behavior than a TV with a camera or an infrared sensor. Individuals would use specific gestures to interact with the system. Depending on how the system works and is explained to consumers, however, people might feel more relaxed because it is not a camera, so no video of their behavior is processed or stored. Having a non-light dependent sensing system is a benefit for TV devices as people tend to watch TV in the dark. Additionally, the TV might have the potential to register activity like someone falling asleep, a house break in, or someone falling. The question is if these activities can be trained, should they be? And, if such an even occurs, what are the responsibilities of the device, especially if there is room for error? For example, the TV shuts off to save power and encourage health of a user that was actually still awake.

The groups also considered potential risks of the technology. One such being that the new technology replaces the older models, making them more powerful, while introducing new ethical dilemmas. Another concern was that the technology could be intrusive and infringe on privacy. Concerning gestures specifically, there was the issue that having to use specific gestures to communicate with the system will make the system creators the arbiters of gesture meanings. This could lead to oversimplification and generalization, as well as the loss of certain cultural aspects of behaviors. The data itself will also lack contextual knowledge but be labeled as the truth. Relatedly, it could be that people avoid using gestures that they normally would when communicating so that they do not accidentally prompt the Smart TV.

Worst case scenarios of technology usage were function creep regarding expanding the use of the technology, the meta data of the tech being used for evil purposes (a different type of function creep), laws and regulations not being enforced, general misuse, and the accuracy being so low that the technology itself is, at best, useless and, at worst, used to make inaccurate judgments and responses.

To increase the positive aspects of the technology and lower potential risks, the groups had several suggestions. Such as, in particular contexts, deliberately making the tech visible for some or all, using proxy data, synthetic data sets, establishing particular laws for particular spaces or use, explicitly informing people that they are surveilled, data processing and storage as close as possible to the sensor system, and data sharing so that everyone can benefit from the powerful insights of collective data procurement.

2.3. Techno-moral Scenarios

Techno-moral Scenarios (TMS) are helpful to analyze and predict social and moral change that may arise from a new and emerging technology. They are rooted in the idea that once a technology is embraced by society it is too late to go back even if the outcomes might have been considered morally egregious in a preceding time. In a sense, once a technology is in society it is already too late, and we are biased towards the perceived opportunities it provides. This means that exploration pre-development is essential for an unbiased view of potential harms. With TMS, depictions of internally consistent worlds form a basis to explore possible implications [18].

The HOLDEN group at Twente University produced a large scale TMS experiment in April 2025 (See Figure 5). This was achieved through an interactive exhibit titled, “This is Not a Camera.” In the bilingual exhibit, patrons were able to use stickers to rank on the exhibit itself to what degree they found specific uses and contexts “creepy” or “cool.” Additionally, users voted on whether they thought each application would change society and share why or why not. A total of 81 people participated with 69 skipping less than four of the 21 questions. The exhibit is described to greater detail in D2.3, but this section overviews the results for the Smart TV case as well as the specific applications of RF sensing that relate to Smart TV.

Figure 5: Portion of "This is Not a Camera!" Exhibit at Tetem in Enschede, The Netherlands

Figure 6 shows results from the exhibit on how "creepy" or "cool" people found various RF monitoring applications. Gesture recognition was viewed relatively neutrally as a feature of the technology amongst participants, as were sleep tracking and heartrate detection. Activity recognition was viewed as creepier than gesture recognition as was person identification and through wall body detection. This could mean that recognition that receives data for a set cause seems more neutral, while more personal and private information detection, such as knowing what activities one is doing, collecting information in unrelated spaces through walls, and identifying particular individuals feels more intrusive. It is curious that sleep tracking and heartrate were seen more neutrally than activity recognition, through wall detection, and person identification. It could be that this data feels less personal to one's identity since they are universal phenomena.

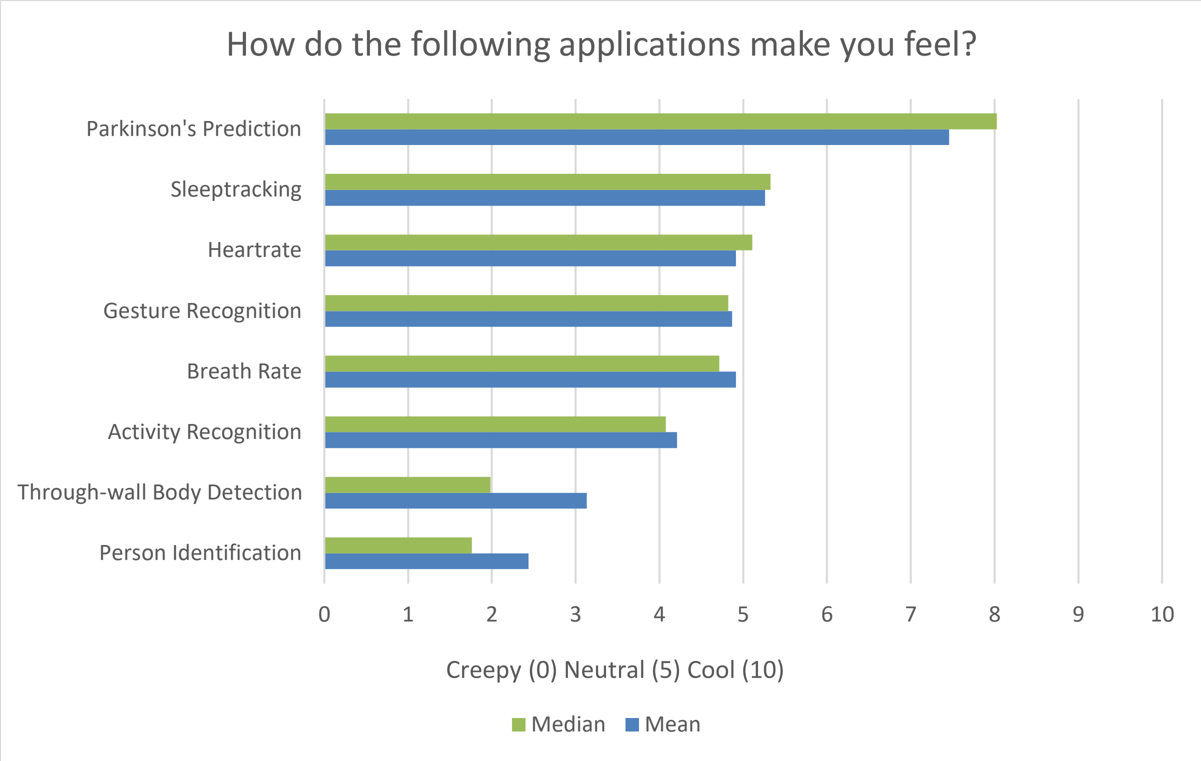

Figure 6: Average Application Preference Rankings Across Three Exhibits in Enschede

Exhibit viewers were asked to envision that it was ten years in the future and that three RF monitoring technologies (Person Object Detection, Elderly Care, and Smart TVs) were already embedded into society. For Smart TVs, patrons were asked to rank how "creepy" or "cool" they found Smart TVs in three contexts: their home, their hotel room, or a supermarket. For all scenarios the technology was seen as more creepy than cool (See Figure 7). This could also be based on the text on exhibit. The hotel room scenario (See Figure 8) was ranked the lowest with only 6 of 73 respondents ranking it as a 5 or above (on a scale from 0 to 10 where 0 is creepy, 5 is neutral, and 10 is cool).

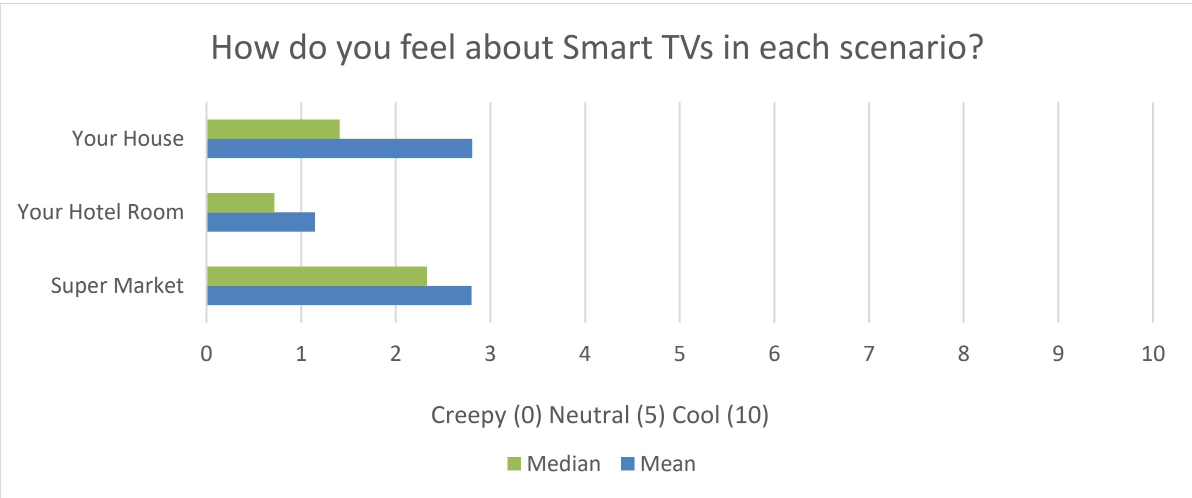

Figure 7: Average Smart TV Creepy to Cool Ranking in all Contexts Across all Exhibits

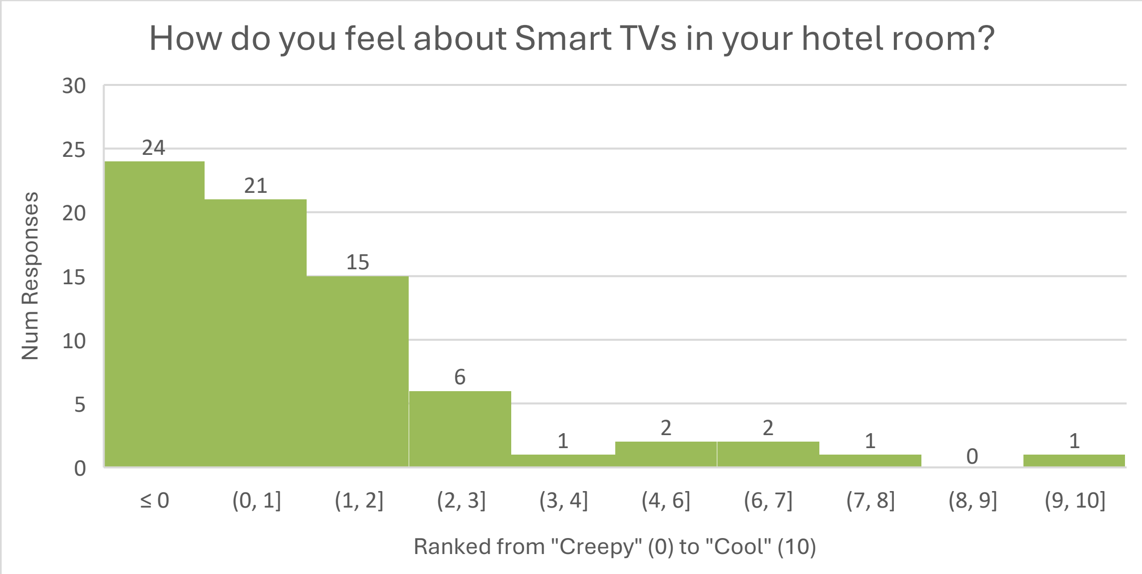

Figure 8: Smart TV Creepy to Cool Ranking for Hotel Rooms Across Exhibits

Smart TVs in the house were viewed more positively than the hotel room scenario with 22 out of 73 respondents ranking the scenario as a 5 or above (See Figure 9). Interestingly, the public context of the supermarket was viewed the least negatively. Although, 19 out of 74 respondents for that question ranked the scenario as a 5 or above (less than that of the home scenario), fewer people ranked the scenario as extremely creepy, which would be considered a score of 1 or below. It is possible that this finding mimics those of the application rankings, where scenarios in which it feels more possible to be spied upon doing personal or intimate activities are viewed more negatively and for some the benefits of home Smart TV usage outweigh potential, theoretical costs to privacy.

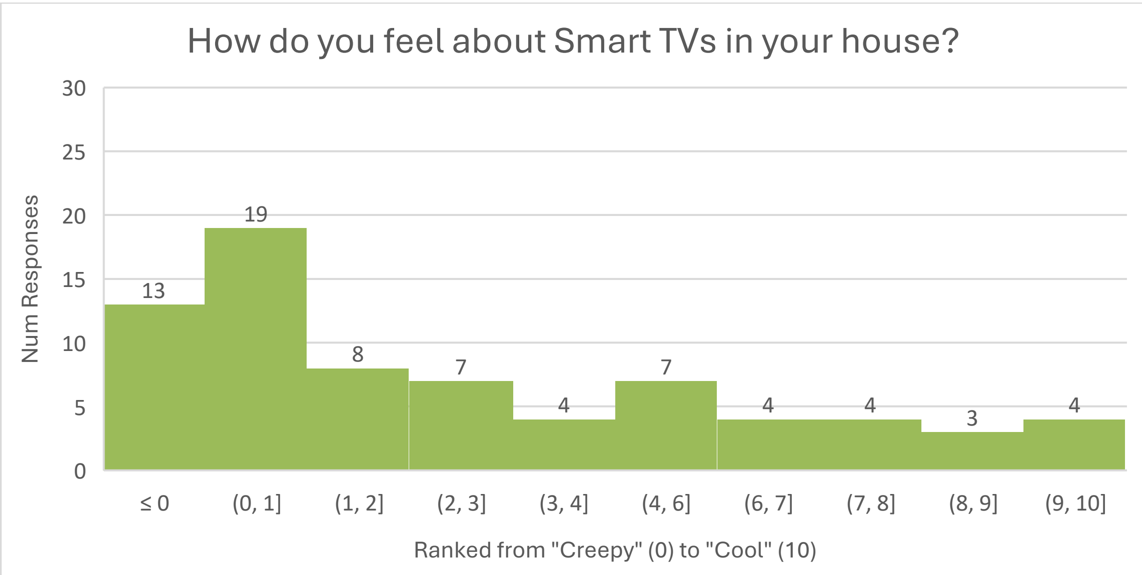

Figure 9 Smart TV Creepy to Cool Ranking for Own Home Across Exhibits

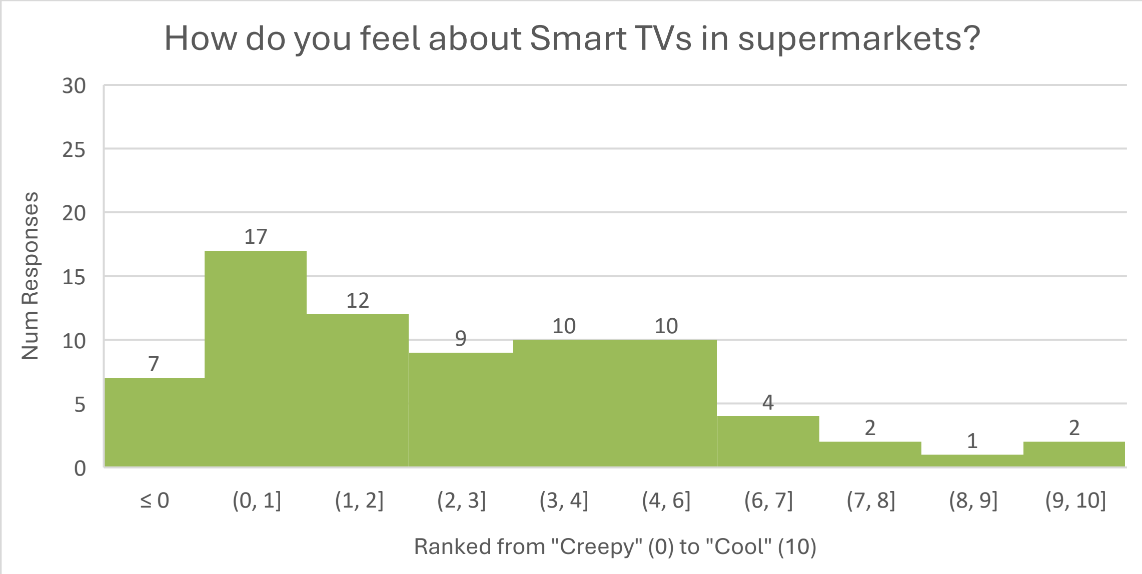

Figure 10 Smart TV Creepy to Cool Ranking for Supermarkets Across Exhibits

20 people voted that the technology would change society while 5 voted that Smart TVs would not influence society. Those who thought that Smart TVs would not change society cited that the difference to what society already has would not be that big as TVs already collect quite some information about people. Additionally, there are already different devices using cameras for things like gesture recognition. Those who thought that Smart TVs would change society considered that, since humans are creatures of habit, a smart TV has the potential to reshape or influence day to day norms and activities. Most had fears such as increased home surveillance and TV addiction, while others thought it would be nice to operate a TV using gesture recognition.

3. Technical Considerations and Design Recommendations

The HOLDEN method uses Value Sensitive Design to arrive at design requirements and additional recommendations such as regulatory considerations. To apply VSD it is necessary to identify morally relevant design alternatives, such as those indicated in Section 1.4. The first subsection briefly recaps the VSD approach used in this project and the values at stake. The second part reviews the technical considerations from D3.4 and D4.4 (including consideration ML and networked systems). Finally, 3.3 outlines design recommendations.

3.1. Value Sensitive Design

Value sensitive design is an approach developed from computer science, which recognizes that technologies are not neutral and that the values embedded into designs carryover as technologies become embedded into other technological artefacts [14]. The idea is that innovations can be built with relevant moral values in mind and that these values can be translated into design requirements. Figure 10 summarizes the main concerns that will be used to develop design requirements for the Smart TV application, labeled with the ethical criteria developed as a part of D6.1 [5, pp. 15–18] with reference to the Ethics Status Monitor [3] as well as the AI Act [19]. These considerations were brought forth through the HOLDEN Ethics Framework by focusing on the use case of Smart TVs and the capabilities of Aalto's technological developments. Relevant findings from prior and deliverables such as the ESM are also included.

Values (ESM&D6.1)	**Criteria (HOLDEN Ethics Framework + AI Act)**
Privacy	Retain User Privacy
Accountability	Accuracy, Transparent Design, Respond Appropriately to Data Captured
Autonomy	Limit Opportunistic Sensing, Encourage Fair Power Relations, Data Ownership in Terms of Access and Deletion, No infringement on non-TV related activities, No nonconsensual nudging
Equity	Avoid Bias, Culturally Sensitive Gesture Recognition
Sustainability	Limit Power Consumption, Positive Life Cycle Assessment

Figure 10: Value Sensitive Design Criteria for Smart TVs

Findings from the "This is Not a Camera" exhibit and insight from Mediation Theories suggest that HOLDEN innovation III requires much more attention to **Autonomy**, because of the perceived risk of using sensors to manipulate user behaviors (e.g., to cause TV addiction), and **Privacy** to counter potential surveillance. Findings from the Guidance Ethics workshop and additional analysis presented in Section 1 of this report suggest that **Equity** also deserves attention as gesture recognition comes with the risk of excluding user groups based on bodily characteristics or origin (e.g., users of a particular sign language). Matters of **Accountability,** such as Transparency are required under the AI Act [19, pp. 82–83].

3.2. Considerations

3.2.1. Previous Considerations

RF Wave Density and Type: Innovation III deviates from the other HOLDEN innovations insofar as it is not based on Wi-Fi networks, but RF chirping. Chirping as a method is not new and is used in applications such as LoRaWAN as a low energy option to send small, infrequent amounts of data from harder to access locations and measuring distances in smart cities projects, but they are not as ubiquitous as Wi-Fi networks. The chirping method does allow for more precise measurement than Wi-Fi and can operate independently of ambient Wi-Fi. Chirps can also be specialized to reach further distances or gather more precise close-range data.

Location and Positioning: As was the case with Innovations I and II, the placement of the sensors makes a difference for innovation III. Placing sensors on the ceiling may make it easier for gestures to be recognized from multiple angles without obfuscation. For the Smart TV it is likely that all the sensors will be placed in the TV itself. People tend to face the TV while using it, which could be a benefit to capturing TV-relevant gestures. People also tend to place TVs in the heart of their homes such as the living room or bedroom (especially in hotels). This means that it is likely to opportunistically sense intimate moments that people might prefer the TV not to know about. Location should also be considered when installing TVs in workplaces and public locations.

Visualization: As with Innovation II, the primary purpose of Innovation III is not to generate images, but to classify movement and interactions using machine learning and point cloud data. Visualizations of the point clouds themselves likely will not be understandable by humans, however the point clouds might still be useful to help users understand how the system works. A spectrum exists from the raw point cloud data to the machine learning output. How the data is displayed might have a large impact on how well people understand how the data works. For example, an option to show the level of certainty the system has in a specific decision might help people understand the extent to which they can depend on the data for certain decisions and also possible embedded system biases. There are also different choices to make in how movements or people are represented if in certain applications movement is visualized. Finally, system visibility could also refer to notifying (for example with a light) if the gesture recognition system is active or not.

Machine Learning: Innovation III requires machine learning to identify gestures from point cloud data. The machine learning used is **not** a large language model or general artificial intelligence, but a supervised learning model trained on specific gestures. While the research is mainly focused on gesture recognition, it is important to recognize that the device (put simply) consists of a sensor to collect data and an algorithm to make sense of that data. Different algorithms could be applied to the same device and installed through a routine update without the user's full awareness or consent. Such algorithms could significantly change the functionality of the device (e.g., opportunistic sensing). Already there is consideration to use data obfuscation to reduce the traceability of individual gestures and for users to be able to introduce new gestures.

At the same time, it is worth being wary of the illusion of infinite flexibility which has already been attributed to digital technologies since the 1990s [20]. Finally, the considerations regarding bias auditing as described in the ESM still apply [3, p. 42]. For example, the systems have so far mainly been tested by researchers and students, but not a diverse group of lay persons. This may impact the quality of the training data.

Networked sensors: In contrast to Innovation II, Smart TVs are independent systems. Although they have the potential to be connected to other Internet of Things (IoT) devices, the main challenge does not arise a local network of sensors, but instead a large network of global Smart TVs that collect data which may be processed and analyzed by a singular entity or various 3rd Party Applications. The network effect of processing data from Smart TVs in a variety of locations and contacts increases opportunities of opportunistic data processing. Unforeseen findings may be discovered, such as being able to tell the wall materials in various homes based on qualities of RF chirps. Even if the Smart TV provider refrains from opportunistic sensing, a 3rd party service could offer an application that works on various TV models and demands full access to point cloud data. This service could then pursue whatever interests they like. Data storage amount and time as well as data sharing limitations are design elements that might limit more negative network effects.

Finally, the following considerations apply to a lesser extend to Innovation III:

- **Penetration Capacity:** Given the focus on fine gesture recognition, penetration capacity is less of a concern for Innovation III.
- **Passive Tags** are no alternative for the task of fine gesture recognition, although they may provide opportunities for Opt-Out-Technologies.

3.2.2. New Considerations

Interaction: To perhaps a greater extent than the prior innovations, Innovation III is an interface that will have direct interactions with users. This means that machine learning classifications will have immediate feedback with users if they are using gesture recognition to interact with or operate the device. The device will also have the capability to use passive behaviors of the user to prompt specific interactions such as pausing a film if someone leaves the room or turning off the system if it appears that the watcher has fallen asleep. These interactions have the potential to reshape human behavior and reduce or extend autonomy depending on the perspective of the user and the specific system design. For example, the TV shutting off if someone is becoming tired may counterbalance the autonomy limiting addictiveness of one's favorite TV show. Off-loading human decision making and interactions to a statistical model is not without risk, so it is important to consider what are the limits of interactive features of the technology.

3.3. Recommendations

Based on the identified values at stake and the technological considerations, the following design requirements (See Figure 11) and potential regulations (see Figure 12) are advised for Innovation III, Smart TV. Unfortunately, there will always be opportunities for misuse and opportunistic use outside the locus of control of responsible design. Therefore, much of the design requirements are inspired to limit opportunities for misuse and function creep. A Smart TV should be a helpful, interactive device for the user and not a tool for surveillance and control. Internal features, however, might not be enough to prevent the market incentives to use the addictive and potentially coercive features of TVs to surveil and control, especially in environments where the primary users do not opt into the service. In those circumstances regulatory measures may be necessary to encourage fairer power relations. It should be noted that some regulatory measures may be harder to enforce than others, such as guaranteeing that hotels use the Smart TV only on non-intrusive settings.

3.3.1. Design Requirements

Values (ESM&D6.1)	Design Requirements
Privacy	*Retain User Privacy* 1) Limit range of data collection (and data stored) to viewing radius 2) Obfuscate all stored data that could potentially reveal identity to limit opportunistic sensing 3) Process all raw data locally, deleting all features unnecessary for Smart TV operation before sending data to the cloud 4) No historical data (post Smart TV usage) storage of non-registered device users (Ex: guests, passerby) 5) Registering as a user requires the individual's clear informed consent
Accountability	*Accuracy, Transparent Design, Respond Appropriately to Data Captured* 1) The Smart TV must show when it is collecting RF sensor data either on the screen, through a light, or sound 2) The Smart TV must have a tutorial feature that explains how it works and data management 3) The Smart TV should react appropriately to uncertainty by notifying the user and giving them back control (contestability). 4) The system must be able to fully shut off and stop collecting data 5) Users should be able to access a log of local historical data by type and timestamp locally and for the cloud 6) The RF chirping should be safe for prolonged human contact at close range
Autonomy	*Limit Opportunistic Sensing, Encourage Fair Power Relations, Data Ownership in Terms of Access and Deletion, No infringement on non-TV related activities, No nonconsensual nudging* 1) Only store data relevant to TV interactions (to limit opportunistic sensing) 2) All cloud data of an individual with a set profile should be downloadable and able to be deleted by that individual 3) All nudging features should be opt out 4) The system may learn individual/household specific gestures with their permission (only for private ownership and use) 5) All third-party applications must be consented to with consent that can be revoked at any time.

Equity	*Avoid Bias, Culturally Sensitive Gesture Recognition* 1) The system must be operable without an account 2) The system should work similarly for diverse individuals regardless of size or mobility 3) The system should operate using sets of culturally acceptable and natural gestures even if that means having varying options
Sustainability	*Limit Power Consumption, Positive Life Cycle Assessment* 1) Chirping should only start when it is likely that someone is about to interact with the Smart TV (this may require some gestural cue that is more easily picked up on a low power setting) 2) Design for repair, upgrading, and recycling, power consumption and lifecycle assessment should be on par with or equal to other TVs

Figure 11: Design Requirements for Smart TVs

3.3.2. Regulatory Measures

Values (ESM&D6.1)	**Regulatory Recommendations**
Privacy	*Retain User Privacy* 1) Consent required for cloud storage 2) Consent required for all 3rd party applications 3) Consent can be taken away 4) Third party applications may not gain more data than needed to operate the Smart TV
Accountability	*Accuracy, Transparent Design, Respond Appropriately to Data Captured* 1) All opportunistic data findings from networked Smart TVs must be published and explained within a 6-month period
Autonomy	*Limit Opportunistic Sensing, Encourage Fair Power Relations, Data Ownership in Terms of Access and Deletion, No infringement on non-TV related activities, No nonconsensual nudging* 1) Third party applications cannot use RF interaction data to sell products, rate users, or change pricing 2) Smart TVs in rental homes, shared offices, and public environments must operate on base settings without nudging features
Equity	*Avoid Bias, Culturally Sensitive Gesture Recognition*

	1) Bias should be regularly tested and reported to prevent data misuse
Sustainability	*Limit Power Consumption, Positive Life Cycle Assessment*

Figure 12: Regulatory Recommendations for Smart TVs

4. Conclusion

This deliverable addressed the social implications and design criteria for Smart TVs, developed on the basis of Aalto's fine gesture recognition technology through RF chirping. This technology is dependent upon machine learning and has great potential for opportunistic sensing through networked devices. The deliverable was built on prior work developed during the HOLDEN project, including the 2023 Guidance Ethics Workshop, the 2025 "This is Not a Camera" appropriation study exhibit using a Techno-moral scenarios framework, mediation theories, two interviews with Adant and the full Aalto HOLDEN team, and research insights from prior deliverables D2.3, D3.4, D4.4, D6.1, and the most up to date ESM D8.11.

Valuable insights from this research formed the basis of prerogatives for value sensitive design. Finally, implementation options for Smart TVs and ongoing considerations for RF sensing were used to inform the design requirements and regulatory recommendations. As the technology is in pre-prototype phase, the considerations should be considered malleable – it may be that some essential restrictions are missing that will be informed later in development.

The values of privacy, accountability, autonomy, equity, and sustainability formed the basis for guidelines for Smart TVs with RF recognition capabilities. These guidelines included possible solutions for bias, negative power relations, exclusion and privacy intrusion. Additionally, measures were introduced for the highest tier social concerns voiced in the Not a Camera Exhibit and Guidance Ethics workshop, which were the perceived risk of behavior manipulation, surveillance, and exclusion due to the technology being inaccessible either due to cultural or physical difference. Key design requirements limit the possibility of misuse by building in consent, transparency, and accountability measures, ensuring that opting out and still using the system is possible, limiting data that can be processed on the cloud and shared with 3rd parties, limiting the scope of raw data collected, stored, and shared both in physical proximity and in data type. Finally, included are regulatory suggestions to force Smart TVs to solely operate as Smart TVs and not surveillance devices in public and semi-public environments.

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