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Towards Smart Adaptive Care Toilets

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Abstract. Standard toilets in Western countries often do not meet the needs of elderly and disabled people with physical limitations. While the existing concept of barrier-free toilets and the emerging "changing places" concept offer more space and support, the fixed height of the toilet seat still imposes a major problem during all phases of toilet use and can limit the users' autonomy by requiring personal assistance. Thus, in the EU project iToilet an innovative ICT-based modular height adjustable toilet system was designed to support the autonomy, dignity and safety of older people living at home by digital technology enhancements adapting the toilet to their needs and preferences. The main requirements were: double foldable handrails, height and tilt adjustment, emergency detection and call, and ease of use. The ICT component in this approach serves a double purpose of enhancing usability of the base assistive technology while at the same time providing safety for independent use. A field test of a prototype system in real environments of a day care center and a rehabilitation clinic has been successfully finished. The application of the iToilet concept also in semi-public settings is currently studied in the Toilet4me project.

Keywords. AAL, toileting, autonomy, care, smart toilet, robotic toilet, barrier-free toilet

1. Introduction

Standard toilets in Western countries often do not meet the needs of elderly and disabled people [1, 2, 3]. For individuals with physical disabilities therefore barrier-free toilet concepts have been introduced, which provide more room e.g. for wheelchairs or assistants and a fixed height raised toilet seat with grab bars for support during transfer and when sitting. Recently further improvements by a changing bench and a hoist have been proposed via the "changing places" consortium [4] mainly in the UK. Still, such concepts are difficult to implement in users' homes, and they do not solve one of the main challenges, the fixed toilet height during all phases of toilet use, which might be unsuitable and prevent fully-autonomous toilet use or transfer. Therefore, in the EU project iToilet an innovative ICT-based modular height adjustable toilet system was designed to support the autonomy, dignity and safety of older people living at home by digital technology enhancements adapting the toilet to their needs and preferences.

A main motivation of Assistive Technology design has always been to support autonomy – at least in the sense that there are alternatives between personal assistance and technological support to choose from. Such independence can be accomplished by

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appropriate tools, for example, by providing intelligent assistance based on digital technologies in everyday life as proposed since many years in the field of Ambient Assisted / Active and Assisted Living (AAL). Given that toileting is a "taboo" or "embarrassing" area for most people, *not* being dependent on personal assistance can lead here to a strong gain in felt autonomy for affected people. In this way, people are able to adhere to their own values and plans and are independent from others, that is, they can act autonomously.

On the contrary, people with physical disabilities often experience restrictions in autonomy when certain activities of daily living require them to rely on personal assistance and then struggle to overcome barriers on their own which also poses a threat to safety, as overexertion or sudden indisposition is not unlikely to cause accidents. Therefore, besides the design of physical support and the usability of functions as an alternative to personal assistance, a main emphasis in the iToilet project (www.itoilet-project.eu) has been to also offer a safe day-by-day choice [5].

In an institutional setting, an assistive toilet tightly embedded in the care provision process can also reduce the burden for care persons reducing their physical involvement during daily work or in the toilet room. Digital technologies which monitor the toilet use and parameters can deliver early hints about emerging user/patient problems and provide reliable information for the care documentation which otherwise has to be manually collected.

We now take a detailed look at the steps involved in using a toilet in order to identify potential 'pain points' that might hinder independent toilet use. We then use these critical steps to infer required design features of assistive toilets like iToilet.

- Entering the toilet room. Difficulties can arise when the (self-closing) door is not easy to open especially when the user needs some kind of walking aid.
- Moving close to the toilet bowl with wheelchair or deposit walking aids.
- Undressing. This can be difficult when hands are needed for standing upright. A high raised toilet seat to lean on and handrails can help in maintaining a standing position during undressing.
- Sitting down or transferring from wheelchair. While sitting down from standing usually is not effortful, the abrupt motion can cause discomfort and instability. For wheelchair users the transfer should not be "uphill" i.e. the toilet height should be slightly lower than or equal to the wheelchair seat and handrails should not block their way.
- Stable sitting. The most stable position is with both feet fully on the ground (often not the case in fixed raised seats) and with support by a backrest and armrests on both sides. A low "squatting" position is also known to be helpful for defecating, especially for elderly people [1].
- Cleaning. The cleaning process can be supported by easily reachable toilet paper (on both sides), not requiring the sheets to be fetched with both hands and by preventing the torn-off paper (or the complete paper roll) from falling to the floor when released. For persons with restrictions in reaching behind for cleaning a washing and drying support by a bidet function can be helpful.
- Flushing. Pressing a button behind ones' back or on the wall can be difficult. An automatic flush function or flush by command should be easier to use.
- Standing up from a low sitting position is the most difficult action for some users. Motorized support for lifting users to a position where standing up is possible is a main feature of iToilet. For wheelchair users the transfer should

be not "uphill" i.e. the toilet height should be slightly higher than or equal to the wheelchair seat height.

- A raised toilet seat and armrests support the users in standing upright and again facilitating the process of dressing.

An assistive, height adjustable toilet (in form of an ICT enhanced robotic toilet) therefore should support three to four different individual heights in the range between ca. 35 to 80cm during the toileting process. The individual settings can be retrieved from a database, thus making it possible to use one adaptive toilet for many users e.g. in institutional settings with IT infrastructure.

In the reminder of the paper, chapter 2 outlines the iToilet project approach covering user requirement gathering, prototype development and evaluation for home and institutional use. Chapter 3 provides an overview of the toilet4me study project on a possible extension of the iToilet concept from use in home and institutional settings to the area of semi-public spaces.

2. iToilet Approach for Home or Institutional Use

2.1. Collected Requirements

In the iToilet project presumptive users (n=41, all with mobility restrictions but able to walk with a technical aid) [6, 7] were first asked to rank the relevance of problems in relation with toilet use based on their personal experience to collate the project assumptions right at the start (see Table 1).

Table 1. iToilet Ranked User Requirements

Rank	High priority user requirement
1	bilateral (general stability and support), removable/foldable handrails (wheelchair)
2	height adjustment (in a wide range) and tilt adjustment
3	fall detection, emergency recognition and emergency call
4	simplicity (few, straightforward buttons on both handrails)
5	fixed toilet paper holder (on both handrails)
6	sit down and stand up support
7	custom settings (tilt and height) w. user identification

Rank	Medium priority user requirement
1	self-sanitizing seat and bowl
2	shelf/tray area (to put objects)
3	upgradability, modularity
4	automatic or button operated flush
5	care documentation
6	spoken commands
7	individually formed toilet seat
8	voice guide
9	automatic dispensing of toilet paper
10	bidet with dryer
11	urine meter /analyzer

The same questions were also given to 21 secondary users (care givers) and 12 tertiary users (managers of health care organizations and insurances). While primary users generally gave lower scores to problems than secondary and tertiary users, the highest

ranked problems all dealt with the height of the toilet and the transfer to and from the seat followed by hygiene issues.

Moreover, a set of questions regarding proposed support functions of an ICT enhanced toilet was ranked by the same users. Here fall detection, emergency recognition and custom settings were the most favored functions. Overall, the idea of iToilet to provide ICT enhanced physical support for independent and safe use was found to be clearly coincident with existing problems and appreciated by the users. The users' ranking of iToilet functions is documented in more details in [6, 8] and led to prioritized features for prototyping.

While all of the high priority requirements (see Table 1) were implemented in the iToilet prototypes some of the medium priority items were either only tested in laboratory (automatic dispensing of toilet paper) or left for the design of a future product (self-sanitizing seat and bowl, shelf/tray area, individually formed toilet seat etc.) where commercial solutions are already available. This approach allowed the consortium to focus on the most important user needs when designing, implementing and testing prototypes.

2.2. iToilet Prototypes

Based on the requirement lists (Table 1) two different prototypes (PT), both based on the existing sanitary products "Lift-WC" and "mobile toilet chair" of company Santis Kft. [9] with the same interaction concept [10] and base functionality, were developed: a chair-like prototype of a motorized stand-up support "PT1" (see Fig.1 left) which can be easily placed over any existing toilet bowl (for single users at home, appropriate for temporary use without complex installation as only the seat is movable) and another prototype "PT2" based on a wall-mounted base toilet system where the whole toilet including the bowl is movable. PT2 needs more installation efforts and might be more suitable for use in multi-user settings of institutions (see Fig.1 right).

Figure 1. Chair-like iToilet prototype PT1 (left) and wall mounted prototype PT2 (right) as installed for user tests (see section 2.3 iToilet Field Tests).

Despite the taboo area of toilet and personal hygiene considerable involvement of users in participatory design activities could be accomplished [11, 12, 13]. In the

design of toilet paper dispensers, speech recognition, different buttons and armrests the users actively contributed their ideas to the development in the form of co-design activities.

Both prototype versions offered the following features:

Base system:

- Adjustable motorized height and tilt of seat (approx... 40-75cm height and 0-10 respectively 30 degree tilt), position monitoring by sensors
- Arm rests for support on both sides, foldable for wheelchair transfer
- Manual operation by a user interface with big buttons featuring clear symbols and tactile feedback (on both sides)
- Motor amperage draw monitoring and safety contacts for collision detection
- Wireless configuration via microcontroller, Wifi and MQTT (see next item)

Add-ons via wireless configuration:

- Hands-free operation via speech recognition (German and Hungarian tested)
- User identification e.g. by RFID tag at door entrance (for multi-user settings)
- Detection of users entering the room, optional audio signal greeting
- Recall of user preferences and toilet positioning for sitting-down (upon entry)
- Automatic adjustment of stored sitting position with a single user command
- Automatic adjustment of stored stand-up position with single user command
- Instructions and information to users by Text-to-Speech synthesis
- Monitoring of user presence and usage time for emergency detection
- Monitoring for falls by a dedicated (commercial) fall detector
- Storing of preferred individual toilet positions and user settings when leaving the toilet; optional entry in care documentation system
- Emergency call via GSM with bi-directional hands-free voice connection upon manual activation, speech command or detected emergency

Additional features in PT2 (wall mounted system):

- Activation of flush by command or automatic mechanism
- Bidet washing and drying included in seat with activation by command

As captured by this list, ICT together with the mechanical base modules not only allows hands-free control of functions via speech recognition but also enables the system to perform actions like automatic change of positions or flushing based on user preferences while the emergency recognition component monitors safe use and instructions can be given to users by the system or via the GSM voice link if needed.

2.3. iToilet Field Tests

The PT2 system was tested autonomously under real daily use conditions by a total of 50 users, 23 clients of a Multiple Sclerosis day care center and 27 patients of a rehabilitation clinic [14], during a period of at least 4 weeks after approval by the appropriate research boards had been granted. The testing in institutions was chosen

because of easier access to the necessary number of users with fitting profile and the better support to users in case of problems.

After this four-weeks experience of the toilet, during the final interviews all provided functions (c.f. 2.2) were rated as useful by at least 75 to 100% of users, except the bidet function, which was not so well accepted at the day care center and the recognition of spoken commands (as alternative to pressing buttons) which achieved only around 60% rating on both test sites. The reliability of the prototype functions was rated high for the core support functions but some additional features like the speech recognition or the emergency monitoring were criticized because of too many false positives (caused by the initially underestimated range of behaviors).

During the field trials around 500 toilet visits have been logged. The use patterns, ranging from 5 minutes (on average) to sometimes 30 minutes, clearly showed that individual, higher sit-down and stand-up heights have been preferred by the majority of users which is in line with the good rating from interviews. The user identification by RFID tag was technically reliable but was not always easy to use because the participants were required to hold the personal tag against a reader. For plain home use for single users this will not be necessary, for institutional use additional more ergonomic methods of user identification should be investigated.

2.4. iToilet Ethics Approach and Autonomy Study

iToilet implemented comprehensive ethical governance and monitoring throughout the project, because of the sensitive research area. Besides dedicated reports dealing with safety and ethics, the MEESTAR tool [15] was successfully applied in several consortium meetings to elaborate ethical implications of the iToilet approach and to raise awareness among consortium members [13].

As a specific extra effort after the field trials the users at the day care center were asked to engage in discussions with an independent researcher who was not involved in the earlier project work. The aim of this in-depth fieldwork with 15 people with Multiple Sclerosis, most of them participants of the recent field trials, was to get better insight into the attitudes of the users towards technological assistance and preferred autonomy support in their daily practice. In this way, the study triggered deeper reflections on the implications of technology use for assisting people as well as for monitoring user behavior. The interviewees confirmed in these open discussions the benefits of the iToilet concept of providing personalized toilet settings. Still, they also emphasized that, depending on their “daily shape” and their physical capabilities, from time to time they want to try refrain from using assistive technology to train their remaining strength [5].

These positive results of the iToilet tests which have demonstrated the benefits of an ICT enhanced toilet encouraged us to prepare the investigation of solutions similar to iToilet in additional areas. In the next section, we describe our ongoing study in public settings (e.g., restaurants).

3. Toilet4me for Semi-Public Use

The Toilet4me study project (www.toilet4me-project.eu), which started after the completion of iToilet project, addresses people of all ages with impairments/disabilities

and their needs when using a toilet outside home in public or semi-public environments (e.g. in community centers, shopping malls, theatres, hotels etc.).

The main idea of Toilet4me is simple but challenging: As iToilet already demonstrated the benefits for supporting people during toilet use at home (or in a care institution), we now want to proceed and explore the feasibility of this type of supportive toilet in places outside the own home. Offering the support in places which people frequently visit or would like to visit, if appropriate toilet facilities would be available, should allow people to closer participate in society, which should contribute to their independence and quality of life. A service or technical solution which allows the users to always "take their own preference settings with them in the pocket", in the form of a digital personal use profile, can facilitate a lot of new possibilities for several user groups, inside and outside the home. Toilet4me together with end users (older or disabled people, their caregivers and managers of public places and hotels) will elaborate the requirements for such service.

It is expected that the principles of accessible toilets for home or institutional use can also be applied in semi-public settings but of course challenges like costs for installation, maintenance and service as well as suitable methods for the safe and easy data exchange for preferences have to be solved. The Toilet4me project shall deliver facts for informed estimations about the chances of a successful market introduction.

4. Discussion and Conclusions

iToilet has demonstrated that ICT enhanced physical support can assist people in using a toilet without personal help while safety is preserved. Accessible and barrier-free toilets are important for the autonomy of older or disabled users which otherwise would be without choice and dependent on personal assistance in this taboo area. This affects people both in their daily life at home, but also when going out and when participating in social life as they are often guided by the availability of suitable toileting facilities.

While toilet rooms with traditional barrier-free design are a step into the right direction and further improvements towards "changing places" lower the barriers for many users, additional motorized support for optimum seat height for all phases of toilet use and for people of all body sizes can be essential elements for supporting many old or disabled people. ICT enhancements can aid the operation and enhanced safety features can give users the feeling of safety even when no personal assistant is in reach. Digital technologies can add a smart adaptive layer to the assistive base technology which empowers the users to customize the assistive service according to their individual needs wherever they are and to select the level of safety they prefer and at the same time help providers to integrate the technology based support smoothly into modern (health-) care services. Thereby a sound individual balance between wanted autonomy and personal assistance in a location independent way can be achieved.

Well designed, "really" barrier-free smart and adaptive care toilets, enabling personalized assistive settings and the integration with other health services, also might open new market fields from the economically underdeveloped core AAL market towards accessible tourism not only for public places like theaters or museums but also for hotels and recreation or wellness sites. This is currently under investigation in the Toilet4me project, as outlined above.

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