Chapter 2
User Model

Poster Boy - presenting user model at Research Council UK's meeting in Delhi

2.1 Introduction

User model can be defined as a machine-readable representation of user characteristics of a system. We have developed a user model that considers users with physical, age-related or contextual impairment and can be used to personalize electronic interfaces to facilitate human–machine interaction. We have identified a set of human factors that can affect human–computer interaction, and formulated models [2] to relate those factors to interface parameters. We have developed inclusive user model, which can adjust font size, font colour, inter-element spacing (like line

P. Biswas, *Inclusive Human Machine Interaction for India,*
Human–Computer Interaction Series, DOI 10.1007/978-3-319-06500-7_2,

spacing, button spacing, etc.) based on age, gender, visual acuity, type of colour blindness, presence of hand tremor and spasm of users. The model is more detailed than GOMS model [9], easier to use than cognitive architecture-based models [1, 14], and covers a wider range of users than existing user models for disabled users. The user profile is created using a web form and the profile is stored in cloud. Once created, this profile is accessible to the user irrespective of application and device.

The user modelling process started with a survey on users with physical and age related impairment. The survey was not exhaustive but still found out requirements and problems of elderly users, while using existing electronic systems. We formulated a user model to solve a few of these issues. The user model took help from our previous work on inclusive user modelling. This new user model is implemented like an application and device agnostic web service. We have worked with different development teams to integrate this user model into their applications. In parallel we conducted user trials to validate the user model. Finally, we were able to integrate this user modelling web service with a few applications and conducted user trial to evaluate the efficacy of the adaptive system.

2.2 User Modelling Framework

The user survey was conducted only on 33 users. The statistical results may need further validation with more data but the subjective trends lead to specific user requirements. Almost all users preferred bigger font sizes in electronic interfaces and one-third of them had colour blindness. It was also noted that elderly users found existing computing applications complicated, but they will use a system if it is simple to learn and use. We also found a gradual decline of grip strength and active range of motion of wrist of elderly users, as they turned older, resulting reduced control of precise wrist movements.

We have tried to address these uses through the inclusive user modelling system. Existing challenges with user models are

- Having an application-agnostic format
- Compatibility to multiple applications
- Integration to multiple applications
- Relating human factor to interface parameters
- Collecting representative human factors to personalize interface

We have developed the Inclusive User Model and used it to develop a user modelling web service that can automatically adjust font size, colour contrast, line and button spacing of interfaces based on visual acuity, type of colour blindness, grip strength, active range of motion of wrist and static tremor of users. The user modelling system addressed the above issues in the following way.

The user modelling system:

- Follows a standardized user profile format specified by an EU cluster [11] and published by International Telecommunication Union [8]

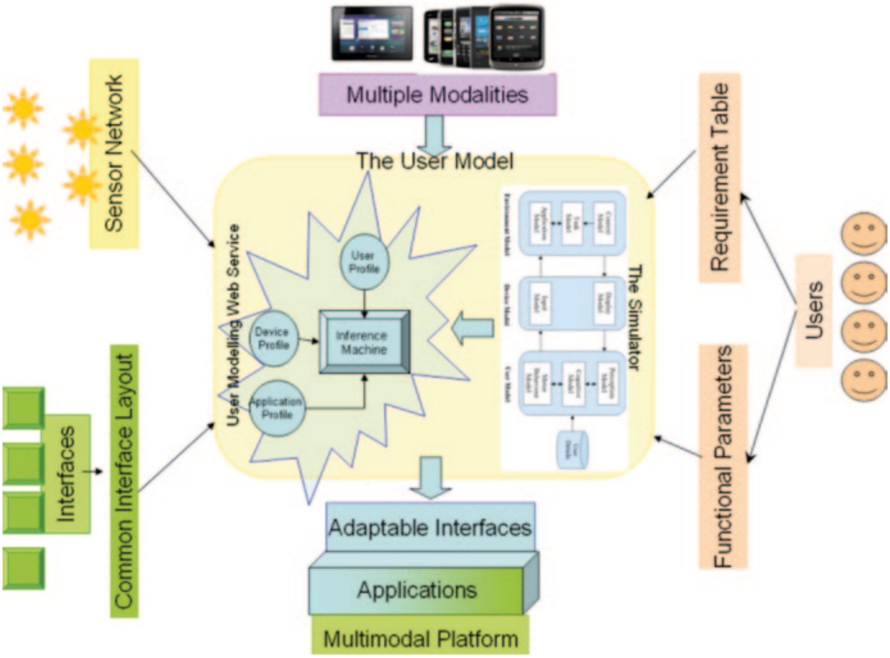


Fig. 2.1 Personalization framework

- Does not propose to change content of an interface rather specifies layout parameters, so it is easily integrated to different applications
- Can automatically convert interface parameters (like font size or button spacing) for multiple devices (e.g. TV, computer, laptop, mobile phone etc.) by assuming a viewing distance for different devices and taking the screen resolution as input parameter [6]
- Has investigated details of visual, auditory and motor functions of humans and is developed through extensive user trials to relate human factors to interface parameters [2–6]

Figure 2.1 illustrates a diagram of the personalization framework. The framework takes input about users' functional parameters (like visual acuity, colour blindness, short-term memory capacity, first language and dexterity level) and subjective requirements. These requirements are fed into the Inclusive User Model that consists of perception, cognition and motor-behaviour models. The Inclusive User Model 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 (ROMW) w will use a pointing device.

Figure 2.2 shows an example of the output from Inclusive User Model. Figure 2.2a shows the original interface. Figure 2.2b shows the perception and probable cursor trace for a user with protanopia colour blindness, early stage of dry macular degeneration and Parkinson's disease. The colour contrast of Fig. 2.2b is

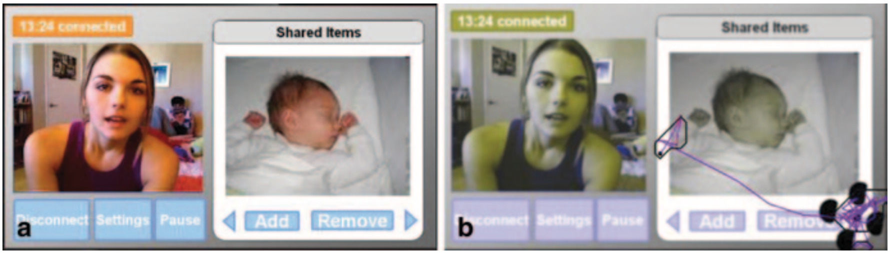


Fig. 2.2 Example of the simulator. **a** Original interface. **b** Simulated interface

changed to simulate effect of colour blindness. The black spots and overall blurring is resulted due to simulate effect of early stage of dry macular degeneration. The blue (gray in B&W) line shows how the cursor will move for a person having tremor of the hand due to Parkinson's disease.

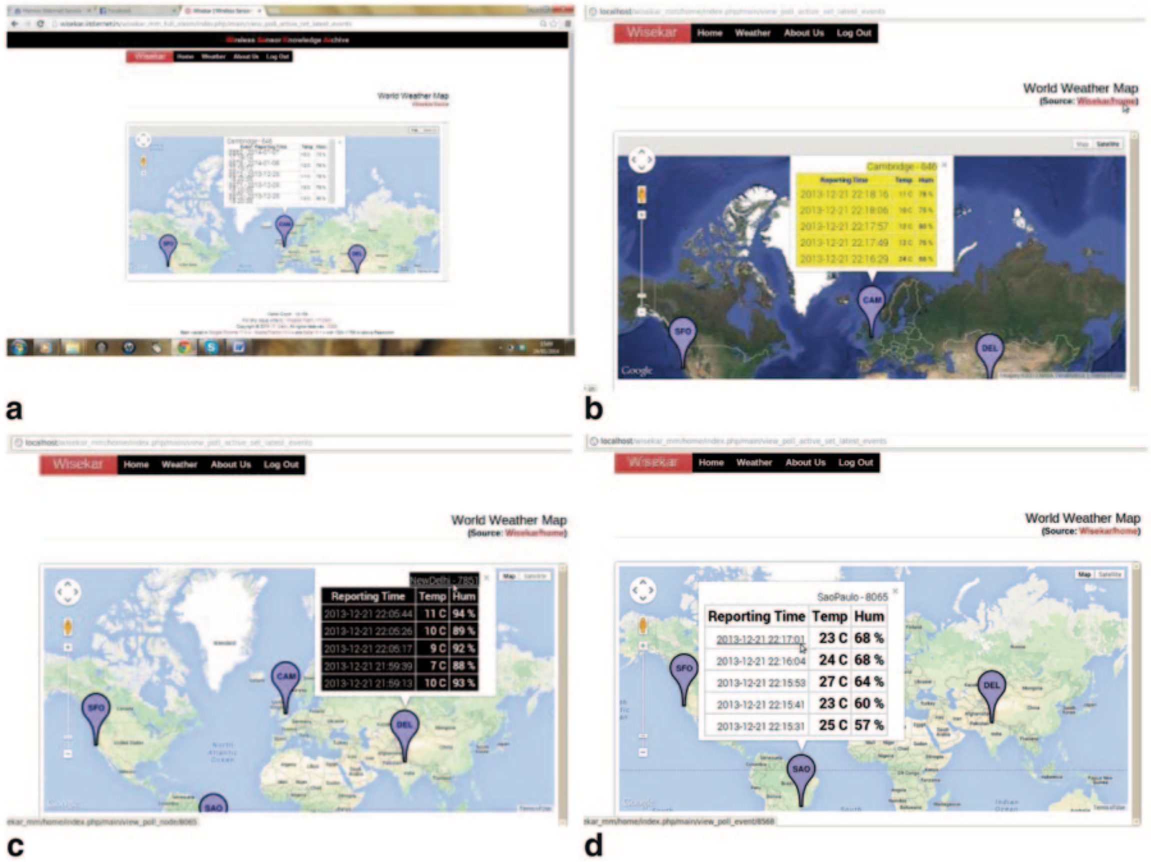
The survey described in the previous chapter generated the range of visual acuity, colour blindness, grip strength and ROMW of users. This range of values is used in Monte Carlo simulation to predict a set of rules relating users' range of abilities with interface parameters like font size, colour contrast, line spacing, default zooming level, etc. Detail on the simulator can be found in separate papers [3, 4], while a set of rules can be found in the Appendix. The rule-based system along with user, device and application profiles is stored in a cloud-based server (Fig. 2.1). The client application can access the web service using a plug-in.

The framework is integrated to applications using a client application. The client application reads data from the user model and sensor network and changes the font size, font colour, line spacing, default zooming level and so on by either selecting an appropriate pre-defined stylesheet or changing parameters for each individual webpage or standalone application.

Figure 2.3 below shows four different renderings of a weather monitoring system for people with different range of visual and motor impairments. The system is part of the WISEKAR system [16] developed at the Indian Institute of Technology, Delhi. All these figures are reporting temperature and humidity data of different cities with possible extension to show pollution data as well. The system changes the foreground colour to blue and background colour to yellow for users having red-green colour blindness (Fig. 2.3b). It uses bigger font size and turn on high-contrast for people having blurred or distorted vision due to severe myopia, macular degeneration or diabetic retinopathy (Fig. 2.3c). Finally the system also adjusts the default zooming level and line spacing, if the user has tremor or spasm in hand. A higher zooming level separates screen elements to reduce chances of wrong selection (Fig. 2.3d).

The system has also been integrated to an agriculture advisory system that promotes use of technology to increase the agricultural efficiency by providing farm-specific, crop-specific advisory to farmers. The agriculture advisory system has two components:

- The Pest–Disease Image Upload (PDIU) application is used by farmers to upload images of infested crops, while they are in the field. The uploaded images



NewDelhi - 7851

Reporting Time	Temp	Hum
2013-12-21 22:05:44	11 C	94 %
2013-12-21 22:05:26	10 C	89 %
2013-12-21 22:05:17	9 C	92 %
2013-12-21 21:59:39	7 C	88 %
2013-12-21 21:59:13	10 C	93 %

SaoPaulo - 8065

Reporting Time	Temp	Hum
2013-12-21 22:17:01	23 C	68 %
2013-12-21 22:16:04	24 C	68 %
2013-12-21 22:15:53	27 C	64 %
2013-12-21 22:15:41	23 C	60 %
2013-12-21 22:15:31	25 C	57 %

Fig. 2.3 Personalized weather-monitoring system. **a** Non Adapted. **b** Adapted for red-green colour-blind. **c** Adapted for blurred vision. **d** Adapted for blurred vision and hand tremor

are automatically sent to remotely located experts, who advise farmers about remedy. The application runs on low-end mobile phones or smart phones. It not only makes it easy for farmers who have difficulty in operating a keypad but also accommodates those suffering from poor vision or cognitive impairments.
- A web-based Dashboard system runs on a personal computer and is used by experts to advice farmers. Experts can be across all age levels, and it is, therefore, important to design a user interface that takes into account impairments of different kinds that an expert might possibly be dealing with.

Figures 2.4 and 2.5 demonstrate different rendering of the Dashboard and PDIU applications for different user profiles. This system is developed at the Rural Technology and Business Incubation Centre of the Indian Institute of Technology, Madras.

The weather monitoring system can be found at http://wisekar.iitd.ernet.in/wisekar_mm/index.php/main, while the eAgri system can be found at http://e-vivasaya.rtbi.in/aas_cambridge/login.php. Renderings similar to the above can be generated with usernames user-1, user-2, user-3, user-4, etc. In each case, the password is same as the username.

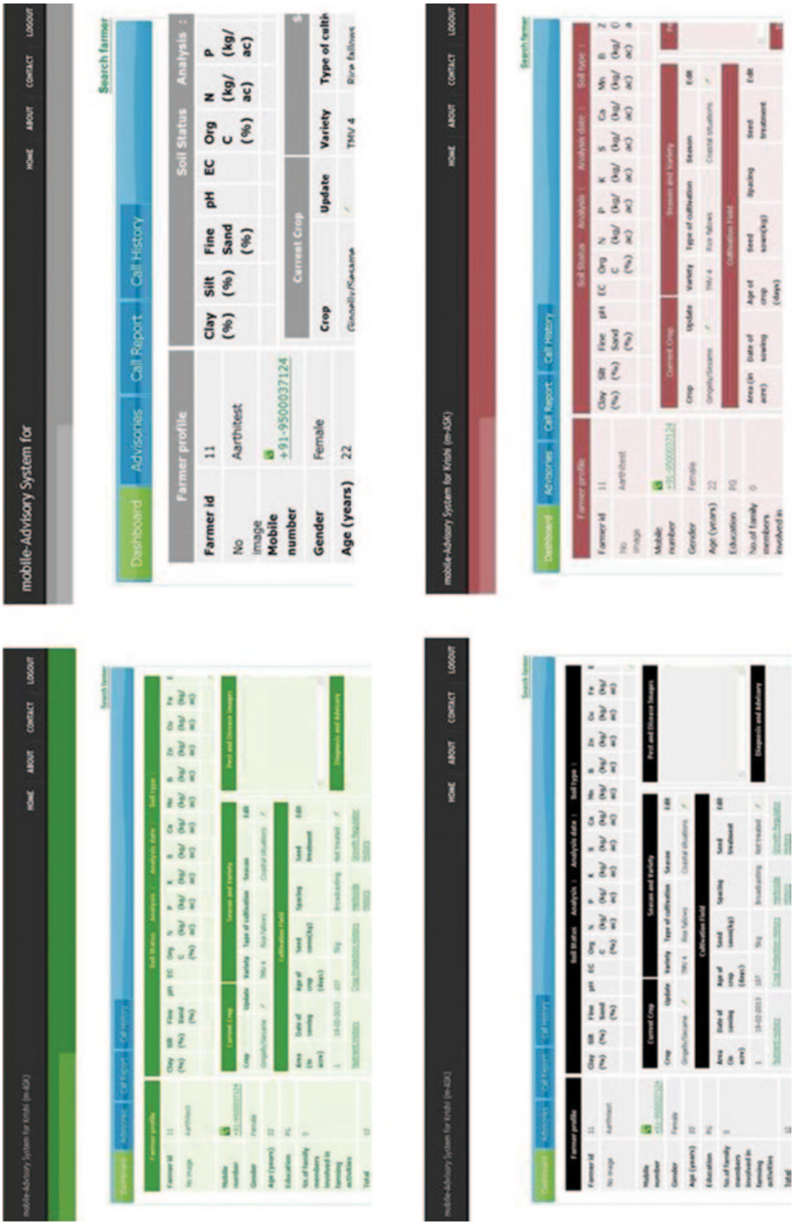
2.3 User Trials

We have conducted a series of user trials to validate the adaptive interfaces generated through the user modeling web service. The first trial [2] conducted an icon searching task involving users with age-related and physical impairment. The study was conducted on a desktop PC and a tablet computer using different organizations of icons in a screen and with and without integrating the user model. It was found that users could select icons quicker and with less error when the screen was adapted following the prediction of user model.

The second user study [5] evaluated the prediction of the user model for situational impairment using a text searching task on a tablet computer, while users were walking in a field. Again it was found that a screen adapted through the user model was quicker to use and produced fewer errors.

2.3.1 User Trial on Wisekar Weather Monitoring System

The following user trial reports a controlled experiment on a real life weather monitoring application. It compared users' objective performance and subjective preference for an adaptive and a nonadaptive versions of the weather monitoring system. We purposefully used two different devices for signing up and using the application to highlight the notion of transporting user profile across multiple devices.



mobile-Advisory System for

Farmer profile	
Farmer id	11
No image	Aarthitest
Mobile number	+91-9500037124
Gender	Female
Age (years)	22

Soil Status Analysis :

Clay (%)	Silt (%)	Fine Sand (%)	pH	EC	Org C (%)	N (kg/ac)	P (kg/ac)

Current Crop

Crop	Update	Variety	Type of culti
Gingelly/Sesame	✓	TMV 4	Rice fallows

Fig. 2.4 Different renderings of the Dashboard application

Farmer Details

Mobile Number Of Farmer*

1234567870

Farmer ID*

Farmer Details

Mobile Number Of Farmer*

1234567880

Farmer ID*

Farmer Details

Mobile Number Of Farmer*

1234567760

Farmer ID*

Fig. 2.5 Different renderings of the PDIU application

Table 2.1 List of participants

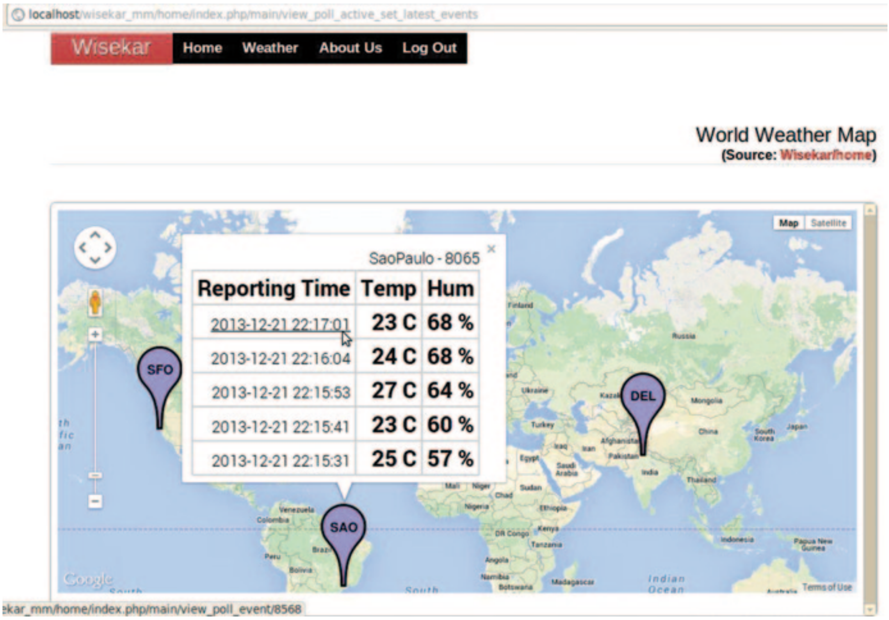
Participant	Age	Gender	Impairment
P1	60	Male	+2.5 Dioptre power
P2	57	Male	−2.5 Dioptre power
P3	59	Male	+2.5 Dioptre power
P4	42	Male	5/6 vision
P5	50	Female	+1 Dioptre power
P6	57	Male	Recently operated cataract, blurred vision
P7	59	Male	+1.5 Dioptre power

2.3.1.1 Participants

We collected data from users with age-related visual or motor impairment. Table 2.1 furnishes details of participants. The study was conducted at Delhi, India.

2.3.1.2 Material

We have used a Windows 7 HP computer with 54 cm×33 cm monitor having 1920×1080 pixels resolution to record users' performance with the weather monitoring system. We used a standard Logitech mouse for pointing. Users signed up using a HP T×2 laptop with 30 cm×20 cm screen and 1280×800 pixels resolution.



SaoPaulo - 8065

Reporting Time	Temp	Hum
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2013-12-21 22:15:41	23 C	60 %
2013-12-21 22:15:31	25 C	57 %

Fig. 2.6 Screenshots of WISEKAR weather monitoring system

2.3.1.3 Procedure

The participants were initially registered with the user modelling system using the Laptop. The sign-up page can be accessed at www-edc.eng.cam.ac.uk/~pb400/CambUM/UMSignUp.htm.

After that, participants were briefed about the weather monitoring system. The task was to report temperature and humidity of cities on a specific date (Fig. 2.6). Each participant was instructed to report temperature and humidity six times for each of adapted and nonadapted conditions. The order of adapted and nonadapted conditions was altered randomly to eliminate order effect.

2.3.1.4 Results

During the sign-up stage, we found that different users preferred different font sizes ranging from 14 to 18 points. We also noticed that one user was protanomalous colour blind and he read 45 instead of 42 in the plate 16 of Ishihara colour blindness test.

During the use of the weather monitoring system, we measured the time interval between pressing the left mouse button on the bubble with the city name (round shape in Fig. 2.7a) and reporting of the required temperature and humidity data (Fig. 2.7b).

In total, we analysed 84 tasks (42 for adapted and 42 for nonadapted). We found that users took significantly less time in adapted condition (average 8.25 s, stan-

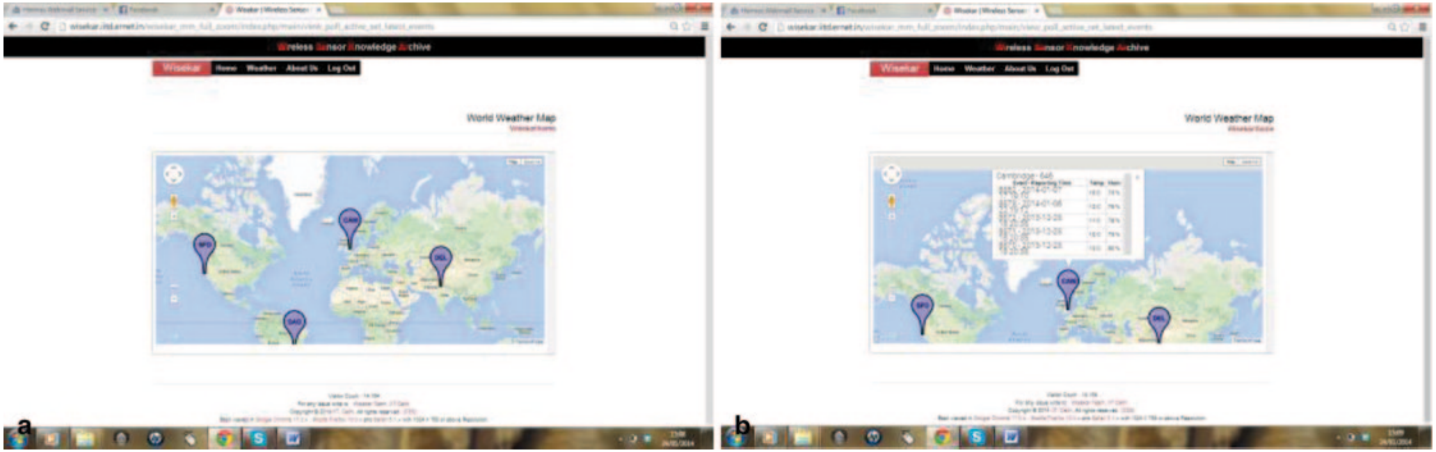

Fig. 2.7 The experimental task. **a** The screenshot shown to user for selecting city. **b** The weather reporting screen

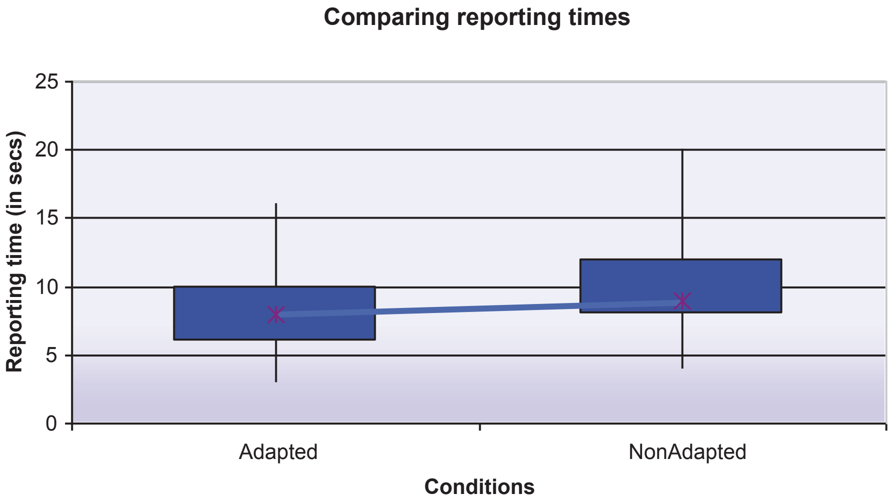

Fig. 2.8 Comparing weather reporting times

dard deviation 3.1 s) than nonadapted condition (average 9.75 s, standard deviation 3.63 s). All participants were already familiar with mouse and also practiced the system before the actual trial. So we assumed that each pointing task was independent to each other. Under this assumption, the difference is significant in a two-tailed paired *t*-test with $p < 0.05$ and with an effect size (Cohen's *d*) of 0.44 (Fig. 2.8).

Without this assumption, the difference is significant in Wilcoxon signed-rank test ($Z = -2.1$, $p < 0.05$).

We conducted a subjective questionnaire to understand users' subjective preference. All users noticed bigger font and preferred it. One user was colour-blind and he preferred the change in colour contrast too.

2.3.1.5 Discussion

The user study shows that users prefer different font sizes and colour contrast even for a simple system. The study also confirms that even for a simple text searching task, users performed and preferred an adaptive system that can automatically adjusts font size, line spacing and colour contrast. The user modeling system successfully converted users' preference across two different devices having different screen resolutions. Future studies will collect data from more users and will use more complicated tasks than the present study.

2.3.2 User Trial on PDIU Agriculture Advisory System

The following study aimed to improve the PDIU interfaces by recording interaction patterns and then analysing task completion times and wrong key presses by users. Based on the analysis, we recommend a few changes in the interface and application logic to facilitate users' interaction. The study is not a comparison between adaptive and nonadaptive interface, rather it is an overall external validity test of the adaptive PDIU system. This last study is described in the following sub-sections.

2.3.2.1 Participants

We collected data from five young users (age range 24–40 years) and five elderly users (age range 56–65 years) from Mandi. They were all male, related to farming profession and use low-end mobile phones. Young users were educated above matriculation level. One of the young users needed big font size and one had protanopia colour blindness. Elderly users' education levels vary from high school to matriculation. All elderly users preferred biggest text size and two had colour blindness. They can all read English words used in the PDIU interfaces. The study was conducted at Mandi, India.

2.3.2.2 Material

The study was conducted on a Nokia 301 mobile phone.

2.3.2.3 Procedure

The task involved taking photographs of three leaves arranged on a desk using the PDIU application. At first, they were registered to the application. The system then asked their preferred font size and conducted the Ishihara colour blindness test [5] using plate number 16. Based on their response, the application adapted itself, and users were asked if they found the screen legible. Then they were demonstrated the task of taking photographs and after they understood it, they were requested to do the same. The experimenter recorded a video of the interaction. During the task, users needed to go through the screenshots shown in Fig. 2.9. The sequence of actions were as follows:

1. Select PDIU from PDIU home screen (Fig. 2.9a).
2. Scroll down to Open Camera under Image 1 (Fig. 2.9b).
3. Select OpenCamera and take a photograph.
4. Scroll down to Open Camera under Image 2 (Fig. 2.9b).
5. Select OpenCamera and take a photograph.
6. Scroll down to Open Camera under Image 3 (Fig. 2.9c).

Mobile Number Of Farmer*
1112223111

Fig. 2.9 PDIU interfaces used in the study. **a** PDIU home screen. **b** Open camera screen. **c** Menu screen

7. Select OpenCamera and take a photograph.
8. Press Menu (Fig.. 2.9c).
9. Scroll Down to Save option (Fig. 2.9c).
10. Select Save (Fig. 2.9c).

After they completed the task, we conducted a general unstructured interview about their farming experience and utility of the system.

2.3.2.4 Results

The following graphs (Figs. 2.10 and 2.11) plot the task completion times for the operations involving taking three pictures and saving them. In these figures, C1–C5 stands for young participants while P1–P5 stands for their elderly counterpart. An one factor ANOVA found a significant effect of type of tasks among all ten participants ($F(3, 36) = 4.05$, $p < 0.05$). Users took only 21.9 s on average to record the first image while they took 51.2 s on average to record the second image, 48.4 s on average to record the third image and 50.7 s on average to go to the Menu and press Save button.

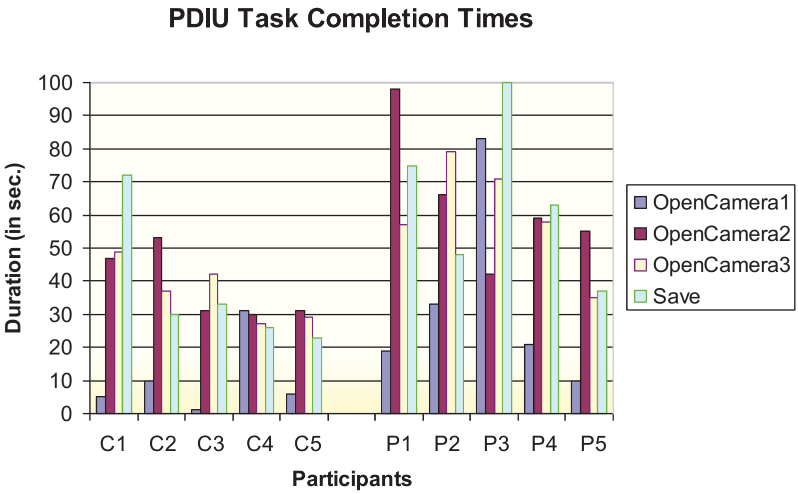

Fig. 2.10 Task completion times for participants

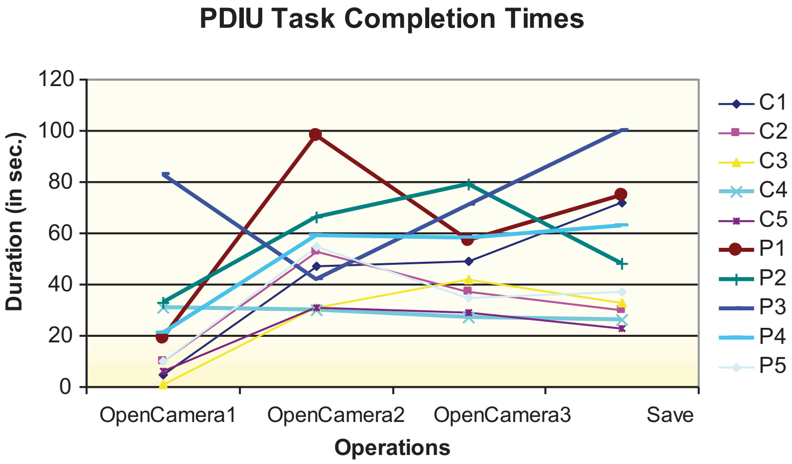

Fig. 2.11 Task completion times for each operation

We also analysed all instances of wrong key presses and Table 2.2 lists them with respect to each participant. In Table 2.2, C1–C5 stands for young participants, while P1–P5 stands for their elderly counterpart.

During the open structured interview, it emerged that they belonged to different sections of the society. They were farmers, landlords, part-time farmers of their ancestral agrarian land pursuing another profession like bus driving. They mostly harvested crops like corn, maize, bajra, wheat, etc. One of their major problems was

Table 2.2 Lists of wrong selection

Participants	Wrong key presses
C1	Went back from OpenCamera2 to OpenCamera1, scrolled up instead of down, recovered himself
	Cancelled Save option was confused but then recovered and finished successfully
C2	Pressed middle button to select the PDIU in home screen
	Selected OpenCamera1 second time instead of scrolling to OpenCamera2
C3	No wrong key press
C4	Scrolling up instead of scrolling down before reaching OpenCamera buttons
C5	Pressed Submit instead of selecting Save had trouble between selection and scroll down buttons
P1	Scrolling up instead of scrolling down before reaching OpenCamera buttons
	Pressed Back button instead of Selecting OpenCamera2
	Pressed Back button again in the PDIU home screen
	Pressed Back button again instead of Selecting OpenCamera2
	Could not scroll down to Save button in Menu items
P2	Pressed middle button of Scroll Button instead of selecting Capture in OpenCamera2
	Pressed Menu instead of going to OpenCamera3
P3	Pressed Back button in PDIU Home Screen
	Pressed Back button from the OpenCamera Screen
	Pressed Back button again from the OpenCamera Screen
	Pressed Left button instead of Middle button in one system message screen
	Pressed OpenCamera1 second time instead of scrolling down to OpenCamera2 button
	Pressed Back button instead of capturing image in OpenCamera3
	Scrolled up to OpenCamera2 from OpenCamera3
	Scrolled down from Save button but then get back to Save button
P4	Pressed middle button instead of Capture button in OpenCamera2
P5	No wrong key press

the quality of grains. One of them reported problem with harvesting corn, which often suffered from disease resulting in white ends and less grain than usual. Another one complained about wheat, which suffered from a disease causing dried stalks. They face massive problems in farming, as they do not get enough modern equipment for harvesting good quality crops. One of them reported about a help centre in their capital town, but it was nearly a hundred kilometers away from their farming place with no good public transportation available. So they hardly could get help from them.

2.3.2.5 Discussion

The farmers found the system useful and the interfaces were legible and comprehensible to them. However some of them, especially the elderly ones, faced problem in scrolling and recovering from error. It seemed to us, a simpler interface will be more useful to the elderly users. Based on the study and list of errors, we propose the following recommendations.

a. Initial focus on OpenCamera Screen

This initial focus can alleviate a few scrolling errors, as users will understand that they need to scroll down to select the open Camera buttons.

b. Only one OpenCamera button with automatic Save option

The ANOVA shows that users were significantly slower in taking the second or third photograph and saving them. If there is only one OpenCamera button which automatically saves or submits the picture, a lot of scrolling errors can be avoided and the overall task completion time will also reduce significantly.

c. Confirmation of Back action in middle of interaction

We found users were often confused if they pressed the Back button. It may be useful to add a confirmation dialog if they press the Back button in the middle of taking a photograph or saving it.

d. Overridden buttons while capturing images

Users pressed the middle button to capture image, which is a common feature in most mobile phones with a camera. It will be a good idea to let users do so making the system more intuitive.

2.4 Related Work

This section presents a brief overview of user models developed for people with physical and age-related impairment. The EASE tool [13] 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 [12] measured the difference between able-bodied and motor-impaired users with respect to the Model Human Processor (MHP) [9] 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 [17] used ACT-R cognitive architecture [1] 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 [1]. The technique is interesting but their model still needs rigorous validation through other tasks and user communities. The CogTool system [10] 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. Quade's [15] simulation uses a probabilistic rule-based system to predict the effect of sensory or motor impairment on design, but it does not model the detail of perceptual and motor abilities like our simulation system. The probabilistic rule-based system does not seem to be validated for users with age-related and different types of physical impairment (visual, hearing and motor) like our system. User model-based interface personalization is mainly explored in the domain of content personalization and developing intelligent information filtering or recommendation systems based on user profiles. In most of those systems, content (or information) is represented in a graph like structure (e.g. ontology or semantic network) and filtering or recommendation is generated by storing and analyzing users' interaction patterns. Little research work has been done beyond content personalization. The SUPPLE project [7] personalizes interfaces mainly by changing layout and font size for people with visual and motor impairment and also for ubiquitous devices. However, the user models do not consider visual and motor impairment in detail and thus work for only loss of visual acuity and a few types of motor impairment. The AVANTI project [18] provides a multimedia web browser for people with light or severe motor disabilities, and blind people. It distinguishes personalization into two classes—static adaptation which is personalization based on user profile and dynamic adaptation that is personalization following the interaction pattern (e.g. calculating error rate, user idle time etc., from usage log) with the system.

The lack of a generalized framework for personalization of users with a wide range of abilities affects the scalability of products as the existing systems work only for a small segment of the user population. For example, there are numerous guidelines [19] and systems for developing accessible websites but they are not always adequate to provide accessibility. Moreover designers often do not conform to the guidelines while developing new systems and design non-inclusive applications. It is also difficult to change existing systems to meet the guidelines. There are a few systems (e.g. IBM Web Adaptation Technology, AVANTI Web browser; 18) which offer features to make web sites accessible, but either they serve a very special type of user (motor-impaired for AVANTI) or there is no way to relate the inclusive features with the particular need of users.

2.5 Conclusions

This chapter presents an application of a user modeling system that is used to store a user profile online and uses it to adapt user interfaces across different applications running on different devices. The detail of the user model itself was published earlier. This chapter describes the integration of the user modeling system with multiple applications and reports a user trial to validate the adaptive system. The user model also follows a standardized format to store the profile, so that it can be easily integrated to multiple applications developed by different development teams. Our user studies confirm that systems adapted by the user modeling system are preferred by users and it also statistically significantly reduces task completion times.

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http://www.springer.com/978-3-319-06165-8

Inclusive Human Machine Interaction for India
A Case Study of Developing Inclusive Applications for the
Indian Population
Biswas, P.
2014, XV, 90 p. 73 illus., Hardcover
ISBN: 978-3-319-06165-8