Underneath Your Clothes: A Social and Technological Perspective on Nudity in The Context of AAL Technology

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ABSTRACT

One promising way to tackle healthcare challenges due to demographic change lies in the development of user-tailored AAL technologies. Video-based AAL technologies have the potential to provide rich information - in particular about accidents such as falls. However, as visual AAL is designed to record some parts of daily life at home, privacy concerns may comprise recordings in unwanted appearances and especially while being nude. Here, collaborative research is necessary to enable the development of user-tailored (visual) AAL technologies taking into account future users' needs and concerns. This article presents an interdisciplinary collaboration investigating perceptions of nudity from a social perspective, and developing solutions on nudity detection from a technical perspective. Focusing on first empirical insights and a proposed methodology for level-based nudity detection, this article concludes with interdisciplinary learnings, derived guidelines, and implications for future collaborative research.

CCS CONCEPTS

• **Human-centered computing** → **Visualization systems and tools**; • **Security and privacy** → *Domain-specific security and privacy architectures.*

KEYWORDS

Nudity detection, Privacy, Ambient Assisted Living, Camera Based Monitoring

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1 INTRODUCTION

One of the promising ways to tackle healthcare challenges due to ageing societies and lacking care personnel lies in the development of user-tailored Ambient Assisted Living (AAL) technologies. AAL technologies and systems are intended to be a constant part of the everyday life of older people (in need of care) and aim to improve people's life quality, well-being, autonomy, and safety (e.g., [3, 18]) which also intends to relieve professional and familial caregivers in their care burdens [29]. Taking advantage of Information and Communication Technologies (ICT), different sensors and artificial intelligence can be integrated into home environments and lives of elderly people to provide support and to prevent or detect risky situations, such as falls and emergencies (e.g., [3, 6]). Especially visual components, such as video or depth cameras are promising in the context of AAL, since they are the most directed and natural way to record situations and movements, and provide rich information, e.g., about accidents such as falls [8]. Their importance and efficiency have massively increased by recent advances in intelligent systems and computer vision technologies, so they can be utilized in smart monitoring and automatic human lifelogging. However, there are serious privacy issues and trust concerns for utilizing them in private spaces, since they enable the acquisition of a huge quantity of information that can be easily interpreted by unauthorized viewers. Therefore, the development of privacy aware video-based applications needs to consider "privacy by design" since early stages [33]. Some other authors have proposed a "privacy-by-context" approach which trades off privacy preservation and image understanding [28]. In addition, the individual preferences of the future users should be identified and included in early stages of technology development to allow a user-tailored

adaption of visual AAL technologies fulfilling relevant needs and wishes as well as taking into account existing concerns and fears. The latter is relevant as previous research has intensively shown that privacy concerns represent a main barrier to a sustainable adoption and acceptance of AAL [29, 38]. Indeed, given that visual AAL is designed to record parts of daily life at home, privacy concerns may comprise recordings in unwanted appearances as well as while being nude. However, the aspect of nudity in the context of visual AAL still needs to be researched. Furthermore, the sensitivity of being visually recorded may vary according to different activities (e.g., cooking, resting, showering) or different locations within the home environment (e.g., kitchen, bedroom, bathroom). Exactly these questions and relationships as well as the general perception and preferences regarding the sensible context of nudity are still unexplored. To examine user-specific privacy preferences and to develop concepts for a successful technological realization of future users' preferences an interdisciplinary research collaboration is necessary which combines diverse social as well as technological perspectives.

In this paper, we present intertwined research from two different perspectives regarding nudity in the context of visual AAL. First, we present exemplary results from a social science perspective focusing on people's perception of nudity, and subsequently, we propose a methodology for level-based visualization regarding their privacy preferences from a technical perspective.

2 INTERDISCIPLINARY RESEARCH APPROACH

In the following, both perspectives including each research approach as well as respective results are presented.

2.1 Social Perspective on Nudity

2.1.1 Short Background. From a social science perspective, nudity can mean different things. In a narrow sense, nudity simply means that people are without clothes. In a broader perspective, the feeling of being naked comprises a mostly negative affect according to which people feel embarrassed, exposed, or unprotected for some reason without having control. This feeling is accompanied by the fear that personal privacy and intimacy limits are threatened. In the context of technology-assisted living environments, this has been reported in different usage situations, but evidently most often whenever camera technologies were involved (e.g., [2, 41]). In this sense, using camera technology in the AAL context is also an issue of face keeping [21, 22], privacy protection [12] and protection motivation [31].

While, to our best knowledge, perceptions of nudity in the context of AAL have not yet been studied extensively, acceptance, privacy perceptions, and user preferences regarding camera-based AAL technologies have been studied widely in various ways (e.g., [11, 23, 36]). These works might give hints about what potential users of AAL may think about nudity within this context. Arning and Ziefle [2] used a conjoint analysis approach to examine potential users' preferences and acceptance for different video-based medical monitoring scenarios in the private (i.e., own home) and public (i.e., shopping mall, marketplace, and train station) environment also considering benefits in terms of improved medical safety as well as privacy concerns in terms of data handling processes. The authors reported that medical safety was the most important aspect in the decision process to accept or reject video-based medical monitoring. However, when it comes to the acceptance of such monitoring in the private scenario even an increase of medical safety was insufficient to raise acceptance. Generally, video-based monitoring was perceived as critically or even rejected in the most private space, the own home. The own home was the focus of the study by Ziefle and Himmel [41] who investigated the acceptance of home-integrated ICT including cameras, in a mixed-methods study and repeated the examinations as part of a longitudinal study after five years [17]. The authors' first reports [41] of the qualitative data from focus groups showed that the integration of cameras was not accepted in the bed-and bathroom because of the perceived intimacy of these spaces. Regarding the quantitative evaluation of technology acceptance, participants imagined to be ill and needed medical support. Among the three assessed rooms (i.e., living room, bathroom, and bedroom) participants would accept monitoring technology in the living room but to a much lesser extent in the bedroom and bathroom. Authors' findings [17] five years later suggest the same trend that acceptance of monitoring technology decreases from a rather public domestic environment, such as the living room or the kitchen, to private spaces with intimate character, such as the bedroom and bathroom. Even though, overall low acceptance of monitoring technology and fears of losing one´s dignity and privacy prevailed among all participants, older and ill participants accepted monitoring technology especially including visual systems more than healthy participants [17]. The experimental study of Caine et al. [5] targeted older adults and examined their perceptions of privacy and their inclination to employ privacy enhancing behaviors (i.e., behavior aiming at alleviating or avoiding privacy concerns) while being monitored in a living lab experiment with either a camera or a robot (with camera). The authors observed privacy enhancing behavior when monitored, for instance people were turning their back towards the camera or obscuring objects with their body. In a pre-and post-experiment evaluation, the authors asked participants about their general comfort in performing household activities in a non-monitored home compared to a monitored home. Results show that comfort decreased with the addition of monitoring in nine out of 15 activities, with most of these nine activities having a sensitive or personal character. Among the activities with the greatest decrease of comfort were engagement in sexual activity with a partner as well as by oneself, engagement in physical contact with an intimate partner, taking a shower, or practice personal hygiene. Interestingly, all these activities were related to being nude or being intimate.

Summed up, camera technology for assistive purposes is increasingly less favored the more private and intimate the living space or the activity. Nudity is one aspect or side-effect of the previously named activities like sexual behavior or intimate care which oftentimes happen to be in these critically evaluated rooms like the bed- and bathroom. However, to what extent nudity plays a role in the overall acceptance and evaluation of visual assistive technology is yet to be determined and therefore part of the subsequently presented examinations.

A questionnaire assessing privacy perceptions of visual AAL was delivered online from 29th November to 21st December 2021 in Germany. One part of it assessed the topic of nudity within the context of AAL through quantitative as well as non-mandatory qualitative measurements (i.e., open questions). Participants' answers to the open questions were examined through content analysis [30] and emerging themes will be described. Quantitative results will be reported by means (M) and standard deviations (SD) as well as percentages (%).

In total, 134 participants ranging in age from 17 to 69 (M=31.15; SD=14.75) answered the questionnaire. Among this sample, gender was slightly dis-balanced with 31.2% being male, 67.2% being female and one participant (0.7%) being divers. A very large majority (98.5%) of participants indicated that their health was good or very good and no participants indicated to need care. 24.6% already had experience in caring either professionally or informally for another person.

2.1.2 Empirical Insights on the Meaning and Role of Nudity. As part of the described questionnaire participants were asked in an open question what nudity meant to them. Participants' answers (N=116) can be summarized to five themes. In the first theme named **Nudity is being without clothes**, participants' answers refer to the physical state of being completely undressed. For instance, one answer of a participant was: "*physical nudity is when you have zero clothes on*". The answers of the second theme called **Nudity is being vulnerable and defenseless**, go beyond the mere description of the physical state of nakedness and describe the thoughts and feelings this state might evoke. Besides, some answers may also directly refer to a condition where the individual self, including attitudes, beliefs and values is completely exposed or mentally nude. Indeed, one participant wrote: "*having no protection and revealing yourself as you are.*" Another stated: "*Nudity brings with it a vulnerability that I would like to offer only to certain people*". The fragility and sensitivity that come with being naked are differently expressed in the third theme named **Nudity is a private and intimate matter**. For instance, one participant pointed out: "*Nudity is the privacy of my body and the decision of who sees me naked is mine alone*". Others are very cautious in their answers due to privacy concerns, as such: "*Nudity is a very private subject I am not too open about.*" Contrarily to the previous themes, the fourth one named **Nudity is freedom, nature, and a normal state** gathered answers of participants who seemed to be very open about nudity. Theses participants considered being nude as a liberating experience as their quotes testify: nudity equals "*freedom and no compulsion to wear clothes*" or "*being naked means freedom for me. I feel very comfortable in suitable places (e.g., sauna, nudist beaches).*" Ultimately, the last theme is called **Nudity depends on the context** and picks up aspects of the last mentioned quote, namely that the place and the situation where one is naked plays a major role in how one feels about the own nakedness. Answers that particularly emphasize the context were grouped under this theme, like: "*Nudity depends on the situation, being at the doctor nudity might be inevitable but in other situation it is uncomfortable.*" or "*in a private environment with familiar people (partner) nudity is no problem*" or at last, "*I have no problem with nudity if the other real people are the same gender.*" Overall, these five themes emphasize that answers to the meaning of nudity can be very manifold and even seemingly opposing one and another. Perhaps, the last theme which emphasizes the importance of the context can provide one possible explanation for the variety of themes that have emerged. Nudity not only equals the absence of clothes, but it also implies the exposure of one's true and intimate state of being. In certain benevolent circumstances exposing oneself in such a free and open manner can probably be a liberating experience while in other rather hostile and threatening environments clothes seem to be a potent armor whose absence is perceived as vulnerable and an invasion of privacy. Depending on the contexts participants had in mind while answering the question, their answers may have turned out accordingly.

How nudity is perceived in the context of visual AAL, was explored first quantitatively with rating the comfortableness of being filmed during a variety of daily activities (e.g., cooking, showering, cleaning) on a six-point Likert scale (1 = very uncomfortable; 6 =very comfortable). Participants (N=134) were asked to rate comfortableness when thinking about their daily life as well as when thinking about them needing care. Results show that all assessed activities that inevitably require nudity or the exposure of intimate body parts, were considered as uncomfortable if filmed in participants' daily life but also when they imagined needing care (i.e., washing oneself: $M_{\text{Daily Life}} = 1.60$, $SD_{\text{Daily Life}} = 0.96$, $M_{\text{Needing Care}}$=2.61, $SD_{\text{Needing Care}} = 1.27$; showering: $M_{\text{Daily Life}} = 1.21$, $SD_{\text{Daily Life}} = 0.56$, $M_{\text{Needing Care}} = 2.17$, $SD_{\text{Needing Care}} = 1.19$; changing clothes: $M_{\text{Daily Life}} = 1.43$, $SD_{\text{Daily Life}} = 0.82$, $M_{\text{Needing Care}} = 2.24$, $SD_{\text{Needing Care}} = 1.21$; toileting: $M_{\text{Daily Life}} = 1.16$, $SD_{\text{Daily Life}} = 0.60$, $M_{\text{Needing Care}} = 1.88$, $SD_{\text{Needing Care}} = 1.11$; sleeping: $M_{\text{Daily Life}} = 1.83$, $SD_{\text{Daily Life}} = 1.04$, $M_{\text{Needing Care}} = 3.31$, $SD_{\text{Needing Care}} = 1.56$). In the daily life condition, these sensitive activities were the ones where participants would feel most uncomfortable if they were filmed compared to other activities which were rated as uncomfortable but to a lesser extent. However, when needing care, participants would feel quite comfortable to be filmed during various activities of daily life except during the aforementioned sensitive activities involving nude skin and/or uncovered sensitive body parts. To assess the relevance of nudity in participants' rating choices, a subsequent open question addressed whether the degree of nudity had played a role in rating comfortableness. Only 17.51% participants who answered this question stated that they either did not know or they expressed that nudity had not influenced on their rating. However, the vast majority (82.49%) confirmed the influence of nudity and provided reasons for it in their answers. From the latter, five themes emerged, details are reported in Table 1.

2.1.3 Specific Privacy Preferences regarding Nudity. In two open question participants were requested to name body parts as well as clothes and materials close to the body, they wished to be hidden in the camera output. Among answers regarding body parts (N=125) the intimate area including female breast and the backside was mentioned the most as a body area that should be covered. As a second most frequently, the body part from neck to knee was described, sometimes using the word torso. Some answers named the head or the face as a body part to be protected. The two extremes of covering the entire body and showing every part of the body were also present among participants answers. Additionally, some

Table 1: The relevance of nudity when filmed during activities of daily living (in the context of AAL).

Theme	Exemplary Answers
Data misuse and unauthorized access	*"Once I am fully naked, I don´t want to be filmed before I need care for the fear of images being misused."* *"I would be concerned about my privacy. Who sees my data? Can the camera be hacked?"*
The amount of shown skin	*"The higher the level of nudity in a situation, the less I want to be filmed doing it."* *"The more nudity the more uncomfortable observation feels."*
The Nature of the activity	*"I am more uncomfortable naked in the shower than cooking, where I am dressed."* *"Not necessarily the degree of nudity, more the degree of obscenity (e.g., toileting)."*
Privacy and Intimacy	*"Definitely nudity had an influence, as it is very intimate and private."* *"My body is very private; therefore, it takes up a large part of my privacy."*
Explicit Consent and self-image	*"Nudity is nobody's business unless I consciously agree."* *"Nudity had a little influence. But that has more to do with how you see yourself.* *If you don´t have a problem with your own body, I don´t see how nudity should affect you."*

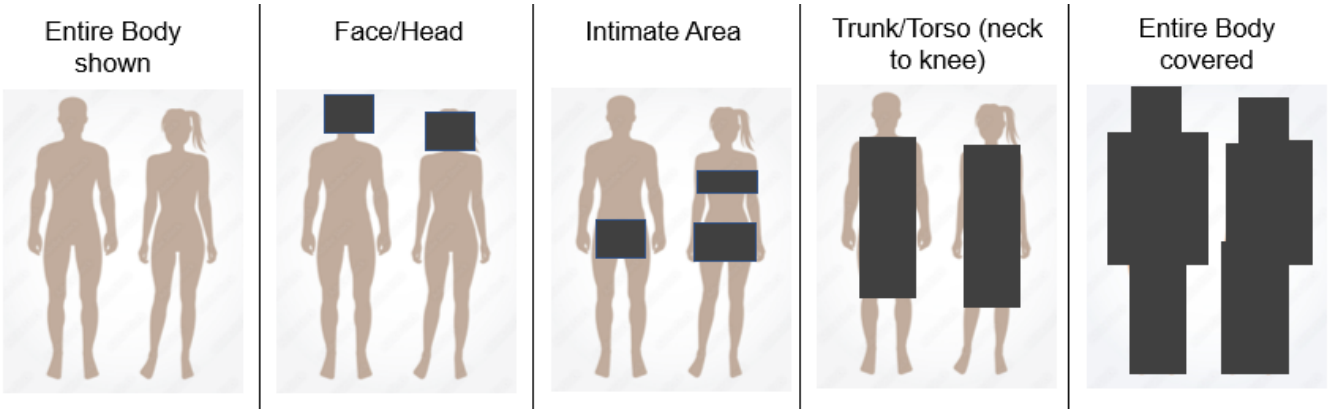

Figure 1: Schematic visualization of participants' nudity preferences in the context of AAL.

participants mentioned that the decision on which body part is shown should be free and individual. Other participants said that only body parts which are necessary for the care monitoring should be present in the camera output. A visualization of participants preferences is provided in Fig. 1. Regarding answers (N=82) about specific clothes or material close to the body that should be hidden in the camera output, the majority said that everything could be shown. However, among the ones that should be covered, underwear or lingerie were the most frequent ones mentioned, followed by towels and logos from brands that determine the clothing style. Again, some participants mentioned that the decision what to cover should be free and individual.

2.2 Technical Perspective and Developments on Nudity Detection

As discussed above, in normal situations, one might most probably not consent to be recorded in private places. However, the acceptance level can change when people are in need of care and support. Furthermore, their concerns may vary according to different variables such as activities, places, health condition, and also the observer, as discussed by Padilla-Lopez et al. [28]. Therefore, next, a methodology for nudity detection and privacy preservation according to the preferences of the users is presented.

2.2.1 Review of Previous Works for Nudity Detection. Regarding the appearance and nudity detection in AAL, though there may not exist many works addressing the exact problem, some homogeneous fields of research can be taken into account. Early works mostly focused on detecting naked persons in an image using human structure models [13] and are able to detect fully naked people in constrained conditions. The other direct approach is obscene or pornographic image and video recognition in which the problem is considered as a classification task between the images including nudity and the non-naked ones. Many works used feature extraction from the whole image to discriminate between nude and normal images. Various hand-crafted and deep convolution network (CNN) features have been utilized [24, 35]. The main problems of these methods are, first, they can not provide nudity levels, and second, they fail to generalize the problem; for instance, when just sensitive body parts are exposed. Since skin regions are widely considered as regions of interest (ROI) for nudity, human skin detection also plays a crucial role. Various methods have been used for detecting skin pixels or regions. Defining explicit thresholds for pixels intensity [27], or for image blobs intensity [14] in different color domains (RGB, HSV, YCbCr) is a popular approach. Nudity is detected if skin pixels ratio are more than a certain threshold for a given region [1, 37]. Another way is to extract hand-crafted features such as shape, texture or color descriptors from detected ROI and feed to a classifier to decide whether or not the skin regions

represent nudity [4, 39]. While these methods are more reliable than the previous ones, they suffer from high error rates regarding wrong ROI detection since skin detection can be a challenging task due to different skin colors, scene illumination and background. Furthermore, the nudity level provided by them could be imprecise or even uninterpretable. Though few works tried to tackle these problems by assigning different weights to each body parts according to their importance in nudity [20], the process would be time consuming and the improvement is not significant which also could be biased to their datasets. It is worth to mention that lacking large and standard datasets both for obscene image and skin detection is a serious issue. Therefore, many papers are validated based on random collection of personal or online public images [25]. A different approach for appearance recognition which recently has been received a considerable amount of attention is garment detection. With supports from fashion industry, several large datasets have been created such as Modanet [40] and FashionPedia [19]. The main focus of research in this field is to detect different clothing parts and wearable accessories, and their attributes and pose, mostly to be used for market analysis and finding trends in fashion. Novel deep learning techniques have been widely used in the methods for segmentation and detection [9, 26]. While considerable progress has been made and the works seems promising for detecting garment parts, they have limited capability regarding nudity detection, since detecting specific clothing on body does not necessarily represent the coverage level of a person. For example, non ordinary clothing styles and shapes, undefined clothing categories, and also variations in garment coverage area even in a same category could increase error risk.

2.2.2 Proposed Methodology for Level-based Nudity Detection. In order to take advantage of cameras in private places privacy-by-context is a potential solution. A privacy-by-context approach ensures privacy protection by means of the development of several visualization models. For achieving this goal, a system should be able to extract and provide enough information about each privacy variable to empower users to apply their preferences. Since nudity is one of the main concerns in privacy, developing a reliable and level-based nudity detection is necessary. Our proposal takes advantage of novel achievements in computer vision advances in conjunction with the studies on peoples preferences in different situations for an efficient design.

With the rise of deep learning, not only many methods have been proposed to tackle new problems, but also the accuracy and performance of previous tasks were improved significantly. With the invention of Fully Convolutional Networks (FCN) for semantic segmentation by Shelhmer et al. [34] and increasing computation powers, semantic segmentation has boosted both in accuracy and speed. Inspired from that, methods such as UNet [32], DeepLab [7] are able to segment multiple objects precisely. Therefore, these methods have been utilized for human skin segmentation too. Although skin characteristics and variations could make it challenging, some works have been proposed based on deep learning to overcome the problem. These methods such as [16] and [42], showed promising results, but there is still room for improvement regarding robustness and accuracy. On the other hand, human body related research such as detection, segmentation and pose detection has a long history in computer vision which also improved drastically thanks to novel deep learning methods. By having these methods in hand and combining them, level-based nudity detection can be achieved.

Table 2: Nudity levels based on social studies

Nudity Level	Description
1	*Completely covered*
2	*Covered torso (neck to knee)*
3	*Covered intimate areas*
4	*Covered faces*
5	*Full body or exposed intimate areas*

Our proposed methodology is illustrated in Fig. 2. It shows the general pipeline of video-based AAL system including multiple variables, with the focus on nudity. Regarding the appearance, the skin detection module extracts the skin exposure map from a video frame, while the body detection module segments the frame for different body parts such as hands, torso, and legs. Skin detection consists of an FCN model which outputs skin probability map of the input image. For body part detection, the state-of-the-art method namely DensePose [15] is utilized. DensePose is a FCN model, developed specifically for surface-based representation of human body and pixel-level segmentation of 24 different body parts. It can perform robustly in a vast variation of poses and backgrounds. After obtaining body parts areas and skin mask, by overlapping skin exposure map and body map, exposure ratio for each part can be achieved separately. We will consider a body part uncovered, if the exposure ratio will be greater than a threshold. For intimate areas and faces, the threshold can be lowered in order to increase the sensitivity of the system. In any case, the user might have the capacity to select these thresholds. These predictions then go to the Nudity Level Recognition block. In this stage, user preferences regarding the appearance are applied as levels of nudity which will be defined according to social studies (Section 2.1.2). The levels varies from complete nakedness (high skin exposure ratio on all body parts) to fully covered body (no body part exposure). The in-between levels are defined according to the perception of nudity from social studies. According to table 1, 5 different levels for nudity are proposed. For example naked hands and arms and covered torso are assumed as low level nudity which could be acceptable for daily activities, or exposure of skin in sensitive areas (intimate parts) could be an alarm for the system as high exposure level, even if other parts are covered. In this way, detecting nudity in appearance will not be a binary task, but will be interpretable and defined based on studies on peoples' preferences. At the final stage, the nudity level in combination with other context variables will enable the AAL system to provide level-based visualization according to user preferences regarding different variables.

3 INTERDISCIPLINARY DISCUSSION: LEARNINGS, GUIDELINES, AND IMPLICATIONS

The previous section started with understanding the concept of nudity and its relevance for the context of visual AAL from a social

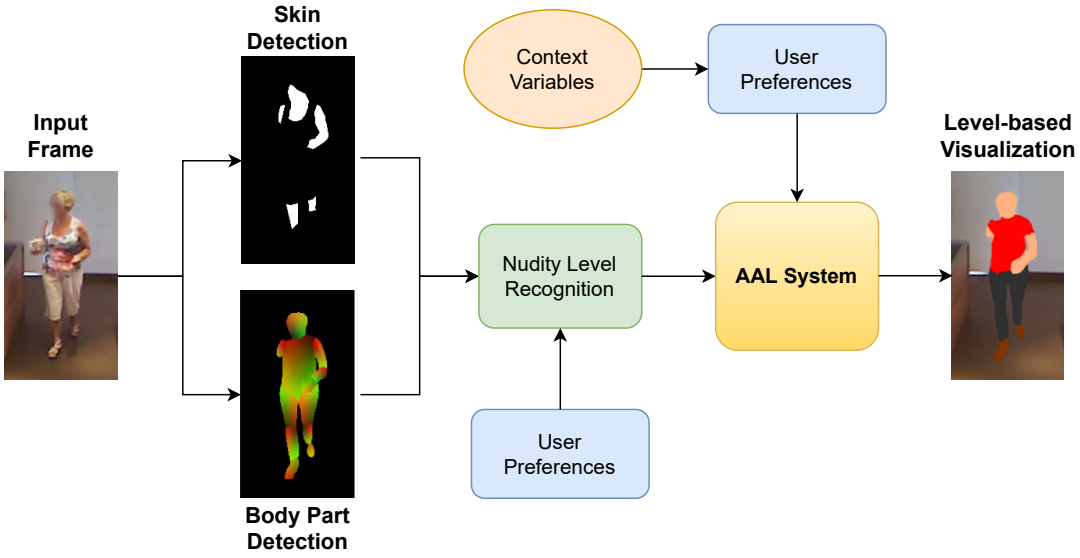

Figure 2: Example frame from Toyota Smarthome dataset [10] within the workflow of the proposed level-based visualization in AAL system based on adjustable nudity detection module.

science perspective. Therefore, exploratory findings from a questionnaire study were reported which built on similar findings in the previously reviewed literature (e.g.,[5, 17]). The filming of intimate activities such as showering, washing oneself, toileting, changing clothes, as well as sleeping resulted to be very uncomfortable even when care is needed, and nudity was reported to determine the comfortableness to be filmed. In addition, answers about potential users' preferences of how naked body parts should be visualized when dealing with visual AAL were reported. Potential technical implementations of such nudity visualizations in AAL were described subsequently with first reviewing several existing methods for nudity detection. However, as these methods are not ideal for such privacy sensitive contexts like AAL and elderly care a methodology for level-based nudity was proposed which takes into account users'necessities and preferences which were outlined previously.

Results from the social science assessment strongly suggest that nudity does play a major role for future potential users of AAL, and therefore technological efforts to develop new methods for nudity detection specifically for the AAL domain are not only reasonable but are also required for a successful user acceptance and sustainable implementation into daily care. However, how people interpret the general meaning of nudity differs widely and depends on the context, as well as general personal attitudes. Similarly, nudity preferences for AAL vary and range from the two extremes of covering the entire body to showing the entire body. Claims were made that only nude parts which are necessary for care should be shown or that the person involved should be able to choose nudity preferences individually. This unanimity in preferences and the desire for individual solutions are a strong support for a level-based nudity detection approach which is proposed in the previous technical chapter. While developing these technological functions, as requested by potential users, the component of consent which gives the user the power over the visualization of her or his body parts should be integrated technologically. Further, the finding that the perception of nudity depends on the activity performed should be informative for the technical development. Overall, data security and regulated access should be guaranteed technologically as this was mentioned as one of the main concerns when it comes to nudity. Combining these insights, the need for strong and continuous collaborations among disciplines becomes evident for a successful development of an accepted and well-tailored AAL product and service. In fact, only informed by the social perspective such methodology of level-based nudity can develop its full potential.

From a technological perspective, the total efficiency of the proposed methodology for an AAL system relies on the performance of skin detection and body segmentation modules. While existing work can provide acceptable results, due to the importance of privacy in home environments, lowering the errors regarding appearance detection is crucial for future research. Therefore, developing and utilizing novel methods to further improve their accuracy, can increase robustness and reliability, and ultimately make positive impact on the acceptance for such system.

For future research it has to be mentioned that the findings from the social science perspective were taken from a relatively small, young, and healthy German sample. Regarding such a delicate topic of nudity it is urgent to examine participants worldwide with a specific focus on the old and frail population as well as integrating different cultural, religious, and political backgrounds. Further, results are exploratory and qualitative, and can neither be generalized nor quantified. Future work should assess the topic quantitatively based on these initial results and give participants possibilities to familiarize with the technology. Also, activity-specific, and context-dependent preferences from various stakeholders - such as caregivers and caretakers, but also family members who may access the data and possible bystanders – should be assessed. The authors plan

to continue their joint work to expand the presented exploratory and propositional findings within the ongoing visuAAL project.

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