A Novel Accessibility Assessment Framework for the Elderly: Evaluation in a Case Study on Office Design

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ABSTRACT

Elderly and impaired persons constitute an important part of our societies. Existing practices to test accessibility features on forthcoming consumer products and services rely on tests with real impaired users on the industrial prototypes. Our approach comes to automate the evaluation process and introduce it in early phases of the product design. The proposed accessibility assement framework is based on the Virtual User Models (VUMs) concept. VUMs are models containing several parameters used for the emulation of the behavioural characteristics of impaired and elderly populations. In this paper, the simulation framework and a number of VUMs corresponding to real persons are evaluated using two variations of a workplace office design. Results indicated that VUMs are efficient predictors of the corresponding end user's behaviour and thus, their simulated performance can lead into decision making during the product test-and-redesign cycles.

Categories and Subject Descriptors

H.5.2 [**User Interfaces**]: Ergonomics; I.6.4 [**Simulation and Modeling**]: Model Validation and Analysis; K.4.2 [**Social Issues**]: Assistive technologies for persons with disabilities

Keywords

Accessibility Assessment, Virtual User Models, Office Ergonomics, Elderly and Impaired People Simulation.

1. INTRODUCTION

Elderly and people with physical deficiencies are often faced with significant challenges to independently participate in various aspects of daily life. Taking into account the different user capabilities, besides their anthropometrics, is a necessity when developing "design-for-all" workplaces. However, for a long time developers have relied on an existing range of principles, guidelines and standards for accessibility design [2] in order to develop accessible products [11]. Such approaches can be considered simplistic as they do not consider the special needs of specific user groups or people with impairments.

More advanced approaches make use of the "personas", i.e. models of empirically-based abstract descriptions of people. Personas are employed in [1] in order to support the design of products for elderly and disabled people. Another example is the personas based application proposed in [6], which was created for improving the quality of life of the older adults with chronic conditions by monitoring their health and by improving the communication with their caretakers. Specifically, the authors created a TV user interface for the elderly taking into account the persona profiles.

Several accessibility evaluation tools are also used in industry, such as the RAMSIS automotive modelling tool [9], and a tool for workplace accessibility assessment, SAMMIE [8]. The drawback of such tools is that they fail to model properly the special characteristics of populations of elderly and people with disabilities, as they perform using personas of only fully capable virtual humanoids. Also, workplace simulators have used user models for participatory design [7], but not for accessibility. Moreover, theirs methods were based on ready-made human motion data from databases without allowing the VUMs to perform the tasks 'alive' in the simulated environment and thus, not allowing dynamic motion adjustment in differentiated designs.

Our proposed framework is based on the precise modelling of users, with or without disabilities. The implemented simulation engine runs on a fully dynamic environment, allowing the recording of the virtual body's energy consumption, force needs and sereral other comfort factors. Our framework has been created to fill these gaps by enabling automatic accessibility evaluation based on the concept of the Virtual User Models (VUMs). The novelty of the VUMs is that they include motor, vision, hearing and cognitive models of elderly and impaired populations, in comparison to the personas' model which implements single user characteristics. The methodology is part of the VERITAS FP7 project [10] which is a multi-domain approach to the matter, as it supports workplace, living spaces, healthcare, infotainment and automotive applications. In the present manuscript, two workplace design setups are evaluated in terms of accessibility, using real elderly people and a variety of virtual user models. Additionally, the simulation models' accuracy is discussed.

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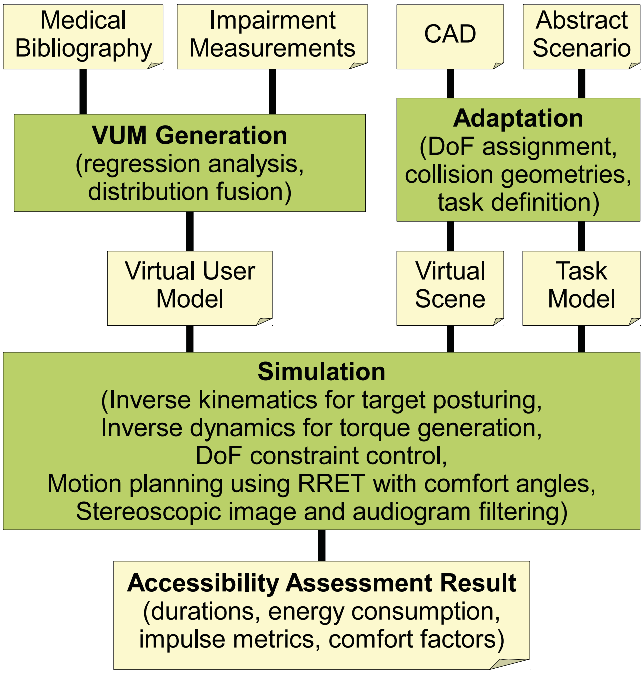

Figure 1: Methodology block diagram.

2. VUM SIMULATION METHODOLOGY

The virtual accessibility assessment methodology includes three basic steps (Figure 1): a) generation of the Virtual User Models, b) design and scenario adaptation into the virtual environment, and c) the simulation testing.

Virtual User Models contain sets of parameters used to describe the behavioural characteristics of population groups. Many people, elderly or people with physical deficiencies, were measured using a customized multisensorial platform. Several parameter distributions have been constructed in order to model as accurate as possible the special characterstics of these populations [3]. Values resulted from the measurements were fused with data gathered from the respective medical bibliography using hybrid regression models [5] in order to generate a repository of Virtual User Models covering a great variety of impairments. Motor, vision, hearing and cognitive impairment parameters are included in each model definition. The designer may use the Virtual User Model generator, part of the VERITAS toolset, in order to customize the severity factor of the impairment or even combine the information of two or more VUMs in order to create multi-domain VUMs, e.g. arthritis with cataract.

Any design to be tested has to be adapted first into the virtual environment. This process includes the conversion of the CAD model to a fully physical, interactable environment. Degrees of freedom, masses, points of interest and scene-rules need to be assigned to the virtual furnitures and equipment. These steps are performed by the designer using our platform's editor and adaptation tools. The tasks that will be performed in the experiments are organized in logical structures called task models. A task model describes which activity sequences which should be carried out by the VUMs in order to reach certain goals. The UsiXML markup language was used to organize tasks and handle the desired level of abstraction. Following this schema, interaction tasks may be grouped under abstract tasks and so on up to a common root. Simple tasks, such as reach and grasp, can be combined into more complex tasks.

Table 1: Specifications of the two office designs.

Design element	**1st Design**	**2nd Design**
Corridor	1 meter wide	1.45 meters wide
Drawer	Over the desk	Under the desk
Telephone	On the desk	Mounted on the wall
Stapler	Sized stapler	Small, light stapler
Printer	Operated from the side	Operated en face

Finally, the simulation takes place. The virtual humanoid is parted by several inter-connected rigid bodies and its performance is adapted to the VUM parameters, affecting several body aspects, such as joint torque generation, degrees of freedom, maximum velocities, etc. Using inverse kinematics and inverse dynamics the virtual humanoid is set into motion. Advanced motion planning, based on Rapidly-exploring Random Trees [4], takes into account the VUM impairment constraints and delivers a natural body movement. Potential limitations of the product prototype accessibility restrictions are detected using the simulation session report, which includes statistics regarding the several human factors from strength, energy and comfort domains.

3. EXPERIMENTAL RESULTS

In order to test the validity and accuracy of the VUM simulation, an experimental test with real people took place first. The group of participants consisted of twenty (N=20) elderly persons who were invited by phone to participate in the pilot study. They were selected as retired individuals with long professional life, able to recall their personal experience on workplaces.The recruitment targeted visual, acoustic and motor impairments by applying inclusion criteria before enrolment.

The office design was developed by intuitive thoughts over known everyday problems related to office spaces. The result was a typical office installation with common features as it would be expected by most employees and professionals. A spacious room was reserved by the pilot site to make an office implementation. The office space was equipped with furniture and equipment, including a desk, chair, stapler, telephone device and printer. For comparison reasons an alternative workplace design was created, with its objects altered both in nature and position. The two designs differences are depicted in Table 1.

To objectively measure the tester's performance, a laptop computer was used during tests to implement measures of gait speed, number of steps, tasks completion times and overall scenario duration. The person responsible for the pilots -at any given time- was using the laptop and a custom made time-recording application to get synchronized with elderly person's performance. The final recording for each tester consisted of timestamps indicating task completion times. The participants were asked to perform five interaction scenarios, presented in Table 2. A young mid-aged person had the role of the “Optimal User”, whose scores were compared the elderly’s in order to make a meaning and finally, to conclude on which design features should be changed and which should remain unchanged. All mentioned times are depicted in seconds.

Table 2: Scenario definitions.

Scenario	Tasks
Gait	Walking through corridor for about 10m
Drawer	Reach drawer handle Pull drawer out 10cm
Telephone	Reach telephone Pick up the earpiece
Stapler	Reach the stapler Use it on A4 papers
Printer	Reach printer’s handle Pull it out

Table 3 presents the real-users task durations of the two designs. As it is depicted, the alternative design had an positive impact on the durations. It is obvious that, from all scenarios, the “Use of Printer” was benefited the most by reducing the duration distance to the optimal user by 54.69%. Similarly, the rest scenario scores reduced their differences to the optimal, giving an average of 31.91% in total. The only exception was the “Drawer Use”, in which the completion time was 3.518 sec the second time, instead of 3.475 sec recorded by the first design. This looks like an oxymoron, but results like that are not uncommon: a different design may affect human behavior in multiple ways and in our pilots, the Optimal User needed more time to reach the handle of the drawer. This could be explained as that alternative designs benefit in different ways different kinds of users. Finally, the first drawer position, which is on the table, is more preferable, because of the better absolute time scores.

Transferring of the real-world office setup into the virtual space required the adaptations of both the original and altered designs (Figures 2 & 3). The real-user scenarios were transcribed into task models and were binded with the virtual scene using the simulation editor tool. Seven different Virtual User Models were created for the evaluation of the two office designs: a fully capable user (referred as the ‘optimal user’); two elderly persons with mild and severe strength limitations; two persons with stroke having mild and severe motor deficiencies; and two Parkinsonians (mild and severe case). The natures of these VUM models were selected having in mind the capabilities of the real subjects.

Table 3: Result of the real user tests in seconds.

Scenario	1st Design		2nd Design	
	Optimal	Elderly	Optimal	Elderly
Gait	11.076	15.731 std=3.732	10.965	14.199 std=2.750
Drawer	2.262	3.475 std=1.063	2.948	3.518 std=0.827
Phone	1.529	2.364 std=0.694	1.716	2.197 std=0.399
Stapler	3.744	4.825 std=1.001	3.619	4.182 std=1.121
Printer	2.512	4.228 std=3.031	2.496	2.889 std=0.899

Figure 2: Drawer scenario in real and virtual space.

In Table 4, the results of the VUM-based workplace design evaluation are presented. It is confirmed that a wider corridor can offer faster office entering to all VUM categories. This result is in line with the results of the tests with real beneficiaries, so there is no doubt that a wider corridor should be included in the final accessible design to enhance accessibility and comfort. In the real user case, the drawer scenario resulted into lower task duration having the drawer placed on the table (1st design). The same was confirmed by VUMs as they gave higher time values. On the other hand, the virtual users with stroke failed to complete the task using the first design, due to the restricted motion kinematics. Thus, in order to make an accessible design for such users, the decision should follow the second design. Elderly with severe kinematics reduction and Parkinsonians needed more time to reach a telephone mounted on the wall (2nd design). For all others, the position of the phone device does not affect their scores. Based on the scores of real people, it is assumed that users prefer the telephone device on the table, so again VUMs confirm the real results. The same is true for the use of a lighter stapler too. In the final scenario regarding the printer, all VUMs, including the optimal VUM, gravitate towards the use of the printer from the side (second design).

The verdict was that the proposed VUM methodology and tools worked in most of the office scenarios as expected: The deviations between the various performed scenarios were found to be 44.58% in average (extracted from the whole scores’ population), in which the worst cases can be ex-

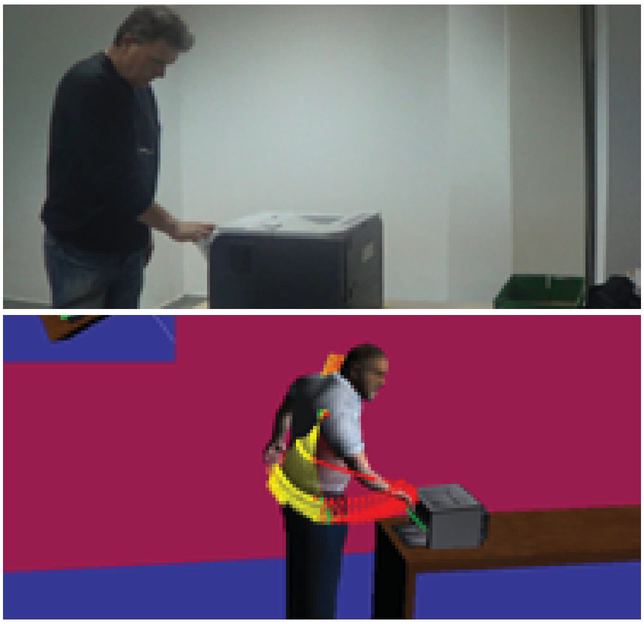

Figure 3: Printer scenario in real and virtual space.

Table 4: Results of the virtual user simulation tests; both design iterations are depitcted. The values represent the respective task durations (in seconds).

Scenario	VUM	1st Design		2nd Design	
		mild	severe	mild	severe
Gait	Optimal	13.10		10.86	
	Elderly	14.27	20.35	11.83	16.87
	Stroke	32.17	55.96	26.67	46.40
	Parkinson	18.40	21.93	15.25	18.18
Drawer	Optimal	2.72		3.02	
	Elderly	2.90	3.08	3.20	3.10
	Stroke	Failed	Failed	3.24	3.28
	Parkinson	3.16	3.22	3.27	3.43
Phone	Optimal	0.31		0.32	
	Elderly	0.32	0.35	0.32	0.75
	Stroke	0.32	0.33	0.32	0.33
	Parkinson	0.32	0.32	0.75	0.91
Stapler	Optimal	1.24		1.24	
	Elderly	1.33	1.5	1.29	1.46
	Stroke	1.42	1.59	1.34	1.57
	Parkinson	1.44	1.55	1.30	1.60
Printer	Optimal	1.67		1.29	
	Elderly	1.77	1.83	1.36	1.38
	Stroke	1.95	Failed	1.40	1.59
	Parkinson	1.94	2.01	1.51	1.6

plained easily, because of the inclusion of VUMs with high diversity characteristics, such as the severe Parkinson's case.

4. CONCLUSION

The simulation framework and the VUMs were tested in a real world study to meet success in design features evaluation. Both evaluation lines (VUMs and real persons) gave similar indications to workplace designers regarding accessibility features in most of the design alterations. Decision making based on simulation findings can be more detailed when particular VUM groups are taken into consideration, like in the case of Strokes who failed to complete certain tasks on the first workplace design. There are experimental factors such as the time-stamping accuracy in real person recordings, performance factors of real humans, clarity on starting and ending positions, the effect of previous knowledge, that could not be inserted into the user modelling schema due to their abstracted nature. Nonetheless, the vision of the proposed platform is to be commercially exploited by mainstream manufacturers in terms of the "design for all" philosophy in industrial production. There are many application areas in which our approach could be applied including, but not limited to, smart homes design, automotive, healthcare, and infotainment.

5. ACKNOWLEDGMENTS

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