GUIDE
Gentle User Interfaces for Elderly People

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Final User Model

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Abstract:

This document presents the GUIDE user model and its implementation through the virtual user simulator and the run time user model in GUIDE core. The report also highlights GUIDE project's contribution to standardization activities.

Executive Summary

Elderly and disabled people can be hugely benefited through the advancement of modern electronic devices as those can help them to engage more fully with the world. However, existing design practices often isolate elderly or disabled users by considering them as users with special needs. This report presents the GUIDE user model, which helps to make user interfaces more accessible and usable to elderly population. The report presents a brief literature survey on the state of the art of user models mainly developed for users with physical or age-related impairment and in that context describes the GUIDE simulator and run time user model. The simulator can reflect problems faced by elderly and disabled users while they use computer, television and similar electronic devices and the run time user model helps to adapt interface during interaction. The report describes the application and validation of the GUIDE user model and briefly highlights its contribution toward standardization through VUMS. This report is a continuation of work earlier presented in D5.2 and D3.2.

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1 Introduction

Older adults are the fastest growing demographic group while currently around 10 per cent of the total world's population, or roughly 650 million people, live with a disability. Modern research in intelligent interactive systems can offer valuable assistance to elderly and disabled population by helping them to engage more fully with the world. Many existing user interfaces often work for 'average' user and does not cater the need of the growing population of elderly users. For example, we may consider a modern smartphone and may find that it is difficult for an elderly person accustomed with traditional telephones, to make a call using the smartphone. Similar case studies are quite prevalent with interfaces of modern digital televisions, computers and other electronic control systems. As an example of digital exclusion, statistics shows about 70 % users between 65 and 74 had never used internet and 39 % can not use mobile phones in European countries [Los mayors, 2012].

However these issues often need slight tweaking of the design like changing colour contrast, increasing font size, changing layouts of buttons and can make them far more usable as well as increase the market coverage of the products. Additionally, systems and services developed for elderly or disabled people often find useful applications for their able bodied counterparts – a few examples are mobile amplification control, which was originally developed for people with hearing problems but helpful in noisy environments, audio cassette versions of books originally developed for blind people, standard of subtitling in television for deaf users and so on. Lack of knowledge about the problems of disabled and elderly users has often led designers to develop non-inclusive systems. The GUIDE user modelling system helps designers in developing accessible systems and personalizes interfaces for end users. The user modelling system has two main parts:

- A Simulator
- A Runtime User Model

The simulator embodies both the internal state of a computer application and also the perceptual, cognitive and motor processes of its user and helps designers to understand, visualize and measure effect of age and impairment on design using graphical user interfaces. The runtime user model customizes interface parameters across a wide range of devices based on the range of ability of user, collected through an easy to use User Initialization Application(UIA).

1.1 Purpose

This is the final report on user model, so discusses application of the user model within GUIDE project in detail. The application includes design improvements of interfaces for all GUIDE applications and run time adaptation through GUIDE core. The report also highlights contribution of GUIDE user model towards standardization.

1.2 Work plan task and partner contribution

Table 1 shows contributions by the different GUIDE partners according to the responsibilities in each task covered in this deliverable.

Table 1. Work plan

Task	Partners	Effort	Time span
T3.8 **T7.2**	CAM	• Implemented User Models in virtual user simulator • Developed run time user model using simulator	PM18 – PM30
T3.6	CCG	• Optimized design of Virtual character	PM13 – PM18
T4.1 **T4.3**	FFCUL	• Optimized interface layout of User Initialization Application	PM13 – PM18
T6.1 **T6.2**	IGD	• Optimized interface layout of Home Automation Application • Optimized interface layout of Video Conferencing Application	PM13 – PM30
T6.3	TC	• Optimized interface layout of Media Access Application	PM18 – PM30
T6.4	VSX	• Optimized interface layout of Tele-Learning Application	PM18 – PM30

1.3 Related documents

This document is a continuation of the work reported in D5.2 and D3.2. The document also relates to the results reported in D7.4. The user model is also briefly described in D4.2 in the context of multimodal adaptation through the GUIDE core.

1.4 Document organization

This report is organized as follows. The next section presents a brief literature survey on user model followed by a section pointing the objectives of the GUIDE user model. Sections 4, 5 and 6 present simulation, adaptation and standardization issues of the GUIDE user model respectively with conclusion drawn at section 7.

2 Related Work

Research on simulating user behaviour to predict machine performance was originally started during the Second World War. Researchers tried to simulate operators' performance to explore their limitations while operating different military hardware. There was a plethora of systems developed during the last three decades that are claimed to be user models. Many of them modelled users for certain applications – most notably for online recommendation and e-learning systems. These models in general have two parts: a user profile and an inference machine. The user profile section stores details about user relevant for a particular application and the inference machine uses this information to personalize the system. A plethora of examples of such models can be found at the User Modelling and User-Adapted Interaction journal and proceedings of User Modelling, Adaptation and Personalization conference [UMAP, 2012]. However most of these models are closely tied to an application limiting their scalability to different projects. On a different dimension, ergonomics and computer animation follow a different view of user model [Duffy, 2008]. Instead of modelling human behaviour in detail, they aim to simulate human anatomy or face which can be used to predict posture, facial expression and so on. Finally, there is a bunch of models which merges psychology and artificial intelligence to model human behaviour in detail. In theory they are capable of modelling any behaviour of users while interacting with environment or a system. This type of models is termed as cognitive architecture (e.g. SOAR [Newell 1990], ACT-R/PM [Anderson and Lebiere, 1998], EPIC [Kieras and Meyer, 1990] and so on) and has also been used to simulate human machine interaction to both explain and predict interaction behaviour. A simplified view of these cognitive architectures is known as the GOMS model [John and Kieras, 1996] and still now is most widely used in human computer interaction. However, the GOMS (Goal, Operator, Model, Selection) family of HCI models (e.g. KLM, CMN-GOMS, CPM-GOMS) is mainly suitable for modelling the optimal (skilled) behaviour of users, while models developed using cognitive architectures consider the uncertainty of human behaviour in detail but have not been widely adopted for simulating HCI as their use demands a detailed knowledge of psychology.

There is not much reported work on systematic modelling of assistive interfaces. McMillan [1992] felt the need to use HCI models to unify different research streams in assistive technology, but his work aimed to model the system rather than the user.

The AVANTI project [Stephanidis and colleagues, 1998; 2003] modelled an assistive interface for a web browser based on static and dynamic characteristics of users. The interface is initialised according to static characteristics (such as age, expertise, type of disability and so on) of the user. During interaction, the interface records users' interaction and adapts itself based on dynamic characteristics (such as idle time, error rate and so on) of the user. This model works based on a rule based system and doesnot address the basic perceptual, cognitive and motor behaviour of users and so it is hard to generalize to other applications.

The EASE tool [Mankoff 2005] simulates effects of interaction for a few visual and mobility impairments. However the model is demonstrated for a sample application of using a word prediction software but not yet validated for basic pointing or visual search tasks performed by people with disabilities.

Keates and colleagues [2000] measured the difference between able-bodied and motor impaired users with respect to the Model Human Processor (MHP) [Card, Moran and Newell, 1983] and motor impaired users were found to have a greater motor action time than their able-bodied counterparts. The finding is obviously important, but the KLM model itself is too primitive to model complex interaction and especially the performance of novice users.

Serna and colleagues [2007] used ACT-R cognitive architecture [Anderson and Lebiere, 1998] to model progress of Dementia in Alzheimer's patient. They simulated the loss of memory and increase in error for a representative task at kitchen by changing different ACT-R parameters [Anderson and Lebiere, 1998]. The technique is interesting but their model still needs rigorous validation through other tasks and user communities.

Our previous user model [Biswas and colleagues, 2005] also took a more generalized approach than the AVANTI project. It broke down the task of user modelling into several steps that included clustering users based on their physical and cognitive ability, customizing interfaces based on user characteristics and logging user interactions to update the model itself. However the objective of this model was to design adaptable interfaces and not to simulate users' performance.

Gajos, Wobbrock and Weld [2007] developed a model to predict pointing time of users with mobility impairment and adapt interfaces based on the prediction. They estimated the movement time by selecting a set of features from a pool of seven functions of movement amplitude and target width, and then using the selected features in a linear regression model. This model shows interesting characteristics of movement patterns among different users but fails to develop a single model for all. Movement patterns of different users are found to be inclined to different functions of distance and width of targets.

The CogTool system [2012] combines GOMS models and ACT-R system for providing quantitative prediction on interaction. The system simulates expert performance through GOMS modelling, while the ACT-R system helps to simulate exploratory behaviour of novice users. The system also provides GUIs to quickly prototype interfaces and to evaluate different design alternatives based on quantitative prediction. However it does not yet seem to be used for users with disability or assistive interaction techniques.

This GUIDE user modelling system aims to strike a balance between the usability of GOMS models and details of Cognitive Architecture considering the needs of users with disability and age related impairment. The models are implemented through a simulator described in the following section.

3 Objectives

The main objectives of the GUIDE user model is

- **Simulation:** simulating interaction patterns of users with and without impairment.
- **Adaptation:** adapting response of the GUIDE system during interaction.
- **Standardization:** contributing to develop an international standard of user modelling for both able bodied and disables users.

The following sections describe each of these objectives in detail.

4 Simulation

4.1 The simulator

The GUIDE user model has been implemented through the virtual user simulator [Biswas et al, 2012a], it has the following three main component (figure 1).

The Environment model contains a representation of an application and context of use. It consists of:

- **The Application model** containing a representation of interface layout and application states.
- **The Task model** representing the current task undertaken by a user that will be simulated by breaking it up into a set of simple atomic tasks following the KLM model.
- **The Context model** representing the context of use like background noise, illumination and so on.

The Device model decides the type of input and output devices to be used by a particular user and sets parameters for an interface.

The User model simulates the interaction patterns of users for undertaking a task analysed by the task model under the configuration set by the interface model. It uses the sequence of phases defined by Model Human Processor.

- The perception model simulates the visual perception of interface objects and auditory perception of speech output. It is based on the theories of visual attention and auditory perception.
- The cognitive model determines an action to accomplish the current task. It is more detailed than the GOMS model but not as complex as other cognitive architectures.
- The motor behaviour model predicts the completion time and possible interaction patterns for performing that action. It is based on statistical analysis of screen navigation paths of disabled users.

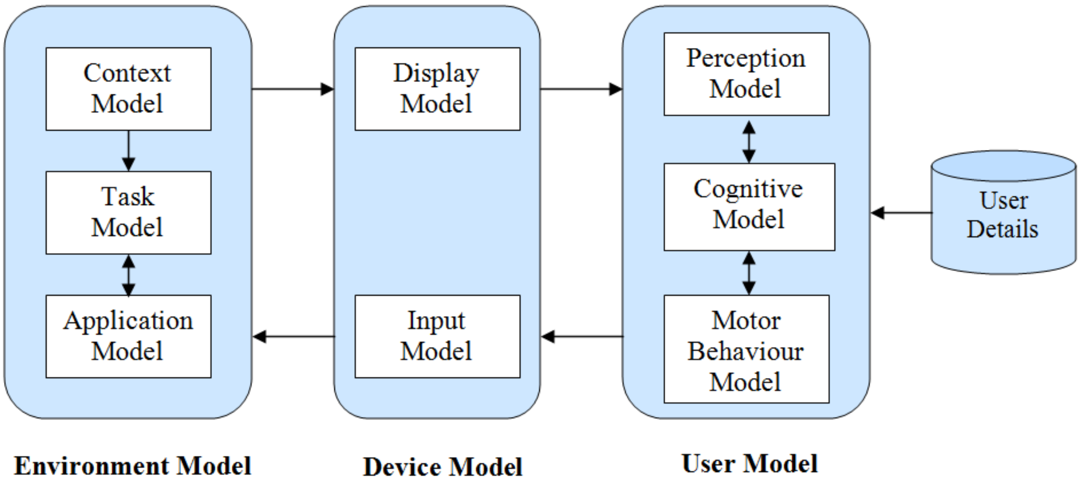


Figure 1. Architecture of the Simulator

The details about users are store in xml format in the user profile following the VUMS exchange format. The ontology stores demographic detail of users like age and sex and divide the functional abilities in perception, cognition and motor action. The perception, cognitive and motor behaviour models takes input from the respective functional abilities of users.

The visual perception model [Biswas and Robinson, 2009] simulates the phenomenon of visual perception (like focusing and shifting attention). We have investigated eye gaze patterns (using a Tobii X120 eye tracker) of people with and without visual impairment. The model uses a back-propagation neural network to predict eye gaze fixation points and can also simulate the effects of different visual impairments (like Macular Degeneration, colour blindness, Diabetic Retinopathy and so on) using image processing algorithms. Figure 2 shows the actual and predicted eye movement paths (green line for actual, black line for predicted) and points of eye gaze fixations (overlapping green circles) during a visual search task. The figure shows the prediction for a protanope (a type of colour blindness) participant and so the right hand figure is different from the left hand one as the effect of protanopia was simulated on the input image.

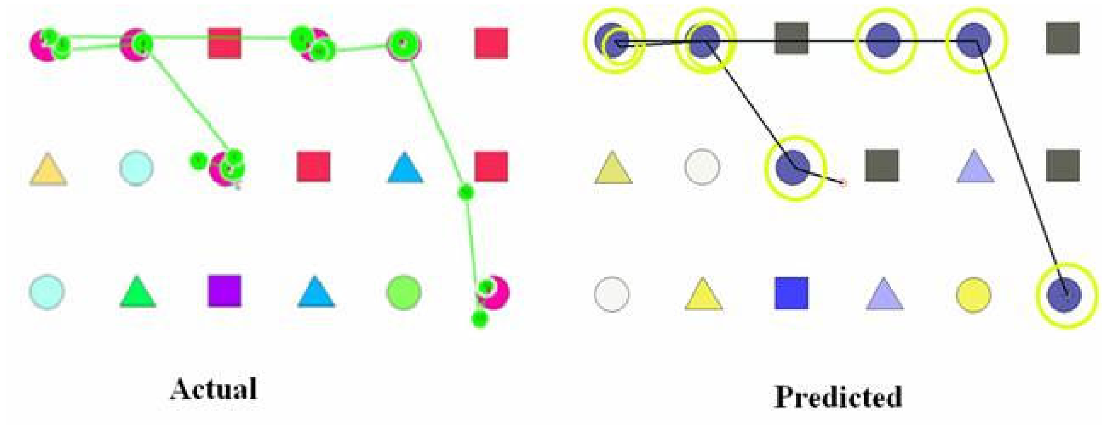


Figure 2. Eye movement trajectory for a user with colour blindness

The auditory perception model can simulate effect of both conductive (outer ear problem) and sensorineural (inner ear problem) hearing impairment. The model is developed using frequency attenuation and smearing algorithm [Nejime and Moore, 1997] and is calibrated through audiogram tests.

The cognitive model [Biswas and Robinson, 2008] breaks up a high level task specification into a set of atomic tasks to be performed on the application in question. The operation of it is illustrated in figure 3. At any stage, users have a fixed policy based on the current task in hand. The policy produces an action, which in turn is converted into a device operation (e.g. clicking on a button, selecting a menu item and so on). After application of the operation, the device moves to a new state. Users have to map this state to one of the state in the user space. Then they again decide a new action until the goal state is achieved.

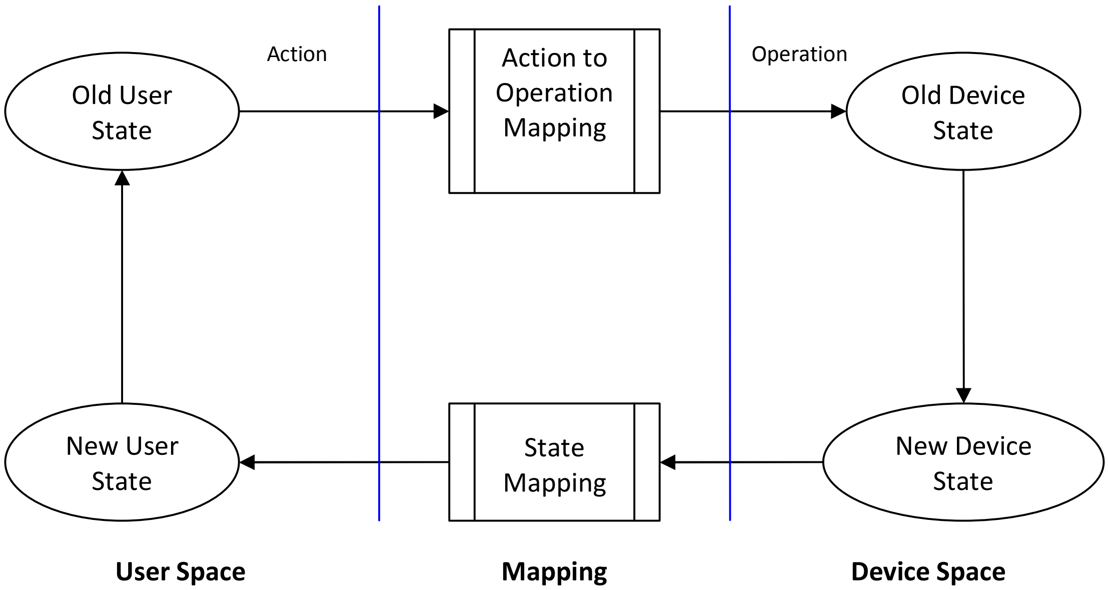


Figure 3. Sequence of events in an interaction

Besides performance simulation, the model also has the ability to learn new techniques for interactions. Learning can occur either offline or online. The offline learning takes place when the user of the model (such as an interface designer) adds new states or operations to the user space. The model can also learn new states and operations itself. During execution, whenever the model cannot map the intended action of the user into an operation permissible by the device, it tries to learn a new operation. To do so, it first asks for instructions from outside. The interface designer is provided with the information about previous, current and future states and he can choose an operation on behalf of the model. If the model does not get any external instructions then it searches the state transition matrix of the device space and selects an operation according to the label matching principle [Rieman and Young, 1996]. If the label matching principle cannot return a prospective operation, it randomly selects an operation that can change the device state in a favourable way. It then adds this new operation to the user space and updates the state transition matrix of the user space accordingly. In the same way, the model can also learn a new device state. Whenever it arrives in a device state unknown to the user space, it adds this new state to the user space. It then selects or learns an operation that can bring the device into a state desirable to the user. If it cannot reach a desirable state, it simply selects or learns an operation that can bring the device into a state known to the user.

The model can also simulate the practice effect of users. Initially the mapping between the user space and the device space remains uncertain. It means that the probabilities for each pair of state/action in the user space and state/operation in the device space are less than 1. After each successful completion of a task the model increases the probabilities of those mappings that lead to the successful completion of the task and after sufficient practice the probability values of certain mappings reach one. At this stage the user can map his space unambiguously to the device space and thus behave optimally.

The motor behaviour model [Biswas and Robinson, 2009; Biswas et al, 2012ab] is developed by statistical analysis of cursor traces from motor impaired users. We have evaluated hand strength (using a Baseline 7-pc Hand Evaluation Kit) of able-bodied and motor impaired people and investigated how hand strength affects human computer interaction. Based on the analysis, we have developed a regression model to predict pointing time. Figure 4 shows an example of the output from the model. The thin purple line shows a sample trajectory of mouse movement of a motor impaired user. It can be seen that the trajectory contains random movements near the source and the target. The thick red and black lines encircle the contour of these random movements. The area under the contour has a high probability of missed clicks as the movement is random there and thus lacks control.

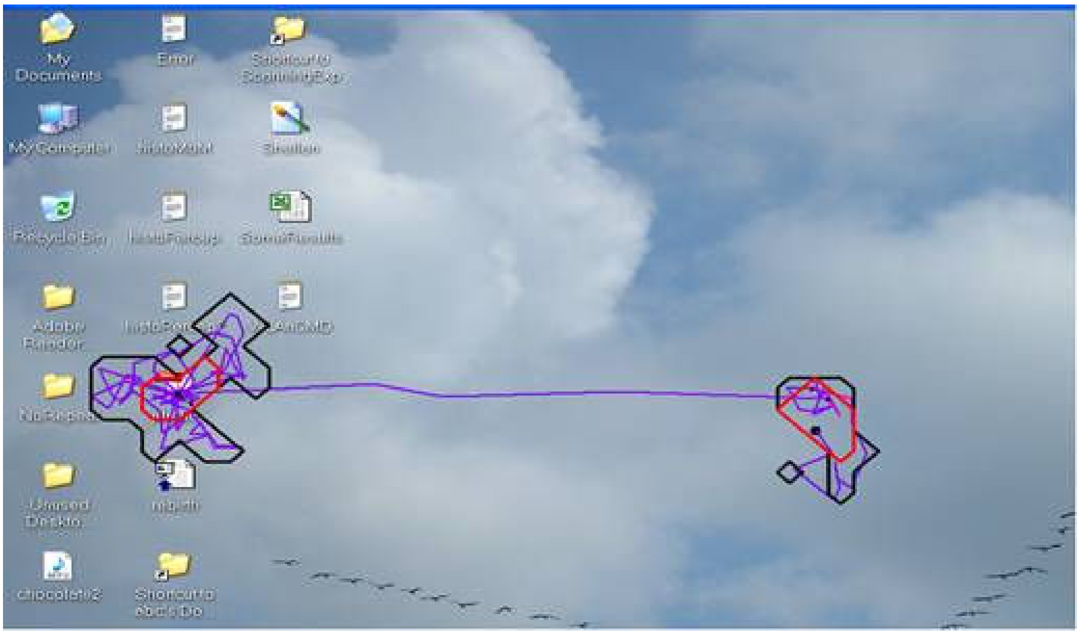


Figure 4. Mouse movement trajectory for a user with cerebral palsy

4.2 Validation of the simulator

Each of the perception, cognitive and motor behaviour models were calibrated and validated separately involving people with and without visual and mobility impairment.

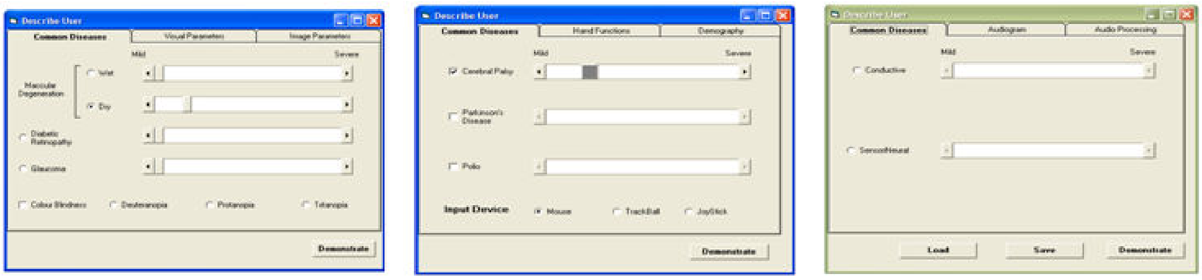
The visual perception model was validated through an eye gaze tracking study for a visual search task. We compared the correlation between actual and predicted visual search time, eye gaze and also investigated the error in prediction. The actual and predicted visual search time correlated statistically significantly with less than 40% error rate for more than half of the trials [Biswas and Robinson, 2009a].

For the auditory perception model, we recorded a set of equally intelligible sentences [MacLeod and Summerfield, 1990] by a native English speaker and played them back to hearing impaired users. Then we simulated the sentences and played them to non hearing impaired users and compared the responses of hearing impaired users with that of non impaired users listening simulated sound. The result shows the present implementation can accurately simulate hearing perception for spoken voice.

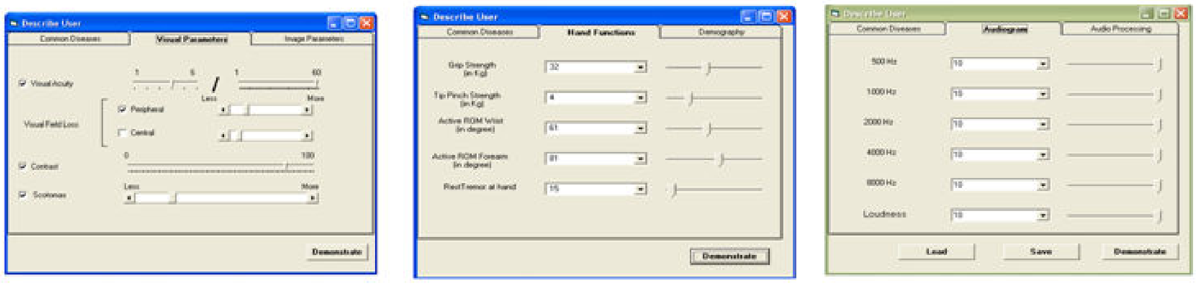
The cognitive model was used to simulate interaction for first time users and it can simulate the effect of learning as well [Biswas and Robinson, 2008].

The motor behaviour model was validated through ISO 9241 pointing task. The actual and predicted movement time correlated statistically significantly with less than 40% error rate for more than half of the trials [Biswas and Robinson, 2009b; Biswas et al, 2012b].

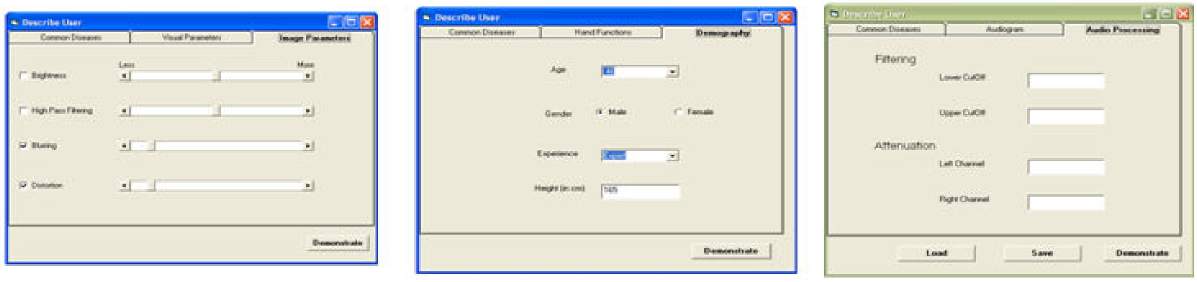
These models do not need detailed knowledge of psychology or programming to operate. They have graphical user interfaces to provide input parameters and showing output of simulation. Figure 5 shows a few interfaces of the simulator.



a. Interfaces to simulate the effects of different diseases



b. Interfaces to simulate the effects of different visual functions and hand strength metrics



c. Interfaces to run image processing algorithms and set demographic detail of users

Figure 5. A few interfaces of a prototype of the toolbox

At present it supports a few types of visual and mobility impairments. For both visual and mobility impairment, we have developed the user interfaces in three different levels:

- In the first level (figure 5a) the system simulates different diseases.
- In the next level (figure 5b) the system simulates the effect of change in different visual functions (like Visual acuity, Contrast sensitivity, Visual field loss and so on.) hand strength metrics (like Grip Strength, Range of Motion of forearm, wrist and so on), and auditory parameters (like audiogram, loudness and so on).
- In the third level (figure 5c), the system allows different image processing and digital filtering algorithms to be run (such as high/low/band pass filtering, blurring etc.) on input images and to set demographic detail of users.

A demonstration copy with user manual can be downloaded from the GUIDE website (http://www-edc.eng.cam.ac. uk/~pb400/CambridgeSimulator.zip).

4.3 Design improvement

The simulator can show the effects of a particular disease on visual functions and hand strength metrics and in turn their effect on interaction. For example the simulator can predict how a person with visual acuity *v* and contrast sensitivity *s* will perceive an interface or a person with grip strength *g* and range of motion of wrist *w* will use a pointing device. We collected data from a set of intended users and clustered their objective assessment metrics, the data collection and clustering processes are discussed in detail in D7.4. The clusters represent users with mild, moderate or severe visual, hearing, cognitive and motor impairment with objective measurement of their functional abilities. We have used the simulator to customize interfaces for all applications for each cluster of users. So we have customized interfaces for a group of users with similar type of perceptual, cognitive and motor abilities. The process is depicted in figure 6 below.

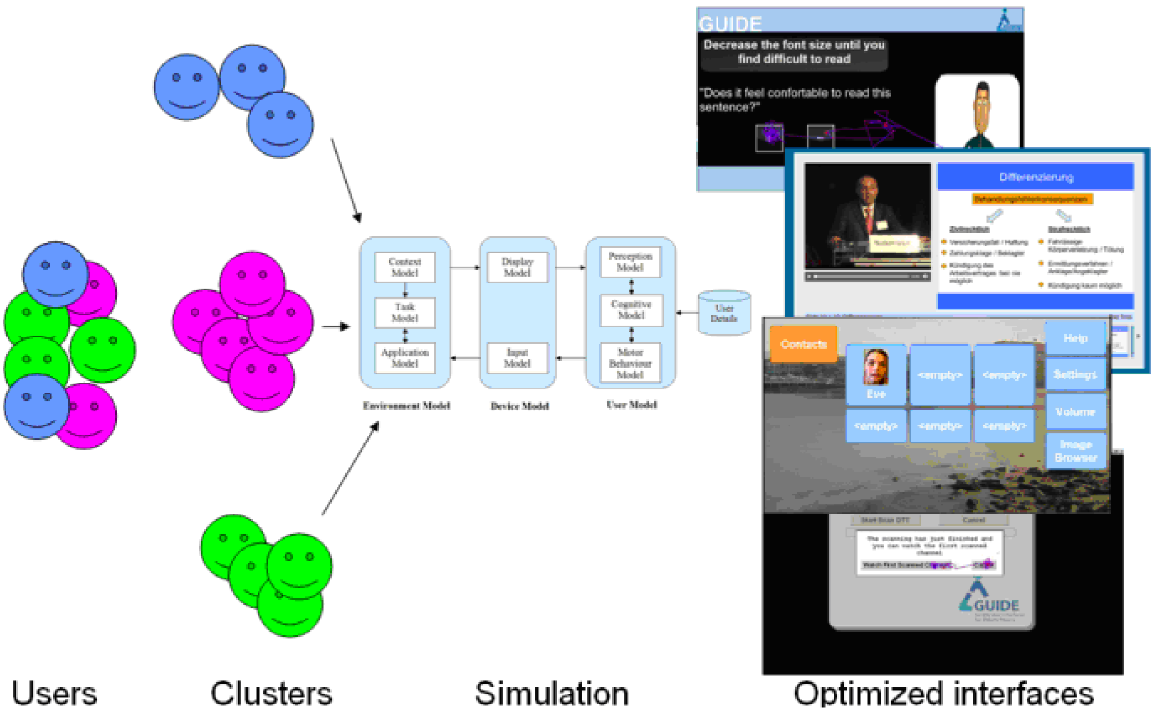


Figure 6. The design optimization process

The following subsections describe the use of the simulator in verifying and improving application interfaces of GUIDE project

4.3.1 User Initialization Application

The user initialization application used the simulator to check the font size and button spacing. The simulation screenshots below shows that the font size can accommodate visual acuity loss due to mild Macular Degeneration and Diabetic retinopathy (figure 7). The buttons are also kept well separated to avoid missed clicks by users with moderate spasm or tremor in finger (figure 8).

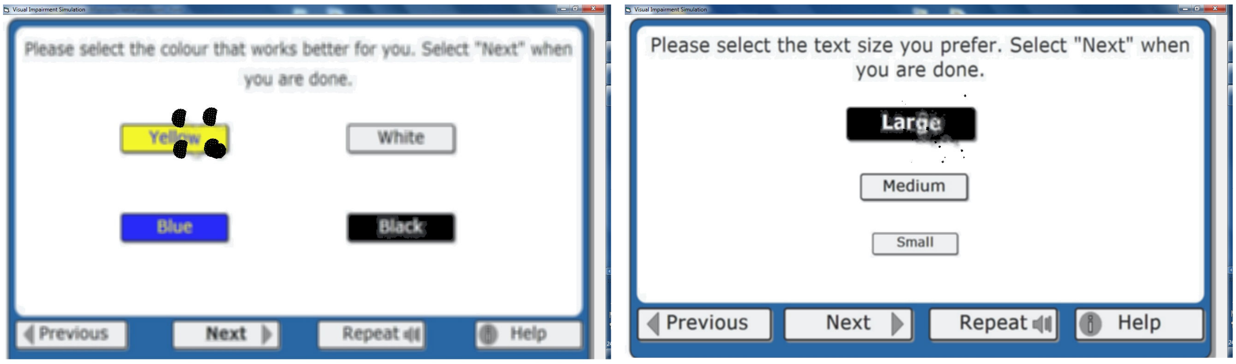


Figure 7. Simulation output for User Initialization Application for visual impairment

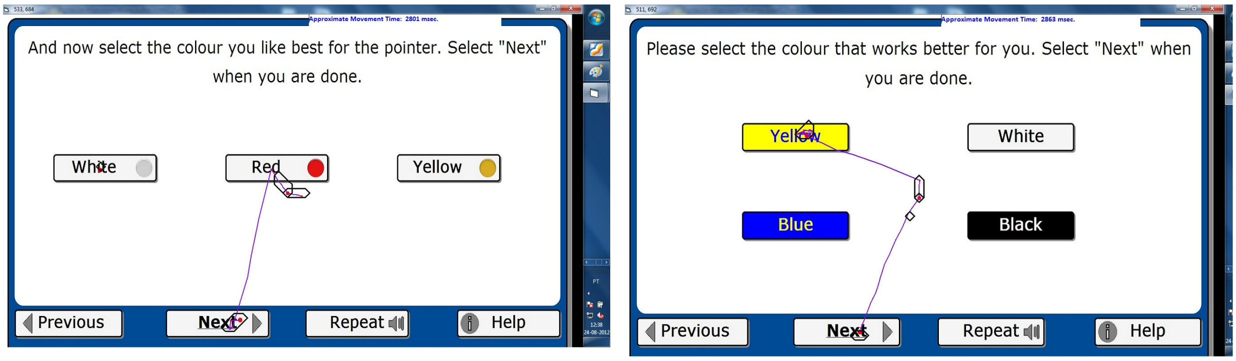


Figure 8. Simulation output for User Initialization Application for motor impairment

4.3.2 Media Access Application

The Media Access application has been improved after checking simulation results for profiles of users having disabilities, such as myopia and Parkinson's disease. Thus, some adjustments were done after analysing the simulator results found in figure 9 where the white background was seen as too bright, especially for a user with mild visual impairment or where the focusable arrows were seen as not enough distinguishable.

Therefore the background was decided to be darker and the focusable parts were bordered and enlarged when possible.

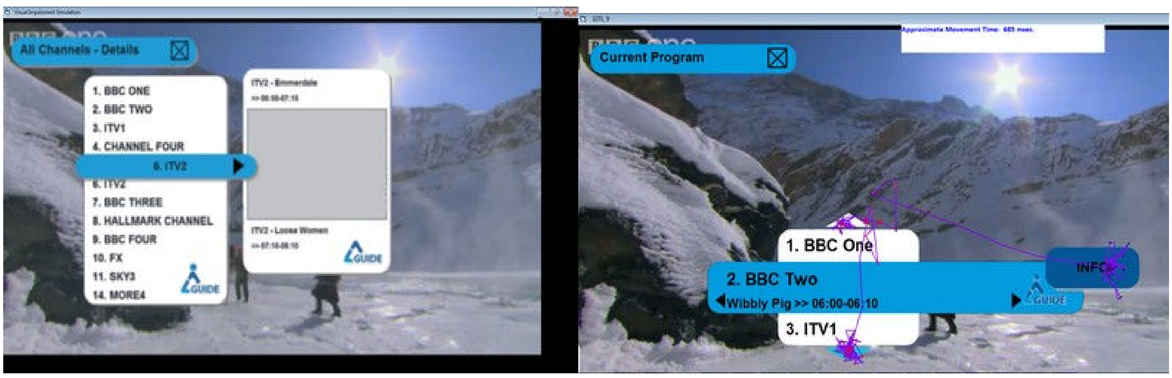


Figure 9. Simulator results for mild visual and severe motor impairment on the first version

After doing these modifications, the simulator was reused on the new designs to control the efficiency of the recommendations.

These new design simulator results can be seen in figure 10 where a greyish background has been preferred and the selectable zones have been increased not only containing the newly bordered arrows but also the full displayed zone.

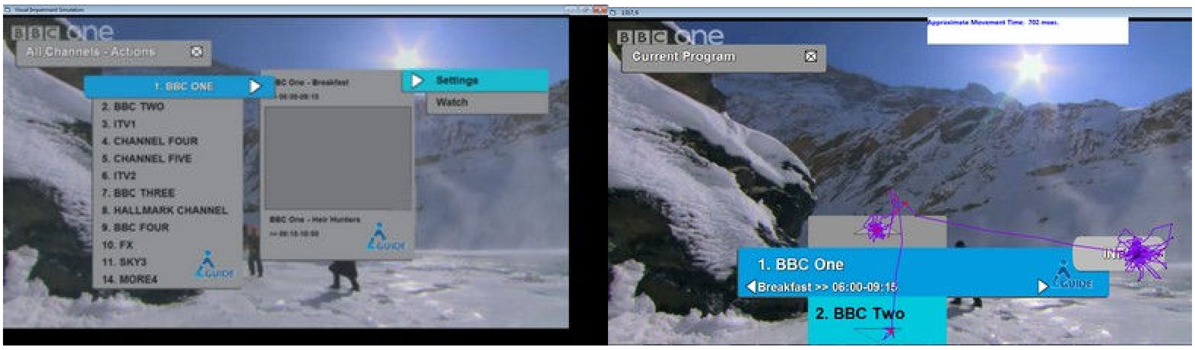


Figure 10. Simulator results for mild visual and severe motor impairment on the new design version after the application of the recommendations

This last simulation step was perceived as conclusive enough. Therefore no more refinement was decided on the Media Access application.

4.3.3 Tele Learning Application

The TeleLearning (TL) application is built around two central tasks: Users select a lecture from a set of subscriptions and watch the combined video and slide content of the lecture. Exemplarily, two UI designs of the currently developed TL application are studied, as shown in figure 11. The content is from a lecture series, and for each lecture the title, the presenter and some short description are given (left). The user can select the video by scrolling up and down in the list. Selection is done by pressing on the example slide or the description text right of it. The selected lecture is presented using the setting on the right. In principle, the user can simply sit back and get the presentation, but additionally navigation in the lecture is possible touching one of the thumbnails to select the respective slide (the one in the middle is the active one), touching on the large slide or by using the control bar below the speaker video.

Figure 11. Overview lecture list and lecture presentation in the TL application

The simulation on this prototype was performed for several central screens that are representative of the interaction necessary in the TL application. A range of four profiles was tested with mild to medium-strong visual and motor impairments combined.

In the simulations, it became clear that for some users the text sizes play a decisive role for accessibility, and adaptation of the menu font size has been implemented. Furthermore, the colour scheme has been kept variable in the current version of the application. This notwithstanding, the application is not far from what would be implemented for able-bodied users.

Lecture selection: Using the simulators on the list view results in two findings: The partition of the screen for selection is unproblematic for mild to moderate motor impairments, as the area to select a particular item is about a quarter of the screen. What has been done compared to the initial version is that lectures now have become a field rather than a row, thus reducing the required touch precision for selection of details and watching. Another main problem was scrolling, and in a design iteration, first explicit buttons have been introduced to provide an alternative to up and down gestures, which, however, are simple enough to work generally.

The other finding is about text size, figure 12. While the event heading is legible under the conditions of the moderate visual impairment profile in question, the important headings for the lectures are not, or not conveniently. Here adaptation to a larger text size is indicated.

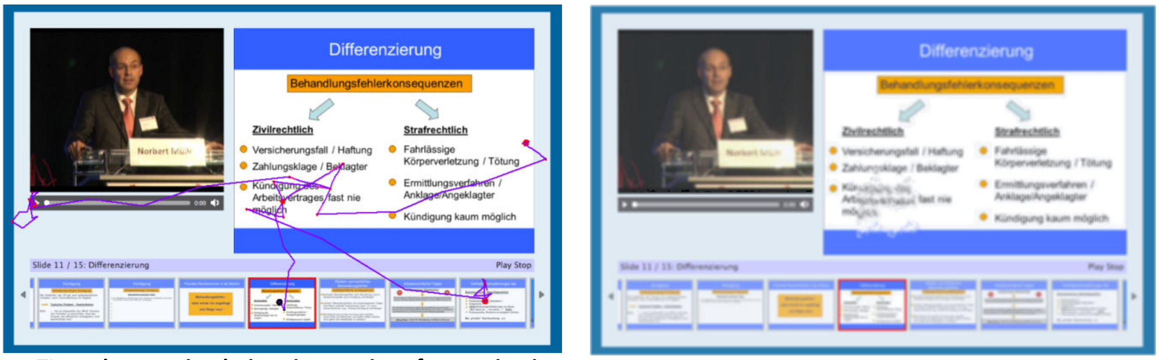
Webcast watching and navigation. For watching lectures and navigating in content, again two findings could be made. Using a person with medium-strong motor impairment results in the slide icons that act as navigation buttons to be not easily accessible, cf. figure 13a, while mild levels of tremor seem to give the user still adequate control. The main adaptation to this is to provide large versions of control buttons for navigation or make the left and right part of the slide active for rewind and forward navigation.

Furthermore, visual impairment as simulated in figure 13b results in finding that text size is often too small on the slides to be legible. In full-screen mode where only the slide is shown, this is alleviated because text size increases by approximately factor 1.5. However, as there is only restricted control on

Figure 12. Overview lecture list seen through the eyes of person with medium-strong visual impairment

the content presented, additional means of multi-modal presentation need to be considered, starting from guidelines for authors and ending with the possibility to adapt text size in slides. However, the latter is difficult to achieve because slide content is often laid out relying on a certain visual composition that is usually broken if text dimensions change dramatically. What may be done is to provide a means to “touch up” text and present visual captions, for instance in connection with the tablet. This may be pursued in the final project year. Regarding navigation for more severe visual impact, a similar approach to the motor impact adaptation is envisioned: Reusing large areas on the screen for a minimum set of interaction commands. In addition, speech commands and the visual human sensing component are expected to be handy interaction modalities with familiar commands, apart from the tablet as navigation device.

In conclusion, the simulation of the different impairment profiles indeed gives great insight into the perception and interaction from impaired users. While most developers have a layman’s understanding of the potential impact that a certain design has on a disability, simulation allows quantifying and concretizing this. For the example of the TL application, this became clear in two design adaptations that will be introduced in the next version developed.



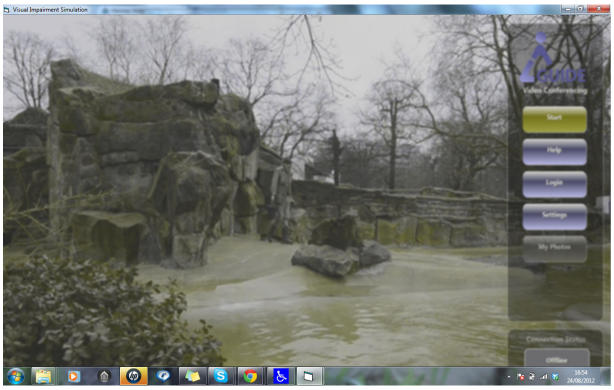
a. TL webcast, simulating interaction for navigation (profile of an 81-year old with a polio history)

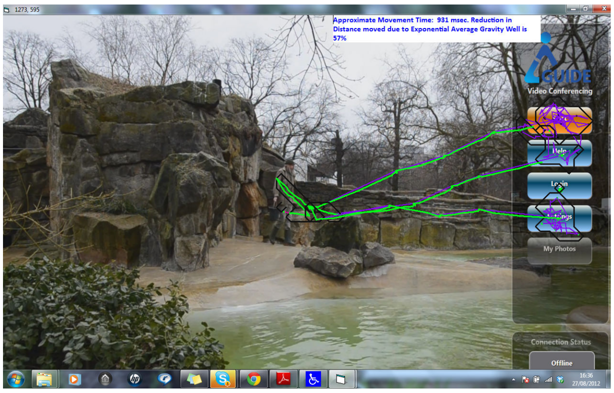
b. TL webcast in navigation mode: visual appearance for medium-strong visual impairment (profile as in Fig. 6)

Figure 13. Motor and visual impairment simulation for Tele-Learning application

4.3.4 Video Conferencing Application

The video conferencing application (figure 14) seems to have inadequate font size for moderate visually impaired users. In the motor impairment simulation, the blue lines show cursor traces for a person having tremor in finger and the green line show modified cursor trace after application of gravity well adaptation algorithm. It may be seen the buttons are too closely spaced increasing chances of wrong selection, however the gravity well system may reduce chances of missed clicks by stopping random movement on the buttons.





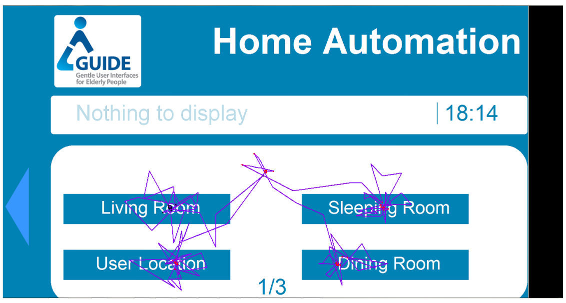
Visual impairment simulation

Motor Impairment Simulation

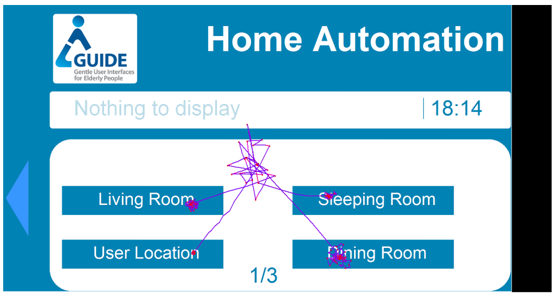
Figure 14. Simulation screenshots for Video Conferencing Application

4.3.5 Home Automation Application

We have undertaken similar tests as in the previous sections for Home Automation application. We investigated effects of mild to moderate visual and motor impairments. It can be seen from figure 15 below that the fonts are sufficiently large to accommodate slight visual acuity loss for aging or disease like Myopia or distorted vision due to disease like macular degeneration. The colour combination is selected as white in blue background so that it can remain legible for dichromatic colour blindness. The buttons are sufficiently large to accommodate random cursor movement during homing on a target using a pointing device.



Simulation of mild motor impairment on Home Automation GUI.



Simulation of moderate motor impairment on Home Automation GUI.

Figure 15. Affect of visual and motor impairment on Home Automation applications

4.3.6 Virtual character design

In this section we present some examples of simulator utilization for Antropomorphic virtual character design specification and implementation. Considering the actual status of the simulator, given a user with visual impairments, it enables the simulation of the impaired perception of the virtual character. Using the simulator it is possible to find new visual requirements or parameterization points for the virtual character component, like for example the virtual character size on screen, the color intensity and contrast, the facial and body expressions, among many others, and these have been the main goals performing these design studies.

The first example of visual test was done based on the Virtual character display in close-up mode (see Figure). This test shows how the impaired user would perceive the emotion (facial expression) conveyed by the virtual character.

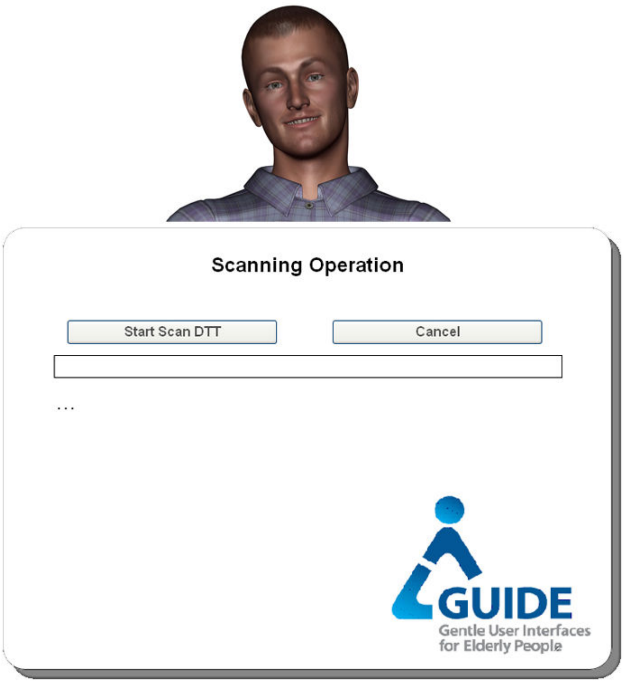


Figure 16. Screen capture showing Virtual character close-up mode

The simulation of a user with mild visual impairments is shown in Figure . The virtual character is not perceived as in the original image, however it is still possible to distinguish the emotion transmitted by the Virtual character, since the facial expression remains sufficiently clear.

Figure 17. Simulation of on screen virtual character perception by user with low visual impairments

In contrast, both the user with moderate and the user with severe visual impairments (see Figure) will hardly notice the expression of the virtual character. Possible solutions (i.e. adaptations) at the level of the virtual character component may involve the use of the hearing sense and of an emotional voice of the virtual character to convey the emotions (but emotional TTS is rare and has its issues), increasing the resolution of the close-up (e.g. instead of using a screen fraction, use the entire screen), or even (more difficult to tune) controlling the color intensity and contrast of virtual character representation.

Figure 18. Display with moderate visual impairments (left) and display with severe visual impairments (right)

Another visual simulation performed was based on the Virtual character display in medium shot mode (see Figure 19). In this test we intended to understand how the impaired user perceives the non-verbal communication of the Virtual character body. In the original presentation of the Virtual character, a pointing gesture is clearly visible. The intention was to evaluate if this expression is perceived by all users (different degrees of impairment).

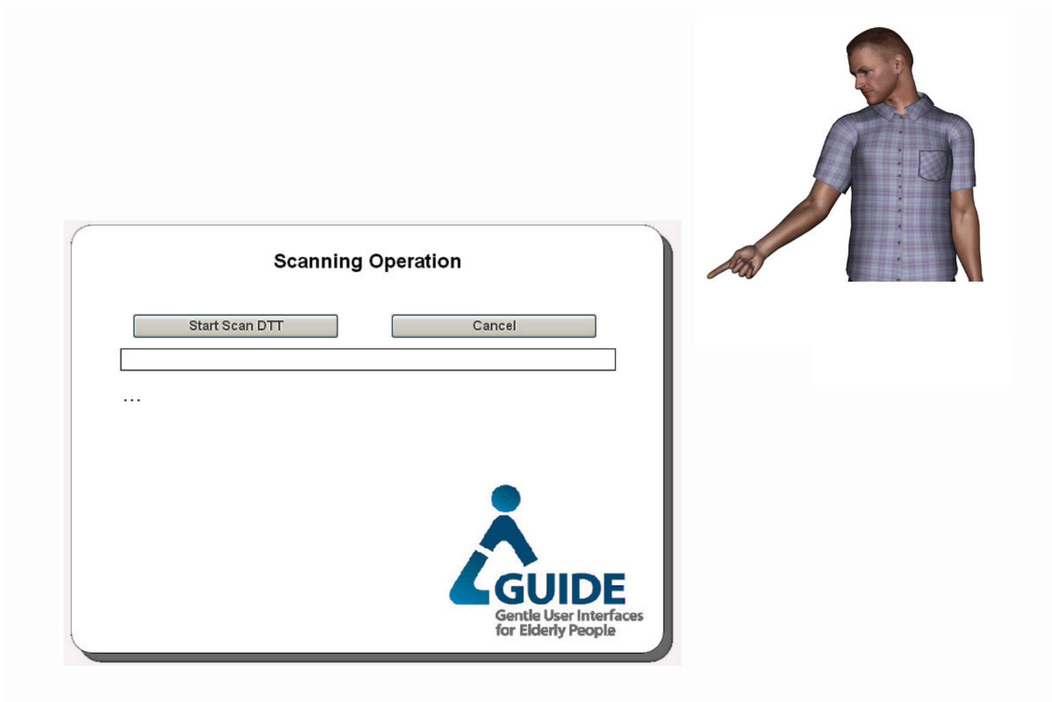


Figure 19. Virtual character medium shoot display

The simulation of users with mild visual impairments is depicted in Figure 20. The nonverbal communication transmitted by the Virtual character body is neatly recognizable.

Figure 20. Display with mild visual impairments

Both the user with moderate and the user with severe visual impairments are still able to perceive well the nonverbal communication transmitted by the Virtual character's body (Figure 21). As in the first test, it is difficult to perceive the Virtual character facial expression. It is evident that in the case of severe impairments, the black areas (screen areas not perceptible by visual impaired user) could also hide the pointing gesture, depending on its placement on screen. The simulation of still images does not yet allow deciding whether this possible issue requires further adaptation measures, as recognition here is probably further facilitated by the perception of the movement of the arm. A close-up of the arm and hand as further adaptation would be technically feasible, but requires additional camera steering algorithms and user tests.

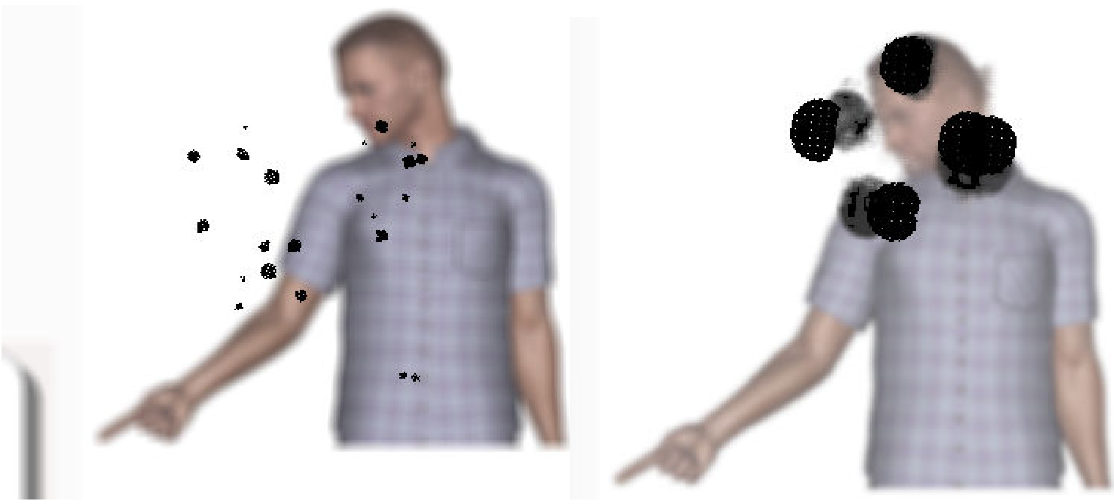


Figure 21. Display with moderate visual impairments (left) and display with severe visual impairments (right)

In general, even when users have moderate or severe visual impairments, the silhouette of an image of the Virtual character is easily perceptible; this should allow them to easily recognize the moving Virtual character as well. This finding is also important because the emotional expressiveness of the Virtual character movement can enable the disambiguation of the Virtual character's facial expression, which is more difficult to recognize for the visually impaired.

Further studies will be realized as soon as other modules of the simulator are available, for example the simulation of hearing impairments, which will permit refinements on the actual implementation of Virtual character synthetic speech (TTS) and extract conclusion on how to setup TTS according to the user profile.

5 Adaptation

The GUIDE system adapts its response to users through the runtime user model. The adaptation process begins with the User Initialization Application (UIA) that allows for the acquisition of primary assumptions about the user. The UIA is presented to the user as a simple step-by-step configuration of a generic interface. In each step, different types of content and different contexts of interaction are presented, so the user can test different components and parameters. During this process preferences and characteristics of the user are collected, which are then forwarded to the user model where the user is assigned to a profile. In the individual tests, we do not need an accurate measurement of functional abilities again, rather an approximate estimation is sufficient to map the user into one profile. For example we can use the age, gender, height and a self assessment on presence of any spasm or tremor in hand of a person to interpolate his objective hand strength data [Angst et. al., 2010] to map him into a previously stored profile. From that moment on, and for any application the user interacts with, the system is adapted to him or her. Identification of users is supported by facial recognition, which allows the system to load the correct user profile whenever the user starts interacting with it. The following subsections illustrate the user initialization process and the runtime user model.

5.1 User Initialization Application (UIA)

With the User Initialisation Application, the GUIDE system starts collecting data about users to make possible any kind of adaptation. The User initialization application consists of a list of tests represented in a game-like fashion to users. It collects data on basic visual, cognitive and motor skills of users and also their preference about several interface properties. The data is sent to the run-time user model to extract a basic profile for the user. A brief description of all the variables collected by each screen of the application is listed below:

1. A screen for welcoming the user and introducing him/her to the modalities of interaction possible in GUIDE (a general introduction only).
2. A screen for introducing the user to the several contexts of interaction present in GUIDE.
3. Five screens for introducing the interaction with remote control (standard and gyroscopic functions), speech interaction, pointing interaction, and speech and pointing (multimodal) interaction, and also tablet interaction. The goal of these screens is to instruct users on how to interact using GUIDE input components.
4. Three screens for button and menu configuration (size, colour and font preferences). For user preferences collection.
5. One screen for choosing between several cursor appearance configurations (3 different colours, 3 different shapes - hand, cross, arrow -, and 3 different sizes). Also for user preference collection.
6. One screen for audio perception tests, for measuring hearing capabilities and preferences.

7. One screen for a TMT game for measuring user visual and cognitive capabilities.

8. One "follow-me" game (user has to point to the screen and follow a button), for measuring if users have motor tremor problems.

9. One screen for collecting user age, gender and height. Indispensable for measuring motor capabilities like grip strength.

10. One screen for testing the Virtual Character preference (male or female).

11. One screen for testing the speed of speech (3 options to choose from).

12. One screen thanking the user.

All data collected by in this process is sent to the user model component, so that a representation of the user capabilities and preferences can exist inside the system, making adaptation possible. The following section describes this adaptation process.

5.2 GUIDE User Model

Besides the design optimization process, the simulator is also used for developing a runtime user model. The runtime user model maps user parameters collected by UIA to interface parameters (figure 22).

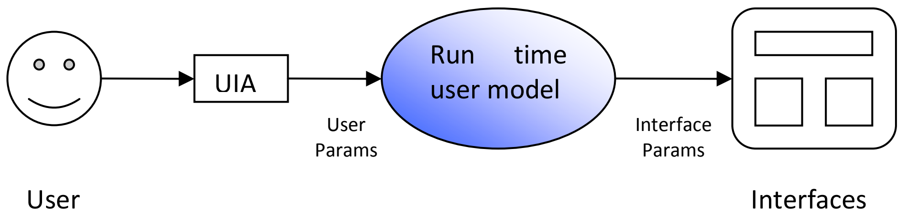


Figure 22. Mapping user parameters to Interface parameters

We ran the simulator in Monte Carlo simulation and developed a set of rules relating users' range of abilities with interface parameters. For example the following graph (figure 23) plots the grip strength in kilograms (kg) with movement time averaged over a range of standard target width and distances in an electronic screen. The curve clearly shows an increase in movement time while grip strength falls below 10 kg and the movement time turns independent of grip strength while it is more than 25 kg.

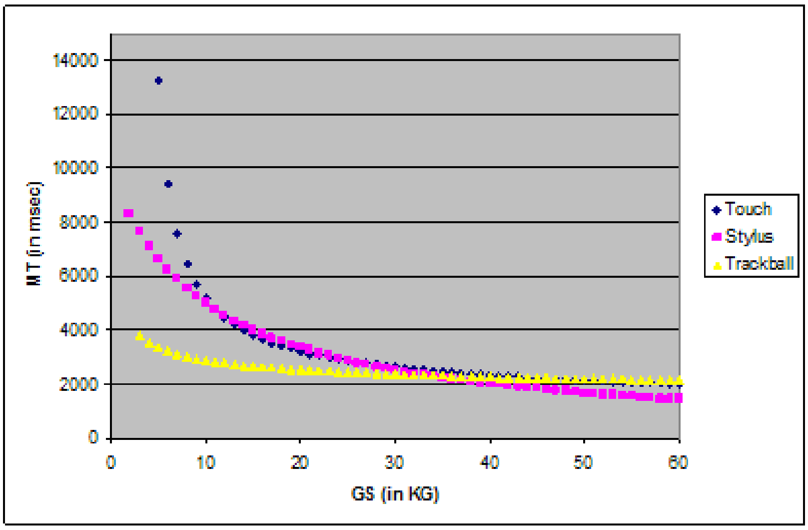


Figure 23. Relating Movement Time with Grip Strength

Similar analyses have been done on fontsize selection with respect to visual acuity and colour selection with respect to different types of dichromatic colour blindness. Taking all the rules together, the GUIDE User Model predicts three sets of parameters:

1. User Interface(UI) parameters for Multimodal Fission Module
2. Adaptation Code for Input Adaptation Module
3. Modality Preference for Multimodal Fusion Module

In the following sections we briefly describe these prediction mechanisms.

5.2.1 User Interface parameter prediction

Initially we selected a set of variables to define a web based interface. These parameters include:

- Button spacing: minimum distance to be kept between two buttons to avoid missed selection
- Button Colour: The foreground and background colour of a button
- Button Size: The size of a button
- Text Size: Font size for any text rendered in the interface
- Cursor Type: The shape and colour of the cursor

The user model predicts minimum button spacing required from the users' motor capabilities and screen size. The simulation predicts that users having less than 10 kg of grip strength or 80º of Active Range of motion of wrist or significant tremor in hand produce a lot of random movement while they try to stop pointer movement and making a selection in an interface. The area of this random movement is also calculated from the simulator. Based on this result, we calculated the radius of the region of the random movement and the minimum button spacing is predicted in such a way so that this random movement does not produce a wrong target selection. The exact formula is as follows:

```
If users have Tremor, less than 10 kg of Grip strength or 80° of ROM in wrist
    Minimum button spacing = 0.2 *distance of target from centre of screen
```

```
If users have Tremor, less than 25 kg of Grip strength or 80° of ROM in wrist
       Minimum button spacing = 0.15 *distance of target from centre of screen
else
       Minimum button spacing = 0.05 * length of diagonal of the screen
```

Regarding the other parameters, the UIA already takes preferences from user for colour, text size and cursor type. The user model stores these preferences. However if a user has colour blindness it recommends foreground and background colour blindness as follows:

```
If the colour blindness is Protanopia or Deuteranopia (Red-Green) it recommends
       White foreground colour in Blue background
For any other type of colour blindness it recommends
       White foreground in Black background or vice versa
```

5.2.2 Adaptation code prediction

The adaptation code presently has only two values. It aims to help users while they use a pointer to interact with the screen like visual human sensing or gyroscopic remote. The prediction works in the following way

```
If a user has tremor in hand or less than 10 Kg Grip Strength
       The predicted adaptation will be Gravity Well and Exponential Average
Else
       The predicted adaptation will be Damping and Exponential Average
```

In the first case, the adaptation will remove jitters in movement through exponential average and then attract the pointer towards a target when it is near by using the gravity well mechanism. Details about the gravity well algorithm can be found in D5.2. If the user does not have any mobility impairment, the adaptation will only work to remove minor jitters in movement.

5.2.3 Modality prediction

The modality prediction system predicts the best modality of interaction for users. Though users are free to use any modality irrespective of the prediction, the fusion module uses this prediction to disambiguate input streams when there is more than one. The algorithm works in the following way:

```
If Grip Strength is less than 10 kg or user has tremor in finger or can not see
screen
       Best Input is Speech
If Grip Strength is between 10 and 20 kg and user does not have tremor and can
see screen
       Best Input is Gyroscopic Remote
For other cases
       Best input is Visual Human Sensing
If user can see screen
       Best Output is Screen
Otherwise
       Best Output is Audio Captioning
```

Table 2 below shows representative output for different clusters of users, detail of the recommendation and clusters are discussed in D7.4.

Table 2. User model prediction

GS (in kg)	Tremor	ROMW (in degree)	FontSize (in point)	Colour Blindness	Adaptation	Modality	Colour Contrast	Button Spacing
16	YES	71	14	Protanopia	Gravity Well	Pointing/Screen	Blue White	20*
25	NO	52	14	Protanopia	Damping	Pointing/ Gesture/Screen	Blue White	20
59	NO	66	12	Deuteranopia	Damping	Pointing/ Gesture/Screen	Blue White	20
59	NO	66	0	N/A	Damping	Speech/Audio	N/A	20
25	YES	52	14	None	Gravity Well	Pointing/Screen	Any	20
59	NO	120	14	Tritanopia	Damping	Pointing/ Gesture/Screen	White Black	5*

*20 means: 0.2 *distance of target from centre of screen
5 means: 0.05 * length of diagonal of the screen

5.3 Validation of the user model

The user model is validated in two stages. The internal validation considered a representative pointing and clicking task and conducted over seven participants in controlled laboratory settings. The external validation is performed through an Electronic Program Guide (EPG) application implemented through the GUIDE framework. The following sections presents detail of these studies. A separate deliverable (D7.4) presents more detail on trials involving the GUIDE system.

5.3.1 Internal Validation

5.3.1.1 Participants

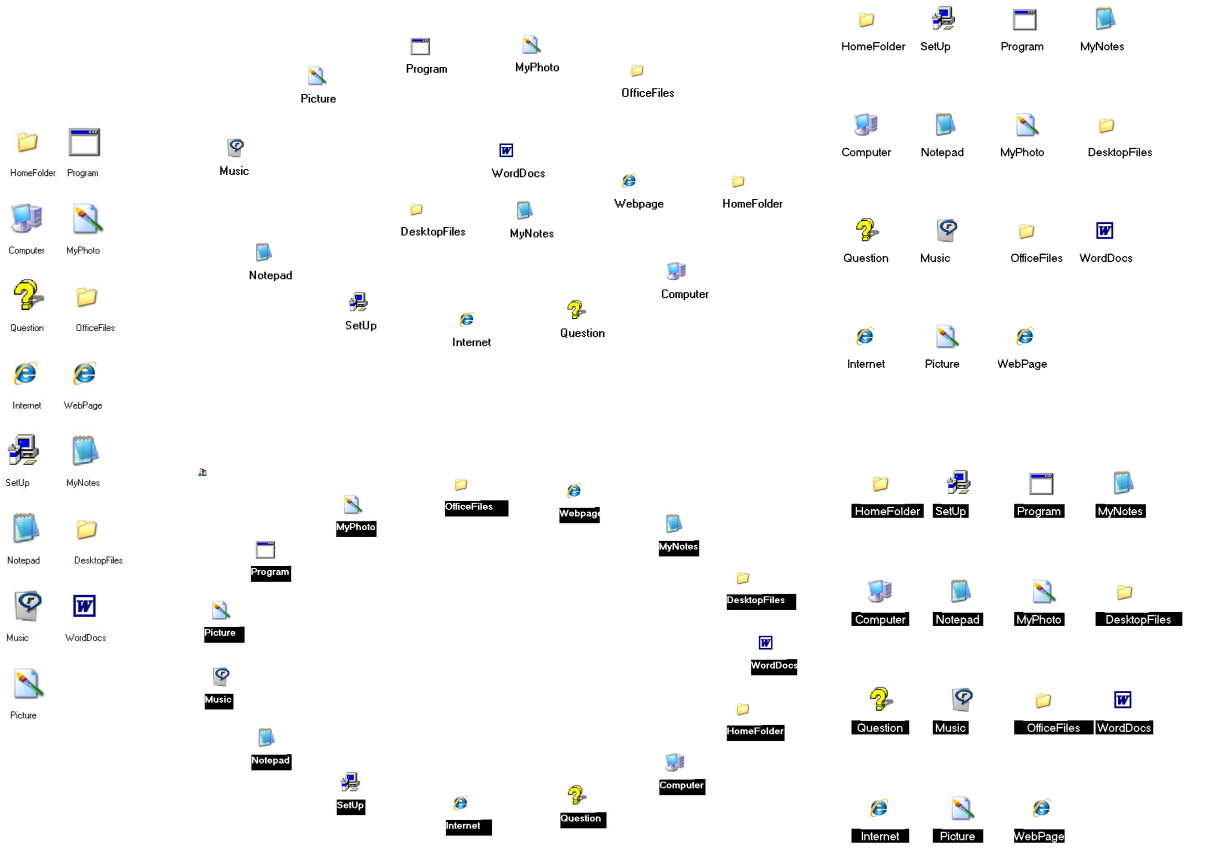
We collected data from the following seven users with physical or age related impairment (Table 3). These users were recruited through a local user organization in UK, they all use computers or laptops everyday and volunteered for the study.

Table 3. Participants

Participants	Age	Sex	Impairment
P1	44	M	Tunnel Vision, Spasm in finger
P2	48	M	CerebralPalsy
P4	57	F	CerebralPalsy
P5	34	M	Polio
P6	45	M	Spina Bifida
P7	48	F	Spina Bifida
P8	73	M	Glaucoma, age related dementia

5.3.1.2 Design

The study simulates a situation of pointing and clicking in a direct manipulation interface. For example, users often click an icon on desktop to open a folder and then click another time to select the required file. This study first showed users a couple of familiar icons and then asked them to click on these two icons from a list of icons. The list of icons was presented in three different ways. In one case they use the default parameter settings (font size, button spacing) of Windows operating system. In the two other cases, the list of icons was adapted according to the prediction of the user model. We considered two different organizations of icons in the adapted version – elliptical and rectangular. Figue 24 below shows examples of the control and adapted versions of the icon searching screens.



Control Condition　　Adapted Elliptical Condition　　Adapted Rectangular Condition

Figure 24. Icon searching screens

5.3.1.3 Material

The study was conducted using a computer and a Tablet device. Both of these devices had Windows 7 operating system. The computer has a 20" screen with 1280 × 1024 pixel resolution while the Tablet had a 10" screen with 1280 × 800 pixel resolution. The participants used a standard mouse and the tablet touchpad in control condition, while they were allowed to use a TrackBall and Stylus in experimental condition.

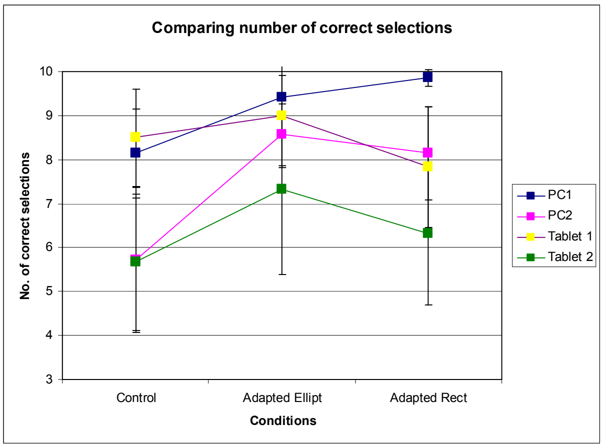
5.3.1.4 Procedure

Initially the participants used part of the UIA to create a user profile. Then they undertook the icon searching task. The control (non-adapted) and experimental (adapted) conditions were randomly chosen. For each screen, participants needed to remember two icons and click on them. Each participant used both computer and Tablet. They undertook 10 icon searching tasks under each condition for each device.

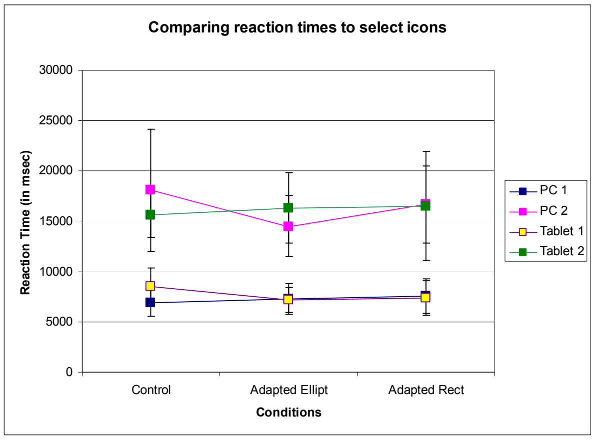
5.3.1.5 Results

We analyzed the number of correct click for each participant and the average reaction time for those clicks. Each pointing and clicking task involved two icon selections. We compared the number of correct clicks and reaction time for first and second selection. Figure 25 below shows the number of correct selections and average reaction time.

It can be found that participants selected more correct icons with the adapted elliptical version than control condition under all circumstances ($t(28,1) = 0.01$, paired, two-tailed) though the difference in reaction time was not significantly different. We also found that the number of correct selection and reaction time was higher for the second selection as participants struggled to remember the second target mostly due to age and Cerebral Palsy related dementia. We did not find any significant difference in terms of reaction time or number of correct selections between computer and Tablet.



Comparing number of correct selection



Comparing average reaction time for correct selection

Figure 25. Results from Internal Validation

5.3.2 External Validation

This study has used the user model implementation within the GUIDE core in a setting mimicking users are watching TV at home.

5.3.2.1 Pilot Study

We conducted a study to evaluate the UIA and its ability to assess the user's profile and adapt the interface accordingly. Herein, we briefly summarize the results obtained in two countries, Spain and UK, with a total of 40 elderly people, with different age-related disabilities. In this study, all participants ran the UIA and used adapted and non-adapted versions of an Electronic Program Guide (EPG). The average age of participants was 70.9 years old and the different user profiles were assigned to the participants based on a cluster analysis. The analysis assigned 14 users with profile A (no adaptation), 22 users with profile B (increased button spacing), and 4 users with profile C (increased button spacing and changed color contrast).

To understand the benefits of the user model and the adaptations performed, we undertook an analysis restricted to the subjective understanding and acceptance of the created profiles and consequent interface changes. Results showed that participants perceived the adaptation both during the UIA and the adapted EPG tasks. It was also found that those were subject to adaptations rated the adaptive version as an improvement over the non-adapted one. The baseline EPG already had improved accessibility features over traditional EPGs, a fact that may have reduced the impact of the adaptations in such a short term evaluation. The participants showed to be positive about the adaptations, which is relevant as a requirement for adoption, particularly in the elderly population.

These results, together with the positive acceptance of the GUIDE concepts and their expected impact in the quality of life of its users, validate the approach followed so far and pave the road for the project's future developments, which will be verified in a longitudinal trial for better assessing the effects of adaptation based on our user model.

5.3.2.2 Detailed analysis

We conducted a task-by-task video analysis of 15 users sampled from all users (6 Spanish users, 6 British users and 3 German users). We first constructed a list of the necessary variables to look for while watching each user interacting with both the UIA and different adapted and non-adapted versions of the EPG. Following that selection, the 15 users more relevant and which cover every user model profile were selected. Finally the 15 videos were watched once (several were watched and then revised to make sure all variables were classified in the same manner for every user) and the list of variables was filled accordingly.

The detailed analysis performed with 15 users with different profiles showed that there was a clear distinction between the adapted and non-adapted EPG versions. A great percentage of the participants (94%) perceived the interface elements and adaptations therein in the Adapted version without any intervention from the evaluation monitors. In the Non-adapted version, unaided perception of the interface elements was lower (77%). The main reasons for this difference were the visual adaptation mechanisms in the adapted version that helped the users in perceiving the interface elements. The Virtual Character in the adapted version also showed to be paramount in the perception of the interface elements.

During execution of tasks, the adaptations performed also showed to improve the participants' autonomy and overall performance. This was visible in the amount of times they stopped during a trial without being able to continue on their own (11% vs 16%) but also in the percentage of tasks that were accomplished without requiring any help from the test monitor (49% vs 61%). The number of helps requested also showed to be higher in the non-adapted version (0.33 times per task) than in the adapted version (0.16 times per task) revealing that the adaptations ease the usage of the EPG and make the user more comfortable.

The acceptance ratings of the participants towards the adaptations showed that almost half of the users were satisfied with the adaptations performed (7 participants – 47%) This could seem as a low value but looking in detail only 2 participants (13%) disagreed with the adaptation. The remaining 6 participants were mildly satisfied with the adaptation as they wished it to be more evident (even bigger fonts and buttons and more contrast).

5.3.3 Discussion

The internal study demonstrated that even with only seven participants the adaptations predicted by the user model can help them to remember, search and select targets in a screen in a standard icon searching task. The number of correct selection was higher in both computer and Tablet. It has also been found that increasing font size or button spacing do not reduce the average reaction time for searching and clicking.

The external validation confirmed that user also preferred adaptation in a real life application. Overall, the evaluation showed strong evidence that the adaptations help the user perceive interface elements and improve the users' autonomy and overall experience with the application. Conversely, part of the users asked for more adaptations which suggests for a more refined clustering process and reinforces the need for dynamic adaptation.

6 Standardization

The GUIDE project takes active part in ITU-T ITU Focus Group on Audiovisual Media Accessibility and European Union Task Force on Virtual User Modelling and Simulation.

The ITU-T Focus group looks at existing problems in accessibility and based on that sketch a vision for 2020. It has 10 different working groups looking at different aspect of accessibility like Captioning, Audio Captioning, Visual Signing, Participation and Media and so on. The focus group meets every two months and plan to submit a report to the parent ITU-T SG 16 committee by 2012.

The EU VUMS cluster [2012] identified user modelling as a prospective means to provide accessibility and aims to develop

- Common data storage format
- Common calibration / validation technique
- Standard for collaboration on ethical issues

The cluster initiated its work by defining a common glossary of terms which enable user model developers to exchange concepts. Later it defined a set of variables to describe a user and a common format to store this detail. Finally it prepares a few use cases to demonstrate the utility of a common user model and profile across different projects and applications. At present we have developed a common set of variables to describe perception, cognition, motor action and anthropomorphic details of users and in the process of developing systems to use these variables to adapt interfaces across different platforms and devices. The VUMS white paper can be downloaded from http://www.veritas-project.eu/vums/?p=165. We have developed a converter to import VUMS profile in GUIDE system. The following case study presents an example of using the VUMS user profile across different projects.

6.1.1 Case Study

The VUMS exchange format enables all projects to share a single profile and simulate and adapt interface based on this common profile. The following example considers a representative persona and shows examples of simulation and adaptation for different applications.

Mr John Brown is a 70-year old gentleman with spinal cord injuries and glaucoma. Due to his functional limitations, John encounters difficulties in walking, grasping and reading. John uses some assistive devices, including a wheelchair and reading glasses. He does not suffer from any form of colour blindness though has age related hearing impairment having higher threshold of hearing for high frequency tones. He does not also have any cognitive impairment as reflected by his scores in cognitive tests like Trail Making and Digit Symbol Tests.

Figures 26 and 27 show a simulation of a situation while Mr Brown is trying to close the boot of his car. The simulation predicts whether he can complete this task and how long he takes to close the boot.

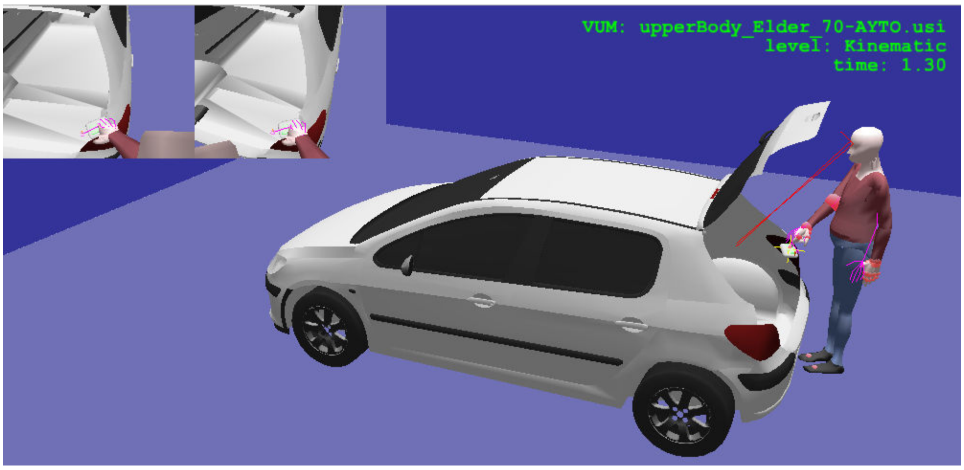


Figure 26. Simulation for automobile interface in VERITAS project

Figure 27. Simulation of a task of opening boot in VERITAS project

Figure 28 shows a screenshot of the Home Automation Application of GUIDE project. Figure 29 shows how Mr Brown perceives a Television screen. The black spots appear in the screen due to Glaucoma. The blue line shows the movement of cursor in the screen while the user operates the application using a direct manipulation input device like a gyroscopic remote or trackball and the message box predicts task completion time. Beyond simulation, the common user profile is also used to adapt interfaces. Table 4 presents a set of interface parameters predicted by the GUIDE system for this particular user. GUIDE interfaces use these parameters to adapt application interfaces by updating a UIML (User Interface MarkUp Language) description of interface layouts.

Figure 28. GUIDE Home Automation Application

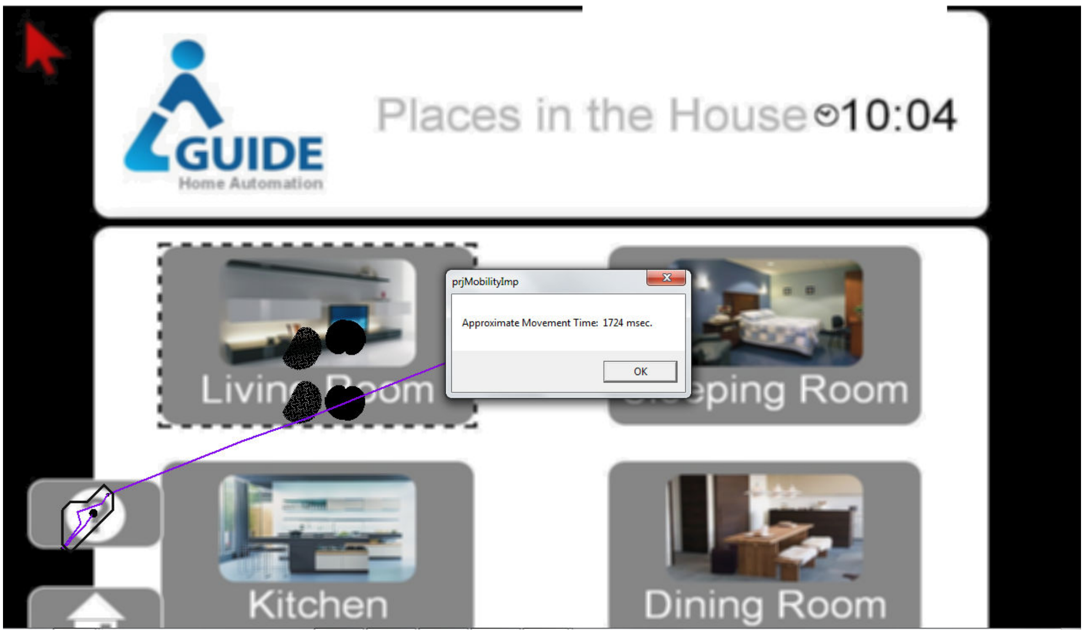


Figure 29. Simulation for Mr Brown

Table 4 Interface parameter prediction for common persona

Devices	Horizontal Button Spacing	Vertical Button Spacing	Minimum Font Size	Colour Contrast	Best Input Modality	Best Output Modality
	(in pixel)					
Mobile	48	80	26	Any	BigButton	Screen
Laptop	128	80	24	Any	TrackBall	Screen
Tablet	128	80	23	Any	Stylus	Screen
TV	200	120	58	Any	Second Screen BigButton	Screen

The MyUI system uses the same profile to show how the main menu of the MyUI adaptive user interface would look like for John Brown. For him The MyUI system proposes following adaptation based on the simulation shown in figure 30.

- Font size is increased due to his perceptual problems (I guess your "reading" problems are not related to cognitive impairments)
- in addition to simple cursor navigation, numeric key navigation is enabled due to his motor problems ("grasping"). This results in displaying the respective numbers on every interactive element.
- as a consequence of enabling numeric key navigation, the number of displayed interactive elements (here menu buttons) is reduced to a subset of not more than ten options (keys 0 - 9)

Figure 31 shows the modified or adapted interface of the MyUI home page.

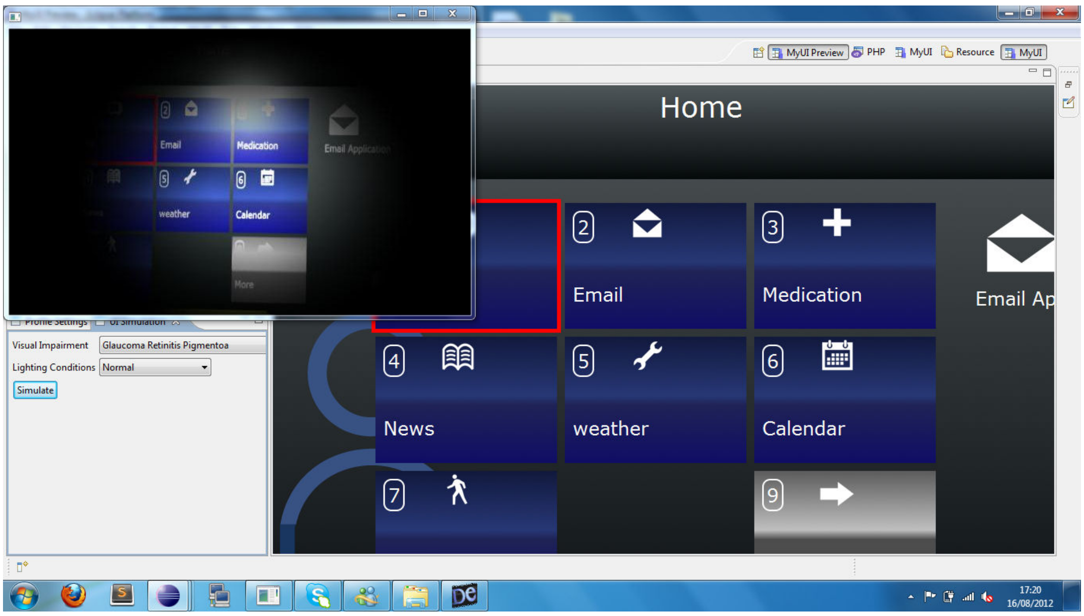


Figure 30. MyUI home page and simulation

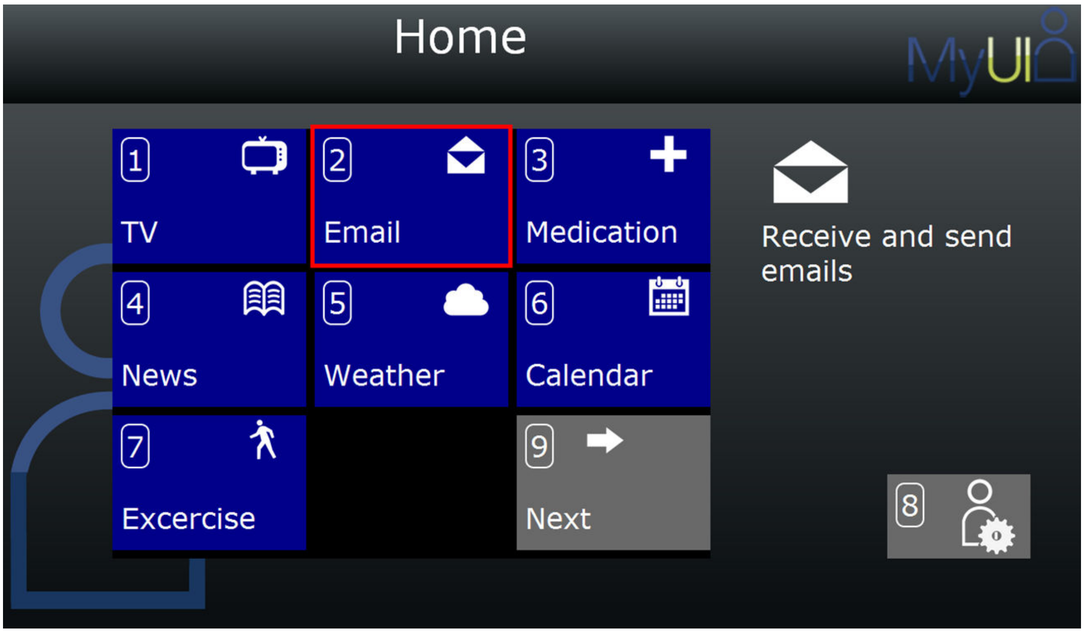


Figure 31. Adapted Interface in MyUI system

7 Implications and limitations of simulation & user modelling

User trials are always expensive in terms of both time and cost. A design evolves through an iteration of prototypes and if each prototype is to be evaluated by a user trial, the whole design process will be slowed down. Buxton [2010] has also noted that "*While we believe strongly in user testing and iterative design…… each iteration of a design is expensive. The effective use of such models means that we get the most out of each iteration that we do implement*". Additionally, it often turns difficult for developer to conduct trials with users with a wide range of abilities, which in turn reduces the scalability of the corresponding applications across different users. A good simulation with a principled theoretical foundation can be more useful than a user trial in such cases. Exploratory use of modelling can also help designers to understand the problems and requirements of users, which may not always easily be found through user trials or controlled experiments. This work show that it is possible to develop engineering models to simulate human computer interaction of people with a wide range of abilities and that the prediction is useful in designing and evaluating interfaces. According to Allen Newell's time scale of human action [figure 32, Newell, 1990], our model works in the cognitive band and predicts activity in millisecond to second range. It can not model activities outside the cognitive band like micro-saccadic eye gaze movements, response characteristics of different brain regions (in biological band [Newell, 1990]), affective state, social interaction, consciousness (in rational and social band [Newell, 1990]) and so on. Simulations of each individual band have their own implications and limitations. However the cognitive band is particularly important since models working in this band are technically feasible, experimentally verifiable and practically usable. Research in computational psychology and more recently in cognitive architectures supports this claim. We have added a new dimension in cognitive modelling by including users with special needs.

TIME SCALE OF HUMAN ACTION		
SCALE (sec)	SYSTEM	STRATUM
10^7 10^6 10^5		SOCIAL
10^4 10^3 10^2	Task Task Task	RATIONAL
10^1 10^0 10^{-1}	Unit Task Operations Deliberate Act	COGNITIVE
10^{-2} 10^{-3} 10^{-4}	Neural Circuit Neuron Organelle	BIOLOGICAL

Figure 32. Timescale of human action (adapted from [Newell, 1990])

8 Conclusions

This deliverable presents the GUIDE user model and its implementation through the simulator and a runtime user model in GUIDE core. This document describes the design improvement process and detail of the run time user model. Both the GUIDE simulator and run time user model has been validated extensively and results suggest that the adaptation generated through the user model indeed gives a better interaction experience to end users. The report also highlights the contribution of GUIDE user model towards standardization activities through EU VUMS cluster.

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