Holistic accessibility evaluation using VR simulation of users with special needs

Panagiotis Moschonas, Athanasios Tsakiris, Nikolaos Kaklanis, Georgios Stavropoulos, and Dimitrios Tzovaras

Informatics and Telematics Institute, Centre for Research and Technology, Hellas
{moschona, atsakir, nkak, stavrop, Dimitrios.Tzovaras}@iti.gr

Abstract. In this paper, we present a novel methodology to evaluate the accessibility of products using virtual prototypes. The novelty is that the product evaluation is based on simulating the interactions of users with physical deficiencies in virtual and immersive environments. Virtual users with special needs, e.g. elderly or impaired people, were modelled using both literature data and real subjects' measurements. User modelling includes data from human motor, vision, hearing and cognition domains.

1 Introduction

It is a fact that the number of people with special needs and physical deficiences is increasing, while global population is growing older [1]. This results into requirements of better accessibility and ergonomic features in every day or specific-purpose products. Thus, assessment tools are needed by the designers for delivering accessible-for-all products to the community.

The present paper introduces a holistic way of performing automatic accessibility evaluation to a wide range of products. The great importance of our system lies in the fact that it simulates virtual and immersive environments where pre-modelled users interact with the designed product. The virtual users (avatars) are modelled after fully-capable real subjects or subjects with special needs, such as elderly and impaired people, who have specific motor, vision, hearing and cognitive characteristics. The proposed approach can be considered as holistic because it includes three phases: user modelling, simulation of the environment and accessibility evaluation. Evaluation tests from automotive, workplace and home products have shown that the proposed framework can be a valuable tool to the designer, as a way of increasing the product's accessibility.

2 Modelling users with special needs

In order to properly model a virtual user, several parameters were both measured from real subjects (Table 1) and gathered from the respective medical bibliography. Parameters from several domains were measured. More specifically, motor and anthropometric parameters included ranges of motion, reach envelops, strength and gait characteristics (e.g. stride length), users' height , weight and limb sizes. Vision parameters included visual acuity, contrast, glare and spectral sensitivity, and blind spot characteristics. Hearing was modelled using the users' audiograms. Cognition models were based on Fitt's law. The measured data was fused with data from medical literature using hybrid regression models [2].

From the resulted data distributions, specific user profiles were created. Each data profile, which is stored in an UsiXML file (Fig.1), contains the representative characteristics of an impaired or elderly population. We will refer to the data profiles as Virtual User Models (VUMs). A database of VUMs has been created in order to model a variety of impairments, deficiencies and elderly characteristics. Examples of VUM include elderly users, users with Parkinson's, multiple sclerosis, cerebral palsy, arthritis, stroke, color deficiencies, glaucoma, macular degeneration, otitis, otosclerosis, presbycusis, and more.

Subject category	n
Elderly	59
Parkinson's disease	17
Stroke	36
Multiple sclerosis	20
Cerebral palsy	17
Amputated	3
Coxarthritis	7
Gonarthrossis	5
Vision impaired	25
Hearing impaired	20

Table 1. The number of subjects measured.


```xml
<anthropometric>
    <weight measureUnits="kgr" value="81.023056"/>
    <stature measureUnits="cm" value="174.586060"/>
    <headLength measureUnits="cm" value="19.533623"/>
    <headBreadth measureUnits="cm" value="16.409887"/>
    <sittingHeight measureUnits="cm" value="92.134407"/>
    <bideltoidBreadth measureUnits="cm" value="48.190166"/>
    <waistCircumference measureUnits="cm" value="98.818848"/>
    <upperLimbAnthropometric leftRight="left">
        <shoulderElbowLength measureUnits="cm" value="33.710236"/>
        <forearmHandLength measureUnits="cm" value="47.450768"/>
        <bicepsCircumferenceRelaxed measureUnits="cm" value="25.926586"/>
        <forearmCircumferenceFlexed measureUnits="cm" value="28.615967"/>
    </upperLimbAnthropometric>
    <upperLimbAnthropometric leftRight="right">
        <shoulderElbowLength measureUnits="cm" value="33.710236"/>
        <forearmHandLength measureUnits="cm" value="47.450768"/>
        <bicepsCircumferenceRelaxed measureUnits="cm" value="25.926586"/>
        <forearmCircumferenceFlexed measureUnits="cm" value="28.615967"/>
    </upperLimbAnthropometric>
```


Fig. 1. Part of a UsiXML file; a small portion of the anthropometrics section is depicted.

3 Simulating users and accessibility evaluation in virtual environments

The simulated virtual environment contains two main entities: the avatar and the prototype to be tested. The avatar's body is modelled using an hierarchical multi-rigid body structure. Anthropometric VUM data are used to adjust the sizes and weights of the avatar limbs, while motor data define their kinematic and dynamic characteristics. Inverse kinematics and inverse dynamics are used in order to set the avatar to motion [3]. Vision simulation is implemented using two virtual cameras placed on the avatar's eyes where the captured image is filtered using the VUM vision parameters (Fig.2). Hearing simulation is performed by filtering the captured audio using the VUM hearing parameters.

Fig. 2. Vision simulation: normal vision (left), cataract (middle) and glaucoma (right).

The proposed platform supports two ways of performing the simulation: purely virtual and immersive. In the first case, a scenario file, which contains a series of tasks' specifications, is used in order to lead the avatar's actions through the simulation session. Motion, gait and grasp planning algoritms are used [3] to lead the avatar, while cognition factors are used to apply delays to its actions. In the immersive case, a real user is immersed into the virtual environment. The user's movements are tracked and translated into avatar motions. Then, the platform applies the limitations included in the VMU, such as range of motion restrictions and appropriate filters to captured vision and audio. Support for assistive devices (haptics) and alternative multimodal interfaces (speech synthesis, recognition) is also provided, in order to perceptually help the designers evaluate the accessibility of products which target vision impaired populations.

Accessibility evaluation of the product design is based on physical, anthropometric and comfort human factors [4]. Distributions of torques, impulses, energies and comfort factors are presented to the designer after each session and are used to compare two product designs and decide which provides better accessibility and ergonomics. Examples include, but not restricted to, automotive, workplace and smart living spaces products (Fig.3).

Fig. 3. Examples: automotive in 1^{st} and 2^{nd} column; smart living spaces in 3^{rd} column; workplace navigation in top right sub-image; immersive mode in lower right sub-image.

4 Future plans and conclusion

The present paper introduced a holistic framework for modelling and simulating users with special needs, in order to facilitate product accessibility evaluation in virtual enviroments. Applications on various domains reveal its great importance. Future plans include the implementation of a wheelchair motion planner and better cognition modelling.

Acknowledgment: this work is supported by EU (project VERITAS FP7-247765).

References

1. WHO, World Heath Organisation: The world is fast ageing - have we noticed? http://www.who.int/ageing/en/, 2007.
2. Yao-San Lin, Small sample regression: Modeling with insufficient data, International Conference on Computers and Industrial Engineering, 2010.
3. Siciliano, B., & Khatib, O., Handbook of Robotics. Springer-Verlag New York, Inc., Secaucus, NJ, 2007.
4. Moschonas, P., Kaklanis, N., & Tzovaras, D., Novel human factors for ergonomy evaluation in virtual environments using virtual user models, VRCAI '11.

Holistic accessibility evaluation using VR simulation of users with special needs

Panagiotis Moschonas, Athanasios Tsakiris, Nikolaos Kaklanis,
Georgios Stavropoulos, and Dimitrios Tzovaras
{moschona, atsakir, nkak, stavrop, tzovaras}@iti.gr

Abstract

- A novel methodology to evaluate the accessibility of products using virtual prototypes.
- Product evaluation based on simulating the interactions of users with physical disabilities in virtual and immersive environments.
- Virtual users, e.g. elderly or impaired have been modelled using both literature data and real subjects' measurements.
- User modelling data cover motor, vision, hearing and cognition

1. Introduction

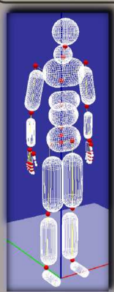
- We introduce a holistic way of performing automatic accessibility evaluation to various products by simulating user-product interaction in virtual environments.
- Virtual users are modelled after fully-capable, impaired, as well as elderly subjects.
- The proposed holistic approach includes three phases: user modelling, simulation of the user and environment, as well as accessibility evaluation.
- Evaluation tests with automotive, workplace and smart living spaces products have shown that the proposed framework can be a valuable tool, increasing product accessibility and usability.

User Modelling — VR Simulation — Accessibility Evaluation

2. Modelling users with special needs

- Motor and anthropometric parameters: ranges of motion, reach envelops,strength and gait characteristics (e.g. stride length), user height , weight and limb sizes.
- Vision parameters included visual acuity, contrast, glare and spectral sensitivity, and blind spot characteristics. Hearing was modelled using the users' audiograms.
- Cognition models were based on Fitt's law.
- Measured data was fused with medical literature data using hybrid regression models.


- Each data profile, stored in an UsiXML file as Virtual User Model, contains representative characteristics of an impaired or elderly population.
- A database of VUMs has been created in order to model a variety of impairments and elderly users' characteristics.
- Tools for creating a mixed VUM, e.g. an elderly person with vision impairments, have also been implemented.
- VUM models include elderly users, users with Parkinson's, MS, cerebral palsy, arthritis, stroke, color blindness, glaucoma, macular degeneration, otitis, otosclerosis etc.



Hierarchical multi-rigid body structure

Subject category	n
Elderly	59
Parkinson's disease	17
Stroke	36
Multiple sclerosis	20
Cerebral palsy	17
Amputated	3
Coxarthritis	7
Gonarthrossis	5
Vision impaired	25
Hearing impaired	20

Several real subjects were measured for varius parameters


```
<anthropometric>
    <weight measureUnits='kgr' value='81.023056'/>
    <stature measureUnits='cm' value='174.586060'/>
    <headLength measureUnits='cm' value='19.533623'/>
    <headBreadth measureUnits='cm' value='16.409887'/>
    <sittingHeight measureUnits='cm' value='92.134407'/>
    <bideltoidBreadth measureUnits='cm' value='48.190166'/>
    <waistCircumference measureUnits='cm' value='98.818848'/>
    <upperLimbAnthropometric leftRight='left'>
        <shoulderElbowLength measureUnits='cm' value='33.710236'/>
        <forearmHandLength measureUnits='cm' value='47.450768'/>
        <bicepsCircumferenceRelaxed measureUnits='cm' value='25.926586'/>
        <forearmCircumferenceFlexed measureUnits='cm' value='28.615967'/>
    </upperLimbAnthropometric>
    <upperLimbAnthropometric leftRight='right'>
        <shoulderElbowLength measureUnits='cm' value='33.710236'/>
        <forearmHandLength measureUnits='cm' value='47.450768'/>
        <bicepsCircumferenceRelaxed measureUnits='cm' value='25.926586'/>
        <forearmCircumferenceFlexed measureUnits='cm' value='28.615967'/>
    </upperLimbAnthropometric>
    <lowerLimbAnthropometric leftRight='left'>
        <ankleHeight measureUnits='cm' value='7.696402'/>
        <hipBreadth measureUnits='cm' value='36.022629'/>
        <kneeHeightSitting measureUnits='cm' value='53.685188'/>
```


UsiXML Virtual User Model (VUM)

3. Simulating users and accessibility evaluation in virtual environments

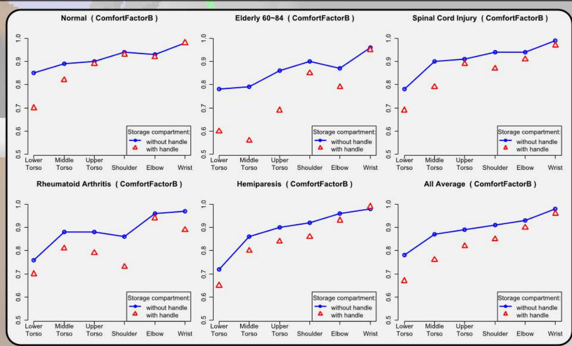
- The avatar is modelled using an hierarchical multi-rigid body using motor parameters to define kinematic and dynamic characteristics as well as anthropometric data
- State of the art inverse kinematics and inverse dynamics algorithms are used in order to set the avatar to motion.


- Vision simulation is implemented using two virtual cameras placed on the avatar's eyes where the captured image is filtered using the VUM vision parameters.

- Hearing simulation is performed by filtering captured audio using the VUM hearing parameters.
- Two modes of simulation: virtual and immersive. In the former, a scenario file, which contains a series of task specifications, is used activate the avatar through the simulation session using gait and grasp planning algoritms, while cognition factors apply delays to the actions.


- In immersive mode, a real user is tracked and the user motions are translated into avatar motions applying the limitations included in the VUM.


- Support for assistive devices (haptics) and alternative multimodal interfaces (speech synthesis, recognition) is also provided.
- Accessibility evaluation is based on human comfort, physical and anthropometric factors, which are used to compare product designs.



Acknowledgment: this work is supported by the EU funded project VERITAS (FP7-247765)