VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

Eglė RADVILĖ

NATURAL USER INTERFACE USABILITY RESEARCH IN CONTEXT OF CURVED DISPLAYS SYSTEMS

DOCTORAL DISSERTATION

TECHNOLOGICAL SCIENCES,
INFORMATICS ENGINEERING (07T)

VGTU LEIDYKLA TECHNIKA
Vilnius TECHNIKA 2015

Doctoral dissertation was prepared at Vilnius Gediminas Technical University in 2010–2015.

Supervisor

Prof. Dr Habil. Antanas ČENYS (Vilnius Gediminas Technical University, Informatics Engineering – 07T).

The Dissertation Defense Council of Scientific Field of Informatics Engineering of Vilnius Gediminas Technical University:

Chairman

Prof. Dr Olegas VASILECAS (Vilnius Gediminas Technical University, Informatics Engineering – 07T).

Members:

Prof. Dr Habil. Romualdas BAUŠYS (Vilnius Gediminas Technical University, Informatics Engineering – 07T),

Assoc. Prof. Dr Arnas KAČENIAUSKAS (Vilnius Gediminas Technical University, Informatics Engineering – 07T),

Prof. Dr Habil. Vincas LAURUTIS (Šiaulių University, Informatics Engineering – 07T),

Assoc. Prof. Dr Raimundas MATULEVIČIUS (University of Tartu, Estonia, Informatics Engineering – 07T).

The dissertation will be defended at the public meeting of the Dissertation Defense Council of Informatics Engineering in the Senate Hall of Vilnius Gediminas Technical University at 1 p.m. on 20 November 2015.

Address: Saulėtekio al. 11, LT-10223 Vilnius, Lithuania.
Tel.: +370 5 274 4956; fax +370 5 270 0112; e-mail: doktor@vgtu.lt

A notification on the intend defending of the dissertation was send on 19 October 2015.

A copy of the doctoral dissertation is available for review at VGTU repository http://dspace.vgtu.lt and at the Library of Vilnius Gediminas Technical University (Saulėtekio al. 14, LT-10223 Vilnius, Lithuania).

VGTU leidyklos TECHNIKA 2340-M mokslo literatūros knyga

ISBN 978-609-457-852-6

egle.radvile@vgtu.lt

VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS

Eglė RADVILĖ

NATŪRALIOS VARTOTOJO SĄSAJOS TAIKYMO TYRIMAI LENKTŲ EKRANŲ SISTEMOSE

DAKTARO DISERTACIJA

TECHNOLOGIJOS MOKSLAI,
INFORMATIKOS INŽINERIJA (07T)

Vilnius LEIDYKLA TECHNIKA 2015

Disertacija rengta 2010–2015 metais Vilniaus Gedimino technikos universitete.

Vadovas

prof. habil. dr. Antanas ČENYS (Vilniaus Gedimino technikos universitetas, informatikos inžinerija – 07T).

Vilniaus Gedimino technikos universiteto Informatikos inžinerijos mokslo krypties disertacijos gynimo taryba:

Pirmininkas

prof. dr. Olegas VASILECAS (Vilniaus Gedimino technikos universitetas, informatikos inžinerija – 07T).

Nariai:

prof. habil. dr. Romualdas BAUŠYS (Vilniaus Gedimino technikos universitetas, informatikos inžinerija – 07T),

doc. dr. Arnas KAČENIAUSKAS (Vilniaus Gedimino technikos universitetas, informatikos inžinerija – 07T),

prof. habil. dr. Vincas LAURUTIS (Šiaulių universitetas, informatikos inžinerija – 07T),

doc. dr. Raimundas MATULEVIČIUS (Tartu universitetas, Estija, informatikos inžinerija – 07T).

Disertacija bus ginama viešame Informatikos inžinerijos mokslo krypties disertacijos gynimo tarybos posėdyje 2015 m. lapkričio 20 d. 13 val. Vilniaus Gedimino technikos universiteto senato posėdžių salėje.

Adresas: Saulėtekio al. 11, LT-10223 Vilnius, Lietuva.
Tel.: (8 5) 274 4956; faksas (8 5) 270 0112; el. paštas doktor@vgtu.lt

Pranešimai apie numatomą ginti disertaciją išsiųsti 2015 m. spalio 19 d.

Disertaciją galima peržiūrėti VGTU talpykloje http://dspace.vgtu.lt ir Vilniaus Gedimino technikos universiteto bibliotekoje (Saulėtekio al. 14, LT-10223 Vilnius, Lietuva).

Abstract

Continuous development of information technologies makes us review existing rules and recommendations designed to improve the efficiency of IT use, to ensure optimal working conditions for the users, to increase productivity, security and to protect human health.

Relevant researrch in the field of computer engineering is performed in the dissertation. The thesis analyzes natural user interfaces and their usability (efficiency, productivity and satisfaction with witch a particular user can reach specific goals in a specific environment) for performing of various functions. This dissertation examines factors, which determine efficiency of usability, and how efficiency is influenced by a curved display. The problem is relevant and the raised goal and objectives are new from the point of view of science. First of all, the thesis examines how to improve working conditions by developing graphical user interface of the information systems. Secondly, the influence of information submission to human, while one is performing task and specific domain tasks using graphical user interface, is examined. As there is no common opinion on how to create natural user interfaces and there is no definite set of parameters which determine the efficiency of usability, performed experimental research is an important contribution to the solution of these problems.

Reziumė

Informacinių technologijų nuolatinis vystymasis verčia peržiūrėti galiojančias taisykles bei rekomendacijas, kuriomis siekiama efektyvinti IT panaudojimą, užtikrinti optimalias vartotojų darbo sąlygas, didinti darbo našumą, saugumą bei tausoti žmogaus sveikatą.

Disertacijoje šia tema pateikti aktualūs bei svarbūs informatikos inžinerijos tyrimai. Darbe yra tiriamos natūralios vartotojų sąsajos ir jų panaudojamumas (efektyvumas, našumas ir pasitenkinimas, su kuriuo konkretus naudotojas gali pasiekti konkrečių tikslų konkrečiose aplinkose) funkcijų atlikimui. Disertacijoje nagrinėjami faktoriai, kurie lemia panaudojamumo efektyvumą ir kaip efektyvumą įtakoja lenktas ekranas. Nagrinėjama problema yra aktuali, o iškeltas tikslas bei uždaviniai yra nauji moksliniu požiūriu. Darbe visų pirma, nagrinėjama kaip pagerinti darbo sąlygas tobulinant informacinių sistemų naudotojo grafinę sąsają. Antra, tiriama informacijos pateikimo įtaka žmogui atliekant užduoties ir srities lygio (angl. „Task and Domain", CIM) užduotis, naudojant vartotojo grafinę sąsają. Kadangi iki šiol nėra vieningos nuomonės, kaip reikėtų kurti natūralias vartotojo sąsajas ir nėra nustatyto vieningo rinkinio parametrų, kurie lemia panaudojamumo efektyvumą, atlikti eksperimentiniai tyrimai yra svarus indėlis į šių problemų sprendimą.

Notations

Symbols

$A1$, A_n	–	variables from formula (distance)
$D1$, D_n	–	variables from formula (distance)
D_{dp}	–	two dimensional projection distance
D_{le}	–	screen plane space distance
D_s	–	three dimensional distance
ID	–	the index of difficulty
L	–	screen width measured in meters
R	–	screen width measured in pixels
T_0, T_1	–	depicted points
X_1, X_0	–	coordinates from display
α	–	the angle α (measured in radians)

Abbreviations

CIM	–	Computation-Independent Model
EEG	–	Electroencephalography
CRF	–	Cameleon Reference Framework
EUI	–	Environment User Interface
GUI	–	Graphical User Interface
HCI	–	Human Computer Interaction
HUI	–	Human Interface
MDA	–	Model-Driven Architecture
MDD	–	Model-Driven Development
NUI	–	Natural User Interface
OLED	–	Organic Light Emitting Diode
OOUI	–	Object Oriented User Interface
PIM	–	Platform Independent Model
PSM	–	Platform Specific Model
TFR	–	Time Frequency Representations
UI	–	User Interface
UID	–	User Interface Design

Contents

Introduction

The Investigated Problem

Development of the user interface (UI) has become a time consuming and expensive process. Commonly, the graphical user interface (GUI) of an interactive system represents about 48% of the source code, requires about 45% of the development time and 50% of the implementation time, and covers 37% of the maintenance time (Myers, Rosson, 2000). These figures are evaluated in the early nineties, increases dramatically with new methods of interaction (conditions of voice, gestures, different sizes of screen), resulting in additional requirements (Petrasch 2007). In order to optimize time creation costs of UI needed to address challenges of interaction methods (Meixner et al 2014).

As new technology of curved monitors becomes widely used in workplaces, there is a need to determine how to design user interface displayed in such monitors so that the new technology could meet expectations of its usability (efficiency with which a particular user can solve specific tasks in specific environments). In this context the old technology is understood as a flat display and user interface rules for designing.

The new technology – curved display and expanded user interface rules for the interface design are presented in Fig. 0.1.

At the moment manufacturers of monitors do not have clear arguments to prove that the curved screens are better suited while dealing with heterogeneous CIM class tasks than the flat screens and are preferable for advanced users. In the absence of the method allowing reasonably choose a curved monitor of defined dimensions for specific heterogeneous CIM class tasks tt is more technological progress for itself.

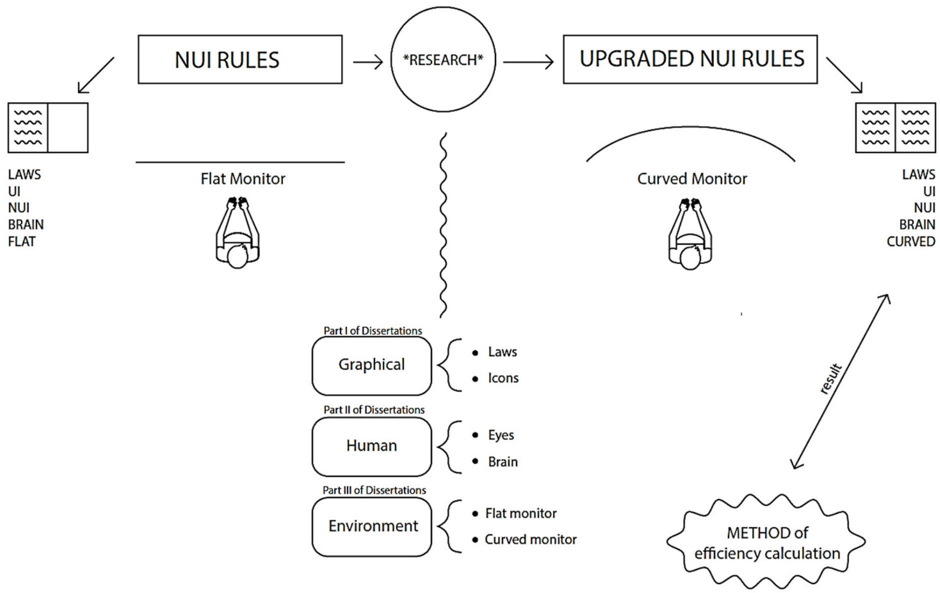


Fig. 0.1. A Visualization of the Research

Importance of the Thesis

In the face of technological leap, the same natural user interface rules are used for large curved screens and for middle-sized flat screens while such factors as a distance and time to achieve result or the degree of user's motivation to complete a task are not strictly considered. The main focus is on the physical screen parameters such as size, resolution and form. Designing time-critical graphical interface systems and assessing inaccurately natural user interface features may cause major use problems, which, in turn, may have negative effects especially for health. In specific applications for example aviation and autopilot equipment control these negative effects crucial. Having in mind that there are additional factors in usage of large curved screens, which influence the usability of natural user interface, it is necessary to explore rules in use and to expand them.

The Object of Research

The Object of Research is the efficiency measurement rules of natural user interface.

The Goal of the Thesis

The Goal of the Thesis is to expand efficiency measurement rules of natural user interface for designing the interface in curved monitors.

The Tasks of the Thesis

The following objectives were raised to achieve the goal of the thesis and to solve the scientific problem:

1. Perform literature analysis on the specifics of the curved displays and analysis of the application of natural user interface in both flat and curved displays;
2. Determine efficiency measurement rules of natural user interface and its dependence on empirical coefficients of Fitts' Law;
3. Expand efficiency measurement rules of natural user interface and propose a functional method on their basis to determine NUI efficiency of a curved display;
4. Evaluate feasibility and efficiency of the method, performing the research of the application case.

Research Methodology

These research methods are applied in the thesis:

- Observational evaluation (Eng. "Observational Evaluation"):
  - Atribute Testing (ISO 9241-8);
  - Effectiviness Testing (ISO CD 9241-13/16);
  - Observational method – CLCIK interaction.
- Heuristic evaluation ("Cognitive Walkthroughs"):
  - REACTION interaction.

- Evaluation of user behavior:
  - Specialized hardware and software (brain wave scanners (“Brain computer interface technology “and “Mind wave”);
  - Specialized hardware and software (eye reaction readers “Mirametrix”);

Importance of Scientific Novelty

The main scientific innovation of the thesis is extensive efficiency measurement rules of natural user interface for interface design in the environment of curved monitors. Their application in the early phase of user interface design (UID) is one of the ways to cope with time and cost challenges and reduce all the efforts involved in the chain which is needed to design UI ensuring the quality of UI. Also new are the following results:

- The most efficient plane for particular UI can be defined applying an extensive set of efficiency measurement rules of natural user interface. It is thus possible to calculate advantage of the same user interface, by using the plane of examined type or comparing it with the other (two dimensional projection, screen plane, three dimensional space).
- The definition of the back plane is used for the first time in the context of curved displays. It refers to situation when features of the user interface are calculated projecting the image behind the plane of the screen. This projection plane enabled to reveal imperfection of hardware calculation and recalculation mechanism was created. It can be used with the above mentioned equipment for more precise evaluation of the parameters of user interface of a curved screen (GUI).
- For the first time in the context of natural user interface brain wave activity of 2-4 years old children using curved and flat displays were examined. Human brain wave activity is related with the parameters of user interface. The authorization is given for this research by the Lithuanian Committee of Bioethics. Following this authorization Committee began to consider issues of human information security.
- Samsung Lithuania gave the first curved screen in Lithuania to perform experiments (54.6" Measured Diagonally OLED Samsung).

These results and their wide scope of use allow to state that work is scientifically innovative.

Practical Significance of Achieved Results

Using upgraded NUI rules, efficiency of the task performace can be calculated. This allows the UI designers to determine and analyze interactive advantage of software from a more high level rather than starting immediately address challenges of specific design. It would enable the designers to focus on more important aspects in their work, not to be confused with the details of implementation.

Extended rules as well as obtained intermediate results can influence software manufacturing process. Applying improved rules while developing software it is possible to predict quality and required time of action of a user, i.e. final result. As a result it is possible to increase user's satisfaction. Obtained results are particularly relevant when several large, curved, interconnected high resolution screens are used for the information processing by the user. Spead of information processing could be vital in such areas as air traffic control, war machine control, and medical surgical process. Appropriate use of research results in daily work can save hours or even days. This is particularly important for large scale production or maintenance companies.

In parallel the results could be used to investigate the development of software, possibility of managing information only with eyes (so to maximize the speed or in the case of people with disabilities), experiments and research.

The Defended Statements

The following statements based on the results of presented investigation may serve as the official hypotheses to be defended:

1. Efficiency of the task and domain of heterogeneous problems can be determined using NUI efficiency measurement rules of curved display.
2. Using curved display with specially prepared interface, efficiency of user interaction with interface (speed of the action) is higher than efficiency of user interaction with interface applied to the flat displays.
3. Human-computer interaction and ergonomic model (Fitts' Law) can be applied to measure efficiency of the curved displays when eye speed of specific system operation is used under the method proposed to determine NUI efficiency of curved display.

Approval of the Results

Research results related to the dissertation subject are published in five publications. Three of them are published in reviewed scientific journals. One in the journal that has Impact Factor. The results published in two conference proceedings and collections. The results were presented in four international and Lithuanian scientific conferences:

Publications:

Švedaitė, E. 2012. Experience Influence of Natural User Dependence on Information Distribution Patterns, *Mokslas – Lietuvos ateitis* 4(1): 35-38. ISSN 2029-2341.

Radvilė, E., Čenys, A., Ramanauskaitė, S. 2015. Electroencephalography and Eye Gaze Movement Signals' Usage for Estimation of User Interface Usability, *Elektronika ir Elektrotechnika* 21(5): 75-81. ISSN 1392-1215.

Radvilė, E., Čenys, A., Ramanauskaitė, S., Bičiūnaitė, Ž. 2015. Analysis of the pattern for icon selection and relation to positive/negative actions in desktop applications, *British journal of mathematics & computer science. Tarakeswar: Sciencedomain international* 7(6): 391-406. ISSN 2231-0851.

Conference proceedings:

Radvilė, Eglė; Čenys, A. 2015. Research of Fitts' law Characteristics using Curved Display, Electroencephalography and Eyes Tracker, *In Proceedings of the Electrical, Electronic and Information Sciences (eStream).* New York: IEEE, 1-4. ISBN 9781467374453

Radvilė, E., Čenys, A. 2015. Research: what eyes and brain reveals about visual performance in the curved display, *In Proceedings of the 14th International Conference on Perspectives in Business Informatics Research (BIR 2015).* Tartu: *Workshops and Doctoral Consortium* 1420: 173-180. ISSN 1613-0073.

International and Lithuanian scientific conferences

Radvilė, E., Čenys, A. 2015. Research of Fitts' law Characteristics using Curved Display, Electroencephalography and Eyes Tracker, *Electrical, Electronic and Information Sciences (eStream).*

Radvilė, E., Čenys, A. 2015. Research: what eyes and brain reveals about visual performance in the curved display, *BIR 2015 Workshops and Doctoral Consortium co-located with 14th International Conference on Perspectives in Business Informatics Research (BIR 2015).*

Radvilė, E., Čenys, A., Ramanauskaitė, S. 2014. Fitts Law Curve Screen Usability Testing with Children, *6th International Workshop Data Analysis Methods for Software Systems.*

Švedaitė, E. 2011. Natūralaus vartotojo potyrio įtakos priklausomybė nuo informacijos paskirstymo, *Jaunųjų mokslininkų konferencija „Mokslas – Lietuvos ateitis“.*

Dissertation Structure

The dissertation consists of introduction, four main chapters, general conclusions, references, a list of publications by the author on the topic of the dissertation and a summary in Lithuanian. The total scope of the dissertation is 106 pages, 13 equations, 14 figures and 6 tables, 75 literature review sources.

Acknowledgements

Dissertation writing years taught me the main lesson: to be able to find something when you don't know what you are looking for and to believe in what you are doing. In informatics, dissertation means not only a possible Dr., but rather it marks that you are among the best, which delve, know and feel the pulse in the field of technologies.

I am great full to my mother Birute, who 20 years ago found time to take me to computer school, and to my father Viktoras, who paid for all of this, I want to thank my incredibly technologically innovative and smart husband Lukas, IT Dr., who I met with the help of a computer and with whom, apart IT world, we have a son Kipras and going to have more beautiful children. I also want to thank my mother-in-law Janina for giving time to write when my son wanted this time the most. To my grandmother and grandfather sitting on the clouds, because they are my muses and science highlands.

From the bottom of my heart I say thanks to my supervisor Prof. A . Čenys – you are the one person in the science world, which I do not want to disappoint. Thank you for your temper, advices, time, personal lectures and optimism.

And special thanks:

- Prof. Olegas Vasilecas for psychological support and strictly deliberated criticisms – because of you the high quality could be achieved.
- IT colleges: for technical support, experiments development and current containment.
- My sister Rasa for an example that any system – political, economical or IT – can be “cracked”.
- And VGTU for a possibility to study.

1

Analysis of Literature

In this Section we review the main concepts, background techniques and challenges facing usability. The results presented in this Chapter are published in (Švedaitė 2012), (Radvilė *et al.* 2015a).

1.1. Research Questions

1. *What kind of factors influence the usability of NUI and how to predict or evaluate the usability level of designed GUI?*
2. *How could slope periphery of human qualities influence the NUI usage efficiency?*
3. *How could Fitts law be applied on curved screen and what changes have to be made to use it for NUI efficiency prediction?*

1.2. From GUI to NUI

In the decades since the first digital computers were programmed using mechanical switches and plug boards, computing and the ways in which people interface with computers have evolved significantly. Some aspects of this evolution have both been anticipated and withstood the test of time. Moore's law is an example. The law states that *the number of transistors that can be placed inexpensively on an integrated circuit will double approximately every two years*. The trend that this law describes has created opportunities for the growth of computing and its adoption into many aspects of our lives. As computers have increased in power and decreased in size and cost, new form factors have been created (e.g., smart phones, PDAs, and digital cameras), new platforms have evolved (e.g., the Internet), new infrastructures have become widely available (e.g., GPS), new industries have arisen (e.g., computer games), and new application families (e.g., spreadsheets, document processing, image creation, modification and sharing) have flourished. All of these trends have resulted in the democratization of computing as the number of people directly interacting with computers has steadily increased. This proliferation of computing has transcended national boundaries and permeated nearly all economic classes. It has changed the way people work, play, and interact with one another (Wigdor, Wixon 2011).

While the increase in computing power has been more or less continuous, the interfaces between human and computers have evolved more discontinuously. A widely held perspective is that interfaces have passed through phases. These phases are loosely defined but can be thought of as the phase of typing commands (the command line), followed by the graphical user interface (GUI). More specifically, most computers with which people interact regularly are based on the desktop metaphor (so called because windows are allowed to overlap, like paper atop a desk) and rely on a known set of user interface elements, commonly referred to as WIMP: windows, icons, menus, and pointers

Usability refers to the quality of a user's experience when interacting with products or systems, including websites, software, devices, or applications. Usability is about effectiveness, efficiency and the overall satisfaction of the user.It is important to realize that usability is not a single, one-dimensional property of a product, system, or user interface. 'Usability' is a combination of factors (F) including:

- **Intuitive design** (F(i)): a nearly effortless understanding of the architecture and navigation of the site.
- **Ease of learning** (F(l)): how fast a user who has never seen the user interface before can accomplish basic tasks.
- **Efficiency of use** (F(e)): How fast an experienced user can accomplish tasks.

- **Memorability** (F(m)): after visiting the site, if a user can remember enough to use it effectively in future visits.
- **Error frequency and severity** (F(er)): how often users make errors while using the system, how serious the errors are, and how users recover from the errors.
- **Subjective satisfaction (**F(s)): If the user likes using the system.

The user interface (UI), in the industrial design field of human–machine interaction, is the space where interactions between humans and machines occur. Going deeply in computing an object-oriented user interface (OOUI) is a type of user interface based on an object-oriented programming metaphor. In an OOUI, the user interacts explicitly with objects that represent entities in the domain that the application is concerned with. Many vector drawing applications, for example, have an OOUI – the objects being lines, circles and canvases. The user may explicitly select an object, alter its properties (such as size or colour), or invoke other actions upon it (such as to move, copy, or re-align it). If a business application has any OOUI, the user may be selecting and/or invoking actions on objects representing entities in the business domain such as customers, products or orders.

Today, developers of UI for interactive systems have to address multiple sources of heterogeneity. One of them – heterogeneity of end users: an interactive system is normally used by several different end users. End users differ with respect to their preferences, capabilities, culture (e.g., speaking different languages) and level of experience. The CRF mappings and transformations between levels of abstraction depend on the context of use. The CRF makes explicit a set of UI models (e.g., Tasks, Abstract UI, Concrete UI, and Final UI) and their relationships, to serve as a common vocabulary within the HCI Engineering community to discuss and express different perspectives on a UI.

The **Task and Domain** models correspond to the hierarchies of tasks that need to be performed on/with domain objects (or domain concepts) in a specific temporal logical order for achieving users' goals (during the interaction with the UI). Using the wording of the OMG Model-Driven Architecture (MDA) in Software Engineering, the Task and Domain level is either a Computing Independent Model (CIM) or a Platform Independent Model (PIM).

Model-Driven Development (MDD) advocates the construction of three models of the system: CIM; PIM; PSM.

The goal of the analysis phase is to produce the CIM. The goal of the design phase is to produce the PIM. The goal of the implementation phase is to produce the PSM.

The relationships between the CRF models include (Bouillon and Vanderdonckt, 2002): concretization, abstraction, translation, and reflexion.

Concretization is an operation that transforms a particular model into another one of a lower level of abstraction, until executable/interpretable code is reached.

CRF shows a four-step concretization process: **the Task and Domain level** (task model and/or the domain model) is "concretized" into an Abstract UI model, which in turn leads to a Concrete UI. A Concrete UI is then turned into a Final UI, typically by means of code generation techniques.

Orthogonal to the Task-Domain, AUI, CUI and FUI models, CRF makes explicit the context of use that may have an impact on the nature of the transformations used in the transformation process. The term "context of use" denotes an information space structured into three main models.

The **user model** includes attributes and functions that describe the archetypal person who is intended to use, or is actually using, the interactive system (e.g., profile, idiosyncrasies, current tasks and activities).

The platform model includes an integrated collection of software and/or hardware technologies and/or resource specifications that bind together the physical environment with the digital world.

The **environment** model includes spatio-temporal attributes, rules, and functions that characterize the physical and social places when/where the interaction will take place, or is actually taking place. This includes numeric and/or symbolic times and locations (e.g., in the morning, at 4 o'clock, at home, in a public space, on the move in the street, in the train or car), light and sound conditions, social rules and activities (e.g., hierarchical social organization, roles, spatial and temporal relationships).

All these methods and distribution of development UI, indeed is searching for useful and comfortable decision for user. NUI is not a natural user interface, but rather an interface that makes user act and feel like a natural. An easy way of remembering this is to change the way to say "natural user interface" – it's not a *natural* user interface, but rather a *natural user* interface (Wigdor, Wixon 2011).

1.3. Laws in Design World of Apps

Human activities are related to smart phones, tablets and systems based on Web technologies, which imperceptibly results in becoming an experienced user: the same principles are applied for using programs, the intuitive treatment of the motion sensitive display or the unconscious (logical links) perception of organizing the obtained information. Even the actions taken bring happiness.

This is not supposed to be a habit or spontaneous emotions – rather, it appears as the common work of analysts, researchers, methodologists, designers and programmers. At present, knowledge of Human Computer Interaction seems to be a vital step towards a right product; nevertheless, the way to achieve it is investigated by a Natural User Interface which is rather wide and multiplex scientific field. HCI finds itself at the crossroads of computer science, psychology, sociology, engineering and a number of other subjects. Human is a unique and tricky organism, and a computer – a complex system, and therefore their interaction is also of a complex character. HCI is aimed at understanding how the users perform actions on the tasks they need to carry out and how a computer system can facilitate the completion of tasks – to make it more efficient and comfortable. To accept the user means to perceive his/her abilities, skills, interests, etc., including memory, vision, hearing, cognitive or movement skills. It should be also realized how a computer system can help the user and what method of the interaction between the system and human is the best one. The employment of the computer system requires knowledge of the user's tasks, its relations with other assignments and the best ways of performance. Moreover, information about the human working environment (cultural, geographical and social) is essential (Moroz-Lapin 2008). While examining HCI, all data fall into two groups: collecting information about a person (consumption habits and needs of a specified target group) and the use of the obtained information against him/herself (relevant information is purposefully provided in the right place according to the already given targeted description of the user (human). The paper analyses the theoretical models proposed in Chapter 2 (Schelkes 2003). The models are based on the laws and their variations that have already been used in psychology for a number of years, and some of those – even for decades. They help with understanding human mind, choices, attitudes and behaviour. The application of the laws in informatics facilitates the design of interaction, assists in making it more flexible and enjoyable to the user and provides additional data with reference to which appropriate decisions can be made.

1.3.1. Fitt's and Hick-Hyman Laws

Fitts's Law

Fitts's law is a model for speed-accuracy tradeoffs used in human–computer interaction and ergonomics. The law predicts that the time required to rapidly and accurately move to a target area is a function of the ratio between the distance to the target and the size of the target: the further the user must move the mouse cursor along the object, the more effort to take the action will be embedded. The smaller is the object, the more difficult it will be to click on it, which means that the most visible and most easily clicked are the objects closest to the current position of the cursor and having a lot of target area. The worst possible object is considered to be of a very small size and the farthest one from the current position of the cursor. Designers are tend to make toolbars at the top, bottom or sides of the screen due to the edges of the monitor created by artificial boundaries. According to Fitts's law, the cursor will be placed plenty of times on these targets, because they can be easily noticed. The Law recognizes they must be provided with a huge target area.

A line around the label shows the clickable area of the button. A solution suggested on the left requires using a very small clickable area of the button. The biggest part of the space of the button remains unused, as the area around the text only is active. The further you need to move the mouse pointer to approach the clickable area of the button, the easier is to make an error. In certain cases, only the label, which, depending on the font size, may be very small, can be clicked. A solution proposed on the right allows employing the whole clickable area of the button, which makes easier clicking on it.

Hick-Hyman Law

The Hick–Hyman Law is required to make a decision when the number of possible choices increases. The Law provides that the time necessary for reaching a decision depends on the number of available choices. For example, when an airplane pilot has to react to an event, i.e. to click the panic button, Hick's Law predicts that a higher number of alternative buttons may result in the delay in making a decision before clicking the necessary button. A complex task calling for reading sentences and intensive concentration, considering three options, can be usually performed longer than a simple stimulus-response compatibility task having six options. Hick's Law is mainly applied for dealing with simple tasks having a unique answer to every stimulus. For instance, in the case of event A, click on button 1, and in the case of event B, click on button 2. The Law is less frequently applied when the complexity of the task increases (Schelkes 2003).

1.3.2. Accot-Zhai Steering Law and Gestalt Laws

Accot-Zhai Steering Law

Accot's Law is a predictive model for the time required to navigate, or steer, through a 2-dimensional tunnel that can be thought of as a path or trajectory on a plane that has an associated thickness or width where the latter one can vary along the tunnel. The goal of the steering law is to navigate from one end of the tunnel to the other as quickly as possible without touching the boundaries of the tunnel (as for the website, this is supposed to be a buying process that starts from the user's entry to the site up to the purchase of a good or service) (Faulkner 2003). Also, the steering law predicts both the instantaneous speed at which we may navigate the tunnel, and the total time required for navigating the entire tunnel. In this context, the steering law is a model for predicting human movements related to the speed and total time the user of which can operate a pointing device in the 2-dimensional tunnel on the screen thus trying to go as fast as possible from one end of the tunnel to the other and to stay within the boundaries of the tunnel.

Gestalt Laws

Gestalt Laws are the main principles of how different elements can be perceived when combined applying a certain method or sequence. Gestalt Laws may help with creating a structure and a sense of unity on the website or the user interface. The Laws can attract the user‘s attention to a certain element or a group of elements as well as assist in experiencing a sense of balance and stability. Gestalt Laws are of psychological origin, and first were introduced in the 20th century. The Laws mainly focus on how elements make the complete wholeness and must be clearly acknowledged developing systems for the users.

1.3.3. Laws of Understandings and ISO

Law of Proximity

The Law of Proximity states that the elements that are near each other seem to be perceived as a single unit, i.e. the wholeness. The Law is applicable to the website to display two sets of elements, each of which has more than one piece of content. The grouped pieces of one set are placed closer to each other (used by Google, Youtube) (Dix *et al.* 2004).

The Law of Similarity identifies that the elements similar to each other tend to be perceived as a single unit. Thus, the elements of the same colour, form or having other common characteristics are perceived as belonging to the same set. This phenomenon can be very useful for grouping elements (used by Gmail, Amazon).

Law of Closure

The Law of Closure explains why elements are recognized even if they are not complete (Faulkner 2003). This is due to prior human experience and previous knowledge of possible forms and numbers, as this is the way human mind fills in the missing pieces of the element. For instance, when a white background with rounded corners extends to the bottom of the page, we do not realize this is the end of the page, as we imagine that the content still goes on.

Law of Continuity

The Law of Good Continuation is applied in terms of both design and the content of elements. Eyes can easily and naturally follow the elements set out along a continuous line, and the elements will be perceived as a unit. Moreover, the elements that follow each other are perceived as a single unit. Website applies the law of 'good continuation' with the help of a small pointing device on the right-hand side of the page thus redirecting users' gaze.

Law of Figure and Ground

The Law of Figure and Ground describes how human perceives an object (picture or other figure) depending on the foreground and background. If the foreground is sharp, and the background is smooth and unremarkable, the shape of the object is first perceived looking at the foreground; however, the other object in the same picture can be recognized as consisting of the background. Thus, the foreground is accepted as a context. The Law is often applied for designing logos.

Law of Simplicity

The Law of Simplicity points out elements are always perceived the easiest way possible. In general, simplicity emphasizes the importance of characteristics, which can be an advantage of the website. Thus, consider simple things and focus on what is really important. Fig. 4 shows an example of the website – simplicity and purity as much as possible.

Law of Symmetry

The Law of Symmetry considers the fact that a priority is given to symmetrical rather than asymmetrical objects. Symmetrical objects associate with positive aspects such as stability, consistency and structure while the asymmetrical ones make a rather negative impression that something is wrong, something is missing or a balance is hard to achieve. Certainly, the website can never be completely symmetrical but the accepted symmetry can be given attention. Thus, symmetry does not have to be designed in accordance with the content or aesthetic elements like colour or design elements. For instance, a BBC website designer uses an abstract image of the globe in the background to create harmonious and balanced appearance.

Law of Experience

The Law of Experience explains that we can expect people will apply to the previous knowledge to perceive certain elements. A common example is related to grammar and spelling. For instance, sometimes spelling errors are invisible because the word is remembered in general and each letter is not watched carefully (Moroz-Lapin 2008). The process of creating the natural user interface involves more laws; however, they cannot be the only tools for designing systems. Also, research in terms of architecture and culture (European, American, Ukrainian and Chinese styles) is required, which becomes extremely relevant to the use of international projects. Some laws are unique, some partly overlap with each other and some are more useful for designing a website or the user interface while the others are less beneficial and can be easily customized on the contrary to others. In general, in can be concluded that HCI laws act as the basis the correct formation of which can assist other experts in the field (architects, designers, marketing profesionals, vendors) in proceeding with their work, whereas researchers and analysts will investigate newly emerging laws and search for appropriate methods of application.

ISO 9241-9

ISO 9241-9 was in Draft International Standard form in 1998 and became an International Standard in 2000. If one considers mouse evaluations in research not following the standard, throughput ranged from about 2.6 bits/s to 12.5 bits/s. On the contrary, studies conforming to the standard reported throughput from about 3.7 bits/s to 4.9 bits/s (Soukoreff and MacKenzie 2004). The data appear much more uniform and consistent. In short, ISO 9241-9 improves the quality and comparability of device evaluations.

Although several papers follow ISO 9241-9 and dozens of others use Fitts' law to evaluate non-keyboard input devices, Ware and Mikaelian published in 1987 what remains the only Fitts' law evaluation of an eye tracking system (Ware and Mikealian 1987). They used a serial Fitts' law task to test three eye tracking techniques. Task completion time was the only performance measure used. They compared eye tracking with the mouse but did not calculate or report on throughput as a performance measure. No eye tracking evaluation paper has ever been published since then using Fitts' law (or ISO 9241-9).

By following the standard and comparing throughput for eye tracking with a baseline technique (i.e., a mouse), we can determine how good an eye tracking system is. This paper is the first eye tracking evaluation conforming to ISO 9241-9.

The result of Fitts' experiments was that the speed of the movement is not limited by the muscle force; the subjects showed the same performance independent of the weight of the stylus. Instead the measured times fitted to the concept of information processing.

Beside the fact that the performance, or bit transfer, did not depend on the weight of the stylus, the bit transfer was within 8 to 12 bits/second for all tasks. This means that the human nervous system has a general limit for control tasks independent from the details of the task. Therefore it is very surprising that the International Standardization Organization ISO defined the standard ISO 9241-9 based on Fitts' law to characterize the performance of input devices. Additionally, the ISO 9241-9 does not use the a- and b-constant but defines the throughput TP which merges both values to a single one. There is a critical voice against the definition of TP (Zhai 2004). However, it is questionable whether the ISO standard makes sense at all. Seeing the performance as a property of a device is the opposite of Fitts' idea, who sees performance as a property of the nervous system. Comparing a small laptop mouse against a big desktop mouse in the context of a student exercise did not show differences in the performance. Comparing a trackball against a standard mouse device typically shows that people perform better with the standard mouse device. However, people who use a trackball for their daily work show the same performance with a trackball. This means the performance on a pointing device depends on the subject and especially on her or his training on the device. It seems that nobody uses the ISO-standard and manufacturers of mouse devices do not state a throughput value for their products.

First eye tracking evaluation conforming to ISO 9241-9 results (Zhang and MacKenzie 2007). The evaluation used throughput (in bits/s) as a measurement of user performance in a multi-directional point-select task. The "Eye Tracking Long" technique required participants to look at an onscreen target and dwell on it for 750 ms for selection. Results revealed a lower throughput than for the "Eye Tracking Short" technique with a 500 ms dwell time. The "Eye+Spacebar" technique allowed participants to "point" with the eye and "select" by pressing the spacebar upon fixation. This eliminated the need to wait for selection. It was the best among the three eye tracking techniques with a throughput of 3.78 bits/s, which was close to the 4.68 bits/s for the mouse.

1.4. Distance of the Eye Diversion and Movement

1.4.1. Diversion of Glance

Diversion of glance from one point to the center of the object of appropriate size time prediction in curved display. The curved display allows the user to understand environment more realistically, because it reminds him more of a natural field of inspection (within a certain radius around the visible world). However, such a decision is highly dependent on the curved display, a sitting position, muscle tone (hands and eyes) and so on. 2 main cases are distinguished intuitively that determine the behavior of the user while working with the curved display and its system: when the entire view of the screen gets into the user's field of vision, when the part of it does not. These two cases are connected but when the user's field of vision is smaller than the entire view of the curved display, then the time of eye jump from one point of the screen to another is hard to predict due to additional head movements. Not knowing how human eye moves from one object to another, the time cannot be assessed that can be used not only transferring glance to another location of the screen but turning the head to see it. The concern is diversion of glance from one point to the center of the object of appropriate size time prediction in the curved displays (a circular part) or screen systems that make deflection (a circular part).

According to the facts, firstly is focused on how the required time should be calculated for diversion of the user's glance in the curved display from one point to another when they are both in its field of vision. Only knowing how to predict this time, it can be applied to detect eye movements to the user's unseen location of the curved display. Even though existing discussions on whether the Fitts' law is suitable for eye movement (Drewes 2010) and limitations of Fitts' law to achieve accurate results when ID is close to zero (Welford 1960; Meyer *et al.* 1982), this law is still actually used in system usability testing and the only usability related quantitative law proved by experiments. However there are just a few papers on how Fitts' law is related to user's properties (usually medical condition) (Smits-Engelsman *et al.* 2007; Despard *et al.* 2013; Felton *et al.* 2009).

1.4.2. Time of diversion from one point of the curved display

Time of diversion of glance from one point of the curved display of user's sight in space to an appropriate size of the object in his field of vision in the curved display. The curved display is more convenient for the user, when large enough displays are used. According to the position of the user in respect of the display, the illusion of a larger visual area can be created for the user.

However, the curved display also causes some problems to graphical user interface creators. The most important of them – a created graphical image, its proportional representation is highly dependent on the curved display and the user's distance to the display. If it is not considered properly, "density" of visual data is possible observing at a larger distance than the curved display radius and observing at the closer distance than the curved display radius, image of the edges of the display becomes ”rarefied”. As visual information on the display becomes unevenly distributed to the user's review, existing eye movement fixation equipment is not able to assess accurately what exactly the user looks at on the display. This is conditioned by the fact that eye movement fixation equipment is calibrated to set marginal and central limits. As shown in Figure 1.1., marginal and central positions in the curved display (shown in red) match a two-dimensional projection of the curved display (shown in blue). The user sees a two-dimensional projection when he reviews overall view of the screen, but not its separate details. Meanwhile, the positions between them distort because of the curved display and uneven layout of density of pixels on the screen in a two-dimensional but not three-dimensional space. Only some facilities use more than 9 pixels for calibration and even those who apply 16 pixels for calibration do not take into account related disparities of the curved display. Therefore, both for eye movement fixation equipment and diversion of glance from one point to another working with curved displays, adjustment of glance, the position of cursor calculation should be used.

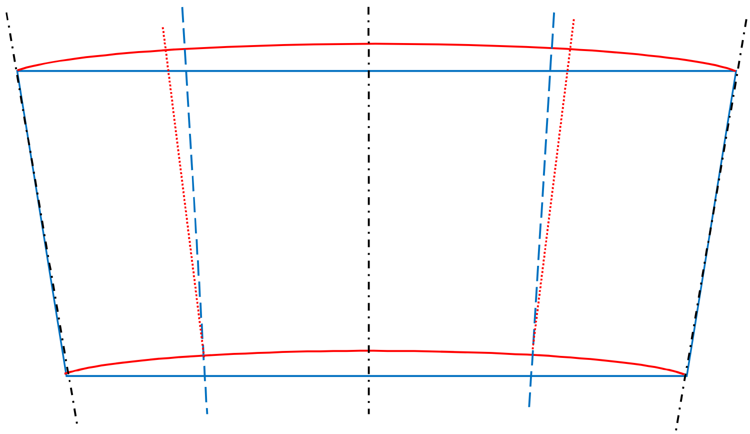


Fig. 1.1. Marginal and central positions in the curved display (shown in red) match a two-dimensional projection of the curved display (shown in blue)

It is necessary to know a radius r of the screen (measured in meters) to assess the differences of the distance between the two curved display and two-dimensional projection. As the screen is curved only in respect of x axis, differences will not be in respect of y axis. Meanwhile, knowing the width of the screen l (measured in meters), can be assessed what the angle α (measured in radians) is the curved display (1.1). It is determined comparing the width of the screen with its possible perimeter and converted into radians. The proportion between the width l of the screen and the curved display radius r is searched.

$$\alpha = \frac{l}{2\cdot\pi\cdot r}\cdot 2\cdot\pi = \frac{l}{r}\,. \tag{1.1}$$

Since it is only focused on those situations, when the entire screen is in the user's field of vision, so α should not be more than π (180o).

1.4.3. Distance between two points on the surface of the curved display (Three-Dimensional Screen)

Changes of the distance in respect of x axis on the surface of the curved display can be measured regardless of density and rarefied of visual information, because at the moment existing curved surfaces convey a created graphical two-dimensional image, transferring it to a curved surface. In cases, when the distance between two points of the screen is measured in pixels the change of x axis can be calculated simply as the difference between two points of *x* coordinates (1.2):

$$\Delta x = \left| x_1 - x_0 \right|. \tag{1.2}$$

However, if it goes to length measures (meters) it is necessary to know the width of the screen L (measured in meters) and resolution of the screen in respect of *x* axis *R* (measured in pixels). Thus, each pixel of the curved display corresponds the change of the angle α / *R*. In such case, the distance between any two depicted points T0 and T1 in respect of x axis in the curved display D_{le} (1.3) is:

$$D_{le} = l\cdot\frac{\left| x_1 - x_0 \right|}{R} = \frac{l\cdot\Delta x}{R}\,. \tag{1.3}$$

1.4.4. Distance between two points of the curved display (Two-dimensional projection)

However, working with the curved displays the user can look at the image as a two-dimensional projection of the curved display, thereby distorting the distances between two points of the screen. The user's distance from the surface of the screen has the greatest impact on these inaccuracies. If the user sits further from the screen then the width of the screen projection will be less than sitting particularly close to the surface of the screen, see Figure 1.2.

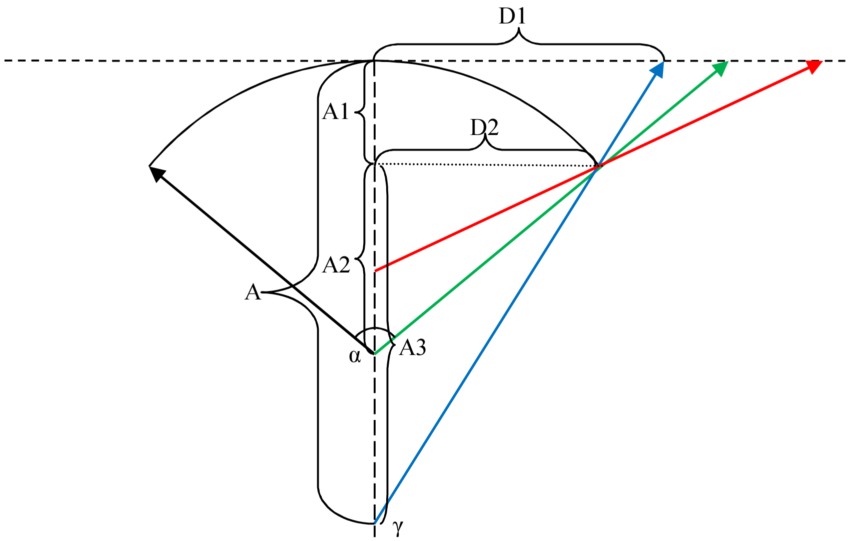


Fig. 1.2. Variables of calculation (Curved Display)

We have to take into account the distance from the screen A and properties of the curved display (radius r and bending angle of the angle α) to find out an image of the point in the curved display x coordinate projection on the plane

Based on the marking of Figure 3, the distance A2 can be calculated as cosine of the angle α / 2 (4) and D2 – as sine of the angle α / 2 (1.5).

$$A1 = \cos\left(\frac{\alpha}{2}\right) \cdot r \tag{1.4}$$

$$D2 = \sin\left(\frac{\alpha}{2}\right) \cdot r \tag{1.5}$$

Considering that $R = A1 + A2$ can be found $A2$ (1.6), on the basis of similar properties of triangles can be learnt $D1$ (1.7).

$$A1 = R - A2 \tag{1.6}$$

$$A3 = A - A1 = A - r + A2$$

$$\gamma = \arcsin\left(\frac{D2}{\sqrt{D2^2 + A3^2}}\right)$$

$$D1 = \tan(\gamma) \cdot A \tag{1.7}$$

Knowing $D1$, projection of the curved display in two-dimensional space can be determined. In that way the width l of the screen in respect of x axis the width l of the screen or the user observing from the screen A is equal to D:

$$D = 2 \cdot D1 = 2 \cdot \tan\left(\arcsin\left(\frac{D2}{\sqrt{D2^2 + A3^2}}\right)\right) =$$

$$2 \cdot \tan\left(\arcsin\left(\frac{\sin\left(\frac{\alpha}{2}\right)\cdot r}{\sqrt{\left(\sin\left(\frac{\alpha}{2}\right)\cdot r\right)^2 + \left(A - r + \cos\left(\frac{\alpha}{2}\right)\cdot r\right)^2}}\right)\right) \tag{1.8}$$

Restriction can also be clarified to the field of vision from that. The curved display must be less than α 180°, as well as the distance to the screen must be more than $A1$.

All things considered, the distance between any two depicted points T_0 and T_1 of the curved display in projection plane in respect of x axis D_{dp} is:

$$D_{dp} = \left|\tan\left(\arcsin\left(\frac{\sin\left(\frac{\frac{x_1 \cdot \alpha}{R}}{2}\right)\cdot r}{\sqrt{\left(\sin\left(\frac{\frac{x_1 \cdot \alpha}{R}}{2}\right)\cdot r\right)^2 + \left(A - r + \cos\left(\frac{\frac{x_1 \cdot \alpha}{R}}{2}\right)\cdot r\right)^2}}\right)\right) - \right.$$

$$\left.\tan\left(\arcsin\left(\frac{\sin\left(\frac{\frac{x_0 \cdot \alpha}{R}}{2}\right)\cdot r}{\sqrt{\left(\sin\left(\frac{\frac{x_0 \cdot \alpha}{R}}{2}\right)\cdot r\right)^2 + \left(A - r + \cos\left(\frac{\frac{x_0 \cdot \alpha}{R}}{2}\right)\cdot r\right)^2}}\right)\right)\right|. \tag{1.9}$$

Formula 1.9 is based on the premise that the screen will not be curved so that it forms an arc of more than 180° (in such case, the entire screen does not fit tinto the user's field of vision). It is assumed that the centre of the screen is at 0°, the distance between two points can be assessed as the difference between projections of those two points.

1.4.5. Length of the string between two points of the curved display

Although the distance between two points is carried out consistently, in the cases when a desired glance is diverse from one object to another, human eye does a bigger jump, saccade to a predictable location. Although eye saccades are primary, secondary, that is, smaller eye movements take place for glance correction but all the objects between these two points are not captured during this eye movement. It does not have any impact on the flat screens as the movement along the surface of the flat screen is the shortest. Meanwhile, human eye on the flat screen searches for the shortest way, so it moves not along the surface of the curved display but its string.

The angle β is found to determine the lenght of the string that forms between two radius of the circle, passing points of the screen – the initial *T*0 and final *T*1 where redirection of eyesight takes place (See Fig. 1.3.). As the screen is curved only in respect of *x* axis, the string is captured between *x* coordinates *x*0 ir *x*1 (1.10) of these points.

$$\beta = \alpha \cdot \frac{|x_1 - x_0|}{R} = \frac{\alpha \cdot \Delta x}{R} \tag{1.10}$$

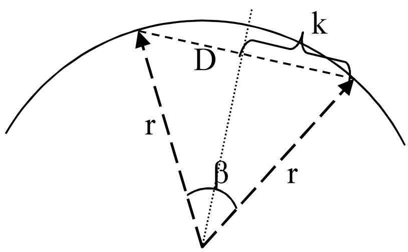


Fig. 1.3. A Calculation of Eyes Saccades

As an equilateral triangle is formed between these two radiuses and the string, it can be divided into two steep triangles and find the length of a half radius *k* and appropriately the same radius of D_s (1.11).

$$D_s = 2 \cdot k = 2 \cdot r \cdot \sin\left(\frac{\beta}{2}\right) \qquad (1.11)$$

1.5. Conclusions of Chapter

After analysis and examination of 11 LAW for NUI projecting and usability evaluation it was noticed that they outline a specific NUI usability aspect, but to get a more precise NUI usability they should be used jointly. For carrying out in this research was planned an experiment (further part of research) for noticed that user's GUI icon evaluation is influenced not only by features defined by LAW, but by other additional features too.

Graphical (GUI), Human (HUI), Environment (EUI) properties of fields could have their own usability factors, also these factors correlated with laws by coherence requirements (see Fig. 1.4).

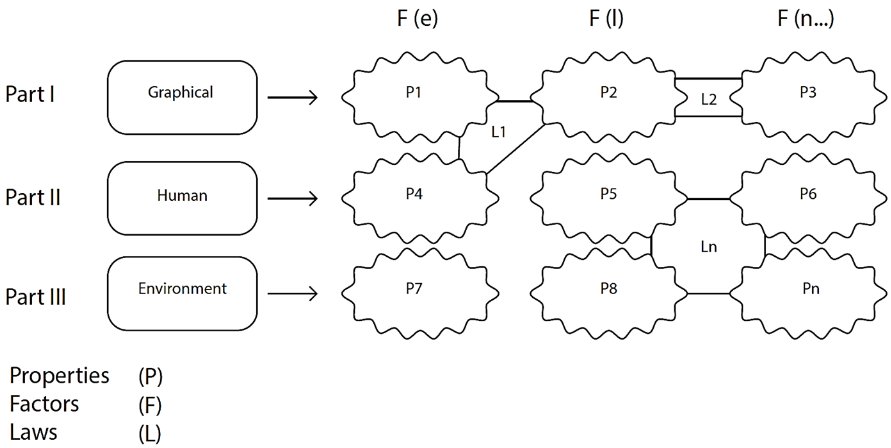


Fig. 1.4. Factors orrelation with Laws by coherence requirements

The above discussed laws allow the user to approach the creator to achieve the desired result; however, different laws under varying circumstances must be considered. An incorrect application of laws may have a negative impact.

The implementation of laws requires methodologies that justify their efficiency and, with reference to relevant parameters, should provide the obtained efficiency indexes of the natural user interface.

2

GUI: Dependence of the Impact on Information Dissemination Patterns

In this Section we review a result of we present investigation of GUI patterns and experimental part, which was to identify the key elements that influence and provided a negative experience.

The results presented in this Chapter are published in (Švedaitė 2012), (Radvilė *et al.* 2015a).

The user interface (UI) is one of the most important elements in the successful promotion of software among those applying it in practise. The user interface has to implement software functionality, to be easily applied and intuitive for different types of users. The design of a suitable UI is a challenging task and requires knowledge of Human Computer Interaction (HCI) in order to create a successful Natural User Interface (NUI), as every situation can be unique. Therefore, what is suitable for one project can be a failure for another; it requires a wide variety of knowledge to design a successful UI. The user interface designer must be sure that all important properties and psychology of the customer have been taken into account and that technical abilities to implement different elements of the user interface have been properly considered. The complexity of the task for UI design can be highlighted by the fact there is no clear, unambiguous rules of how to design a good user interface. There exist only different guidelines and proposals for how to create a suitable UI or a particular type of software for a certain group of users.

A rapid change in technologies and new HCI methods change the user's perception of UI usability. Therefore, knowledge of the NUI has to be frequently renewed; otherwise, it will lead to a failure rather than successful user interface design. Therefore, even the most useful and functional systems have to be updated in order to meet new UI tendencies and user requirements. The aim of this paper is to get more specific guidelines for improvement in natural user interface design, which will be done analyzing the properties of user's work on icon-based desktop applications thus presenting the situation observed in 2013–2014. As new ideas of UI design takes time for spreading worldwide, these guidelines should be helpful in 2015 and in the future if no drastic changes emerge in this area.

2.1. State of the Art

One of the elements used in the UI is an icon – a sign or representation that stands for something by virtue of a resemblance or analogy to it. It plays an important role in the NUI as one good icon can tell more on its purpose comparing to multiple words or even sentences used for describing the function. Therefore, some researches have been done in this area to get more data on the usage, importance and clustering of the icon (Mack *et al.* 2002) suggested that a particularly meaningful icon in displays could capture our attention, and therefore a meaning had to be added to the icon (McDougall, Curry 2004). Examined a broader context of interpretation from a cognitive psychological perspective by analyzing the effects of workload and task complexity, user preferences and aesthetics, time for day effects and user skills. The results of these works proposed additional guidelines. However, the relationship between the icon and the function is not determined by a set of well-defined syntactic and phonological rules. Icon interpretation is still ambiguous and no laws are presented to determine the quality or success of the icon among its users. It is important to find as many factors influencing the success of icon usage as possible in order to better understand this area.

The role of relationships can be noted in works by authors (Niemela, Saarinen 2000; Richards, McDougall 1999) analysed the importance of icon clustering. According to the obtained results, icon clustering allows more effective icon search as well as quicker identification of icon-function relationships. These findings are useful for designing the UI with the help of multiple icons; however, no data on designing one specific icon are given. Research on specific icon design was analyzed three visual features (colour, surround shape and icon size) and five cognitive (familiarity, concreteness, complexity, meaningfulness and semantic distance) features of the icon (Ng; Chan 2008). The results of the conducted research on colour importance do not meet with those obtained by Courtney (Courtney 1986) who proved colour was commonly used for communicating with the meaning – red for danger, green for 'go', etc. Colour conventions appear to have reasonable cross-cultural transferability in Courtney research. Meanwhile, Hg and Chan confirmed the colour of the icon was not the only factor as other properties had to be taken into account to determine icon suitability. They also, among other properties, did not give a quantitative evaluation of icon effectiveness or a factor in colour importance. However, more works state the colour has a big influence on icon usage (Wang *et al.* 2004) found the pictorial-colour was a significant factor in the visual identification of subject performance. There were revealed the pictorial size and circle-slash thickness influenced glance legibility for prohibitive symbols under degraded situations (Shieh, Huang 2004); indicated the pictorial symbol, colour and shape influenced understanding the symbol (Duarte, Rebelo 2005).

Understanding the problem of icon usage is very complex. Thus, some researchers analyzed very specific situations: designing a web icon for travel websites (Syarief *et al.* 2003); mobile interface icons (Gatsou *et al.* 2012); context-aware navigation in mobile games (Jahn *et al.* 2006); differences in shallow and solid icons analysis of the icon for specific purposes and etc. Most of researches investigating the properties of icon usage in a specific area received clearer data, tendencies and insights compared to researches where, at the same time, a very wide application area was analyzed. This shows that icon interpretation and usage depends on the type of application (web, mobile, desktop application, etc.). Unfortunately, the existing researches on different types of the UI concentrate on the identification of icon context rather than on the patterns identifying the relation or selection of the icon. Meanwhile, these two properties are important for the NUI as the relation of the icon holds the first expression and unconsciously influences the judgment of the icon and the system; also, the pattern of icon selection can give guidelines on how icons should be ordered to fit user's natural selection order and to increase system usability.

Time for task execution is one of the most important metrics in HCI and NUI. It allows estimating how quickly the user is able to execute a task and how much time s/he has to waste and wait because of input device properties or an improperly designed UI. Fitt's law (Fitts 1954) proposes a formula for calculating time needed to go from one point to the centre of an area of a certain size. This law is still relevant and used; however, additional data are needed to be able to adopt this law for a successful design of the NUI: if we know users and typical UI overview patterns, we can calculate the most probable time for eye movement needed to overview the UI; if we know what icons are the most noticeable, we can predict time for eye movement needed to find a certain icon.

Therefore, this paper analyzes icon selection properties in the icon-based desktop environment and seeks for two main goals:

- To get data on icon overview patterns that assist in selecting an icon in the desktop environment.
- To highlight some properties that could indicate whether an icon will be related to positive/negative actions treated as positive/negative.

2.2. Methodology

As mentioned above, the pattern for selecting the icon is an important factor in the NUI. If we knew the pattern for overviewing and selecting the icon, we would be able to group and place icons according to their importance and the frequency of usage. A typical pattern for overviewing the UI can be identified experimentally. Software usability is usually evaluated by means of different methods, including reviewing standards, user testing, subjective assessments and barrier walkthrough (Coyne, Nielsen 2001; David 1997). To make sure we will get more realistic results the prospect of indirect survey in was chosen. For conducting the experiment, an internet tool has been created to imitate the icon-based desktop environment (Cooper, Rejmer 2001).

Typically, users have two main eye movement tasks in the UI: the user overviews the whole UI in order to inspect functionality, and the user searches for specific information and the function he needs. Overviewing the UI requires going through all icons while search in the UI requires going through all or some icons in the UI and selecting only the specific ones. Our experiment had to imitate both situations. For the overview, we required to select all icons on the desktop to make sure the user saw the icon. As for the task searching for an icon, we asked the user to select positive/negative icons. This additionally allows estimating properties influencing user opinion on icon positivity/negativity as well as ensures they do not need to remember the icon list we asked to select. If a certain list of icons were given to select, we would have one more unknown parameter in this research – how well the user is capable of remembering what s/he needs to find. Meanwhile, in real life, the user usually decides on what to select by him/her. Tasks to select positive/negative icons should be unusual for all users, and all of them should have no prejudgements what have to be selected. Therefore, we could get data on how selection time changed when a task was given for the first time and repeating it multiple times. This type of the task presents a situation when users make a decision rather than try to remember what have to be selected.

Every experiment involved twenty icons placed in different places of the virtual desktop (see Table 1). The icons were chosen to present all main icons, which most of users met working with desktop applications. The biggest part of icons cannot be met directly on the desktop; however, they can be seen in different software or the Windows operating system (Windows operating system is applied, as the major part of Lithuanian people use it because it is known and popular). This allowed us to prevent from prejudice where a specific icon should be in a real desktop environment and to make sure all icons are known to the user that has some experience of working with them (Desurvire *et al.* 1992).

Also, we assigned the main colour and type of action for each of daily work icons (see Table 2.1.). It was done before the main experiment using a separate group of 26 persons. Each of them had to identify what the main colour (only one colour) of the icon was. All persons were asked to select whether the icon was associated with creation, destruction or neither of these actions. This allowed us to get preliminary classification of icons. At this stage, we did not want refer to the same users as in the real experiment by seeking a more general estimation of all icons in the main experiment as well as by keeping the properties and purpose of the experiments in secret for all users before the main experiment.

Table 2.1. A list of Icons

No.	Icon	Title	Main Colour	Action type
1.		Copy	Blue	Create
2.		Paste	Other	Create
3.		Edit	Other	Create
4.		Help	Blue	Other
5.		Search	Black	Other
6.		Save	Blue	Create
7.		Confirm	Green	Create
8.		Delete	Black	Destroy
9.		Recycle	Black	Destroy
10.		Error	Red	Destroy
11.		Cut	Blue	Destroy
12.		Close	Red	Destroy
13.		Warning	Other	Destroy
14.		Shutdown	Red	Destroy
15.		Picture	Blue	Create
16.		PDF document	Red	Create
17.		Email	Other	Create
18.		Search	Blue	Other
19.		Exception	Green	Destroy
20.		Sound	Black	Other

The main experiment involved all users having to execute three different tasks:

1. To choose all icons from the desktop (by clicking on it) in any order they want.
2. To choose all positive icons from the desktop in any order.
3. To choose all negative icons from the desktop in any order.

The early stages of this experiment showed usual, non-disappearing icons that influenced much dissatisfaction from users in Tasks 2 and 3. The users complained they did not remember what they had already selected. Sometimes, even user frustration was noticed, and therefore different solutions were considered for this survey. To disable icon after selection, as possible solution was eliminated as possible solution current desktop applications do not use this practice very often and it would be unusual for users. Meanwhile, icon, element elimination from the working window is common to many systems of design. Therefore, we decided, after clicking on the icon, it would disappear from the desktop. It gives multiple bonuses to this experiment as the user has no chance to click twice on the same icon doing the same task; it is similar to rating a natural object when the user eliminates the chosen element from the list; it helps with tracking what icons have already been selected and to decrease the number of icons to click.

No explanation in which order icons have to be selected or what should be treated as a positive/negative icon has been given to users. It was done in purpose to invoke the user to find his/her way with no predefined requirements or measurements. In addition, the experiment was executed three times randomly changing the place of icons. The repetition of experiments allows us to eliminate anomalies in user actions as well as to examine if these actions change executing the same task multiple times in a row.

137 users took place in this experiment during the period from May 2013 to September 2014. They also had to provide some data on their gender, age group (from 7 to 14; from 15 to 19; from 20 to 29; from 30 to 39; from 40 to 49; from 50 and above), a field of occupation (Economy, Physiology, Psychology, Technical and Technology scope, Law, Management, Other) they belong to and the country of origin. All personal data were used for analysing if it influenced the pattern for selecting an icon or related results and did not require any specific personal data that could be related to a certain person. The survey was open and everyone who knew the address of the study had a chance to participate. Participation was voluntary. The first page of this tool introduced research as the scientific one. A note shown to all users indicated they had to be at least 18 years old or have a permission of their parents or tutors to attend this experiment.

The results of 69 men and 68 women were analyzed. All other categories were distributed not as proportionally; however, at least 3 persons were participating in each category considering age and the field of occupation. Also, there were 19 respondents who did not live in Lithuania at the moment of the survey (9 different countries).

During the experiment, we logged on the selected ID of the icon, a location on the desktop, icon classification into positive or negative, icon selection order, icon selection time, task number, repetition number and mouse click/icon position on the desktop. To simplify the randomization of icon position (as no icons can be placed in the same place or too close to each other) and storage in the log, the desktop was divided into 8 columns and 8 rows, which allowed having 64 different cells on the desktop.

2.3. Analysis of Properties

All experimental data were carefully analysed from different perspectives. Two main goals have been established in this paper, and the obtained data have been grouped into two subsections each of which will be presented the main results we got seeking the aim.

One of the most important measures for the UI is the distance the user has to cover from one click to another. The analysis of the experiment shows that the distance of mouse movement between two clicks depends on the age of the user (see Fig. 2.1.). The youngest participants (up to 15 years) showed the capability to choose all icons in the shortest path while all other age categories reported similar results – the average distance between two mouse clicks were from 2.21 to 2.24 of cell width. No tendencies how other user properties (gender, speciality, etc) influences the icon selection distance were significant.

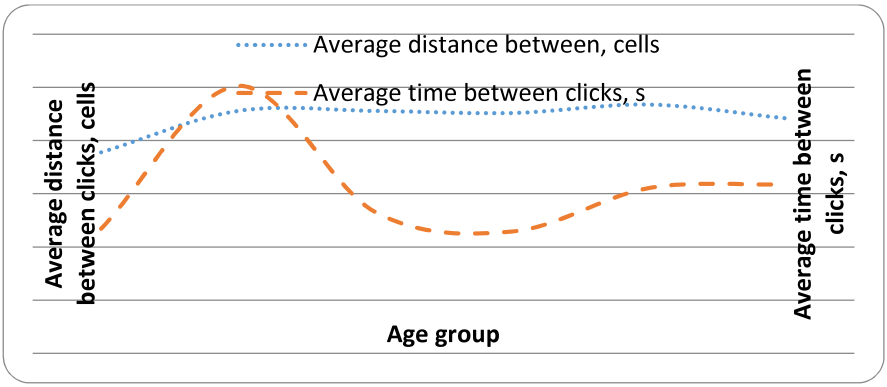


Fig. 2.1. The average distance of mouse movement and time between two clicks considering the users of different age groups participating in the experiment

Next, distance in cells rather than in pixels is calculated, as the size and resolution of the screen for each user might differ. Also, the distance between cell centres is estimated, as the icon is usually placed in the centre of the cell, and we have logged only the cell rather than an actual mouse position in the screen.

Time is another important measure for the UI. The number of the selected icons might differ considering each user in a different task; therefore, the average time between two mouse clicks was compared and made 1.65 seconds. However, we noticed that the maximum time between two clicks was more than 2 minutes, and 8 times for selecting an icon were found unexpectedly large. This shows these users made some breaks or were disturbed from the task. Therefore, we eliminated all records within the intervals of more than 30 second between mouse clicks and used only the corrected data on time calculation. This allowed obtaining the average time between mouse clicks equal to 1.351 seconds.

The analysis of the average time between two mouse clicks showed interesting results as the age group from 15 to 19 years was slower comparing to other age groups. The age group from 15 to 19 has the greatest standard variation in time (2.11), which shows the users of this group are very different and unstable as a deeper analysis of data on separate users have showed there are respondents with longer time between mouse clicks as well some users having a wide range of times. In opposite to this group, the age group of up to 15 years showed a very constant speed for all clicks (were executed up to 2 seconds). This also can be related to the distance between mouse clicks – this group had a smallest distance between clicks, and therefore, according to Fitts' law (MacKenzie 1992), time should be shorter as well.

To evaluate all events of all age groups or even of the users meeting Fitts' law, this experiment would be not correct. Fitts' law takes into account reaction time and task difficulty, which depends on target distance and width. As regards this experiment, all targets are of the same width, and distance to the target should be the same as that between two mouse clicks; nevertheless, no data on what is the reaction time of the users are available. Meanwhile, reaction time can vary extensively in this experiment, particularly if the user needs time for deciding what a positive/negative icon is. The importance of reaction and decision time can be noticed examining variation in time between two mouse clicks – time to go from one cell to another can be different for the same user in different tasks. The analysis of the average time between mouse clicks during different tasks and repetitions differ. The first task requires less time for going from one icon to another comparing to Tasks 2 and 3, as the user does not need to think what s/he identifies as a positive/negative icon. It meets with Hick principle stating that the time it takes to make a decision increases proportionally to the number and complexity of choices (Hick 1952).

Principles of Gestalt psychology state that the icon is recognized easier if it was selected once before (Kepes 1944, Arnheim 1974). We also have obtained analogue results, as time between two mouse clicks is decreasing each time the user repeats the task. It shows less time is needed to identify the icon as positive/negative. However, the times of Tasks 2 and 3 do not reach those of Task 1, and this means there is additional thinking in Tasks 2 and 3 (need to decide once again or to remember what to choose) comparing to Task 1.

Also, the difference between tasks can be noticed analyzing the average distance between mouse clicks. Tasks 2 and 3 have a longer distance between two mouse clicks comparing to Task 1. This can be explained by the fact that the distance between the icons increases as not all icons must be selected. Besides, it is possible the user selects these icons starting from the most positive/negative to the least positive/negative one, and therefore does not try to use the shortest path in contrast to Task 1.

The analysis of how (in which direction) the user usually chooses icons reveals that the biggest part of users has the same start strategy. Task 1 shows how users start from the left-top corner and go to the right or down. Later, they follow the opposite direction or start from a new column/row. Therefore, the first icons the user chooses in Task 1 are usually in the left-top corner. Figure 2.2. suggests that the average icon selection order is the smallest in the top-left corner and increases crosswise at the right-bottom corner. However, a more detailed analysis of icon selection order showed a tendency to go from the left to the right one line by one, which is more frequent than going from the top to the bottom column after column.

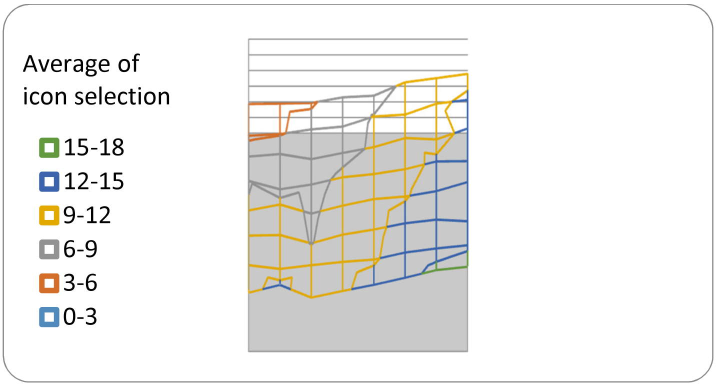


Fig. 2.2. The average order of the selected icons accordingly to the cell of the desktop

An interesting point is that the same pattern for selecting the icon order applies to Tasks 2 and 3. This shows the same "desktop scanning" method is used not depending on what the user has to choose, as s/he overviews the desktop in the same order. We should add the order might be influenced by a position where the user starts the task as buttons for starting and finishing different tasks are also located on the top of the desktop.

The analysis of user age, occupation or location changes different properties of these three tasks showed no significant results or tendencies.

In the beginning of the experiment, we had a hypothesis that the colour of the icon would be one of the most important factors indicating if the user treated it as positive/negative. After data analysis, despites the colour, we had a very similar identification of the icon as positive/negative. We can notice red icons are found as positive more rarely comparing to other colours, particularly black; however, difference is only 1%. Meanwhile, users more frequently discover red icons as negative comparing to other colours; nevertheless, the difference is also only up to 1%, which is not enough to make some conclusions depending on the colour only.

Analysis if the related type of the action of the icon has an influence on icon identification as positive/negative has been conducted. Similar results as those of the colour have been received – on average the icon of each type of action was selected by 91% of users in Tasks 2 and 3. Still, the order of icon selection gives more data: as for Task 2, first of all, the icons that mean creation were selected while those related to destruction were selected the last; Task 3 shows that, first of all, the icons that mean destruction were selected while those related to the creative action were selected the last.

The combination of both properties (icon colour and a related type of action) has an influence on identifying the icon as positive/negative. For example, a green icon that means a creative action was always selected as positive within the first 8 icons as well as the red one that refers to destruction – as negative. However, it seems there are more factors influencing icon classification into positive/negative (personal experience, etc.).

The analysis of how separate icons were classified to positive and negative by the participants of the experiment has also been carried out (see Table 2). The obtained results suggest all icons were selected as positive/negative approximately by 79–82% percent of users. This shows there is no strict division into a positive or negative icon.

As icon colour and related action cannot be used as single criteria for icon classification into positive/negative, we tried to analyze if neighbouring icons influenced icon classification into positive/negative. Therefore, each user of a positive/negative icon selected in Tasks 2 and 3 was related to (depending on a situation up to 8 icons placed in the connecting cell of the desktop) colour and action types of neighbouring icons. As icons were placed randomly on the desktop, there were not enough cases of 9 identical cell combinations to get significant results of the carried out analysis. Meanwhile, the examination of the icon pair (selected icon and its neighbouring icon) had more data. However, the correlation between selecting the positivity/negativity of the icon and a neighbouring colour, action type and positivity/negativity in the same task were too small to exhibit tendencies. This shows the random function was not able to place the icons of similar positivity/negativity level. Besides, it shows that the user analyzes all icons separately to classify them as positive/negative rather than rely on its surrounding.

Table 2.2. List of the icons used in the experiment

No.	Icon	Percentage of the users who selected the icon		Average of selection order for the icon	
		Task 2 / "Positive"	Task 3 / "Negative"	Task 2 / "Positive"	Task 3 / "Negative"
1.		82%	79%	5.87	8.35
2.		82%	79%	6.02	10.77
3.		82%	79%	5.89	7.86
4.		81%	80%	7.40	5.81
5.		82%	79%	5.81	7.89
6.		82%	79%	5.42	7.73
7.		82%	79%	4.09	7.67
8.		81%	80%	6.89	4.24
9.		81%	80%	7.94	5.15
10.		81%	80%	9.92	3.70
11.		81%	80%	7.38	4.95
12.		81%	80%	6.47	3.58
13.		81%	80%	7.48	4.56
14.		81%	80%	6.64	3.73
15.		82%	79%	5.53	5.48
16.		82%	79%	5.93	7.22
17.		82%	79%	4.74	6.37
18.		81%	79%	6.34	8.58
19.		81%	80%	6.98	4.72
20.		82%	79%	6.12	6.30

If we added an additional requirement for selecting a limited number of positive and negative icons, the situation could be slightly different as when analyzing selection order, more obvious results could be noticed. According to the average selection order, the positive icon would be Confirmed, Email, etc., while the negative icon would be Close, Error, Shutdown, Delete, etc.

Bruce Tognazzini made a list of the main principles regarding UI design (Tognazzini 2014). It is one of the most combined materials we have to deal with to ensure the UI will be suitable for usage and satisfaction. These principles are not meant for one specific type of application only and used as "must have" in many cases. Most of Tognazzini principles are abstract and have no exact property value or another measurement how to evaluate if something is achieved or not. The same idea exists in almost all best practices in order to present a guideline or an idea rather than measurement, taking into account it might vary in different situations.

2.4. Conclusions of Chapter

The executed experiment using an indirect survey has showed the same tendencies towards selecting icons in the desktop environment as Hiko and the Principles Gestalt psychology suggest. However, we did not get any significant data on what influences icon relation to positive/negative, and the principles of the colour theory could not be approved.

Changes in icon selection depending on is it automatic task or task which requires additional decisions to be made. This is proved numerically as average time for moving a mouse from one icon to another is up to 2 times faster if the user does not need to make any decisions on choosing the icon. Also, our experiment showed none of the users was able to select the icon faster in Task 2 or 3 comparing to Task 1. This demonstrates an additional time is needed to make a decision.

A comparison of selecting the average distances of the icon in Task 1 showed the youngest age group was capable to select all icons within the shortest path where the average distance did not reach 2 cells. This might be an indication the elder persons gain additional experience and can be distracted by some icons that do not allow them to follow a certain strategy for icon selection.

The conducted experiment showed the positive/negative icon cannot be estimated only by its main colour and action type. These two characteristics influence the selection orders of positive/negative icons. However, these two characteristics are not enough to estimate what the user will select as positive/negative. All users have different experience, which additionally may influence how many icons he will treat as positive/negative and what kind of icons they will be. In order to estimate all influencing factors in icon classification into positive/negative, more additional data have to be gathered from individual users (open questions why he chooses an icon as positive or negative, the previous experience of working on the icon, etc.).

There is no one law, single object or objects system as a whole, which is influenced by the speed of the user's work.

3

HUI: Research of Fitts' law Characteristics using Displays System

In this Chapter we propose to analyse EEG signals of target group (small children) during the usability testing process, when design is created by Fits' law. As target group is more regardless of computer skills, and social factors, results could be a guide to do decision of the usability design in the future works. Otherwise is a study of interface devices between human and computers, experimental paradigms for interpretable readable signals: mapping the task to the brain state of the user (or vice versa).

The results presented in this Chapter are published in (Radvilė *et al.* 2015b), (Radvilė, Čenys 2015a), (Radvilė, Čenys 2015b).

3.1. State of the Art

The design of system usability is a very complicated, multidimensional task. According to J. Nielsen (Nielsen 1995) system usability aims to identify problematic places rather than to find universal rules for perfect system design. This is highlighted by other authors (Sauro, Kindlund 2005; Seffah *et al.* 2006; Gafni

2009; Brooke 2013). In these papers ergonomic properties of various systems are analyzed ergonomic properties of various systems are analyzed and specific recommendations provided. It is pointed out that the usability is strongly dependent on user's properties as well. In the standard of the International Organization for Standardization and the International Electro technical Commission ISO/IEC 9126-1, software quality is divided into seven main categories with one called "Quality in Use" and depending on the system's user properties.

One of metrics in this standard is Task time (Ta) – how long does it take to complete a task. Task type and complexity can vary depending of the type of the system; however the most common task in an information system is to find some information or even to notice some information on the user interface (UI). It takes time to move the eye gaze from one point in the UI to another and just then certain actions are done to finish the task. The eye gaze movement as a usability characteristic is important as current tendencies implies the eye movement can be used as input device instead of mouse or other device (Khanum 2012). Therefore eye gave movement could be used for complex UI task execution rather than visual search only.

The eye gaze movement time depends on a particular user, however range of possible values can be estimated in advance. Fitts' law can be used to estimate part of the task execution time depending on information search on UI since it defines how the movement time from one point to another depends on the target size and distance (Jacob 1991). Therefore if we know the target size and anticipated user eye gaze movement speed we can estimate how long user would take to get to the object from different places of the UI. Therefore Fitts' law can be used to optimize user eye movement time from one object to another by changing objects size or place in the UI.

Fitts' law was published on 1954 in paper "The information capacity of the human motor system in controlling the amplitude of movement" and revealed how the speed and accuracy of muscle movement depends on each other. The author presented the idea that the movement is not straight to the center of the target: first of all there is a jump close to the object (see Figure 3.1.) with some circle of error for the first try and then it is corrected with a smaller circle of error for the second try until the target is reached.

Despite the fact that Fitts did not present a formula by himself, his idea was formalized by other authors (Felton *et al.* 2012) and is presented in formula 3.1:

$$t = a + b \cdot \log_2(ID) \tag{3.1}$$

Here t is the mean time to hit the centre of a target and constants a and b are estimated from a particular experiment. Constant a is called the no informational part or reaction time. Constant b is the informational part in seconds per bit or a slope. There distance from start point to the centre of the target is called amplitude

A while the tolerance of the jump is called width W (radius or width of the target). ID is the index of difficulty formula 3.2:

$$ID = \frac{2 \cdot A}{W} \tag{3.2}$$

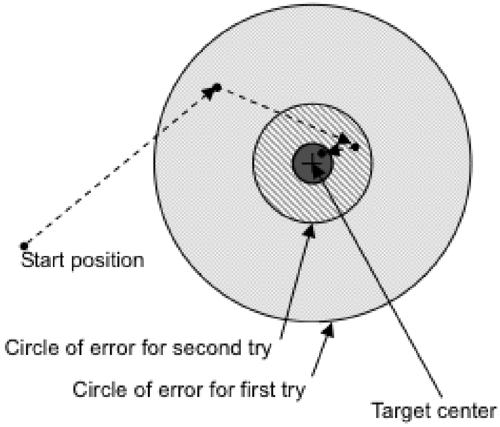


Fig. 3.1. Step-wise movement towards target (Ramanauskas 2006)

There were multiple experiments with Fitts' law, when it was adapted to different Human Computer Interaction (HCI) devices (MacKenzie 1992; Card *et al.* 1978; Soukoreff, MacKenzie 2004; Bi *et al.* 2013) Depending on the used HCI the slope parameter is different; however Fitts' law can be applied to all of them. This also is important in task execution time calculation as we can define how long the user will need to see the object as well as how long it will take to reach the object, using different HCI devices, as while the object is not reached usually any actions can be done with it.

To get the task execution time we can divide certain task into small steps and with the help of Fitts' law to calculate how long it will take for the user to get from one place in the UI to another (by seeing it or by reaching it with some other HCI device). The movement time together with additional time needed to execute certain activity after the object is reached can help to identify the task execution time with more precision. As well it can be used to analyze UI layout efficiently in a sense of task execution time (to identify which layout is more appropriate for a certain task execution, when the most important criteria is task execution time).

For two decades the HCI community lives with different formulas for Fitts' law. It is obvious that the different formulas contradict each other. Instead of a clarification which formula is correct the HCI community gives free choice but demands good statistical values for the chosen formula. This is not a scientific approach as science does not allow contradictions and inconsistencies. Normally, when there are different formulas for the same thing, the formulas were derived from different assumptions and an experiment serves to decide which assumption is wrong. However, in the case of Fitts' law the different formulas are derived from the same assumption, meaning a vague analogy to Shannon's information theory. Consequently, there must be something wrong with some derivations. (Drewes 2010)

One of way to monitor a person's emotions is to analyze electroencephalography (EEG) signals. During the last few years more brainwave research devices appeared (Welford 1960). This allowed investigating user's emotional properties, brainwave activity, to use EEG in HCI (Meyer *et al.* 1982; Smits-Engelsman *et al.* 2007; Despard *et al.* 2013). The analysis of brainwave is not a simple task as different types of brainwaves exists (Felton 2009) and it is still a discussion how to interpret these signals correctly (Jax *et al*. 2007). Previous researches found delta waves are primarily associated with deep sleep and the waking stage. As the signal frequency is very low sometimes it might be confused with signals of bigger muscles of the neck or jaw. Theta waves usually indicate emotional discomforts such as stress, frustration, disappointment as well as creative inspiration or deep meditation. Alpha waves are indicating a relaxed awareness and inattention, while beta waves usually associated with active thinking, active attention, and focus on the outside world or solving concrete problems. Comparing these to brainwaves alpha indicates a mindless state rather than a passive one, and can be reduced or eliminated by hearing unfamiliar sounds, anxiety or mental concentration. Gamma waves has the biggest frequency. Its activity is related to subjective awareness, attention.

Some brainwave association is still discussed as there are many different arguments to what these waves could mean, how it could be caused, how different combinations of brainwave activity should be interpreted. One of ideas is that beta and gamma waves usually are associated with attention while the combination of both of them is correlated to focused attention (Kanfer, Ackerman 2004, Chuang *et al.* 2004).

This means EEG and betas as well as gamma brainwave analysis can be a suitable tool to identify is the child motivated during some task or no, as his or her brain activity might say more on this question comparing the child.

Eyes have become a hot area of research for many neuroscientists, but what they're interested in is not what eyes see, but how they move. Our eyes dart about all day long and researchers estimate we make 200 thousand eye movements each day. Those eye movements can tell a lot about what we are thinking. But it turns out inposible tot see with eyes, than possible see brains. Dr. Doug Munoz, a neuroscientist at Queens University who has actually counted daily eye movements.

Dr. Munoz is the director of the Eye Movement Lab at Queen's and oddly enough his interest in neuroscience all began with keeping his eye on the ball. Alan Kingstone's Research Lab at the University of British Columbia. Dr Kingstone's students clamp on eye tracking devices to watch each other's eye flash around as a way to study how game playing affects attention, distraction, and reflex action. Find out what it all means this week on the show.

These researches neuroscientists and their publications standing forward to main research of this study. The exactly moment is that amplitude and velocity of saccadic eye movements exhibit a consistent relationship in which larger amplitude eye movements are accompanied by greater peak velocity in healthy controls (Paolozza 2015). Thissame main sequence relationship was found for children slope of this relationship was reduced on children group.

3.2. Methodology

In this work we chose to analyse small children from ages 2 to 4. Children of this age are capable to choose freely and have minimal level of prejudice. This allows us to get a real expression to different UI rather than impact of addiction to some kind of UI. In addition small children are easier to motivate for short time period (Chuang *et al.* 2013) therefore it is easier to achieve significant change in motivation levels during the experiment. However when using children in this of experiment rather than adults it is difficult to ask the child how motivated they were during a certain task – the dictionary of children is not enough to express his or her emotions, children might not be aware of the term motivation, how to compare it etc. Therefore additional methods for motivation level estimation have to be used.

To understand how end users are feeling using software is not that same as to understand why they are feeling so. As it was mentioned before, this experiment is one of three pats of research and is more complicated than others. First of course children, even if we decided to call them kids (2–4 years) or exposed group (Hanna *et al.* 1997) of human. This group require the most extensive adaptation of usability testing because their attention span, their motivation to please adults, and their ability to adjust to strange surroundings, things, new people may change from moment to the next. In general, children in this age range should to explore the computer according to their own interests and pacing instead of performing a series of direct tasks. Eye will often be happy to show you what they know, and what they can do on the computer independently. When assessing appeal or engagement, testers will need to closely observe children‘s behavior such as sighing, smiling, or sliding under the table. Children this age often have difficulty expressing their likes and dislikes in words. Why exposed group was selected? They are clear from perfect information or information noise.

In 2014 April Lithuanian Bioethics Committee gave their consent to the study, which was done using special EEG, Eyes Motion tracker and Video hardware and software for 2–4 years children. The Committee decided that the measures are compatible with research for children's rights and is not forbidden. Each child participating in the experiment was with his mom or dad in the common room, feeling safe and calm.

Participants

We recruited participants, as Microsoft recommendation for usability testing experience with children: used single-monitor with special software ("M(n)"), and large curve monitor with special software(L(n)). All participants used computers more than one per week, but not more that 20 min per day. According to our pre experiment questionnaire, their daily/weekly computing activities were Youtube movies, mostly scenario "Masha i Medvedev" The study was conducted in a locked office lab to ensure privacy. Each participant received present upon the compensation of the study. We chose not experienced users as we wanted to see how their interaction and visualization understanding can be view on brain wave log.

There were 5 different UI, which had multiple starting scenes of the movie on each of them, located in different places of the screen. The number of 5 experiments was chosen to make sure the child will not get bored. As well the size, dimension of the movie scene were constant for all pictures. Changes were made only in location of the pictures (random position with no overlapping pictures) as well as two tasks out of five had one new scene as all other were always the same. The additional, unseen scene was added to increase the motivation of the child, as all scenes for him or her are already seen and the new one should be interesting and exciting. All five situations were presented for child in the same order.

The choice to use multiple pictures was done to model situations when a user has a choice which object they want to pick, which way is more suitable for them to do a task they want etc. rather than executing automatic actions to look at one specific object. As the size of the pictures was constant we changed the number of pictures to force a change of distances from one picture to another. As well the number of 6 or 5 pictures was chosen to fill the screen with pictures, distancing each other approximately the same length as the pictures' width. This allowed us to make sure there will be enough space between each object.

For study we had two extra stuff persons and moderator. One was responsible for logging track (special software, brain wave software, eyes tracker software, video for study), other for prepare EEG headphone, pre experiment questionnaire and activity log, last one for talking with children about what they should do.

Most attempts to understand usability and lucky user experience with continuous EEG measurements work by monitoring Beta and Gama, because people cannot learn to change the amplitude of these two waves by making the appropriate mental effort or by raising his or her level of attention. By the fact in experiment, all frequencies were logged (see Figure 3.2.).

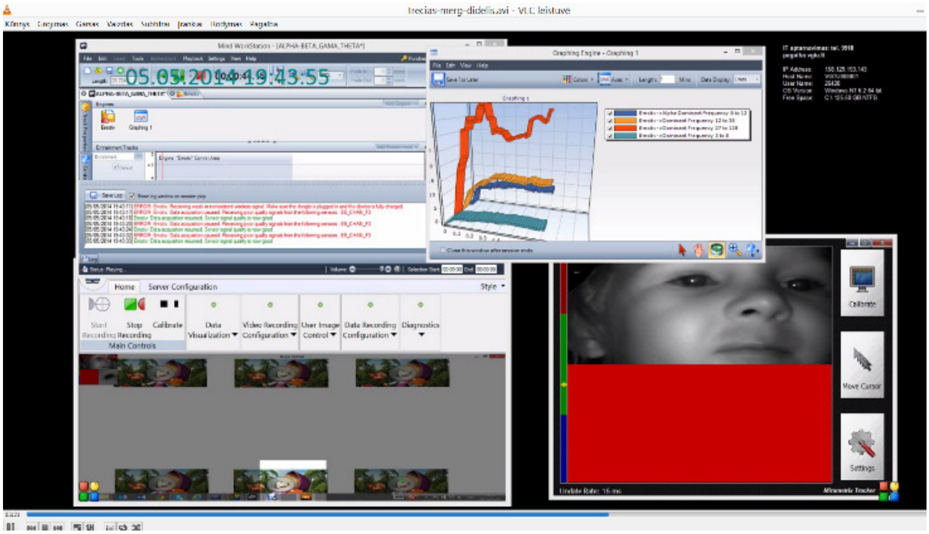


Fig. 3.2. Software and Hardware tools

For exactly this experiments was taken one computer monitor 17″ Philips, also one curved monitor 54.6″ Measured Diagonally OLED Samsung, both 1920×1080 resolution. Place from participant to monitor was as recommendation. Special software and design created by Fitts law recommendation created with Pascal Lazarus 1.2.2. For Brain waves ("Brain computer interface technology") EPOC Emotive, Mind workstation, Brain Computer Interface and Scientific.

Three sessions was done using Neurosky Mindwave hardware and software.

For Eyes tracker (eyes reaction) Mirametrix and viewer software Mirametrix research conform to the Eye – gaze Interface (Hornof, Halverson 2003). The Open Eye-gaze Interface provides a standardized method for performing calibration and acquiring eye-gaze information. The Open Eye-gaze Interface is based on a web services model for data transmissions. Communication is performed using a client / server architecture, passing XML strings over TCP / IP connection. By default the tracking window is 100% of the screen-size and therefore only the screen size is required to convert from reported X, Y coordinates to pixel.

As well all experiments were filmed (both laboratory and working monitors, with all acting systems and executed actions) and summarized by independent observer. The task for independent observer was to log information what the child did, how he acted, etc. The data was useful to analyze possible causes of changes as well as correlation to the child's actions and brainwave activity as well as eye movement: Recording windows, Mouse Event, Noise (logging all screen at once, using special clock for calculating differences between logging information). Also recording experiment processes (Ali – Hasan 2008).

Methods

The success of EEG signal analysis essentially relies on the quality and the relevance of the information extracted from raw records. This experiment presents the signal processing methods related with the aim of the work, the time – frequency methods of signal analysis, used for feature extraction. The traditional analysis tools we use for the analysis of stationary signals, such as the Fourier transform, are no longer adequate for the analysis of most non – stationary signals. Instead, Time – Frequency Representations (TFRs) are more suitable.

Tasks Rate

To analyze eye gaze slope, according to Fitts law we took all data of eye movement from any source area (blank area or another picture) to the target area (picture of movie scene). In total there were 8 aimed and 35 non-aimed targets.

Place and Processes

All experiments were executed separately for each child to make sure there will be no distractions. As well the experiment room was locked to prevent distractions from outside. To make sure the child will be calm he or she had time to get to know the room and the equipment. Then step by step the EEG and eye gaze tracking systems were set to track child's brain activity and eye gaze movement. EEG was analyzed using EPOC Emotive system where all types of brainwave were recorded for later analysis. Mirametrix eye tracking system was used to track eye gaze movements in order to find out what the child saw, where his eyes were looking at. The system logged monitored coordinates were the child was looking. By synchronizing in time and combining data of brainwave activity and eye gaze movement tracking we were able to identify the correlation between these two sources (Gulliver, Ghinea 2004).

To investigate the impact of motivation on eye gaze movement slope we recruited fourteen participants, as recommended by Microsoft for usability testing experience with children. All of them were children from 2 to 4 years old. Current research states children in this age group are too young to clearly express their satisfaction levels. Therefore there are no unified methods to test system usability with this age group. All of them participated in this experiment with one of his or her parents. Parents did not participate in the experiment but were used to keep the child calm and relaxed. Before the experiment started, all parents had to sign an agreement and to provide information about his children's daily/weekly activity with computer. According to our pre-experiment questionnaire all participants used computers more than once per week, but not more that 20 min per day; their daily/weekly computing activities were Youtube movies.

As all children in the experiment were familiar with Youtube and series of "Masha i Medved" movie, all situations were created to imitate UI for Youtube movie view. Children were asked to sit by the computer and to choose which movie they want to see. Children were allowed to click on the picture by themselves, however as some children did not know how to play the movie, they were helped by the personnel – a child had to look at the movie scene and to tell which of these movies he or she wanted to see.

3.3. Analysis of Experiment

Synchronization of EEG signal data, eye movement tracking logs, experiment video records and paper notes of independent observer is required to get a full view of the research. It was done by using the same global time in all of these parts, therefore synchronization at millisecond level was achieved (except the observers data, it has approximately at 3 seconds accuracy).

In the first phase of result analysis the child's motivation level was observed by analysing Beta and Gamma brainwave activity. For each child's experiment a chart of brainwave activity changes in time was made and all times were marked when the eye movement to the object started. Moreover observer's notes were marked to identify additional child's activities during the experiment.

The data cannot be averaged for all 14 children, as there is a big variety in time when child decided to see the movie, what he or she does between different situations etc. Therefore example data of one child brainwave activity in experiments is presented in Figure 3.3 and presents main tendencies, noticed in data of all children.

In Figure 3.3 vertical lines with numbers from 1 to 5 identify the task execution start time. Usually after the task was given and before the task was done the child's beta and gamma brainwave activity increases and starts to decrease after the task was done. It shows that a child concentrates on the task. Children think on what they should do, while after the task is done allow a loss of concentration. This increase of both beta and gamma brainwave activity matches the theory of focused attention in the literature (Kanfer, Ackerman 2004, Chuang *et al.* 2004).

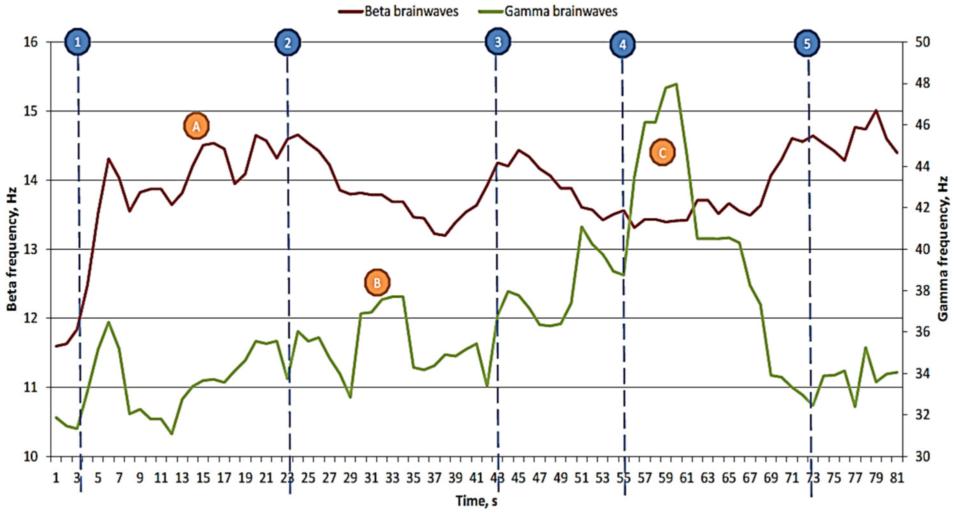


Fig. 3.3. Example of one child's beta and gamma brainwave activity during experiment with 5 different situations.

As the research used 2–4 years old children, additional activities were noticed during the brainwave monitoring. As the example the child after task 1 up to task 2 had more jumps in brainwave activity (area A). In this case it was a child's discussion why after choosing the movie it was not working. Area B shows a situation when a child was distracted by other activities, usually a conversation with parents etc. In this case the beta brainwave activity decreases as a child knows he or she does not need to do any tasks, while concentration might increase.

Task 4 included a new scene. In this case all children showed an increase of gamma brainwave activity. Usually this activity does not decrease instantly as the child really wants to see a new series of the movie and starts interaction with surroundings on why it's not shown. After some time of the task 4 the gamma brainwave activity decreases as children usually lose hope to see the movie. So the task 5 increases both beta and gamma brainwave activity, however the focus is not as high as in task 4, despite the same new scene of the movie that was shown in the task again.

According to the results of brainwave activity analysis we classified all tasks for each child into no aimed (where gamma frequency increased less than 2 Hz) and aimed (where gamma frequency increased more than 2 Hz). The Non-aimed object should represent starting movie scenes which were selected by children, however with not such an immense interest (just because they had to choose one of them). Meanwhile aimed objects were those scenes, which were selected by children with a big interest, revoked by themselves. Therefore usually only task 1 and task 4 was classified as aimed.

After all tasks were classified into aimed, no aimed and not executed (children refused to continue or did not execute the test as requested), the analysis of eye gaze movement was executed to find out how the motivation changes the eye gaze slope in Fitts' law. This was done analyzing the eye gaze movement logs. As the log stored data of all eye movements in the screen, we were able to identify not only the beginning of eye movement but the concentration on certain object (end of the eye movement to a specific target) too. First of all eye jumps were classified into two categories: those who stopped on the area of object, picture; those who did not reach, overlapped with any object. Then according to eye gaze movement data for each jump which reached the movie scene picture the jump duration as well as distance to the object's centre and its width was determined. The data were enough to calculate the index of difficulty and to get the slope value as we assume there is no reaction time a. This assumption was made as specific time or event was not given for the child to start the task – children decided by themselves when they want to look at a certain movie scene.

One of the most obvious results we obtained according to these data – if the task is aimed children always reach the object within target's area. Therefore if a new scene of well known movie was noticed, the motivation level rises and eyes always go to the new object (regardless of whether it is at a greater distance comparing to other pictures). Meanwhile if the task is non-aimed, some child looks over a couple of targets, one after another and even 17% of eye movement is close to the target, however they do not reach it. This shows the child might just overlook, not concentrating on one target.

To analyze eye gaze slope, according to Fitts' law we took all data of eye movement from any source area (blank area or another picture) to the target area (picture of movie scene). In total there were 8 aimed and 35 non-aimed targets.

By applying all eye movement data of reached targets to Fitts' law calculated slope for each of them and found out that the average slope for non-aimed tasks is 1.07 (standard deviation 0.68) and for aimed tasks – 0.21 (standard deviation 0.12). The difference of slope value for aimed and non-aimed tasks can be seen in Figure 3.4. It showed that the eye movement in aimed tasks is approximately 5 times faster, comparing to non-aimed tasks.

In our experiment all movie scenes were of the same dimension, therefore the index of difficulty mostly depends on the amplitude A (the width of the target might vary as well as the objects were rectangular, however the standard deviation of the width W is 14% of radius a circle would have with the same area all rectangles had). Analysing the correlation between index of difficulty and task type (aimed or non-aimed) we would not like to raise any significant results as the position of movie scenes were randomized, however the minimum value of index of difficulty is greater in aimed tasks, comparing to non-aimed (see Figure 3.4). It indicates the same tendency we noticed while analysing the filmed material of all experiments – if a child sees a new scene he is motivated to reach the exact object, despite the fact there is another one within a smaller distance.

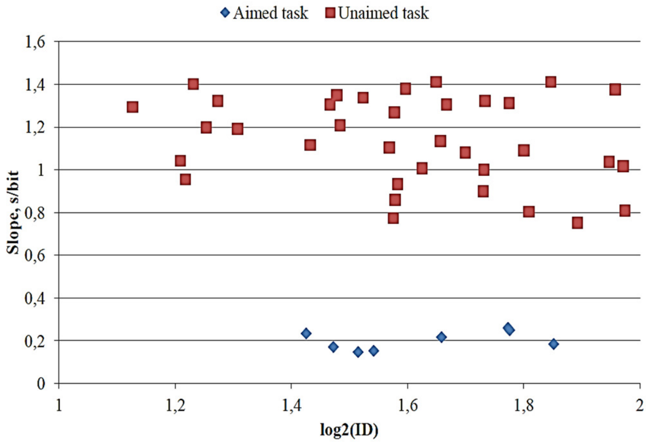


Fig. 3.4. Slope dependency on tasks index of difficulty and motivation level.

Even though there are a deviations on eye movement speed, the line between aimed and no aimed tasks is clearly distinguished according to the slope value b. This allows raising a hypothesis that the motivation level can be calculated according to the eye movement slope. However it can depend on the situation and for some tasks, which are not as different as in our case, the line can be unclear for clustering only on eye movement, rather than both brain activity, eye movement and human supervision.

3.4. Conclusions of Chapter

As states some researchers (Frey *et al.* 2014) and shows our experiment with different tasks, the motivation level can be identified according to the beta and gamma brainwave activity. Experiments with children from 2 to 4 years show their brain activity is not constant and changes many times (in this experiment variation for beta brainwave were 11–16, for gamma – 30–50), probably influence by many different factors not only the task itself. The fact eye movement slope is significantly different in aimed and unaimed tasks, shows we decided correctly to indicate motivated tasks if the gamma brainwave increase is more than 2 Hz.

The motivation level is a big factor for eye movement of 2 to 4 years old, as aimed objects are reached even up to 5 times faster by the eye comparing to un-aimed tasks, where lack of motivation exists and overview method is sometimes used rather than straight look into one object.

For children of age 2 to 4 years new objects increase the motivation, however just temporary as the same object, shown second time, can be threaded as known an uninteresting for the child. Therefore the graphical user interface should always change in some manner to attract small children more.

Experiments with age of 2 to 4 years are complicated as only 54% of tasks were executed properly. Therefore to get more accurate data in experiments with children of this age, the number of children should be increased or executed multiple times to get more data to analyze.

4

EUI: Curved Display on Visual Performance

This Chapter analyzing increasing technological development, the manufacturers launch more and more screens of various sizes and shapes. (Radvilė *et al.* 2015a), (Radvilė, Čenys 2015a), (Radvilė, Čenys 2015b).

4.1. State of the Art

Several studies suggest that the direct distance between targets (A in Fitts' Law) may be insufficient to predict movement time for curved movements. Movements slow down as path curvature increases (Soechting and Lacquaniti 1983), obstacle-avoiding movements take longer to complete than direct movements (Dean, Bruwer 1994), and MT correlates with overall path curvature (Jax, Rosenbaum 2007). Also, when circuitous paths are presented and participants are asked to move a cursor through the path, total MT is well predicted by a "steering law" which takes into account the path's curvature and width (Zhai 2004). These findings go against the prediction of Fitts' Law, taken literally. Yet from this, one does not necessarily want to say that Fitts' Law is wrong, only that it needs to be extended to accommodate movements that are curved as well as movements that are straight or direct. Accot and Zhai's formula – their "steering law" – is certainly a step in this direction, but their formula can only be applied to cases where movement paths have been explicitly specified. Attempt to develop an extension Fitts' Law that can predict MTs for curved movements around an obstacle when the actor is free to select his or her own path around it (Jax, Rosenbaum 2007).

In general, this curvation is based on plate screen by vertical line and it is not the same curvation that is on curved monitor on 2014. Researches in 2006 made an experiments with high-resolution displays and was finding perfomance of evaluation (Shupp *et al.* 2009). This experiment was made using all human properties (head, hand, body, eyes and hands).

The last experiment was conducted of four Koreans (Choi *et al.* 2015) scientists who carried out quite a superficial overview of curved screens and eyes tracking.The purpose of this research was to empirically compare the visual performance between flat and curved displays and, thereby, to help manufacturers understand the strengths and weaknesses of different display forms. The presented experiment observed an improved visual performance in the curved display, especially in terms of visual search and attention. Participants quickly focused their attention on the visual cues presented and effectively scanned the target object among distractors. The study provides guidance for an effective visual communication through a curved display and can help manufacturers understand the strength and weakness of different display forms.

4.2. Methodology

Result of experiment of two monitors of different width but of the same high are combined in one system that displays an image at an angle not in a single plane. Also, experiment was repeated on curved display. For understanding terminology introduction to who is who (Figure 4.1.):

A – Three-dimensional space;

B – Screen plane;

C – Two-dimensional projection.

An additional computer and Mirametrix equipment is used for calibration and eye movement fixation. When Mirametrix calibration is turned on the second computer, analogical image (changing pictures) is displayed in screen system where the user has to look at an appropriate point for calibration. There were also other ways but simplicity was selected (specific software and hardware for calibration through all the screens is not necessary, software eye movement fixation images on the screen does not distract the user).

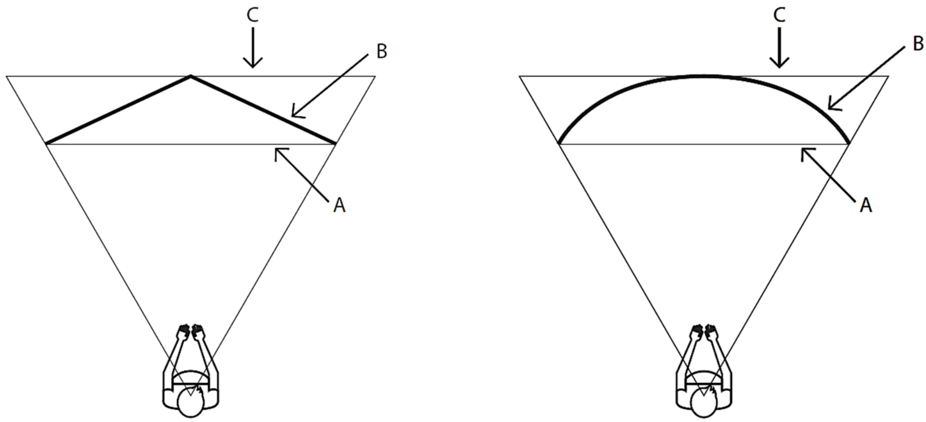


Fig. 4.1. A Visualization of the terminology A, B and C.

It is important to match screen systems and dimensions of the screen for calibration, as Mirametrix software uses proportions of the screen, significant calibration errors are possible.

After calibration the user was given the window through both screens where circles of similar size were depicted on the full screen of 64 columns and 21 rows. One of 1344 circles changed its colour from pale grey to red every two seconds; random number from 0 to 9 was depicted inside. The user was given a task to tell the number in that circle as quickly as possible.

Relative coordinates (meanings from 0 to 1) of eye fixation were recorded by Mirametrix equipment, what time and where a depicted highlighted circle with a number on the screen (what column and row in) was fixated; a man performing an experiment was filming. Dimensions of the screen, resolutions, position by the user’s approach are also measured (between the screens, user’s distance to the angle of the curved displays). All this data was used for the accurate detection of the point of eye fixation position and time prediction required to move glance from one point of screen system to another.

Each user carried out the same test three times during the experiment firstly eye movements were calibrated, and then 10 points in advance and 10 random points were shown to all the users every 2 seconds.

Eye Movement

Fixation in Curved Display and Screen System

Eye tracking is the field of monitoring what people do with their eyes – observing what people choose to look at, how their eyes move, how their visual activities behave. Eye trackers are the instruments that measure our eye behavior. They measure the directions that our eyes are pointed and predict our gaze points, i.e. the locations of the objects in space that we look at. Many modern eye trackers are based on video cameras that observe our eyes and produce high-resolution images of our irises, pupils, and sclera's. Light emitting diodes illuminate the eyes, and these LEDs produce reflections off the corneal surfaces to provide critical geometric information about the orientation of the eyeball. Behind the cameras that capture the images of the eyes, an essential part of an eye tracker is the image processing function that identifies the eyes within the images, measures the geometric features of the eye elements, and computes the spatial positions and orientations of the eyes. Finally, eye trackers project the spatial locations of the eye's gaze points. If a person is looking at a computer screen, for example, the gaze point may be expressed in x, y screen coordinates.

Accuracy is required in the study where issues of time of glance in the curved displays are solved, x and y coordinates are misleading, because equipment for eye scanning is created for the plane it means x coordinate should be recalculated according to the error.

Mirametrix S2 was used during this study. The Mirametrix S2 eye tracker should be located beneath the computer screen when used in a desktop environment, or in front of the screen when used with a laptop. The eye tracker should be centered beneath the screen and as close to the lower edge of the screen as possible. Ensure the eye tracker is level using the universal joint adjustment on the tripod. For laptops an external keyboard and mouse provides better access to the computer around the eye tracker. For best performance the eye tracker should be approximately arms-length from the face of the user or approximately 65 cm. The S2 system should also be operated away from sources of infrared light such as incandescent light bulbs and external windows.

Fixation in Large Curved Displays

As modern eye movement fixation equipment is able to fix movements only in two-dimensional space, coordinates of eye observing points in the curved display should be recalculated and specified. The following is used:

- The distance from the user's eyes to the surface of the curved display is measured;

- The limits M of the user's field of vision are assessed:
  - if not the entire screen is in the user's field of vision, then additional measures and methods of eye movements are necessary for continuation of measurement.
  - if the entire screen is in the user's field of vision:
    - the hardware and sofware is calibrated on the surface L of the entire curved display;
    - the virtual limits R of the screen in a two-dimensional projection of the curved display are determined;
    - the user's eye movements are fixated, accepting that they take place in the projection R of the screen R;
    - obtained coordinates compliance with the surface of the curved display are transformed;
    - calculations are carried out with eye movements on the screen R.

One of the most important actions before starting eye movement measurements is detecting the user's field of vision, so dimension of the screen,a curving radius and human position in the respect of the screen should be assessed first. The study cannot be carried out by common measures, additional decisions and eye movement fixation systems are necessary if, according to Formula 4, the distance to the screen is too small.

If the user's eye distance to the surface of the curved display is appropriate, not too small, then a common calibration of eye movement fixation equipment takes place. Traditionally, the user is given to observe 9 control points in the edges and centre of the screen. Therefore, received eye movement fixation data would not be accurate, as the angles of the user's eye turning are treated as a two-dimensional screen by software and hardware, so we get eye glance into a specific point of a two-dimensional projection of the curved display but not to the point of the surface of the curved display. It is assumed that received eye positions on the screen are fixated in the virtual flat screen R and should be transformed to coordinates of the surface of the curved display.

Fixation in the flat screen system

At present, large diagonal curved displays are not widely spread but screen systems are becoming more popular at present that make counterpart of the curved display. It can be treated as the curved display, if not focusing on such system and absolute disrepancy of consistently curved display, rapid eye jumps from one point to another. However, there is a problem that existing software is not suitable for eye movement calibration on two screens simultaneously. The most appropriate would be to replace existing software eye movement fixation, applying it not only to the curved display eye fixation but also a possibility to use more than one screen, their system. However, while there are no of these changes other solutions are still necessary that will allow applying existing resources to solve the problem.

Measurement inaccuracies, using different distance measurement models between two points: as modern eye movement fixation software is not applied to work with the curved displays, its inaccuracy can sometimes be small and not tolerated using large diagonal curved displays. To assess described models between two points in the units 0–0, comparing with the distance of the screen plane depends on the angle of the curved display and a screen radius as well as the user's distance from the screen.

Advantages and Disadvantages of Curved Screens

The curved displays have been introduced to the market since 2014 and are available for each user as providing astonishing experience and allowing a wider field of vision. The main benefit for which the curved display is known is that the distance between the user and the edges of the screen is much less than the flat display, providing an increased area in the user's peripheral vision. (The main benefit for which the curved display is known is that the distance between the user and the edges of the screen is much less than the flat display, providing an increased area available in the user's peripheral vision). Especially, when it comes to large screens, the users need to use physical navigation (e.g. eye, head and body movements) in order to avoid external – edge visual distortion. In the curved display, however, the entire screen surface is expected to be equidistant from the viewer's eyes, allowing less physical navigation without any loss of detail.

But for now there is still very little empirical comparison of user experience and visual performance between flat and curved displays. Thus, the present study aims to evaluate the effect of the curved display on visual performance and user experience. Finally, studies can help manufacturers to understand strengths and weaknesses of various forms of imaging, providing effective guidelines of visual communication through the curved display.

2015 year has been introduced the 9000nd Samsung SUHD TV series which includes only models with curved screens. It is the first time when the manufacturer did not offer any alternative to its client and focused only to a feature, which hardly can be called popular. Curved screens view somehow reminds three-dimensional revolution, when only the laziest manufacturer did not stressed out attention to support of this technology. Fortunately, now all the fuss about three-dimensional has run low and manufacturers mention this function in the last line. In the first case, to cavil at content developers and equipment manufacturers is difficult, because a new format has matured and in most cases paid off. Technologies enable to start 4K era right now, the only thing left to do is to create high quality content. If TV is very large, in terms of marketing specialists words, the viewer with deeper sense of space. Finally, in movie theaters is used a huge cloth, which, figuratively speaking, covers movie lover. Authoritative film and television industry player THX in order to make a deeper sense of space recommends to sit in such a distance that the screen would cover 40% of visual field. In a case of 55-inch screen, the aforementioned parameter would be 1.7 meters. This dependence is influenced by one more parameter – screen resolution. HD increases the distance up to 3.23 meters, and Full HD – up to 2.18 meters, so we gonna need the Ultra HD resolution TV, and then we are forced to write the phrase that the 4K content is still not enough. LG used the term "horopter line" which defines the difference of distance of points on the screen between viewer's eyes. It's a curve with a viewer in its center. If the surface of TV screen is in distance equal to horopter line, your eyes do not have to change the focus. So, according to this theory, for example, LG 55EC930V TV you should watch in a distance of 5 meters. Taking again 55-inch diagonal. Curved form will reduce the projected width up to 121.7 cm. On the flat model it will be equal to 122 cm. Given the curvature beam (5 meters) and 14 degrees angular beam sector, that is, when we sit in optimal point, we get about 3% enlarged visual width. The prolonged distance from TV by three meters is 9%, because the angle increases up to 24 degrees. Again, all this measurements fit only being in one, ideal, position in front of the screen.

In the end, curved screens reduce optical distortions, because human eyes are not flat, so it is better look to curved screen.

4.3. Analysis of Experiment

Calibration errors were quite big (100 and more) because of the unusual conditions of the test. The user's position in respect of the screen system is changeable and calibration repeated until the error will not exceed 100. An average fixed calibration error is 79.5 (standard diversion 10.9) during the study.

Assessing accuracy of the user's vision, those coordinates of the points are taken from Mirametrix eye fixation point magazine which are stabilized, that is, have 5 points and the coordinate's range 0.5% of the screen area. To simplify comparison, all relative point coordinates converted into the column and row numbers of the circle. It allows comparing different distances from the screen or the angle of the screen. (not tied to specific distance measurement units).

Comparing how much measured values differ from real, it is received that while determining the column, the error is approximately 3.29 width of the column (standard deviation 1.34 width of the column) what the studied situation corresponds to 165 pixels. Meanwhile, determining the number of the row (comparing measured coordinates with shown point) an average error reaches 1.20 width of the row (standard deviation 0.78 width of the row) that is equivalent to 60 pixels of the hight of the studied screen system. The difference between the errors of the columns and rows is close to 3 times, what partly shows that the system is not appropriate for searching positions of determining an accurate point in the curved display systems.

Adjustment of coordinates of two screen systems (recalculation from a two-dimensional projection to the surface of the screen) was applied to adjustment of eye fixation, relative coordinates of eye position. Recalculating y coordinate of each point and converted into an appropriate circle visual column it is received that determining a column an error is 2.30 width of the column (standard error 0, 79 width of the column). It shows that eye fixation point position after recalculation adjusted to one column or about 50 pixels of screen width. Setting of column standard deviation decreased that equaled to setting of column standard deviation. This indicates that the remaining errors are more related to measurement equipment, the errors during calibration, as accuracy of column setting does not depend on curved display systems.

It was also noted that detected and recalculated eye fixation point positions are deviated towards the centre of screen system. This distribution shows that detected coordinates of eye fixation point, expanding proportionally, it would be possible to improve accuracy of eye positioning.

Furthermore, the difference of adjusted and detected coordinates depends on the angle of the screen in respect of the user and the distance of the observed point from the centre of screen system.

10 observed points in real situation of coordinates during one experiment are shown in Figure 4.2. Set by Mirametrix equipment and checked by two monitor model system. The whole diagram shows overall layout of the screen and a blue line almost at the middle of the chart shows where intersection of the screens is, the angle between the screens.

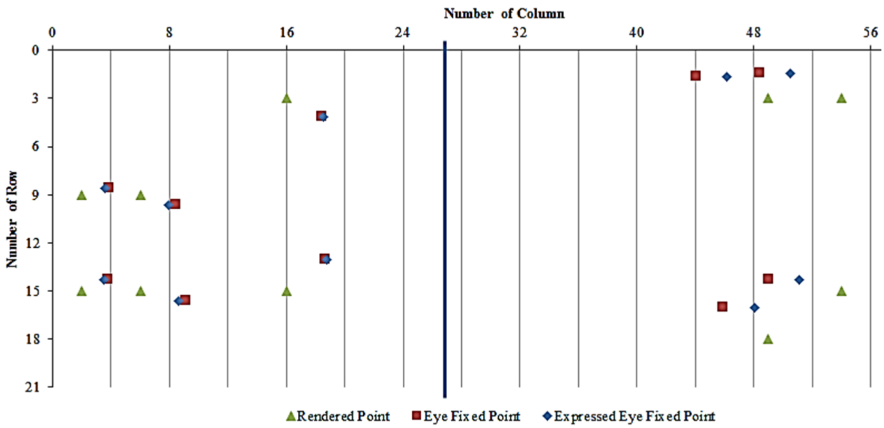


Fig. 4.2. The detection: Eye Movement vs Mirametrix

Distance between two points, diametre of the second point, slope of the user's eye movement and the user's reaction time is necessary for Fitts Law application. It is suggested not to take into account reaction time, so we will equate it to 0 and count time from the moment when eye starts moving when it reaches and stabilizes in the second point during the experiment. As we can detect the time of eye movement, the distance between the points and diameter of the second point during the experiment, the aim of the study is to detect slope of eye movement and comparing it to estimate in two screen systems, more accurate to assess the method of the distance measurement.

Distances between eye jumps from one point to another are calculated for all fixed eye jumps in the study and in all three methods (in a two-dimensional projection, screen plane and three-dimensional space from the point on the surface of the screen to another). Slope of eye movement is calculated according to the time of eye jump from one point to another, diametre of the second point and calculated distances. It is noticed that overall slope value is the same enough in all three methods; the method of a two-dimensional projection distinguishes more, as distances can be expanded with respect to the viewing angle of the point.

It is also compared how slope value changes, when the user diverts his eye from one point to another in the same column and when the column changes. Change of the column is important in this experiment as the differences between these three methods with respect to a curve of screen system are noticable only in respect of x axis and changes in respect of y axis cannot be felt. It is noticed that for measured distances values are similar in a screen plane and three-dimensional space only the results during measured distance in a two-dimensional projection differ (see Table 4.1.).

Table 4.1. The results during measured distance

Method	Average slope values of all jumps	Average slope values of separate jumps		Difference between slope value in the same and different columns
		Jumps in the same column	Jumps between columns	
Two-dimensional projection	0.1133	0.1276	0.0955	0.0321
Screen plane	0.1151	0.1295	0.0972	0.0323
Three-dimensional space	0.1156	0.1298	0.0979	**0.0319**

It is difficult to assess from these rates what method is more accurate that is why comparing jumps in the same column and across the screen is based on the difference of slope value. Such a criterion is chosen as slope value should be approximately the same for all eye jumps, carried out on the same environmental conditions (not changing motivation, situation of test, environment and other parameters that can impact on velocity of eye movement). However, this diffrence is not so significant, but measuring the distance between the points in three-dimensional space and determining slope value minimum differences are obtained in eye jumps vertically, horizontally or crosswise. It allows claiming that distance between two points in three-dimensional space calculated is a more accurate Fitts Law parametre, using not flat but curved multiple monitors at the angle.

Considering the facts that not accurate coordinates of eye fixation (which is found in previous section) are used for these measurements an additional slope detection experiment was carried out. The same data is used as in previuos study during it but Mirametrix systems are adjusted, relative coordinates of eye fixation point are represented. They are adjusted that after adjustment of coordinates transferring them to the surface of the screen (not to a two-dimensional projection) to meet the user watch the positions of the circles. Thus, the same time is maintained for eye jumps from one point to another, the same system of parameters remain but ideal calibration situation is obtained when all eye jumps are diverted to the object needed to observe. This made it possible to atjust distances between initial and final point of eye fixation, so new medium slope values are obtained (see Table 4.2).

Table 4.2 Revised results during measured distance

Method	Average slope values of all jumps	Average slope values of separate jumps		Difference between slope value in the same and different columns
		Jumps in the same column	Jumps between columns	
Two-dimensional projection	0.1137	0.1309	0.0921	0.0387
Screen plane	0.1090	0.1309	0.0817	0.0491
Three-dimensional space	0.1148	0.1309	0.0947	**0.0361**

Differences between vertical and horizontal or crosswise eye movements in two monitor screen system are more clearly noticed during this study as there are no differences between slope values of vertical eye jumps and adjusted horizontal coordinates allow highlighting more similar slope values, assessing them due to the distances of two points in three-dimensional space.

4.4. Evaluation of the Method

For Evaluation of the Method comparing three methods (two-dimensional projection; screen plane; three-dimensional space) were selected. For calculating main results, all components were measured by two types: pointing from the picture (screen plane) and real checkmate (three methods).

For final results of evaluation was made a table for checking all possible measures (a display width; screen height h; screen (curved) radius r; distance to the center of the screen A; screen resolution, pixels; curved screen angle alpha and etc.) for these three methods. For containing all data were selected MySQL database and MS Excel as recalculating tool for main result. For checking possibilities of different variations absolute size or ratio were selected. To simplify similarity calculation among big amount of data and to reduce calculating time, there were used just few examples of evaluation.

The fact that each test result had the same essence – method Three-dimensional space accurate. Finally all the calculations showed the same result.

It is acknowledged that there are values and display the places where curve alpha is so small that log can be sub-zero, so here should be used other next Fitt's law formula, but it is not a part of this study. Display systems (curved) on calcutation by different screen plane points, pixels: x0, x1, y0, y1 (see Table 4.3.).

Table. 4.3. Example of the test result

Two-dimensional projection	Screen plane	Three-dimensional space
A	***A***	***A***
2.533	3.003	**2.532**
2.400	2.835	**2.399**
5.733	6.018	**5.714**
6.133	6.636	**6.109**

All data about each measure in DB were compared between each other. The Three – Dimensional space achieves perfect precision and nearly perfect recall, 100.0% respectively. These results are better than those achieved with other methods (see Table 4.4).

Table. 4.4. Recalculation of Fitts law using *slope b* and *A* from experiment

Two-dimensional projection			Screen plane			Three-dimensional space		
Fitts law			Fitts law			Fitts law		
a	0		a	0		a	0	
b	0.1133		b	0.1133		b	0.1133	
ID	1.68		ID	2.895753		ID	1.676915	
A	4.2		A	7.239384		A	4.192287	
W	5		W	5		W	5	
t	*0.0848*		***t***	*0.1738*		***t***	***0.0845***	

For practical reason this prototype could be used by users counting effectiveness of software (GUI) (see Figure 4.5):

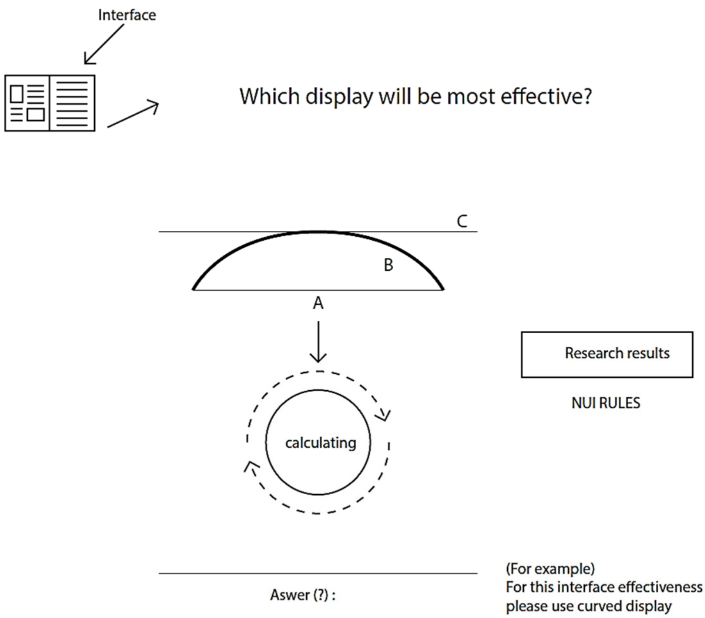


Fig. 4.5. Example of Prototype

If a designer wants to estimate how to draw design elements, which are to be shown on a two-dimensional projection, he takes slope of 0.1137 and puts it into the Fitts formula with all others checkmates. If a designer wants to estimate how to draw design elements, which are to be shown on a screen plane, he takes slope of 0.1090 and puts it into the Fitts formula; for three dimensional – takes slope of 0.1148 and puts it into the Fitts formula. Other wise, for calculating time and effectiveness for special soft design or picture (GUI), designer should use the same slope, a – as const and all others mesurements.

4.5. Conclusion of Chapter

In this Chapter experimentally evaluated three methods: two-dimensional projection; screen plane; three-dimensional space. Those three methods were applied to working with screens system and was found out that measuring the distance between two GUI points with apparent three-dimensional surface slope value variation in performing saccade vertically and in other directions were smaller then by using two other methods. Also, re-estimation of a position of points on three-dimensional space surface helps to correct accuracy of modern equipment for eyes movement tracking by applying it not only to plane, but also to curved screens and their systems. These results show that the use aforementioned method and additional parameters (screen features, person's position in relation to a screen) is expedient if we want to evaluate usability efficiency more accurately.

Additionally was found out that popular current eyes tracing equipment, which is used to perform different studies of curved screens worldwide, does not accurately captures information to be collected. For more accuracy, mathematical recalculation is necessary.

Proposed methods are for calculating Fitts law standard parameters in accordance with a chosen method and movement slope, so they can be used respectively.

General Conclusions

1. Analysis of the literature on specifics of curved monitors and application of natural user interface NUI showed that usability properties, factors and laws define mutually uncorrelated requirements. As a result further analysis and modification of the rules of NUI development are needed.
2. Evaluating human computer interaction and ergonomic model (Fitts Law) parameters it is demonstrated that the value of eye speed of particular system operation in the law is influenced by user motivation. Therefore, the assessment of the effectiveness of NUI must assess not only the graphical interface features, but also in terms of environmental impact on the user.
3. Expanding efficiency of NUI measurement rules of natural user interface, three possible evaluation options of distance between two GUI points are distinguished: in a screen plane, in a two-dimensional projection and in a three-dimensional space. The method is proposed on the basis of the options to specify NUI efficiency for a curved monitor.
4. Applying the proposed method it is determined that, measuring the distance between two GUI points in three-dimensional space, the highest value of eye speed of particular system is obtained as compared to

other distance assessment options. The highest value of eye speed of particular system parameter in the Fitts Law ensures faster task performance. These results show the feasibility and efficiency of the method.

References

Ali-Hasan, N. F.; Harrington, E. J.; Richman, J.B. 2008. Best practices for eye tracking of television and video user experiences, in *Proceedings of the 1st International Conference on Designing Interactive User Experiences for TV and Vide*. Silicon Valley, CA, USA: ACM Press, 5–8. http://dx.doi.org/10.1145/1453805.1453808

Arnheim, R. 1974. *Art and visual perception*: *a psychology of the creative eye*. Berkeley: University of California Press. 272–274.

Bi, X.; Li, Y.; Zhai, S. 2013. Fitts law: modeling finger touch with fitts' law, in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,* 27 April, 2013, Paris, France. http://dx.doi.org/10.1145/2470654.2466180

Bouillon, L.; Vanderdonckt, J. 2002. Retargeting web pages to other computing platforms with VAQUITA, *In Proceedings of the 9th Working Conference on Reverse Engineering WCRE'2002*, 29 October – 1 November 2002 Richmond, VA, USA. Los Alamitos: IEEE Computer Society Press, 339–348. http://doi.ieeecomputersociety.org/10.1109/WCRE.2002.1173091

Brooke, J. 2013. SUS: a retrospective, *Journal of Usability Studies* 8(2): 29–40.

Card, S. K.; Englisch, W. K.; Burr, B. J. 1978. Evaluation of mouse, rate-controlled isometric joystick, step keys for text selection on a CRT, *Ergonomics* 21(8): 601–613. http://dx.doi.org/10.1080/00140137808931762

Choi, K.; Bae, H.; Ju, S. W.; Suk, H. J. 2015. Visual search and attention: what eye-tracking reveals about visual performance in the curved display, in *Proceedings of the*

International Symposium Digest of Technical Papers May 21–5 June 2015, San Jose, CA. ACM Press, 798–801. http://dx.doi.org/10.1002/sdtp.10315

Chuang, J.; Nguyen, H.; Wang, C.; Johnson, B. 2013. I think, therefore i am: usability and security of authentication using brainwaves, financial cryptography and data security, *Lecture Notes in Computer Science* 7862: 1–16. http://dx.doi.org/10.1007/978-3-642-41320-9_1

Coyne, K.; Nielsen J. 2001. *How to conduct usability evaluations for accessibility: methodology guidelines for testing websites and intranets with users who use massistive technology*. Nielsen Norman Group.

Courtney, A. J. 1986. Chinese population stereotypes: colour associations, *The Journal of the Human Factors and Ergonomics Societ* 28(1): 97–99.

Cooper, M.; Rejmer, P. 2001. Case study: localization of an accessibility evaluation, in *the CHI '01 extended abstracts on human factors in computing systems*. New York: ACM Press, 141–142. http://dx.doi.org/10.1145/634067.634154

David, L. 1997. Color and human-computer interaction, in *Handbook of human-computer interaction*. Elsevier 573–578.

Dean, J.; Bruwer, M. 1994. Control of human arm movements in two dimensions: paths and joint control in avoiding simple linear obstacles, *Experimental Brain Research* 97(3): 497–514. http://dx.doi.org/10.1007/BF00241544

Despard, J. L.; Dimech-Betancourt, B.; Ternes, A.; Poudel, G.; Churchyard, A.; Georgiou-Karistianis, N. 2013. Fitts law: modelling upper limb movements in Huntington's disease and the impact of visual cue restriction, in *The 4th Australasian Cognitive Neuroscience Conference 2013 (ACNC 2013),* November 28 – December 1 2013, Monash University, Melbourne.

Desurvire, H. W.; Kondziela, J. M.; Atwood, M. E. 1992. What is gained and lost when using evaluation methods other than empirical testing, in *Proceedings of the HCI '92 Conference on People and Computers VII*. Cambridge, NY: Cambridge University Press, 89–102.

Dix, A.; Finlay, J.; Abowd, G. D.; Beale, R. 2004. User-centered design, in W. Bainbridge. *Encyclopedia of Human-Computer Interaction*. Thousand Oaks: Sage Publications.

Drewes, H. 2010. *Eye gaze tracking for human computer interaction*: Dissertation, LMU Munich.

Drewes, H. 2010. Only one Fitts' law formula please!, in *Proceedings of the International Conference Extended Abstracts on Human Factors in Computing Systems,* 10–15 April 2010 Atlanta, GA, USA. New York, NY: ACM Press, 2813–2822. http://dx.doi.org/10.1145/1753846.1753867

Duarte, M. E. C.; Rebelo, F. 2005. Comprehension of safety signs: Internal and external variable influences and comprehension difficulties by disabled people, in *The 4th International Cyberspace Conference on Ergonomics*, 15 September – 15 October 2005, Rhodes University, Grahamstown, South Africa. Johannesburg: International Ergonomics Association Press.

Faulkner, Ch. 2003. *The essence of human-computer interaction*. Pearson Prentice Hall.

Felton, E. A.; Radwin, R. G.; Wilson, J. A., Williams, J. C. 2009. Evaluation of a modified Fitts law braincomputer interface target acquisition task in able and motor disabled individuals, *Journal of Neural Engineering* 6(5), ID 056002.

Felton, E. A.; Williams, J. C.; Vanderheiden, G. C.; Radwin, R. G. 2012. Mental workload during braincomputer interface training, *Ergonomics* 55(5): 526–537. http://dx.doi.org/10.1080/00140139.2012.662526

Fitts, P. M. 1954. The information capacity of the human motor system in controlling the amplitude of movement, *Journal of Experimental Psychology* 47(6): 381–391. http://dx.doi.org/10.1037/h0055392

Frey, J.; MAijhl, C.; Lotte, F.; Hachet, M. 2014. Review of the use of electroence-phalography as an evaluation method for human-computer interaction, in *Proceedings of the PhyCS 2014 International Conference on Physiological Computing Systems*, 7–9 January 2014, Lisbon, Portugal.

Gafni, R. 2009. Usability issues in mobile-wireless information systems, *Issues in Informing Science and Information Technology* 6: 755–769.

Gatsou, C.; Politis, A.; Zevgolis, D. 2012. The importance of mobile interface icons on user interface, *International Yournal of Computer Science and Applications* 9(3): 92–107.

Gulliver, S. R.; Ghinea, G. 2004. Stars in their eyes: what eyetracking reveals about multimedia perceptual quality, *IEEE Transactions on Systems, Man, and Cybernetic* 34(4): 472–482. http://dx.doi.org/10.1109/TSMCA.2004.826309

Halverson, T.; Hornof, A. J. 2004. Local density guides visual search: sparse groups are first and faster, in *Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting.* New Orleans, LA: ACM Press. http://dx.doi.org/10.1177/154193120404801615

Hanna, L.; Risden, K.; Alexander, K. 1997. Guidelines for usability testing with children, Microsoft, *Magazine Interactions* 4(5): 9–14. http://dx.doi.org/10.1145/264044.264045

Hick, W. E. 1944. On the rate of gain of information, *Quarterly Journal of Experimental Psychology* 4: 11– 6. http://dx.doi.org/10.1080/17470215208416600

Hornof, A. J.; Halverson, T. 2003. Cognitive strategies and eye movements for searching hierarchical computer displays, in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,* 5–10 April 2003, Fort Lauderdale, Florida. New York, NY ACM: 249–256. http://dx.doi.org/10.1145/642611.642656

Jacob, R. J. K. 1991. The use of eye movements in Human computer interaction: what you look at is what you get, *ACM Transactions on Information Systems* 9(3): 152–169. http://dx.doi.org/10.1145/123078.128728

Jahn, S.; Liu, A.; Dimitrov, A.; Mazo, M.; Jurgen, F.; Matthias, K. 2006. Context-aware interaction and navigation in mobile games, *Information Technology and Control* 35(2): 198–202.

Jax, S. A.; Rosenbaum, D. A. 2007. Hand path priming in manual obstacle avoidance: evidence that the dorsal stream does not only control visually guided actions in real time, *Journal of Experimental Psychology. Human Perception and Performance* 33(2): 425–441. http://dx.doi.org/10.1037/0096-1523.33.2.425

Jax, S. A.; Rosenbaum, D. A.; Vaughan, J. 2007. Extending Fitts' Law to manual obstacle avoidance, *Experimental Brain Research* 180(4): 775–779. http://dx.doi.org/10.1007/s00221-007-0996-y

Kanfer, R.; Ackerman, P. L. 2004. Aging, adult development, and work motivation, *Academy of Management Review* 29: 440–458.

Khanum, M. A.; Trivedi, M. C. 2012. Take care: a study on usability evaluation methods for children, *International Journal of Advanced Research in Computer Science* 3(2): 101–105.

Mack, A.; Pappas, Z.; Silverman, M.; Gay, R. 2002. What we see: inattention and the capture of attention by meaning, *Consciousness & Cognition* 11(4): 488–506. http://dx.doi.org/10.1016/S1053-8100(02)00028-4

MacKenzie, I. S. 1992. Fitts' law as a research and design tool in human-computer interaction, *Human-Computer Interaction* 7: 91–139. http://dx.doi.org/10.1207/s15327051hci0701_3

MacKenzie, I. S.; Buxton, W. 1992. Extending Fitts' law to two-dimensional tasks, in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 1992 Monterey, California, USA. 219–226. http://dx.doi.org/10.1145/142750.142794

McDougall, S.; Curry, M. 2004. More than just a picture: icon interpretation in context, in *Proceedings of 1st International Workshop on Coping with Complexity*, 16–17 September 2004, University of Bath: 73–81.

Meyer, D. E.; Smith, J. E. K.; Wright, C. E. 1982. Models for the speed and accuracy of aimed limb movements, *Psychological Review* 89(51): 449–482. http://dx.doi.org/10.1037/0033-295X.89.5.449

Meixner, G.; Calvary, G.; Coutaz, J. 2014. *Introduction to model-based user interface*: *W3C Working Group Note*, 07 January 2014. W3C.

Myers, B.; Rosson, M. B. 2000. Survey on User Interface Programming, in *Proceedings of the 10th Annual CHI Conference on Human Factors in Computing Systems*, 1–6 April 2000, The Hague, The Netherlands, 195–202.

Moroz-Lapin, K. 2008. Žmogaus ir kompiuterio sąveika, *TEV*: 4–7.

Ng, A. W. Y; Chan, A. H. S. 2008. Visual and cognitive features on icon effectiveness, in *Proceedings of the International MultiConference of Engineers and Computer Scientists*, 19–21 March 2008, Hong Kong, 19–21.

Nielsen, J. 1995. *Summary of Usability Inspection Methods* [online], [cited 11 March 2015]. Available from Internet: http://www.nngroup.com/articles/summary-ofusability-inspection-methods

Niemela, M.; Saarinen, J. 2000. Visual search for grouped versus ungrouped icons in a computer interface, human factors, *The Journal of the Human Factors and Ergonomics Society* 42(4): 630–635. http://dx.doi.org/10.1518/001872000779697999

Paolozza, A.; Munn, R.; Munoz, D. P.; Reynolds, J. N. 2015. Eye movements reveal sexually dimorphic deficits in children with fetal alcohol spectrum disorder, *Frontiers in Neuroscience* 9: 76. http://dx.doi.org/10.3389/fnins.2015.00076

Petrasch, R. 2007. Model based user interface design: model driven architecture und HCI patterns. GI Softwaretechnik-Trends, *Mitteilungen der Gesellschaft für Informatik* 27(3): 5–10.

Radvilė, E.; Čenys, A.; Ramanauskaitė, S.; Bičiūnaitė, Ž. 2015a. Analysis of the pattern for icon selection and relation to positive/negative actions in desktop applications, *British journal of mathematics & computer science* 7(6): 391–406.

Radvilė, E.; Čenys, A.; Ramanauskaitė, S. 2015b. Electroencephalography and eye gaze movement signals' usage for estimation of user interface usability, *Elektronika ir Elektrotechnika* 21(5): 75–81.

Radvilė, E.; Čenys, A. 2015a. Research of Fitts' law characteristics using curved display, electroencephalography and eyes tracker, in *Proceedings of the Electrical, Electronic and Information Sciences (eStream)*, 21–21 April 2015. New York: IEEE, 1–4. 10.1109/eStream.2015.7119498

Radvilė, E.; Čenys, A. 2015b. Research: what eyes and brain reveals about visual performance in the curved display, in *Proceedings of the 14th International Conference on Perspectives in Business Informatics Research (BIR 2015)*, 26–28 *August 2015, Tartu, Estonia. CEUR 1*420: 173–180. ISSN 1613-0073.

Ramanauskas, N. 2006. Calibration of vdeo – oculographical eye-tracking system, *Electronics and Electrical Engineering* 8(72): 65–68.

Richards, D.; McDougall, S. 1999. Road traffic signs: how implicit category knowledge improves learning, *Engineering Psychology and Cognitive Ergonomics*: 329–336.

Sauro, J.; Kindlund, E. 2005. A method to standardize usability metrics into a single score, in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,* 2–7 April 2005, Portland, Oregon, USA. http://dx.doi.org/10.1145/1054972.1055028

Schelkes, K. 2003. *User Interface Designer*, SAP AG [online], [cited 15 March 2014]. Available from Internet: http://www.sapdesignguild.org/editions/edition6/kai_sch.asp

Seffah, A.; Donyaee, M.; Kline, R. B.; Padda, H. K. 2006. Usability measurement and metrics: a consolidated model, *Software Quality Control* 14(2): 159–178. http://dx.doi.org/10.1007/s11219-006-7600-8

Shieh, K.-K.; Huang, S.-M. 2004. Effects of pictorial size and circle-slash thickness on glance legibility for prohibitive symbols, *International Journal of Industrial Ergonomics* 33: 73–83. http://dx.doi.org/10.1016/j.ergon.2003.09.001

Shupp, L.; Andrews, C.; Dickey-Kurdziolek, M.; Yost, B.; North, C. 2009. Shaping the display of the future: the effects of display size and curvature on user performance and insights, *Human-Computer Interaction* 24(1–2): 230–272. http://dx.doi.org/10.1080/07370020902739429

Shupp, L.; Ball, R.; Yost, B.; Booker, J.; North, C. 2006. Evaluation of viewport size and curvature of large, high-resolution displays, in *Proceedings of the Graphics Interface*, 7–9 June 2006, Québec, Canada, 123–130.

Syarief, A., Giard, J.R., Detrie, T., McBeath, M.K. 2003. An initial cross-cultural survey of user perception on web icon design for travel websites, *In Proceedings of the 6th Asia Design International Conference,* 14–17 October 2003, Ibaraki, Japan.

Smits-Engelsman, B.; Rameckers, E.; Duysens, J. 2007. Children with congenital spastic hemiplegia obey fits law in a visually guided tapping task, *Experimental Brain Research* 177(4): 431–439. http://dx.doi.org/10.1007/s00221-006-0698-x

Soechting, J. F.; Lacquaniti, F. 1983. Modification of trajectory of a pointing movement in response to a change in target location, *Journal of Neurophysiology* 49(2): 548–564.

Soukoreff, R. W.; MacKenzie, I. S. 2004. Towards a standard for pointing device evaluation, perspectives on 27 years of Fitts' law research in HCI, *Human Computer Studies* 61: 751–89. http://dx.doi.org/10.1016/j.ijhcs.2004.09.001

Soukoreff, R. W.; MacKenzie, I. S. 2004. Towards a standard for pointing device evaluation: perspectives on 27 years of Fitts' law research in HCI, *International Journal of Human-Computer Studies* 61(6): 751–789. http://dx.doi.org/10.1016/j.ijhcs.2004.09.001

Švedaitė, E. 2012. Experience influence of natural user dependence on information distribution patterns, *Mokslas – Lietuvos ateitis* 4(1): 35–38.

Tognazzini, B. 2015. *First Principles of Interaction Design*, 5 Mar 2014.

Wang, A. H.; Chi, C. C.; Hu, Y. C. 2004. Effects of symbol- and wording-color of three hazardous material labels, surround color, and training on users' visual identification performance under different ambient illuminance, *Journal of the Chinese Institute of Industrial Engineers* 21: 597–605. http://dx.doi.org/10.1080/10170660409509439

Ware, C.; Mikaelian, H. H. 1978. An evaluation of an eye tracker as a device for computer input, in *Proceedings of the ACM Conference on Human Factors in Computing Systems – CHI+GI '87.* New York: ACM Press, 183–188.

Welford, A. T. 1960. The measurement of sensory-motor performance: survey and reappraisal of twelve years' progress, *Ergonomics* 3: 189–230. http://dx.doi.org/10.1080/00140136008930484

Wigdor, D.; Wixon, D. 2011. *Brave NUI world: designing natural user interfaces for touch*. Morgan Kaufman.

Zhai, S. 2004. Characterizing computer input with Fitts' law parameters: the information and non-information aspects of pointing, *International Human-computer Studies* 61(6): 791–809. http://dx.doi.org/10.1016/j.ijhcs.2004.09.006

Zhang, X.; MacKenzie, I. S. 2007. Intelligent multimodal interaction environments, in *Proceedings of the 12th international conference on Human-computer interaction HCI'07,* 22–27 July 2007, Beijing, China. Springer-Verlag Berlin: Heidelberg, 779–788.

A List of Publications by the Author on the Topic of the Dissertation

Papers in the Reviewed Scientific Journals

Švedaitė, E. 2012. Experience Influence of Natural User Dependence on Information Distribution Patterns, *Mokslas – Lietuvos ateitis* 4(1): 35–38. ISSN 2029-2341.

Radvilė, E., Čenys, A., Ramanauskaitė, S. 2015. Electroencephalography and Eye Gaze Movement Signals' Usage for Estimation of User Interface Usability, *Elektronika ir Elektrotechnika* 21(5): 75–81. ISSN 1392-1215.

Radvilė, E., Čenys, A., Ramanauskaitė, S., Bičiūnaitė, Ž. 2015. Analysis of the pattern for icon selection and relation to positive/negative actions in desktop applications, *British journal of mathematics & computer science. Tarakeswar: Sciencedomain international* 7(6): 391–406. ISSN 2231-0851.

Other Papers

Radvilė, E., Čenys, A. 2015. Research of Fitts' law Characteristics using Curved Display, Electroencephalography and Eyes Tracker, *In Proceedings of the Electrical, Electronic and Information Sciences (eStream).* New York: IEEE, 1–4. ISBN 9781467374453

Radvilė, E., Čenys, A. 2015. Research: what eyes and brain reveals about visual performance in the curved display, *In Proceedings of the 14th International Conference on Perspectives in Business Informatics Research (BIR 2015)*. Tartu: *Workshops and Doctoral Consortium* 1420: 173–180. ISSN 1613-0073.

Summary in Lithuanian

Įvadas

Problemos formulavimas

Vartotojo sąsaja (UI), pradedant nuo pirmųjų reikalavimų iki programinės įrangos vystymo, tapo daug laiko trunkantis ir brangus procesas. Paprastai grafinė vartotojo sąsaja (GUI) sudaro apie 48 % interaktyvios sistemos kodo, 45 % projektavimo darbų laiko ir 50 % įgyvendinimo darbų laiko, apima 37 % techninės priežiūros darbų laiko (Myers, Rosson 2000). Šie skaičiai, kurie buvo vertinami dešimtojo dešimtmečio pradžioje, dramatiškai didėja atsirandant naujų sąveikos metodų (balso, gestų, įvairių dydžių ekranų), kurie sukelia papildomų vartotojo sąsajos reikalavimų (Petrasch 2007). Siekiant optimizuoti UI kūrimo laiko sąnaudas, reikia spręsti sąveikos metodų keliamus uždavinius (Meixner 2014).

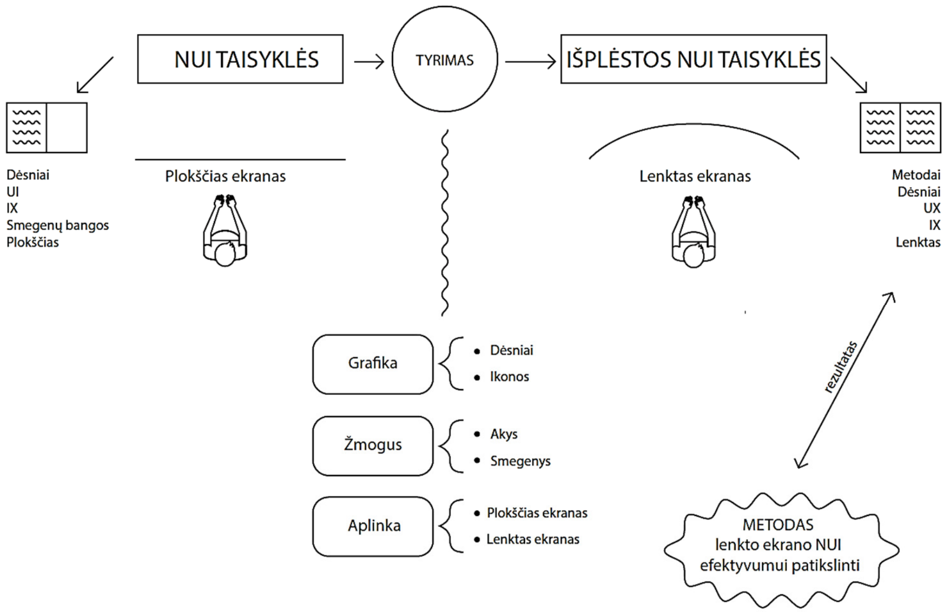
Atsiradus naujam technologijų produktui – lenktiems monitoriams, kurie vis plačiau naudojami darbo vietose, reikia nustatyti, kaip reikia projektuoti tokiuose monitoriuose atvaizduojamą vartotojo sąsają, kad naudojama nauja technologija atitiktų jos tinkamumo naudoti (efektyvumo, kuris padėtų konkrečiam naudotojui išspręsti konkrečius uždavinius konkrečiose aplinkose) lūkesčius.

Šiame kontekste sena technologija suprantama kaip plokščiasis ekranas ir jo vartotojo sąsajai projektuoti skirtos taisyklės.

Nauja technologija – lenktas ekranas ir jo vartotojo sąsajai projektuoti skirtos išplėstos taisyklės (S1 pav.).

Ekranų gamintojai nesutaria dėl argumentų, kurie įrodytų, kad lenktas ekranas geriau tenkina besivystančius pažangių vartotojų, sprendžiančių heterogeninius CIM klasės uždavinius, poreikius nei plokščiasis.

Iki šios dienos tai yra labiau technologijos pažanga dėl pažangos, nes nėra pasiūlyta metodo, kuris leistų pagrįstai pasirinkti apibrėžtų matmenų ir lenktumo ekranus tam tikrai sprendžiamų heterogeninių uždavinių klasei.



S1 pav. Tiriamojo darbo vizualizacija

Darbo aktualumas

Vykstant technologiniam šuoliui, dideliems lenktiems ekranams naudojamos tos pačios natūralios naudotojo sąsajos taisyklės kaip ir vidutinio dydžio plokštiesiems ekranams. Nėra griežtai atsižvelgiama į antrinius veiksnius, tokius kaip atstumas ir laikas, rezultatui pasiekti, naudotojo motyvacijos lygmenį užduočiai atlikti ir pan. Daugiausia koncentruotasi į fizinius ekranų parametrus (dydį, raišką, naują formą). Projektuojant grafinės sąsajos sistemas, svarbias laiko požiūriu, ir netiksliai įvertinus natūralios vartotojo sąsajos savybes, gali kilti esminių naudojimo problemų, sukeliančių neigiamų pasekmių (ypač sveikatos priežiūros ir aviacijos ar autopiloto mašinos valdymo srityse). Atsižvelgiant į tai, kad visgi yra papildomų veiksnių naudojant didelius lenktus ekranus, kurie daro poveikį natūralios naudotojo sąsajos tinkamumui naudoti, būtina ištirti taikomas taisykles ir jas išplėsti.

Tyrimų objektas

Disertacijos tyrimų objektas – natūralios vartotojo sąsajos efektyvumo matavimo taisyklės.

Darbo tikslas

Mokslinio darbo tikslas – išplėsti natūralios vartotojo sąsajos efektyvumo matavimo taisykles, skirtas sąsajai lenktuose ekranuose projektuoti.

Darbo uždaviniai

Darbo tikslui pasiekti ir mokslinei problemai spręsti darbe buvo iškelti šie uždaviniai:

1. Atlikti literatūros, kurioje aprašoma lenktų ekranų specifika ir tokiuose ekranuose naudojamos natūralios vartotojo sąsajos taikymas, analizę.
2. Nustatyti natūralios vartotojo sąsajos efektyvumo matavimo taisykles ir jo priklausomybę nuo Fitso dėsnio empirinių koeficientų.
3. Išplėsti natūralios vartotojo sąsajos efektyvumo matavimo taisykles ir pasiūlyti jų pagrindu veikiantį metodą lenkto ekrano NUI efektyvumui nustatyti.
4. Įvertinti metodo tinkamumą įgyvendinti ir veiksmingumą atliekant taikymo atvejo tyrimą.

Tyrimų metodika

Darbe taikyti šie tyrimų metodai:

- Stebėjimo vertinimas (angl. *Observational Evaluation*):
  - *Atribute Testing* (ISO 9241-8).
  - *Effectiviness Testing* (ISO CD 9241-13/16).
  - Stebėjimo metodas (*CLCIK interaction*).

- Euristinis vertinimas (*Cognitive Walkthroughs*):
  - *REACTION interaction.*

- Vartotojo elgesio vertinamas:
  - Specializuota aparatinė ir programinė įranga (smegenų bangų skaitytuvai – *Brain computer interface technology* ir *Mind wave*).
  - Specializuota aparatinė ir programinė įranga (akių reakcijos skaitytuvai *Mirametrix*).

Darbo mokslinis naujumas

Pagrindinis mokslinio darbo naujumas yra išplėstos natūralios naudotojo sąsajos efektyvumo matavimo taisyklės, skirtos sąsajai lenktų ekranų aplinkoje projektuoti. Šių taisyklių taikymas ankstyvojoje vartotojo sąsajos kūrimo (UID) fazėje padeda sumažinti būtinas laiko sąnaudas ir supaprastinti visos UI projektavimo ir kūrimo grandinės procesus, užtikrinant tinkamą UI kokybę.

Moksliniu požiūriu nauji ir kiti darbo metu gauti rezultatai:

- Taikant išplėstų natūralios vartotojo sąsajos efektyvumo matavimo taisyklių rinkinį, galima nustatyti, kuri plokštuma, taikoma nagrinėjamai sąsajai, yra efektyviausia. Tokiu būdu galima apskaičiuoti tos pačios vartotojo sąsajos pranašumą, naudojant tiriamojo tipo plokštumą arba ją lyginant su kita (ekrano paviršiaus, atstumo projekcijoje, menamojo paviršiaus).
- Moksliniame darbe pirmą kartą lenktų ekranų kontekste minima atbulinė plokštuma, kai vartotojo sąsajos savybės skaičiuojamos projektuojant vaizdą už ekrano plokštumos. Šios projekcinės plokštumos naudojimas vartotojo sąsajos savybėms nustatyti leido atskleisti aparatinės įrangos skaičiavimo netobulumą ir sukurti perskaičiavimo mechanizmą, kurį galima naudoti siekiant minėta įranga kuo tiksliau išmatuoti lenkto ekrano vartotojo sąsajos parametrus (GUI).
- Moksliniame darbe pirmą sykį, tyrinėjant natūralią vartotojo sąsają, tiriama 2–4 metų vaikų smegenų bangų veikla, naudojant lenktus ir plokščiuosius monitorius. Tyrimų metu žmogaus smegenų bangų rodmuo susietas su vartotojo sąsajos parametrais. Šiam tyrimui atlikti gautas Lietuvos bioetikos komiteto leidimas. Šio leidimo suteikimas Lietuvos bioetikos komitete sukėlė diskusijų apie tokio pobūdžio žmogaus informacijos saugumą.
- Atlikti eksperimentus padėjo *Samsung Lietuva* atstovybės suteiktas pirmasis Lietuvoje lenktas ekranas (54.6″ Measured Diagonally OLED Samsung).

Šie išdėstyti rezultatai, jų tinkamumas taikyti ir plačios naudojimo galimybės leidžia teigti, kad darbas moksliniu požiūriu yra naujoviškas ir reikšmingas.

Darbo rezultatų praktinė reikšmė

Dizaineriai, taikydami patobulintas NUI taisyklas savo kasdieniame darbe, turės naujų priemonių, padėsiančių suderinti rezultatus su aukštesnio lygio fazėmis. Tai suteiks jiems galimybių sutelkti dėmesį į svarbesnius aspektus, nepainiojant daugybės įgyvendinimo detalių.

Praplėstos patobulintos NUI taisyklės ir gauti tarpiniai rezultatai gali padaryti didelį poveikį programinės įrangos gaminimo procesui. Kuriant programinę įrangą ir taikant patobulintas NUI taisykles, galima iš anksto prognozuoti naudotojo veiksmų atlikimo kokybę ir laiką, t. y. galutinį rezultatą. Be to, ne mažiau svarbus ir papildomas parametras – vartotojo pasitenkinimas.

Šie rezultatai yra itin aktualūs, kai naudotojo informacijai apdoroti naudojami keli dideli, lenkti, tarpusavyje sujungti, didelės skiriamosios gebos ekranai, o kiekviena sekundė gali būti gyvybiškai svarbi tokiose veiklos srityse, kaip skrydžių valdymas, karo mašinų valdymas, chirurginių operacijų procesai. Plati šių tyrimų rezultatų naudojimo apimtis kasdieniame darbe didelio masto gamybos įmonėse gali sutaupyti daug laiko.

Kartu šie tyrimų rezultatai galėtų būti naudojami programinės įrangos kūrimo procesuose, siekiant įgyvendinti galimybes informaciją valdyti tik akimis – taip būtų pasiektas didesnis informacijos apdorojimo greitis atliekant eksperimentus ir tyrimus, tenkinant žmonių, turinčių negalią, poreikius.

Patogi ir vartotojui artimesnė sąsaja didina motyvaciją, naudojant daugiafunkcę sistemą pasiekiamas didesnis vartotojo sąsajos naudojimo efektyvumas.

Ginamieji teiginiai

1. Heterogeninių užduoties ir srities lygmens uždavinių efektyvumą galima nustatyti taikant lenkto ekrano NUI efektyvumo matavimo taisykles.
2. Naudojant lenktą ekranų su specialiai paruošta sąsaja, vartotojo sąveikos su sąsaja efektyvumas (greitis atliekant veiksmą) didesnis, lyginant su plokštiesiems ekranams pritaikyta sąsaja.
3. Žmogaus ir kompiuterio sąveikos bei ergonomikos modelis (Fitso dėsnis) gali būti taikomas lenktų ekranų efektyvumui nustatyti, kai būdingą sistemos veikimo akies greitį nustatome pagal pasiūlytą darbe metodą.

Darbo rezultatų aprobavimas

Disertacijos tema paskelbti trys moksliniai straipsniai. Jie publikuoti recenzuojamuose mokslo žurnaluose, iš kurių vienas turi ISI citavimo indeksą:

- Švedaitė, E. 2012. Experience Influence of Natural User Dependence on Information Distribution Patterns, *Mokslas – Lietuvos ateitis* 4(1): 35-38. ISSN 2029-2341.
- Radvilė, E., Čenys, A., Ramanauskaitė, S. 2015. Electroencephalography and Eye Gaze Movement Signals' Usage for Estimation of User Interface Usability, *Elektronika ir Elektrotechnika* 21(5): 75-81. ISSN 1392-1215.
- Radvilė, E., Čenys, A., Ramanauskaitė, S., Bičiūnaitė, Ž. 2015. Analysis of the pattern for icon selection and relation to positive/negative actions in desktop applications, *British journal of mathematics & computer science. Tarakeswar: Sciencedomain international* 7(6): 391-406. ISSN 2231-0851.

Disertacijos rezultatai buvo pristatyti tarptautinėse mokslinėse konferencijose ir jų leidiniuose:

- Radvilė, E., Čenys, A. 2015. Research of Fitts' law Characteristics using Curved Display, Electroencephalography and Eyes Tracker, *In Proceedings of the Electrical, Electronic and Information Sciences (eStream).* New York: IEEE, 1-4. ISBN 9781467374453
- Radvilė, E., Čenys, A. 2015. Research: what eyes and brain reveals about visual performance in the curved display, *In Proceedings of the 14th International Conference on Perspectives in Business Informatics Research (BIR 2015).* Tartu: *Workshops and Doctoral Consortium* 1420: 173-180. ISSN 1613-0073.
- Radvilė, E., Čenys, A. 2015. Research of Fitts' law Characteristics using Curved Display, Electroencephalography and Eyes Tracker, *Electrical, Electronic and Information Sciences (eStream).*

- Radvilė, E., Čenys, A. 2015. Research: what eyes and brain reveals about visual performance in the curved display, *BIR 2015 Workshops and Doctoral Consortium co-located with 14th International Conference on Perspectives in Business Informatics Research (BIR 2015).*
- Radvilė, E., Čenys, A., Ramanauskaitė, S. 2014. Fitts Law Curve Screen Usability Testing with Children, *6th International Workshop Data Analysis Methods for Software Systems.*
- Švedaitė, E. 2012. Natūralaus vartotojo potyrio įtakos priklausomybė nuo informacijos paskirstymo, *Jaunųjų mokslininkų konferencija „Mokslas – Lietuvos ateitis“* 4(1): 35–38.

Disertacijos struktūra

Disertaciją sudaro įvadas, keturi skyriai, bendrosios išvados, literatūros šaltinių sąrašas, autoriaus publikacijų disertacijos tema sąrašas, santrauka lietuvių kalba. Darbo apimtis – 106 puslapiai neskaitant priedų, tekste yra 13 formulių, 14 paveikslų ir 6 lentelės. Rašant disertaciją buvo panaudoti 75 literatūros šaltiniai.

1. Literatūros analizė

Šiame skyriuje apžvelgiama literatūra apima tiriamosios problemos metodų ištakas ir iššūkius, kurios toliau reikia spręsti nagrinėjant natūralios vartotojo sąsajos (NUI) efektyvumo matavimo taisykles.

Pereinant nuo GUI prie NUI, pasikeitė ne tik naudojamos informacinės technologijos, bet ir visa jos supanti aplinka: padidėjo kompiuterių galia, jie sumažėjo dydžiu ir kaina, buvo sukurta naujų prieigos prie informacijos būdų ir priemonių (pavyzdžiui, išmanieji telefonai, planšetiniai kompiuteriai, skaitmeniniai fotoaparatai), keitėsi duomenų perdavimo technologijos (pavyzdžiui, atsirado internetas), naujos infrastruktūros tapo plačiai prieinamos (pavyzdžiui, GPS), atsirado naujų pramonės šakų (pavyzdžiui, kompiuteriniai žaidimai), suklestėjo naujos programėlių grupės (pavyzdžiui, skaičiuoklės, dokumentų tvarkymas, įvaizdžio kūrimas ir modifikavimas). Visas šias tendencijas lėmė kompiuterinės demokratizacijos procesai, kai žmonių, kurie tiesiogiai sąveikauja su kompiuteriais, nuolat daugėja. Tokių asmenų skaičius seniai jau nebetelpa į nacionalines ribas ir apima beveik visas ekonomines klases. Pasikeitė viskas – žmonių darbas, žaidimai ir bendravimas vienų su kitais (Wigdor, Wixon 2011).

Nors kompiuterinės galios padidėjimas buvo nuolatinis procesas, visgi vartotojo sąsaja tobulėjo etapais. Etapas, apimantis darbastalio atsiradimą ir naudojimą, ir yra nagrinėjamas šiame darbe. Tai susiję su tokiais vartotojo sąsajos rinkinio elementais, kaip langai, piktogramos, meniu ir pranešimai juos naudojant.

Šiame darbe nagrinėjama tinkamumo naudoti (angl. *usability*) sritis, kuri parodo vartotojo patirties ir kokybės santykį sąveikaujant su kompiuteriniais produktais ar sistemomis, įskaitant interneto svetaines, programinę įrangą, prietaisus, ar pranešimus. Tinkamumas naudoti apima veiksmingumą, efektyvumą ir bendrą vartotojo pasitenkinimą; tai produkto, sistemos ir vartotojo veiksnių (F) derinys, visumos įvertinimas:

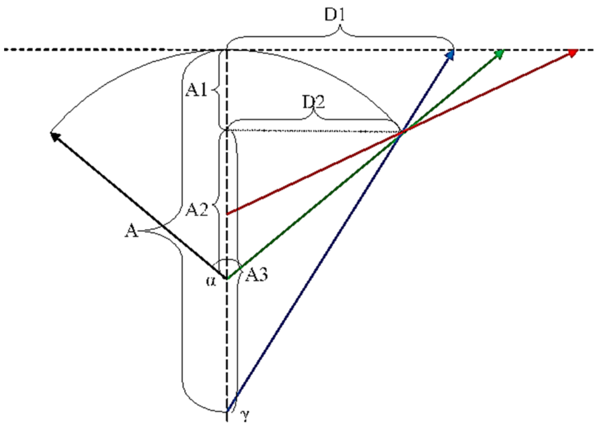
- Intuityvus dizainas (F(i)): kai beveik be pastangų galima suprasti produkto architektūrą ir navigaciją.
- Mokymosi lengvumas (F(l)): kaip greitai vartotojas, kuris niekada nematė vartotojo sąsajos, prieš tai gali atlikti pagrindines užduotis.
- Efektyvumas (F(e)) (angl. *efficiency of use*): kaip greitai patyręs naudotojas gali atlikti užduotis.
- Gebėjimas atsiminti (F(m)) (angl. *memorability*): kai po apsilankymo vartotojas gali prisiminti, kaip naudotis sąsaja kitą kartą.
- Klaidų dažnis ir sunkumas (F(er)) (angl. *error frequency and severity*): kaip dažnai vartotojai gali padaryti klaidų, naudodamiesi produktu.
- Pasitenkinimas (F(ai)) (angl. *subjective satisfaction*): kai vartotojas jaučia pasitenkinimą naudodamas produktą.

Aprašant mokslinio darbo analizės dalį, atsižvelgiama į CRF modelį (Bouillon, Vanderdonckt 2002), kuris apima konkretizavimą, abstrakciją, vertimą ir refleksiją. Šis modelis leidžia visą mokslinį darbą logine prasme sudalyti į tris praktines ir analitines dalis:

- GUI (grafinis modelis, apimantis heterogeninių užduoties ir srities lygmens uždavinių efektyvumą).
- HUI (žmogaus (vartotojo) modelis, apimantis žmogaus smegenų bangų ir akių reakcijas atsižvelgiant į uždavinius).
- EUI (aplinkos modelis, apimantis naujas technologijas (pavyzdžiui, lenkti ekranai))

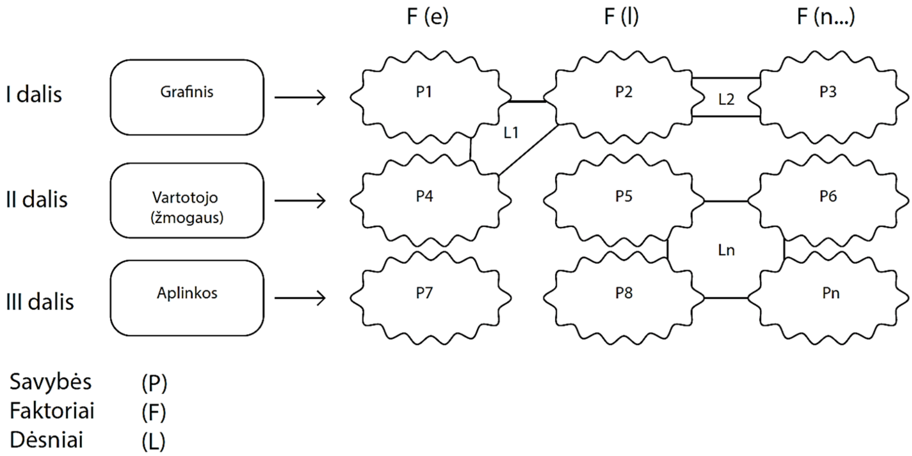
Visų šių veiksnių naudojimas iš tiesų ieško naudingo ir patogaus sprendimo vartotojui. NUI nėra fizinė vartotojo sąsaja, o sąsaja, leidžianti vartotojui sąveikaujant jaustis natūraliai.

Išanalizavus Fitso, Hiko, Akotso, Gestalto, tęstinumo, suprantamumo, paprastumo ir kitus 11 dėsnių bei standartų, pasiruošta GUI tyrimams, kurie bus aprašomi mokslinio darbo GUI ir HUI dalyse. Darbe išnagrinėti lenktų ekranų paviršių (ir tyrimui reikalingų plokštumų) atstumų tarp dviejų paviršiaus plokštumų skaičiavimo būdai ir su šiais skaičiavimais susiję parametrai (žr. S2 paveikslą), siekiant paskaičiuoti pasiūlyto metodo efektyvumą mokslinio darbo EUI dalyje.



S2 pav. Lenkto ekrano skaičiavimo parametrai

Grafinės (GUI), žmogaus (HUI), aplinkos (EUI) savybių sritys gali turėti tik savo tinkamumo naudoti veiksnius, tačiau, apimant bendrus dėsnius ir nusakant NUI taisykles, šie veiksniai taip pat koreliuoja su dėsnių suderinamumo reikalavimais (žr. S3 paveikslą).



S3 pav. Veiksnių koreliacija su dėsniais ir jų tarpusavio suderinamumo reikalavimais

Taigi lenktų Lenktų monitorių specifikos ir natūralios vartotojo sąsajos taikymo sritį nagrinėjančių šaltinių analizė parodė, kad šaltiniuose yra pateikiami savybių, faktorių ir dėsnių taikymo tarpusavio nedarnūs reikalavimai, todėl ši NUI taikymo specifika ir taikymo dokumentacija gali būti toliau panaudota NUI taisyklių tobulinimui.

2. GUI: grafinės sąsajos tendencijų poveikis nagrinėjant jų tarpusavio priklausomybę

Šiame skyriuje aprašomas GUI tyrimas, kurio metu buvo nustatyta pagrindinių GUI elementų visumos sąveika ir jų tarpusavio priklausomybės įtaka teigiamiems ir neigiamiems vartotojo pojūčiams.

Analizuojant duomenis buvo pastebėta, kad piktogramų atrankos metodas yra svarbus veiksnys vertinant NUI. Programinė įranga, kuri formuoja vartotojo sąsają, dažniausiai įvertinama netiesioginiu apklausos metodu, analizuojant vartotojo bandymus, veiksmus ir žingsnius (Coyne, Nielsen 2001; David 1997). Norint įsitikinti, kad gaunami rezultatai bus realūs, taikomas bendras piktogramų analizės metodas (Cooper, Rejmer 2001).

Taikant minėtas rekomendacijas buvo pasirinktas netiesioginės apklausos metodas ir sukurta matavimo priemonė. Priemonės paskirtis – sekti naudotojų veiksmus, atpažįstant monitoriuje naudojamas piktogramas, ir surinktus duomenis išsaugoti vėlesnei jų apibendrintai analizei. Tyrimo metu sistema atsitiktine tvarka priskiria vieną piktogramą vienam matavimo lango tinklelio langeliui. Siekiant įvairiapusiškų rezultatų, kiekvienam naujam seansui sugeneruojamas unikalus piktogramų pasiskirstymas langeliuose, tokiu būdų leidžiant vertinti tų pačių piktogramų pastebimumą (angl. *visibility*) skirtingose lango pozicijose. Nei piktogramų aibė, nei galimų pozicijų išdėstymas nekinta, tačiau kombinacijos „piktograma pozicijoje" visiems matavimo seansams yra skirtingos. Tyrime nuo 2013 gegužės mėn. iki 2014 rugsėjo mėn. dalyvavo 137 tiriamieji nepriklausomai nuo tautybės, išsilavinimo ir amžiaus..

S1 lentelė. Tyrimo metu naudotų piktogramų sąrašas ir vertinimai

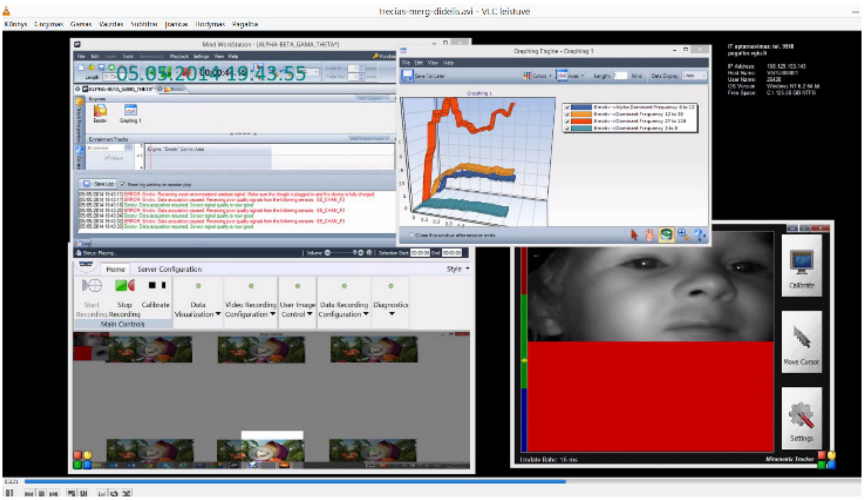
Nr.	Piktog-rama	Piktogramų, kurios buvo pasirinktos, procentinė išraiška		Piktogramų, kurios buvo pasirinktos, vidurkis, vnt.	
		užduotis 2 / „Teigiama"	užduotis 3 / „Neigiama"	užduotis 2 / „Teigiama"	užduotis 3 / „Neigiama"
1.		82 %	79 %	5,87	8,35
2.		82 %	79 %	6,02	10,77
3.		82 %	79 %	5,89	7,86
4.		81 %	80 %	7,40	5,81
5.		82 %	79 %	5,81	7,89
6.		82 %	79 %	5,42	7,73
7.		82 %	79 %	4,09	7,67
8.		81 %	80 %	6,89	4,24
9.		81 %	80 %	7,94	5,15
10.		81 %	80 %	9,92	3,70
11.		81 %	80 %	7,38	4,95
12.		81 %	80 %	6,47	3,58
13.		81 %	80 %	7,48	4,56
14.		81 %	80 %	6,64	3,73
15.		82 %	79 %	5,53	5,48
16.		82 %	79 %	5,93	7,22
17.		82 %	79 %	4,74	6,37
18.		81 %	79 %	6,34	8,58
19.		81 %	80 %	6,98	4,72
20.		82 %	79 %	6,12	6,30

Tyrimo metu nustatyta, kad vartotojo GUI piktogramos teigiamą ar neigiamą įvertinimą suponuoja ne tik grafinei vartotojo sąsajai kurti rekomenduojamų dėsnių nusakytos savybės, bet ir papildomos savybės, kurios neturi aiškaus tarpusavio ryšio (žr. S1 lentelę), todėl toliau analizuojamos kituose darbo skyriuose. Tyrimas ir jo metu gautų duomenų analizė rodo, kad, siekiant tiksliau įvertinti vartotojo sąsajos efektyvumą, reikėtų tikslinti esamus dėsnius, įtraukiant ne tik pagrindines, bet ir papildomas GUI vartotojo ar aplinkos savybes.

3. HUI: Fitso dėsnio parametrus galinčių paveikti savybių tyrimas naudojant ekranų sistemas

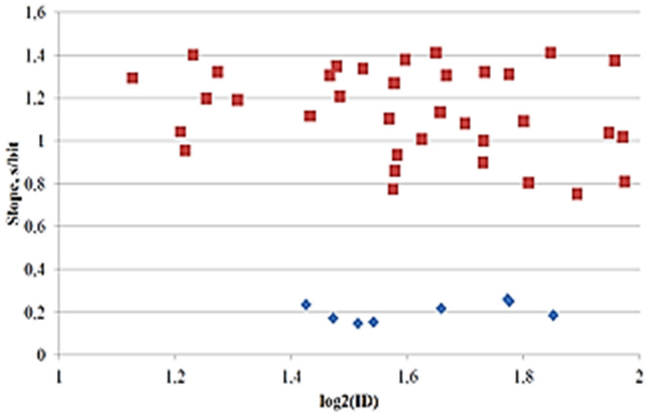
Šiame skyriuje aprašomi HUI tyrimai, kurių metu siekiama įvertinti žmogaus ir kompiuterio sąveikos bei ergonomikos modelio (Fitso dėsnis) parametrus galinčių paveikti savybių sąrašą.

Tyrimo metu taikant euristinį vertinimą analizuojamos žmogaus smegenų bangos ir akies judėjimo greitis. Norint kuo labiau išvengti tinkamumo naudoti veiksnių įtakos ((F(m), F(er), F(l)), pasirinkta tiriamųjų grupė yra 2–4 metų vaikai (Hanna *et al.* 1997). Šiam tyrimui atlikti gautas Lietuvos bioetikos komiteto leidimas. Tyrimui naudoti plokščiasis 17” ir lenktas 54,6” įstrižainės ekranai bei atitinkama smegenų, akių, įrašymo, programinės ir kita reikalinga įranga (žr. S3 paveikslą). Programinė įranga paruošta remiantis Fitso dėsnio efektyvumo išmatavimo galimybėmis, siekiant atkurti tyrimo metu gautus parametrus (akių trajektoriją bei greitį) ir apskaičiuoti būdingo sistemos veikimo (šiuo atveju akies) greičio reikšmės parametrus (a ir b).



S4 pav. Tiriamieji, programinė ir aparatinė įranga, naudota tyrime

Išanalizavus ir sinchronizavus EEG signalų duomenis, akių judėjimo trajektorijos ir greičio duomenis, vaizdo informaciją, specializuotos įrangos ir popierinius užrašus, buvo atliktas išsamus tyrimas. Atskleista, kad smegenų bangų dažnių šuoliai koreliuoja su akių judėjimo greičiu. Atlikus atskiros smegenų bangų dažnių analizę (Kanfer, Ackerman 2004; Chuang *et al.* 2004) nustatyta, kad tiriamasis bangų šuolio diapazonas atsakingas už žmogaus motyvaciją ir šiuo atveju tiesiogiai susijęs su užduoties atlikimo greičio parametrų reikšmėmis (žr. S4 paveikslą).



S4 pav. Fitso dėsnio parametro b *slope* reikšmės priklausomybė nuo motyvacijos lygio (mėlyna spalva – įvykdyta; raudona – neįvykdyta)

Taigi, vertinant žmogaus ir kompiuterio sąveikos bei ergonomikos modelio (Fitso dėsnis) parametrus, galinčius padaryti įtaką savybių sąrašui, nustatyta, kad dėsnyje būdingo sistemos veikimo akies greičio reikšmę veikia žmogaus motyvacija. Tai rodo, kad, vertinant NUI efektyvumą, reikia įvertinti ne tik GUI, bet ir aplinkos sąlygas, jų įtaką žmogui.

4. EUI: lenkti monitoriai ir jiems naudojamų išplėstų natūralios vartotojo sąsajos taisyklių įvertinimas

Šiame skyriuje aprašomas vartotojo aplinkos tyrimas, kuriame svarbų vaidmenį atlieka lenkti monitoriai arba ekranų sistemos,

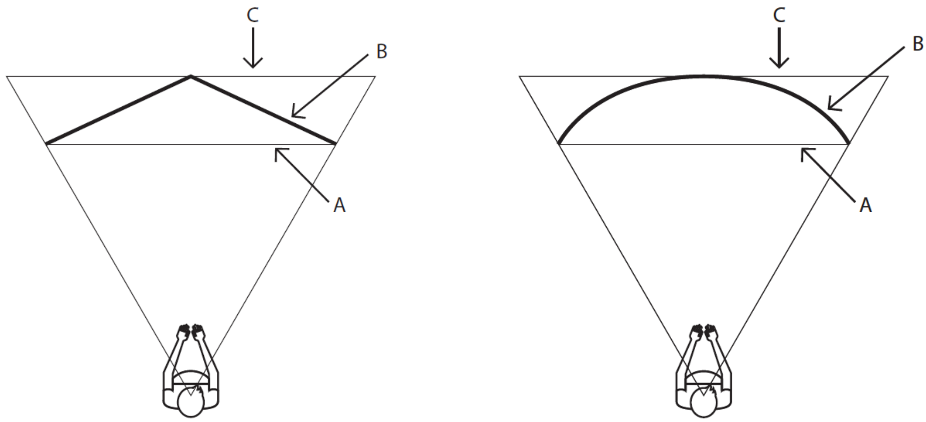
Planuojant tyrimą minėtini keli autoriai, kurie, taikydami Fitso dėsnį, atliko reikšmingus tyrimus, siejamus su lenktumu. Pirmajame tyrime nagrinėjamas kreivė plokštumoje, siekiant apskaičiuoti kreivei įveikti reikalingą laiką (Soechting, Lacquaniti 1983), kitas tyrimas apėmė kliūčių išvengimo judesius (Dean, Bruwer 1994) ir judėjimo laiko koreliavimą su bendru kelio kreivumu (Jax, Rosenbaum 2007). 2006 m. tyrėjai atliko tyrimus su didelės skiriamosios gebos ekranais vertindami užduoties atlikimo našumą (Schupp *et al*. 2009). Šis eksperimentas buvo atliktas naudojant net kelias žmogaus savybes (galvos, rankų, kūno, akių ir rankos). Naujausias lenktų ekranų ir vartotojo sąsajos tyrimas atliktas korėjiečių mokslininkų, naudojant lenktus TV ekranus ir akių stebėsenos įrangą (Choi *et al.* 2015).

Tyrimas buvo atliktas naudojant lenktą ekraną ir ekranų sistemą. Terminijai suvienodinti pateiktas S5 paveikslas:

A – 3D menamasis paviršius;

B – ekrano paviršius;

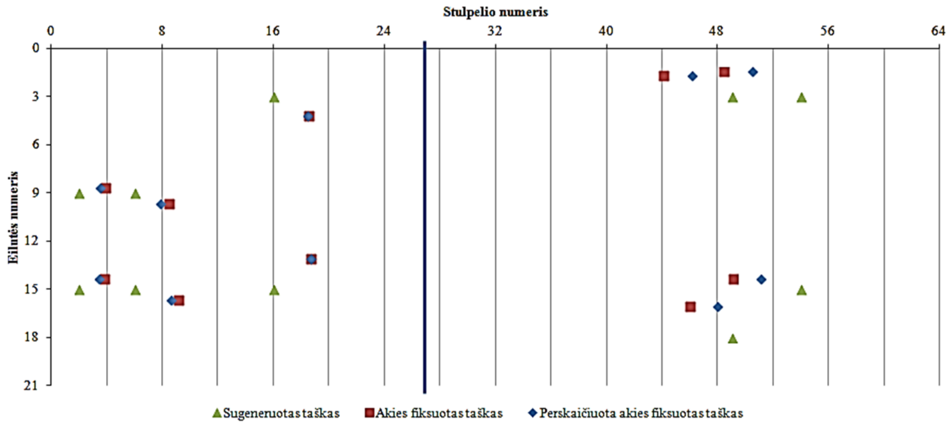
C – atstumas projekcijoje.



S5 pav. Tyrimo paviršiaus ir projekcijų terminijos atvaizdavimas.

Lenktas ekranas vartotojui leidžia realiau suvokti vaizduojamą aplinką, nes labiau primena natūralų apžiūros lauką (tam tikru spinduliu aplinkui regimą pasaulį). Tačiau toks sprendimas labai priklauso nuo ekrano lenktumo, sėdinčiojo pozicijos ir pan. Intuityviai išskiriami du pagrindiniai atvejai, kurie nulemia vartotojo, dirbančio su lenktu ekranu ar jų sistema, elgseną: kai visas ekrano vaizdas patenka į vartotojo regėjimo lauką; kai dalis ekrano vaizdo nepatenka į vartotojo regėjimo lauką. Šie abu atvejai tarpusavyje susiję, tačiau kai vartotojo regėjimo laukas yra mažesnis nei visas lenktame ekrane esantis vaizdas, tuomet akies šuolio laiką nuo vieno ekrano taško į kitą prognozuoti yra sudėtingiau dėl papildomų galvos judesių. Nepaisant to, kaip žmogaus akis pereina nuo vienų objektų prie kitų, negalima įvertinti ir laiko, kuris būtų sugaištas ne tik perkeliant žvilgsnį į kitą ekrano vietą, bet ir pasukant galvą norint jį pamatyti. Todėl šiame tyrime gilinamasi į tai, kaip turėtų būti skaičiuojamas vartotojo žvilgsniui nukreipti reikalingas laikas lenktame ekrane nuo vieno taško į kitą, kai jie abu yra jo regėjimo lauke. Tik žinant, kaip galima prognozuoti šį laiką, galima jį taikyti ir akies judesiams į pradžioje vartotojui dar nematomą lenkto ekrano vietą nustatyti. Nors atstumas tarp dviejų taškų dažnai vykdomas nuosekliai, tačiau atvejais, kai norima žvilgsnį nukreipti tiesiai iš vieno objekto prie kito, žmogaus akis atlieka didesnį šuolį, sakadą į iš anksto žinomą vietą. Nors akies sakados būna pirminės, antrinės, t. y. vyksta smulkesni akies judesiai žvilgsniui aptikslinti, bet šio akies judesio metu nėra fiksuojami visi tarp tų dviejų taškų esantys objektai. Plokščiuosiuose ekranuose tai įtakos neturi, nes judėjimas plokščio ekrano paviršiumi yra trumpiausias. Lenktuose ekranuose žmogaus akis ieško trumpiausio kelio, todėl juda ne lenkto ekrano paviršiumi, o jo styga. Šiuo metu lenkti didelės įstrižainės ekranai dar nėra plačiai paplitę, tačiau vis labiau populiarėja ekranų sistemos, kurios sudaro lenkto ekrano analogą, Neatsižvelgiant į tokios sistemos ir nuosekliai lenkto vieno ekrano nevisišką atitiktį, greitų akių šuolių nuo vieno taško prie kito atveju tokią sistemą galima traktuoti kaip lenktą ekraną arba ekranų sistemą,

Šiuolaikinė akių judesių fiksavimo programinė įranga nėra pritaikyta darbui su lenktais ekranais (Radvilė, Čenys 2015b), tad jos netikslumas, naudojant didelės įstrižainės lenktus ekranus, kartais gali būti didelis ir netoleruojamas. Tyrime kalibruoti ir akies judesiams fiksuoti naudojamas papildomas kompiuteris ir *Mirametrix* įranga. Norint kalibruoti, svarbu atitaikyti ekranų sistemos ir realiam kalibravimui naudojamo ekrano matmenis, nes *Mirametrix* programinė įranga naudojasi esamo ekrano proporcijomis, todėl galimos nemažos kalibravimo paklaidos. Tyrimo metu stebimų taškų koordinačių realioje situacijoje, nustačius su *Mirametrix* įranga ir patikslinus pagal ekranų sistemos pasirinktą modelį. Visa diagrama vaizduoja bendro ekrano išdėstymą, o mėlyna linija, esanti beveik ties diagramos viduriu, vaizduoja, kur yra ekranų sankirta, kampas tarp ekranų toks, kaip S6 paveiksle.



S6 pav. Tyrimo metu gautų rezultatų paklaidų vizualizacija

Perskaičiavus eksperimentiniu būdu gautus duomenis, išlaikomas tas pats laikas akies šuoliams nuo vieno taško prie kito, išlieka tie patys sistemos parametrai, bet gaunama ideali kalibravimo situacija, tada visi akies šuoliai nukeipti į būtent tą objektą, kurį ir reikėjo stebėti. Tai leido patikslinti atstumus tarp pradinio ir galinio akies fiksavimo taško, tad gautos ir naujos vidutinės *slope* reikšmės.

Šio tyrimo metu aiškiau pastebimi skirtumai tarp vertikalių, horizontalių ar skersų akies judesių dviejų monitorių ekranų sistemoje, nes nebelieka skirtumų tarp vertikalių akies šuolių *slope* reikšmių, o patikslintos horizontalios koordinatės leidžia labiau išryškinti vienodesnes s*lope* reikšmes, jas vertinant pagal trimatėje erdvėje matuojamus atstumus tarp dviejų taškų.

S7 lentelė. Eksperimento metu gautų įvertinimo variantų atstumai pagal pasirinktas reikšmes

Atstumas projekcijoje	Ekrano paviršius	3D menamasis paviršius
A	*A*	*A*
2,533	3,003	**2,532**
2,400	2,835	**2,399**
5,733	6,018	**5,714**
6,133	6,636	**6,109**

Išanalizavus duomenis, išskirti trys galimi atstumo tarp dviejų GUI vaizduojamų taškų įvertinimo variantai: ekrano paviršiuje, dvimatėje projekcijoje ir trimatėje erdvėje, Remiantis šiais trimis išnagrinėtais įvertinimų variantais pasiūlytas metodas lenkto monitoriaus NUI efektyvumui patikslinti.

S8 pav. Fitso dėsnio paskaičiavimai iš eksperimento metu gautų duomenų (A ir B slope)

Atstumas projekcijoje			Ekrano paviršius			3D menamasis paviršius		
Fitso dėsnis			Fitso dėsnis			Fitso dėsnis		
a	0		a	0		a	0	
b	0,1133		b	0,1133		b	0,1133	
ID	1,68		ID	2,895753		ID	1,676915	
A	4,2		A	7,239384		A	4,192287	
W	5		W	5		W	5	
t	*0,0848*		***t***	*0,1738*		***t***	***0,0845***	

Atsižvelgus į tyrimo rezultatus, galutiniams rezultatams įvertinti trys įvertinimai buvo perskaičiuoti ir patikrinti (žiūrėti lenteles S7 ir S8). Galiausiai skaičiavimai parodė tą patį rezultatą: matuojant atstumą tarp dviejų GUI taškų trimatėje erdvėje, sistemai būdingo akies veikimo greičio reikšmės tikslumas yra 12 % tikslesnis nei kitų įvertinimo variantų. Todėl, taikant patikslinto varianto sistemai būdingo akies veikimo greičio reikšmes pagal Fitso dėsnio formulę, atliekamos užduoties laikas atitinkamai yra trumpesnis. Šie rezultatai rodo metodo tinkamumą įgyvendinti ir veiksmingumą.

Bendrosios išvados

1. Šaltinių, kuriuose nagrinėjama lenktų monitorių specifika ir natūrali vartotojo sąsajos taikymo sritis, analizė parodė, kad šaltiniuose pateikiami savybių, veiksnių ir dėsnių taikymo reikalavimai yra tarpusavyje nedarnūs. Todėl ši NUI taikymo sritis reikalauja tolimesės analizės it tobulinimo.
2. Vertinant žmogaus ir kompiuterio sąveikos bei ergonomikos modelio (Fitso dėsnis) parametrus nustatyta, kad dėsnyje sistemai būdingo akies veikimo greičio reikšmę veikia vartotojo motyvacija. Todėl, vertinant NUI efektyvumą, reikia įvertinti ne tik grafinės sąsajos savybes, bet ir aplinkos sąlygų įtaką vartotojui.
3. Išplėtus NUI efektyvumo matavimo taisykles, išskirti trys galimi atstumo tarp dviejų GUI vaizduojamų taškų įvertinimo variantai: ekrano paviršiuje, dvimatėje projekcijoje ir trimatėje erdvėje. Remiantis šiais trimis išnagrinėtų įvertinimų variantais, pasiūlytas metodas lenkto monitoriaus NUI efektyvumui pagerinti.

4. Taikant pasiūlytą metodą, nustatyta, kad, matuojant atstumą tarp dviejų GUI taškų trimatėje erdvėje, gaunamos didžiausios sistemai būdingo akies veikimo greičio reikšmės lyginant su kitais atstumo matavimo variantais. Didžiausios būdingo akies veikimo greičio reikšmės Fitso dėsnio formulėje įgalina pasiekti trumpiausią užduočių atlikimo laiką. Šie rezultatai rodo metodo tinkamumą įgyvendinti ir veiksmingumą.

Annexes[1]

Annex A. The Co-authors Agreements to Present Publications for the Dissertation Defence

Annex B. Copies of Scientific Publications by the Author on the Topic of the Dissertation

[1] The annexes are supplied in the enclosed compact disc

NATURAL USER INTERFACE USABILITY RESEARCH
IN CONTEXT OF CURVED DISPLAYS SYSTEMS

Doctoral Dissertation

Technological Sciences,
Informatics Engineering (07T)

Eglė Radvilė

NATŪRALIOS VARTOTOJO SĄSAJOS TAIKYMO
TYRIMAI LENKTŲ EKRANŲ SISTEMOSE

Daktaro disertacija

Technologijos mokslai,
informatikos inžinerija (07T)

2015 10 19. 8,0 sp. l. Tiražas 20 egz.
Vilniaus Gedimino technikos universiteto
leidykla „Technika“,
Saulėtekio al. 11, 10223 Vilnius,
http://leidykla.vgtu.lt
Spausdino BĮ UAB „Baltijos kopija“
Kareivių g. 13B, 09109 Vilnius
www.kopija.lt