A systematic literature review on intelligent user interfaces: preliminary results

Une revue systématique de la littérature sur les interfaces utilisateur intelligentes : résultats préliminaires

Taisa G. Gonçalves
PESC/COPPE
Federal Univ. of Rio de Janeiro
Rio de Janeiro, Brazil
taisa@cos.ufrj.br

Christophe Kolski
LAMIH CNRS UMR 8201
Univ. Polytech. Hauts-de-France
Valenciennes, France
christophe.kolski@uphf.fr

Káthia M. de Oliveira
LAMIH CNRS UMR 8201
Univ. Polytech. Hauts-de-France
Valenciennes, France
kathia.oliveira@uphf.fr

Guilherme H. Travassos
PESC/COPPE
Federal Univ. of Rio de Janeiro
Rio de Janeiro, Brazil
ght@cos.ufrj.br

Emmanuelle Grislin-Le Strugeon
LAMIH CNRS UMR 8201
Univ. Polytech. Hauts-de-France
Valenciennes, France
emmanuelle.grislin@uphf.fr

ABSTRACT

The user interfaces promote the interaction with the software system to achieve the users' goals. In this way different types of interaction are provided, such as direct manipulation, web UI or tangible interaction. These interfaces have evolved, including artificial intelligence and adaptation mechanisms to answer the evolution of the technological areas. From this evolution emerged the intelligent user interfaces that aim to be more effective, efficient, and natural.

IHM '19 Adjunct, December 10–13, 2019, Grenoble, France

ACM ISBN 978-1-4503-7027-1/19/12.

https://doi.org/10.1145/3366551.3370344

Considering the importance of IUI nowadays, we have performed a systematic literature review to investigate the design trends of IUIs in the context of contemporary software systems, such as software systems based on internet of things (IoT) or dedicated to smart cities. Preliminary results show which models and technologies are most used to develop IUIs, and which application domain is mostly represented.

CCS CONCEPTS

• Human-centered computing → User interface design; Empirical studies in interaction design • General and reference → Surveys and overviews.

KEYWORDS

Intelligent user interface; systemic literature review; evidence-based software engineering.

RÉSUMÉ

Les interfaces utilisateur (IU) visent à favoriser l'interaction avec le système pour permettre aux utilisateurs d'atteindre leurs buts. Ainsi, différents types d'interaction sont possibles, tels que la manipulation directe, les interfaces web ou l'interaction tangible. Ces interfaces ont évolué au fil du temps, tout en intégrant des mécanismes issus de l'intelligence artificielle, tels des mécanismes d'adaptation, pour répondre à l'évolution des domaines technologiques. De cette évolution ont emergé les interfaces utilisateur intelligentes (IUI) qui visent à être efficaces et naturelles. Ainsi nous sommes en train de mener une revue systématique de la littérature pour étudier les tendances de conception des IUI dans le contexte des systèmes logiciels contemporains (SLC), tels que les systèmes basés sur l'internet des objets ou dédiés aux villes intelligentes. Les résultats préliminaires montrent quels sont les modèles et technologies les plus utilisés pour développer des IUIs, ainsi que le domaine d'application le plus représenté.

MOTS CLÉS

Interface utilisateur intelligente ; revue systématique de la littérature ; génie logiciel basé sur des évidences.

INTRODUCTION

The concept of software systems and the way to develop them have evolved in the last decade. New kinds of software systems, here called contemporary software systems (CSS) – for instance, systems based on the internet of things (IoT), dedicated to smart cities or smart home, among others – have experienced many challenges regarding their engineering [20].

An essential component of these software systems is the user interface (UI) that also has evolved [14][19]. This evolution generates "*human-machine interfaces that aim to improve the efficiency, effectiveness, and naturalness of human-machine interaction by representing, reasoning, and acting on models of the user, domain, task, discourse, and media*" – intelligent user interfaces (IUIs) [19], which

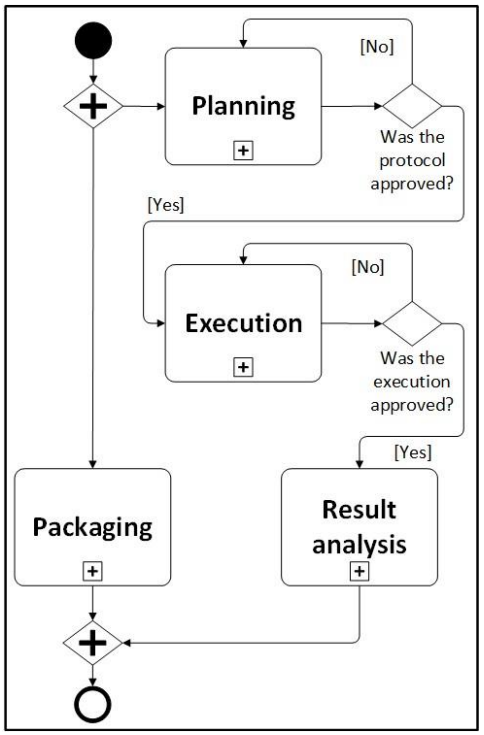

Figure 1. Systematic review process (adapted from [5])

use artificial intelligence (AI), human-computer interaction (HCI), software engineering (SE) and other techniques to promote more natural and usable human-machine interaction.

Besides, these interfaces belong to software systems that are capable of adapting themselves to their users [27]. For this, the behavioral characteristics of the users are stored in different models (such as user model, device or platform model, environment model, interaction model, task model, and others). Thus, the IUIs change their behavior according to the models to adapt to a person or task or, more generally to the context [9] [26].

The technical literature makes available many works analyzing IUIs from different perspectives [6][12][14][26][27]. However, to the best of our knowledge, no work has analyzed IUI in the context of CSS. In this way, this paper presents the review process, the research protocol, and the preliminary results of a systematic literature review (SLR) concerning the design trends of IUIs in the context of CSS.

RELATED WORK

This section presents literature reviews on IUIs. Hefley and Murray [12] discuss design and implementation issues to build intelligent systems; they suggest that user interface management systems (UIMS) architectures can be used to build intelligent interfaces.

Ross [26] discuss IUI paradigms and techniques; the results show how this type of interface can improve communication between humans and machines.

Jaquero et al. [14] discuss the evolution of IUIs looking for the components of these interfaces, artificial intelligence techniques, runtime architecture, and models.

Bittencourt et al. [6] conducted an SLR regarding multiple-device inclusive environments; one of the research questions aims to identify the user interface categories (for example, tangible user interface, natural user interface, among others) that have been used in the design of multi-device inclusive environments.

Sanchez et al. [27] conducted a systematic mapping to identify which applications (such as a ubiquitous system) have adopted IUIs in the context of Ambient Assisted Living (AAL). The interaction mode most commonly used is visual.

All these works discuss IUIs from different perspectives, especially about the evolution of this type of interface over time. However, none of these works investigated the design of IUIs in the context of CSS following an SLR process.

RESEARCH METHOD

The research method followed in this paper is SLR – a method that presents a procedural and rigorous strategy to characterize the current state of researches in different domains [5][16]. An SLR defines a systematic review process to guide the literature search and produce a research protocol enabling search replicability. In this research, we used the review process (Figure 1) proposed by Biolchini et al. [5]. Up to now, five researchers performed all activities – the authors of this paper.

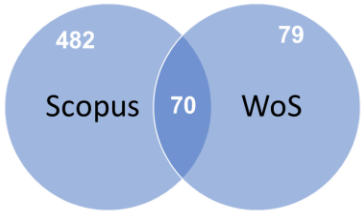

Figure 2. Search engines results

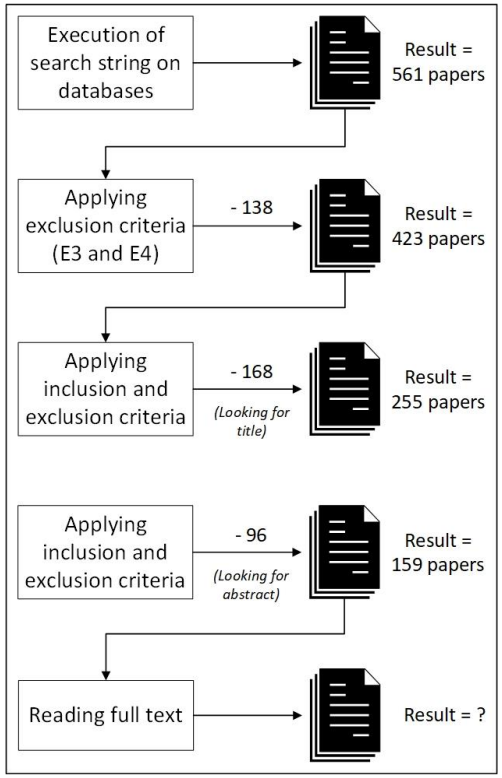

Figure 3. Execution overview

Planning

In this step, we defined the objectives, research questions, and methods for the execution and analysis steps. We also defined the search string, a set of inclusion (I), and exclusion (E) criteria to filter the papers and selected the search engines. All these items and others composed the research protocol (see Table 1). To organize and structure the search string, we used the PICO approach [22]: **Population** of interest, **Intervention,** or exposure being evaluated, **Comparison** intervention (if applicable) and **Outcome**. We did not apply any comparison considering the objective of this research (mainly characterization).

Execution

In this step, we iteratively executed and refined the search string presented in Table 1. The search string was executed twice in two search engines (Scopus – indexes content from 24,600 working titles and 5,000 publishers (source: https://www.elsevier.com/solutions/scopus) - and Web of Science – a complementary search engine of Scopus) – 3rd December 2018 and 5th June 2019. It resulted in 561 papers (482 from Scopus and 79 from Web of Science - see Figure 2). After that, we applied the set of inclusion and exclusion criteria (first E3 and E4, and second E1 and E2) for all papers – see Figure 3. Thus, we got 159 papers for full reading. Unfortunately, we did not have access to five papers (criterion E6) and two papers were not written in English; so they were excluded from the final set. Also, one paper is a systematic mapping study [27]; thus, it was analyzed as related work. Therefore, we selected 151 papers for full reading.

Result Analysis

In this step, we read 151 papers and extracted their relevant data concerning each research question. For the extraction, we used an extraction form (see part of the form in Figure 4). We are currently analyzing the extraction forms to decide which papers will be kept. After that, the extracted data will be assembled and interpreted (quantitative and qualitative analysis using grounded theory methodology [29]) to answer all research questions.

Packaging

In this step, executed throughout the whole process, we keep all decisions, collect and document all SLR data using specific templates and tools (JabRef, spreadsheet, word processor, google drive, QDA Miner for qualitative analysis, among others).

PRELIMINARY RESULTS

Analyzing the 151 papers, we can discuss the preliminary results. Looking for the frequency of papers by year (1986-2019), we have one paper published in 1986 [7] and one paper published in 2019 [30]. Besides, 2007 (17 papers) and 2011 (15 papers) are the years with the most significant number of papers published. In 2007, fourteen papers were published in conferences and three in journals.

Population = ("contemporary software systems" OR "interactive system" OR "intelligent system*" OR "Context-aware* system" OR "ubiquitous system" OR "ambient intelligent" OR "ambient intelligence" OR "assisted living" OR "multiagent systems" OR "systems of systems" OR "internet of things" OR "IoT" OR "Cyber Physical Systems" OR "autonomous systems" OR "autonomic computing" OR "Multi-Agent Systems" OR "Pervasive Computing" OR "Mobile Computing" OR "Distributed Systems" OR "Cooperative Robotics" OR "adaptive systems" OR "Industry 4" OR "fourth industrial revolution" OR "web of things" OR "Internet of Everything" OR "smart manufacturing" OR "digitalization" OR "digitization" OR "digital transformation" OR "smart cit*" OR "smart building" OR "smart health" OR "Healthcare" OR "health* information system" OR "smart environment" OR "Recommender system" OR "Recommendation system")

Intervention = ("smart user interface" OR "Intelligent user interface" OR "adaptive user interface" OR "context-sensitive user interface" OR "multimodal user interface" OR "smart human computer interface" OR "Intelligent human computer interface" OR "adaptive human computer interface" OR "context-sensitive human computer interface" OR "multimodal human computer interface" OR "smart human machine interface" OR "intelligent human machine interface" OR "adaptive human machine interface" OR "context-sensitive human machine interface" OR "multimodal human machine interface" OR "smart graphical user interface" OR "Intelligent graphical user interface" OR "adaptive graphical user interface" OR "context-sensitive graphical user interface" OR "multimodal graphical user interface" OR "IUI")

Outcome = ("Method" OR "Model" OR "Technique" OR "Methodology" OR "framework" OR "technolog*" OR "design" OR "Adaptativity" OR "Evaluation" OR "Platforms")

Table 1. Research protocol

Objective	The objective of this research is to observe and characterize the evolution of IUI design tendencies (methods, models, techniques, methodologies, frameworks, or technologies) in the context of contemporary software systems.
Research questions	Main Question: SQ0 - What are the CSS solutions making use of IUIs? Secondary questions: SQ1 - What are the primary (where) and secondary (for what) domains in which IUI are used? SQ2 - Which are the trends regarding the using of IUI in CSS? SQ2.1 - What characterizes the IUI used in CSS along the time? SQ2.1.1 - What adaptivity criteria regarding IUI are taken into account? SQ2.1.2 - What adaptivity decision(s)/reaction(s) is (are) taken into account? SQ2.1.3 - What are the types of models used in CSS with IUI? (for instance context model, dialogue model, task model, domain model, user model, etc.) SQ2.1.4 - What are the software technologies (e.g., methods, techniques, tools, machine learning technologies, etc.) used to the definition of the IUI? SQ2.1.5 - What are the software technologies (e.g., frameworks, environments, etc.) used to the realization of the IUI? SQ3 - How the IUI has been evaluated in CSS?
Search string	Population AND Intervention AND Outcome
Engines	Scopus http://www.scopus.com/ and Web of Science http://www.isiknowledge.com/
Inclusion and exclusion criteria	Inclusion Criteria: I1 - To talk about IUI; I2 - To present methods, models, techniques, methodologies, technologies, or frameworks used for IUI design. Exclusion Criteria: E1 - Not concerned with IUI; E2 - Not talking about methods, models, techniques, methodologies, technologies, or frameworks dedicated to IUI design; E3 - Books, book chapters that are not from conference proceedings, book prefaces, summaries of conferences, editorials, retracted articles; E4 - Studies in duplicity; E5 - Articles presenting partial results of a complete study that is selected; E6 - Not being available.

Regarding the publication type, journals published 24 papers and 127 in conferences. Looking for journal publications, we can note that: (i) Interacting with Computers had four publications [2][9][13][15]; (ii) ACM Transactions on Computer-Human Interaction had two publications [25][28]; (iii) Intl. Journal of Pervasive Computing and Communications had two publications [10][31], and (iv) the other sixteen papers were published in different journals. Analyzing the main question (*What are the CSS solutions making use of IUIs?*) of this research we have noted that many of the proposed solutions such as Ambient Intelligence, Cyber-physical system, interactive system, smart health, smart home, and smart environment are developed to **healthcare application domain** (e.g. [1] [3] [8] [21].

Type of CSS (SQ0) - The CSS type (Context-aware system, ubiquitous system, IoT, Industry 4.0, Smart cities, among others) discussed in the paper.
Type of IUI (SQ0) - The type of IUI discussed in the paper.
Domain type (where) (SQ1) - The domain type where the IUI is proposed in the paper, according to Kotonya et al. [17].
Application type (for what) (SQ1) - The application type where the IUI is proposed in the paper, according to Kotonya et al. [17].
Adaptivity criteria ("to what") (SQ2.1.1) - To what does the IUI adapt (adaptation/adaptivity criteria)?
Adaptivity decision ("what to do") (SQ2.1.2) - What does the IUI do (adaptation/adaptivity decision/reaction)?
Type of model (SQ2.1.3) - The type of model discussed in the paper (context model, dialogue model, task model, domain model, user model, and so one).
Software Technologies for Definition (SQ2.1.4) - The software technologies (methods, techniques, tools, machine learning based technologies, processes, and others) used to the definition of the IUI.
Software Technologies for Realization (SQ2.1.5) - The software technologies (frameworks, environments, machine learning based components, and others) used to the realization of the IUI.

Figure 4. Part of the extraction form

ACKNOWLEDGMENTS

We want to acknowledge the financial support granted by Brazilian National Council for Scientific and Technological Development - CNPq (award numbers: 154004/2018-9 and 304234/2018-4).

Other solutions are also proposed, such as adaptive system, context-aware system, recommender system, smart city, smart environment, ubiquitous computing, among others to different application domains (e.g., electronic commerce, transportation, museum, and others).
Regarding the user interface categories discussed in the papers, we have identified adaptive user interface (AUI); context-sensitive user interface; intelligent user interface (IUI); multi-modal user interface; and smart user interface. IUI (e.g. [3] [31]) and AUI (e.g. [1] [15] [18] [23] [24]) are the expressions most used.
When we look for the types of models used to design the IUIs, we have identified: abstract user interface model; adaptation model; concrete user interface model; **context model**; device model; **dialog model**; environment model; interaction model; layout model; ontology model; platform model; presentation model; task model; **user model**; among others. Context model, dialogue model, and user model are the models most cited in different solutions (e.g. [1] [11] [15] [18] [23] [24] [31]).
We have identified many software technologies used to design and develop the user interfaces: adaptation rules; development process; generic architecture/framework; machine learning techniques; **model-based approach** [1] [23]; model-based architecture (with transformation rules); model-based user interface development (MBUID) approach; model-driven approach (based on CAMELEON-RT [4]) [1] [18]; multi-agent architecture; natural language processing; user-centered design approach; etc.
In general, the IUIs adapt to the **context of use**; context changes; device characteristics; platform characteristics; **users´ actions**; user behaviors; users´ characteristics; **users´ preferences**; users´ needs; among others (e.g. [1] [11] [15] [18] [23] [24]).

NEXT STEPS

In this paper, we presented the preliminary results of an SLR regarding the design trends of IUIs in the context of Contemporary Software Systems (CSS). We have identified several models, methods, techniques, tools, processes, frameworks, among other technologies being used to develop IUIs.
CSS present specific behavioral characteristics, embedded technologies, heterogeneity of devices, and others. Sometimes the combination of these features can make the user interface "invisible" for the user. In this way, the IUIs in the context of CSS need to manage the behavior of different devices, technologies, and software systems to adapt to a person, a task or a context.
The preliminary results show that the healthcare domain can provide interesting representatives of CSS. Besides, the context model, dialogue model, and user model are the models most cited by different authors, which justifies the use of model-based approaches to IUI development.
The next steps concerning this research are: (i) analyze the extraction forms to decide which papers will be kept; (ii) interpret the extracted data (quantitative and qualitative analysis) to answer all research questions; (iii) propose a new technology for IUI development. To that end, we are applying Ground Theory methodology [29].

REFERENCES

[1] S. Adam, K. Breiner, K.S. Mukasa, and M. Trapp. 2008. Challenges to the model-driven generation of user interfaces at runtime for ambient intelligent systems. *Commun. Comput. Inf. Sci.* 11, (2008), 147–155.

[2] D. Akoumianakis, A. Savidis, and C. Stephanidis. 2000. Encapsulating intelligent interactive behaviour in unified user interface artefacts. *Interact. Comput.* 12, 4 (2000), 383–408. DOI:https://doi.org/10.1016/S0953-5438(99)00016-8

[3] J.C. Augusto, C. Nugent, S. Martin, and C. Olphert. 2005. Software and knowledge engineering aspects of smart homes applied to health. *Stud. Health Technol. Inform.* 117, (2005), 164–171.

[4] Lionel Balme, Alexandre Demeure, Nicolas Barralon, Joëlle Coutaz, and Gaëlle Calvary. 2004. CAMELEON-RT: A Software Architecture Reference Model for Distributed, Migratable, and Plastic User Interfaces. In *Ambient Intelligence: Second European Symposium, EUSAI 2004*, Panos Markopoulos, Berry Eggen, Emile Aarts and James L. Crowley (eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 291–302. DOI:https://doi.org/10.1007/978-3-540-30473-9_28

[5] J. Biolchini, P. G. Mian, A. C. Natali, and G. H. Travassos. 2005. *Systematic Review in Software Engineering: Relevance and Utility.* PESC/COPPE/UFRJ, Brazil. Retrieved from http://www.cos.ufrj.br/uploadfiles/es67905.pdf

[6] Ig Ibert Bittencourt, Maria Cecília Baranauskas, Roberto Pereira, Diego Dermeval, Seiji Isotani, and Patrícia Jaques. 2016. A systematic review on multi-device inclusive environments. *Univers. Access Inf. Soc.* 15, 4 (2016), 737–772. DOI:https://doi.org/10.1007/s10209-015-0422-3

[7] D.P. Browne, B.D. Sharratt, and M.A. Norman. 1986. The formal specification of adaptive user interfaces using command language grammar. In *Conference on Human Factors in Computing Systems - Proceedings*, 256–260. DOI:https://doi.org/10.1145/22627.22381

[8] H.-D. Bui and N.Y. Chong. 2018. An Integrated Approach to Human-Robot-Smart Environment Interaction Interface for Ambient Assisted Living. In *Proceedings of IEEE Workshop on Advanced Robotics and its Social Impacts*, 32–37. DOI:https://doi.org/10.1109/ARSO.2018.8625821

[9] Gaëlle Calvary, Joëlle Coutaz, David Thevenin, Quentin Limbourg, Laurent Bouillon, and Jean Vanderdonckt. 2003. A Unifying Reference Framework for multi-target user interfaces. *Interact. Comput.* 15, 3 (2003), 289–308. DOI:https://doi.org/10.1016/S0953-5438(03)00010-9

[10] E. Castillejo, A. Almeida, and D. López-de-Ipiña. 2014. Modelling users, context and devices for adaptive user interface systems. *Int. J. Pervasive Comput. Commun.* 10, 1 (2014), 69–91. DOI:https://doi.org/10.1108/IJPCC-09-2013-0028

[11] T. Clerckx, K. Luyten, and K. Coninx. 2005. DynaMo-AID: A design process and a runtime architecture for dynamic model-based user interface development. In *Lecture Notes in Computer Science*, 77–95.

[12] William E. Hefley and Dianne Murray. 1993. Intelligent user interfaces. In *Proceedings of the 1st international conference on Intelligent user interfaces - IUI '93*, 3–10. DOI:https://doi.org/10.1145/169891.169892

[13] R. Hervás and J. Bravo. 2011. Towards the ubiquitous visualization: Adaptive user-interfaces based on the Semantic Web. *Interact. Comput.* 23, 1 (2011), 40–56. DOI:https://doi.org/10.1016/j.intcom.2010.08.002

[14] V. López Jaquero, F. Montero, J.P. Molina, and P. Gonzalez. 2009. Intelligent User Interfaces: Past, Present and Future. In *Engineering the User Interface*, Miguel Redondo, Crescencio Bravo, and Manuel Ortega (eds.). Springer London, London, 1–12. DOI:https://doi.org/10.1007/978-1-84800-136-7_18

[15] R.J. Keeble and R.D. Macredie. 2000. Assistant agents for the world wide web intelligent interface design challenges. *Interact. Comput.* 12, 4 (2000), 357–381. DOI:https://doi.org/10.1016/S0953-5438(99)00004-1

[16] B. Kitchenham and S. Charters. 2007. *Guidelines for performing systematic literature reviews in software engineering*. Keele University and Durham University.

[17] G. Kotonya, I. Sommerville, and S. Hall. 2003. Towards a classification model for component-based software engineering research. In *Proceedings of 29th Euromicro Conference*, 43–52. DOI:https://doi.org/10.1109/EURMIC.2003.1231566

[18] G. Lehmann, M. Blumendorf, and S. Albayrak. 2010. Development of context-adaptive applications on the basis of runtime user interface models. In *EICS'10 - Proceedings of the 2010 ACM SIGCHI Symposium on Engineering Interactive Computing Systems*, 309–314. DOI:https://doi.org/10.1145/1822018.1822068

[19] Mark T. Maybury and Wolf Wahlster. 1998. Intelligent User Interfaces: An Introduction. In *Readings in Intelligent User Interfaces*, Mark T. Maybury and Wolfgang Wahlster (eds.). Morgan Kaufmann Publishers Inc., San Francisco, CA, USA, 1–13.

[20] R.C. Motta, K.M. Oliveira, and G.H. Travassos. 2019. On challenges in engineering IoT software systems. *J. Softw. Eng. Res. Dev.* (2019). DOI:https://doi.org/10.5753/jserd.2019.xxx

[21] P. Nilas. 2007. A PDA-based human-robot interaction for disabled persons using electromyography. In *Canadian Conference on Electrical and Computer Engineering*, 2445–2448. DOI:https://doi.org/10.1109/CCECE.2006.277395

[22] M. Pai, M. McCulloch, J. D. Gorman, N. Pai, W. Enanoria, G. Kennedy, P. Tharyan, and J. M. Colford. 2004. Systematic reviews and meta-analyses: an illustrated, step-by-step guide. *Natl. Med. J. India* 17, 2 (2004), 86–95.

[23] K. Park and S.-W. Lee. 2015. Model-based approach for engineering adaptive user interface requirements. *Commun. Comput. Inf. Sci.* 558, (2015), 18–32. DOI:https://doi.org/10.1007/978-3-662-48634-4_2

[24] M. Peissner, A. Schuller, and D. Spath. 2011. A design patterns approach to adaptive user interfaces for users with special needs. *Hum.-Comput. Interact. Des. Dev. APPROACHES PT I* 6761 LNCS, PART 1 (2011), 268–277. DOI:https://doi.org/10.1007/978-3-642-21602-2_30

[25] K. Reinecke and A. Bernstein. 2011. Improving performance, perceived usability, and aesthetics with culturally adaptive user interfaces. *ACM Trans. Comput.-Hum. Interact.* 18, 2, (2011). DOI:https://doi.org/10.1145/1970378.1970382

[26] Edward Ross. 2000. *Intelligent User Interfaces: Survey and Research Directions*. University of Bristol, Bristol, United Kingdom.

[27] Cristina Sanchez, Priscila Cedillo, and Alexandra Bermeo. 2017. A Systematic Mapping Study for Intelligent User Interfaces - IUI. In *Proceedings of the International Conference on Information Systems and Computer Science (INCISCOS)*, 361–368. DOI:https://doi.org/10.1109/INCISCOS.2017.34

[28] L. Sha, P. Lucey, Y. Yue, X. Wei, J. Hobbs, C. Rohlf, and S. Sridharan. 2018. Interactive sports analytics: An intelligent interface for utilizing trajectories for interactive sports play retrieval and analytics. *ACM Trans. Comput.-Hum. Interact.* 25, 2, (2018). DOI:https://doi.org/10.1145/3185596

[29] A. Strauss and J. Corbin. 1998. *Basics of qualitative research: Techniques and procedures for developing grounded theory*. Sage publications.

[30] C.-H. Tsai and P. Brusilovsky. 2019. Explaining recommendations in an interactive hybrid social recommender. In *International Conference on Intelligent User Interfaces, Proceedings IUI*, 391–396. DOI:https://doi.org/10.1145/3301275.3302318

[31] A. Zimmermann and A. Lorenz. 2005. Creating audio-augmented environments. *Int. J. Pervasive Comput. Commun.* 1, 1 (2005), 31–42. DOI:https://doi.org/10.1108/17427370580000111