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On the Prototyping of an ICT-Enhanced Toilet System for Assisting Older Persons Living Independently and Safely at Home

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Abstract. Standard toilets often do not meet the needs of a significant number of older persons and persons with disabilities. The EU funded iToilet project aims at design and development of a new type of ICT enhanced modular toilet system which shall be able to support autonomy, dignity and safety of older persons living at home. Methodologically the project started with gathering user requirements by means of questionnaires, interviews and focus group discussion involving a total of 74 persons, thereof 41 subjects with movement disorders (primary users), 21 caregivers (secondary users) and 12 healthcare managers (tertiary users). Most important wishes were bilateral removable handrails, height and tilt adjustment, emergency detection, simplicity. In parallel to the ongoing technical development participatory design activities have been carried out at user test sites in order to continuously involve users into the design process and to allow quick feedback with regards to early prototype parts. The project currently is working on the finalization of the first prototype ready to enter the lab trial stage in spring 2017. The experiences will be used for redesigning a prototype 2 which is planned to be tested in real life settings early 2018.

Keywords. ADL, hygiene, toilet, AAL, smart home.

1. Introduction

The toilet [1], most commonly used in Western society, is in the form of a fixed height "seat". Considering the diversity of people and the different needs and preferences in personal hygiene, there are a considerable number of deficiencies in this standard form of the toilet. These deficiencies can present serious obstacles to older persons and persons with reduced mobility [2, 3].

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In the project "iToilet" [4, 5, 6], partners are developing an extended toilet, which is based on the existing sanitary products “Lift-WC” and “mobile toilet chair” [7] and is enhanced by ICT-based components, which can support older persons in an active and independent life at home as well as in institutions. Thereby functions such as setting the optimal seat height, dynamic support during standing up and lowering, automatic recognition of user preferences, voice control, safety (emergency detection, fall detection, etc.) are provided. The target groups are older people living alone, as well as their (formal and informal) caregivers, institutions, and costumers.

2. State of the Art

Only a surprisingly small number of research projects in Europe have hitherto been dealt with technical improvements in the area of the toilet for older persons or disabled users. Nevertheless, there is a large research body studying the topic of forces that occur during standing up and sitting down procedure and how physical training to do this most efficiently from the therapeutic point of view should be done.

The "Friendly Restroom" project, coordinated by TU Delft (2002-2005) and partly funded by the EU in the 5th Framework Programme, was a user-centered research project focusing on the design of adaptable toilets and toilet rooms [2]. A basic product of a height-adjustable and tiltable toilet came on the market in 2006 (LiftWC [7]).

The research project "The Future Bathroom" (2008-2011) of the University of Sheffield conducted studies on the user-centered design in the bathroom for people living with age-related disabilities. The project was very concerned with the integration of old people into the design process [3].

In contrast, the "iToilette" project of RWTH Aachen University (2009-2011) focused on the automated measurement of vital parameters [8]. The EU project I-Support, launched in 2015, develops a robotic shower to enable independent living for a longer period of time and thus improve the quality of life of frail people [9].

Products on the market in North America and Europe focus on simple toilet implementations, additional handles, as well as mechanical (and partly motorized) lifting aids (for example LiftWC) as well as add-ons for intimate hygiene (shower WC) and seat hygiene. In Japan there is also a remarkably strong spread of additional toilet facilities such as anal cleaning, bidet, seat heater and odor removal.

3. Approach and Methodology

3.1. User Groups

The iToilet project [4, 5, 6], coordinated by the Vienna University of Technology and launched in 2016, focuses on older people who live independently at home. The wishes and needs to be met when using a toilet at home are to be met as far as possible with ICT-based support modules and thereby empower the elderly to a more independent and dignified life. In addition to the main area of work at home, the system is also intended to bring benefits in institutions and not only to the older persons themselves, but also their caregivers by reducing the burden of personal assistance on the toilet.

As stated above, the needs and wishes of older (or physically impaired) people play a central role in the use of a toilet. The iToilet project, however, also supports the needs

of caregivers with the assistance of users in the toilet room and also takes into account the perspective of nursing and care facilities (mobile and institutional care) and financing / funding organisations, e.g. insurance, social systems. All stakeholders are actively involved, not only on a point-by-point basis but as continuously as possible, and not just during the trial phase, but during the entire project runtime.

The iToilet project aims at developing field test ready solutions for the known problems and this is done by having in mind certain hypotheses, e.g. we expect that adjustability for different toilet heights for different "actions" should make toilet use much easier for (most of) our target users. Additionally, we assume that the adjustability will support users' independence and maintain safety for unattended use. We also planned for testing in institutions because of a broader sample, a safer environment and a better availability of experts from areas of nursing, therapy and medicine. Thus, one of the first tasks in the project was to check if the hypotheses hold true.

3.2. Gathering of User Requirements

During the initial phase of the project it was important to assess user requirements and verify the assumptions in order to provide a clearer view about expectations and needs regarding toilet use (from entering to leaving the toilet room). The eventually derived user requirements also included a ranking of the most needed functionalities. This created a solid basis for specifying the iToilet system and helped to decide about what are the crucial and optional components of the to-be-developed intelligent toilet.

3.3. User Involvement and Participatory Design

In the iToilet project there are challenges due to the special setting. For example it is foreseen that the prototypes are not tested at home, but in two institutions, which makes it easier to carry out the user test. On the other hand, while doing so it must always be taken into account that an innovative product for the home area is the primary project goal.

With regard to the users involved in the project there are (a) older people within a clinical rehabilitation setting (Rehabilitation clinic in Budapest) and on the other hand (b) mostly younger but physically limited users with multiple sclerosis (MS day care centre in Vienna). The evaluation in everyday life must be carried out while the test partners' own day-to-day operational tasks are running.

A basic methodological difficulty is given by the taboo-related context of toileting. This can have significant impact on the participatory design activities. However, the authors already have positive experiences from successful previous projects [2, 10, 11] in which it was shown that, by intensive preparation, well-accepted possibilities for user involvement and participation in the development and design process can be created despite the taboo area. A good, detailed and continuous information strategy, the creation of trust between researchers and users as well as carrying out the initial toilet tests in the laboratory in the dressed state (with cloths on) have proved to be particularly helpful.

Due to the taboo area and due to the target audience of vulnerable people the topic of ethics is particularly important [12, 13]. The safety aspect is also of importance, especially since dynamic physical support (for example during sitting down and getting up) shall be created, whereby all conceivable safety risks have to be eliminated or minimized in the framework of a safety analysis.

Table 1. List of high and medium priority user requirements.

#	High priority user requirements	#	Medium priority user requirements
1	bilateral (general stability and support), removable/foldable handrails (wheelchair)	1	self-sanitizing seat and bowl
2	height adjustment (in a wide range) and tilt adjustment	2	shelf/tray area
3	fall detection, emergency recognition and emergency call	3	upgradability, modularity
4	simplicity (few, straightforward buttons on both handrails)	4	automatic or button operated flush
5	fixed toilet paper holder (on both handrails)	5	care documentation
6	sit down and stand up support	6	spoken commands
7	custom settings (tilt and height) w. user identification	7	individually formed toilet seat
		8	voice guide
		9	automatic dispensing of toilet paper
		10	bidet with dryer and adjustable water jet
		11	urine meter /analyser

In the iToilet project, the involvement of users right from the beginning of the project plays a special role. These actors come from the non-scientific field, and have a very important role in the project structure, as they act as experts for their own life experiences at their home and contribute their own everyday knowledge to the knowledge base of the project. The test sites in Hungary and Vienna serve as a framework for (a) the integration of non-scientific participants, the later users of the iToilet systems, and (b) as an opportunity for the representatives of the other disciplines to enter a continuous dialogue across technical boundaries.

4. Results

This section presents some preliminary results from the ongoing project. It also outlines some selected technical components which will be part of the first prototype of the iToilet system, which currently is in final phase of development.

4.1. Findings from User Requirements Analyses

User requirements were collected by means of questionnaires, interviews and focus group discussions involving a total of 74 persons, thereof 41 subjects with movement disorders (primary users), 21 caregivers (secondary users) and 12 healthcare managers (tertiary users). The user requirement gathering showed [14, 15] that participants of the primary user groups in Austria and in Hungary have heterogeneous diagnosis and dependence levels, thus one could assume that they also might have completely different needs in toilet assistance. Nevertheless, it was found that the iToilet target users have the same primary needs overall: as much physical and as tailored help to all kind of moving and posturing tasks in toileting as possible which could make them independent from personal assistance.

Regarding the potential differences in iToilet use at home or institutions, the results support that most of the user requirements are valid at both settings. Differences might only occur concerning the timespan until arriving of assistance. (e.g. institutions – immediate assistance vs. home – takes time till the ambulance / relatives / neighbours

are arriving). This difference has to be covered in the technical implementation, e.g. the alarm chain.

The requirements were ranked and grouped in high and medium priority according to answers in questionnaires and frequency of mentioning in interviews (Table 1, more details can be found in [14, 15]).

Secondary and tertiary user groups looked at toilet use scenarios from a much wider perspective, nevertheless they come to the same conclusions about user requirements as the primary users themselves.

Concluding, the differences of user groups were diminished by the common needs they have. This is seen by the priority rankings of the user requirements (cf. Table 1). The consortium aims at developing iToilet prototypes able to cover all top priority items from user requirements and 50% of the medium priority items.

4.2. Participatory Design Activities

Despite the taboo-related topic of toileting and corresponding routines of intimacy and personal hygiene the involvement of older and vulnerable users in the design and development activities could be established successfully. Initial topics for the participatory design (PD) activities were: Toilet paper dispenser, speech control, various mechanical buttons and remote controls and grip bars. First initial results [16, 17] are promising and will influence directly the technical development. In the upcoming months the participatory design activities will be continued by involving more users and by providing additional and/or improved hands-on material.

4.3. Modular System Architecture of iToilet

For the system architecture a modular approach has been chosen which allows for a high level of flexibility during research and also during upcoming commercialization, as different combinations of the iToilet components can be selected according to the individual setting, preferences and wishes. The following hardware modules [18] are foreseen for the upcoming prototype system:

- A motorized height and tilt adjustable toilet “chair” forms the mechanical base (see Figure 1). Two separate motors can change height and tilt of the seat. Sensors are integrated to measure the actual position of the toilet and the static or dynamic load (e.g. by a person sitting on or standing up from the toilet).
- A control unit runs the inferences software unit, the dialogue manager and the network coordination of the different (partly optional) modules.
- Sensors in the environment measure activities (e.g. person presence).
- A 3D sensor aims at recognizing falls (manufacturer: CogVis GmbH).
- A speech recognition with microphone in the far field (without the need to be worn by the user) allows control via speech alternatively to the buttons.
- Buttons (tactile commands) for controlling the toilet are available on a remote control connected via cable or as buttons integrated in the grip bars.
- RFID reader at the entrance for user identification. Allows to automatically recall individual user preferences (e.g. height, tilt, language).
- Interface to care documentation systems, useful for storing preferences, for visualization of usage data and as interface for connecting mobile devices.
- The output is given by synthetic speech, sound or devices like smart phones.

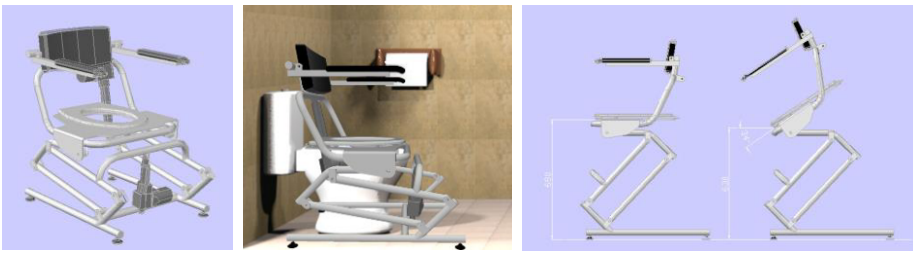

Figure 1. Left: Base toilet seat module of Prototype 1. Height and tilt can be changed by two independent motors. Middle: The toilet seat can be moved over an existing toilet bowl. Right: Base toilet seat module of Prototype 1 (side view) in maximum height position (left: no tilt (horizontal seat), right: tilted seat).

4.4. Base iToilet Chair Module

The base chair (Figure 1) has to be put over a toilet bowl (seat has to be removed from bowl) and connected to mains power.

4.5. iToilet Voice Control Unit

In parallel to the traditional remote control (pressing buttons), users can give voice commands to control the iToilet system. This is especially useful when transferring from the chair device seat using both arms.

The voice control unit (in English, German and Hungarian language) has been developed in two versions: one based on existing Software Developer Kits (SDKs) for Automatic Speech Recognition (ASR), the other on an innovative Speaker Independent Large Vocabulary Continuous Speech Recognition (LVCSR) engine [19], which has been customised to encompass the specificities of the iToilet domain. The vocabulary of the speech recognition system has been limited to some commands defined by PD results of user partners. Extensive acoustic training has been done by native speakers. The system offers powerful personalisation capabilities (it can be easily trained to individual voices). In addition it can be trained to recognise users with mild speech impairment and disturbances. Currently height and tilt of the chair device can be adjusted and flush and bidet can be activated/stopped via the following basic speech commands in the three project languages: “sit down”, “stand up”, “higher”, “lower”, “flush”, “bidet on”, “bidet off”, “forward”, “backward”, “stop”. Additionally the “help” command initiates an emergency call to pre-stored phone numbers.

The toilet rooms where the iToilet system is going to be installed are an enough silent space for the speech recognition system to work fine (verified by PD). In addition, to avoid interferences, an omnidirectional microphone with background noise deletion is adopted and the microphone is activated only when a person enters the toilet room (people entering are recognised by the User ID Module and the relevant speaker profile is uploaded to the system) and deactivated when the person leaves the toilet room. This allows the system to achieve high accuracy in the recognition of commands.

The voice control unit activates speech synthesis when the user enters the toilet room (to give instructions how to use it) and as a reaction to the “help” command.

The mounting position of the voice control unit and its microphone is opposite from the chair device in a distance between 1 to 1.5 meters. The voice control unit is connected to the other iToilet units via a private local wireless network and communicate with them using the MQTT protocol.

4.6. Control Module

This component is implemented in a so-called control box. It has an integrated microphone, speaker, and GSM interface which enable outgoing hands-free voice calls to specific preconfigured phone number(s), provided that the control box is supplemented with an adequate component to trigger the call, e.g. a corresponding wireless emergency button. An integrated WiFi interface enables connection to other iToilet subsystems.

Safety sensors are connected wirelessly to the sensor box. Their purpose is to trigger alerts in case of emergency situations, e.g. in case of fall or panic button activation. An off the shelf Visonic MCT-220 Wireless Emergency Button is used for its technical characteristics and the fact that it is already integrated with the iToilet sensor box, i.e. the CareSignal sensor gateway.

In iToilet, a panic button can be used by a toilet user to trigger an alarm in emergency situations. In case of such alarm relevant caregiver is notified and hands free emergency call is established through sensor box between the iToilet user and relevant caregiver.

5. Conclusion and Outlook

In the iToilet project, ICT-based support measures are being developed to improve existing toilet modules and support the independent and safe life of older people at home. To reach these goals the project uses existing toilet base modules and develops ICT-based add-on modules. The architecture foresees a very modular toilet system, which is individually adjustable and can be installed over an existing WC bowl as typically found in private homes or institutions. In parallel to the technical development participatory design (PD) activities are carried out. A key concern is to ensure the relevance of the solution to the users, that is, to enable the users to experience the desired assistive toilet system as useful and usable.

In spring 2017 first complete prototypes of the height and tilt adjustable seat module for lab testing will be available. An improved prototype of the iToilet system, taking up the results from lab trials, is planned to be available for real life evaluation in 2018.

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