IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received 8 June 2024, accepted 30 June 2024, date of publication 8 July 2024, date of current version 17 July 2024.

Digital Object Identifier 10.1109/ACCESS.2024.3425330

APPLIED RESEARCH

Principles of User Interface Design Enabling People With Blindness Professional Work in Administration of Energy Systems in Intelligent Buildings Comparable to Sighted Workers

MILAN HUDEC[1] **AND ZDENEK SMUTNY**[2]
[1]Faculty of Natural Sciences, Matej Bel University, 974 01 Banská Bystrica, Slovakia
[2]Faculty of Informatics and Statistics, Prague University of Economics and Business, 130 67 Prague, Czech Republic

Corresponding author: Zdenek Smutny (zdenek.smutny@vse.cz)

This work was supported in part by the research and development of the ambient intelligence system RUDO through the Long-Term Support of Scientific Work on the Faculty of Natural Sciences, Matej Bel University, Banská Bystrica; and in part by the internal funding mechanism provided by Prague University of Economics and Business under Grant F4/1/2023 and Grant IP400040.

This work involved human subjects or animals in its research. The authors confirm that all human/animal subject research procedures and protocols are exempt from review board approval.

ABSTRACT The development of ubiquitous computing in today's society and the associated design of smart environments entails many new possibilities in supporting the daily activities of disabled people (i.e., people with blindness, seniors). The aforementioned also brings the development of ecologically oriented intelligent buildings (IB) that adapt to the needs of disabled people. At the same time, it is necessary to administrate these IB. The article presents the remote monitoring and administration of energy systems in an IB, which people with blindness can perform through a special user interface (UI) to handle complex professional tasks. The article is based on design science methodology. Using technical action research for evaluation and the cognitive walkthrough, observation, and work speed measurement for data collection, the article proposes and validates the UI for people with blindness providing heating regulation, zonal regulation and home photovoltaic power plant management and operation monitoring in an IB equipped with an ambient intelligence system. The UI allows people with blindness to work at a speed comparable to that of a sighted worker. Based on the implemented and evaluated solution, generalized principles of UI design for people with blindness are derived. The main scientific contribution of this article is to broaden the knowledge base with the principles of more complicated UI design for people with blindness for cases, where possibilities of mobile UI or speech remote control are insufficient, e.g. in professional work, where they must be competitive with the sighted workers. From a practical point of view, the article provides recommendations for designing UI for people with blindness with an emphasis on ensuring the speed, reliability, and accuracy of control. Furthermore, the article discusses new job opportunities for people with blindness in connection with the remote administration of IB, the number of which will increase.

INDEX TERMS Action research, ambient intelligence, cognitive walkthrough, disabled people, human-computer interaction, blind people, remote work, RUDO, smart environment, remote control.

I. INTRODUCTION

One of the most important goals of non-profit organizations and scientific activities aimed at helping people with blindness is the effort to integrate them into society, including

The associate editor coordinating the review of this manuscript and approving it for publication was Orazio Gambino.

their work involvement [1], [2], [3]. This is achieved by using new technologies and approaches, mainly based on ubiquitous computing and artificial intelligence, expanding the possibilities of involving people with blindness in new types of activities that were not possible before, e.g., to develop prototypes from electrotechnical components [4]. However, integration does not mean only increasing their independence by expanding their existing personal abilities. Part of the integration of people with blindness into society is also the creation of suitable single-purpose aids and smart environments (SmE), thanks to which the development of new abilities of people with blindness occurs and, consequently, the creation of new job opportunities.

SmE, which also include intelligent buildings (IB), should take into account the needs and abilities of disabled people (e.g., people with blindness, deaf people, seniors). An example can be an IB that also includes adequate user support and an automatic assistance service for disadvantaged people [5], [6], [7], [8]. With this approach to the design of SmE, the IB must first enable a person with blindness to operate the environment and support movement around the building. Thereafter, other individual needs can be solved with additional compensatory aids. Therefore, such solutions intended for people with blindness should use the principles of ambient intelligence (AmI), i.e., the IB should be sensitive and responsive to the presence and special needs of people with blindness.

AmI systems in IB can be connected to energy systems [9]. With such a connection, they can also assist administration and monitoring by administrators (with blindness) of such buildings. Since the number of IBs with energy-saving systems is constantly increasing, with their number expected to increase from 45 million to 115 million worldwide in 2026 [10], design research of assistive technologies for disadvantaged people for IB is justified.

In this context, the article deals with the possibilities of special UI and remote control used in IBs, which enable new employment opportunities for people with blindness in the context of IBs administration. In the following subsections, the problem context is presented, followed by the article's aim and contribution. In the presentation of the problem context, the emphasis is placed on the definition of previous UI solutions or approaches, which are unsuitable for the professional work of a person with blindness because he or she must be competitive with the sighted workers in the labor market.

A. PRESENTATION OF THE PROBLEM CONTEXT AND UNSUITABILITY OF PREVIOUS SOLUTIONS OR APPROACHES

The problem context includes IBs with their energy subsystems, the user interface (UI) and remote control for people with blindness. This is also linked to the idea that people with blindness could hold new professional jobs thanks to new technological possibilities. In our case, it is the administrator of IB. For this purpose, two consecutive searches in citation databases were conducted to investigate the problem context, and their outputs are described in detail.

Unfortunately, relevant research focusing on people with blindness in the field of IB energy system administration connected with professional work is lacking. In our first search of the citation databases Web of Science and Scopus in December 2023, we did not find any thematically fully relevant article with the topic keywords: (“people with blindness” OR “blind people”) AND (“intelligent building” OR “smart environment” OR “ambient”); (“people with blindness” OR “blind people”) AND “energy”. Two articles dealing with smart households for people with blindness were found to be thematically closest. The first paper focuses on home automation through a unified mobile application interface [11]. The second article focuses on an appliance power management system [12].

Therefore, in the second search, we focused on other topic keywords related to remote control and UI: (“people with blindness” OR “blind people” AND (“remote control” OR “user interface”)). Found articles deal with finding physical control panels on individual home appliances [13] or these are solutions [11], [12], [14], [15], most often for smart homes, built on smartphones with touch screen and home appliances connected to a network based on the Internet of Things principle. The person with blindness uses a smartphone connected to the Internet, which offers a generally usable UI for visually impaired people as part of an operating system, which, however, is time-consuming to operate, as it uses speech recognition and voice and vibration response.

These articles focus on the ability of people with blindness to perform specific system settings via a smartphone with a touch screen in their home environment. But these articles do not address parity with sighted people, which is important in a work environment. The person with blindness should be competitive in the case of work activities with the sighted, especially in terms of speed, accuracy (or small error rate of settings) and reliability. Otherwise, companies would prefer sighted workers to the highly responsible positions of energy system administrators.

According to the study [16], people with blindness aspire to reach parity with sighted users regarding their smartphone usage speed. However, articles [17], [18] mention that the speed of controlling applications in a smartphone is one of the challenges that people with blindness still face. Among the most fundamental problems associated with using smartphones are text and speech input, low readiness of applications for users with blindness, complex UI, and application updates, which can dramatically change the way of operation.

Text-entry problems – despite the use of aids such as iOS braille – are connected with editing, copying and pasting text and are cumbersome [17]. This also applies to speech input, where the user spends up to 80% of the time correcting an error [16], [18], [19]. The use of other assistance tools of operating systems for smartphones is also problematic, as the applications do not follow the recommendations for the creation of UI and use, e.g. inadequate labels, inability to scroll through lists or smaller UI elements [17], [19]. The article [17] states that even expert users get lost when using a more complex application and must start the application again or hard reset their device. Another problem is application updates because they "force people to rebuild their mental model about the apps' structure and behaviors" [17].

In the scientific literature, qualitatively oriented papers mainly focus on the usefulness and ability to control a smartphone and subjective satisfaction with the speed of control. A quantitative comparison of the speed of controlling applications on smartphones between the sighted and people with blindness was not found when searching the Web of Science and Scopus.

Nevertheless, the findings indicate that in the home environment, smart home solutions using smartphones for their control can be sufficient, but not in work activities, where people with blindness must be competitive with sighted workers regarding speed and error rate.

In this regard, it should be mentioned that the adoption of smartphones among people with blindness is not as high as among the sighted. Only 47 to 67% of people with blindness use a smartphone [20], [21]. On the other hand, up to 88% of people with blindness use the computer [21]. The advantage of computers is the possibility of connecting hardware aids (e.g., Braille display), which allow them to fully use the excellent tactile skills of people with blindness [22] and thereby speed up their work. For example, when editing text on a computer, you can also use parallel voice and tactile reading with immediate cursor movement and correction of errors in the text. Similarly, the multitasking solution is a more reliable solution on a computer when you can easily switch between different applications (e.g. switching between different IBs and their subsystems).

In this respect, using a computer and its associated tools offers a more reliable solution for professional work than using smartphones, which can be used more as an additional option in this context.

In our search of the citation databases, only the article [23], which presents a distributed UI accessibility framework for people with blindness, was different by approach. The framework offers a superstructure in the form of UI components that provide simplified blind-friendly UI on smartphones and smartwatches, which solves the problem of learnability and reduces cognitive overload. However, with its simplification of UI, the proposed framework is only suitable for personal use, and it faces limitations during work. In the case of complex work tasks, the simplification of device setting options can be problematic and in conflict with the work activity and the needs of a person with blindness.

All the papers mentioned above are focused on enabling certain activities to be performed by people with blindness, for example, to enable or help a person with blindness to set up a particular device in the household. These approaches are sufficient for ordinary or private life, but insufficient to ensure the competitiveness of people with blindness in terms of time and quality of work with a sighted worker. This is a research gap that this article addresses in the defined problem context.

According to our search, there is only one comprehensive AmI system for people with blindness [7] mentioned in the scientific literature, which is installed in an IB. The other smart or intelligent systems found most often deal with assistance support of the elderly [24], [25] because their numbers are increasing rapidly in developed countries, being a rapidly growing business market.

B. THE AIM AND CONTRIBUTION OF THE ARTICLE

This article aims to present special UI and derive generalized principles of UI design for people with blindness to administrate energy systems in an IB, which involves complex tasks. In this context, the emphasis is placed on three subsystems used in an IB: a photovoltaic power plant, heating regulation and zonal regulation. The main area of application of the solution is the professional work of people with blindness in an IB, where the quality and speed of work must be competitive with a sighted worker. The proposed solution is based on the RUDO AmI system for people with blindness, which has been experimentally developed since 2000 [7]. The presented solution can help other researchers in the development of inclusive SmE or IB for disabled people.

The research question and the connected technical research issue is: how to design a UI (supported by an AmI system) that would satisfy the needs of people with blindness so that they would be able to administrate energy systems professionally in IBs and at the same time, their work would be competitive with sighted workers? The presented research in the area of IB energy systems administration by people with blindness has three contributions:

1. From a broader perspective, it is a presentation of the next iteration of the long-term development of the RUDO AmI system for people with blindness, which focuses on operating ecological energy systems in IBs. This is a significant contribution to science and practice related to the principle of iterative solution design using design science methodology [26], on which the entire development of the RUDO AmI system is built. Presented iteration also contributes to UI design for people with blindness. The contribution to science is related to the extension of the knowledge base of proposed solutions in the field of UI for people with blindness, with an emphasis on professional work and occupational competitiveness. From a practical perspective, this article presents current best practices in implementing UI for people with blindness.
2. Increasing the independence of people with blindness and their integration into society, including their work involvement when living or working in IB.
3. An indirect benefit of this research is that the presented solution can support the creation of new job opportunities for people with blindness in the field of IB administration. Using UI principles introduced in the proposed solution enable people with blindness to be competitive with sighted workers in IB administration.

The first contribution is technologically oriented and the other two are socially oriented. This article is structured as follows: Section II presents a brief description of the RUDO AmI system for people with blindness. The design-oriented methodology is introduced in Section III. A description and evaluation of the UI design are presented in Sections IV and V. Based on previous sections, Section VI presents generalized user interface design principles. Section VII provides a discussion of the principles for UI design and possibilities of future development of employment opportunities for people with blindness. Section VIII concludes the article and summarizes its main findings, benefits and limitations.

II. AmI SYSTEM FOR PEOPLE WITH BLINDNESS AS DESIGN RESEARCH PREREQUISITE

A fundamental prerequisite for this research is the RUDO AmI system for people with blindness, which is further used for experimental design and behavioural research aimed at users with blindness. Such an extensive AmI system primarily intended for people with blindness is unique in the world; see Section I. This AmI system is being expanded in modules, and the technological solutions of individual modules and design principles are continuously published.

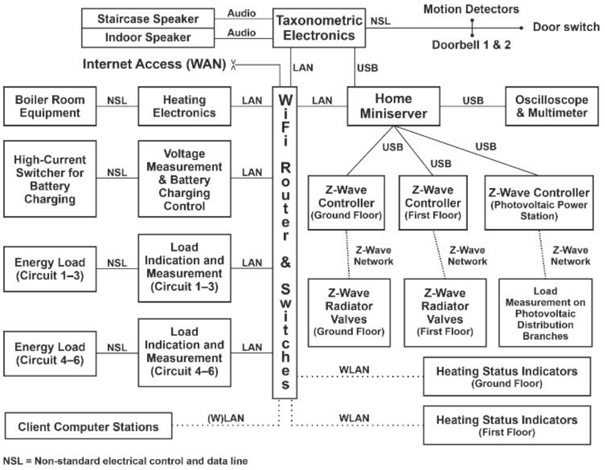


FIGURE 1. Diagram of the RUDO system in the current 7th version.

Article [7] presented the fourth version of the RUDO AmI system in detail with a description of all the major hardware and software components. Other articles deal with the scenes that the RUDO AmI system provides for people with blindness [6] and professional work in informatics, including an introductory presentation of the HANIBAL unified UI [4]. These previous articles did not address the complex energy subsystem, including the photovoltaic power plant and the related extension of the recognition of internal and external scenes in connection with the ambient behaviour of the building, as it is in the current seventh version of the RUDO AmI system. The basic components of the current version of the RUDO system are shown in Figure 1.

An important part of the current version is the UI called HANIBAL [4] ensuring the unification of the UI. The special interface for people with blindness uses software services providing orientational sounds [6] together with voice synthesis [27], Braille display [28], [29] or unique input in Braille from the basic keyboard [7]. The purpose of connecting these three approaches in parallel is to speed up the reception of information by a person with blindness.

III. METHODOLOGY

In engineering and information system development, the design science (DS) methodology is mainly applied in the case of solution design [30], [31]. DS research takes the form of a design or engineering cycle in which the proposed artifact is iteratively improved [26]. In the case of the development of the RUDO system and its parts, the engineering cycle consists of five basic stages, where the first three stages correspond to the design cycle [26]:

- problem identification and definition;
- description of the proposed solution;
- design validation (use of quantitative and qualitative methods to estimate the future usefulness of the design for users);
- implementation;
- implementation evaluation (use of quantitative and qualitative methods to determine usefulness for users in practice).

There are two main benefits of DS research conceived in this way. The first benefit is the introduction of generalized principles of the solution design to the defined problem, which will be usable in other similar problem contexts. The second benefit is the instance of the solution on which the technological procedures are tested (e.g., prototype). This article focuses mainly on four stages: defining the problem (Section I), description and implementation of the proposed solution (Sections II and IV) and evaluating the implementation in practice (Section V).

Starting with RUDO version 5 (2017), individual development iterations are described in Slovak in [32] – it can be translated by any tool for machine translation. Among these iterations, individual UI improvements for people with blindness can be seen, which are directly related to the energy system and its technical properties.

The principles of technical action research (TAR) are used to evaluate the implementation using the RUDO system (research prerequisite). It is a qualitative approach for evaluating the proposed solution under special conditions, where the researcher plays three logically separated roles, namely of "artifact developer, artifact investigator and client helper" [33]. The reason for choosing TAR is that the designed solution is very specific and designed only for a globally limited number of people with blindness. Since there are not many such buildings at present, there are very limited opportunities to obtain users of such solutions for evaluation, taking into account the specific physical disability of people with blindness. According to our literature search in the citation databases Web of Science and Scopus in Section I, no references to other functional prototypes of AmI systems for people with blindness were found except the RUDO system. The mentioned is related to the gradual development of intelligent environments and buildings and their accessibility for disadvantaged people [34].

When using action research, it may be appropriate to involve one of the co-creation approaches as experience-based co-design [35] or technology co-design relevant to DS and computer science and build on sociotechnical systems theory [36], [37].

Due to the very specific context focused on people with blindness and the focus on only one IB, the co-creation approach for "collaborative generation of knowledge by academics working alongside stakeholders from other sectors" [37] was not used. The prerequisite for the co-creation approach is that the proposed solution affects or includes multiple stakeholders. For example, it is the design of a complex socio-technical solution in an organization. However, with the solution proposed here, there is only one side of the solution's users: people with blindness; therefore, even during the evaluation, the main participant is a person with blindness with clearly defined cognitive and knowledge abilities. In addition, the goal of the long-term RUDO project is to show that even with minimal help from sighted colleagues, a person with blindness can create complex hardware and software systems while being fully self-sufficient in their use.

An alternative for building co-creation knowledge is the involvement of at least other scholars [37]. Here, we come across a fundamental problem when other scholars have cognitive abilities or possibilities different from those of the potential users of the solution. The involvement of the sighted in the design of aids for the blind has already been criticized in the past [38]; therefore, in our case, the principal conceptual designer is a person with blindness who is assisted by other scholars if necessary.

Therefore, for the evaluation, we decided to use TAR and three specific methods of data collection: cognitive walkthrough (CW) [39], [40], observation, and work speed measurement. In our case where locally small numbers of respondents are available, qualitative approach is used instead of quantitative approach. On the other hand, the target group of people with blindness who can potentially become system administrators in IB is large enough on a global scale to justify our research [41].

A similar qualitative approach with a small number of participants is not exceptional in the field of, e.g., medical engineering in connection with the design of aids for people with a specific physical disability connected with their skills, (technical) knowledge and experiences (with administration of IB or SmE), which are very few in a particular region of the world [42], [43], [44]. It can also be found computer science-oriented articles [45], [46], [47] where only two participants with blindness were used in the study. Two participants are also used in our solution evaluation. The first participant is a person with blindness who has technical knowledge and is used to staying in an IB and cooperating with the AmI system – there are not many such participants with special knowledge and experience in our region. The second participant is a sighted technician who assembles and administrates photovoltaic systems, which will be used to compare the work speed.

CW [43], [48] is a research method used to verify the usability of designed UI at the level of socio-technical interaction. CW is oriented towards more complex tasks consisting of several simple steps. Based on the theory from the cognitive exploratory learning [49], it can be concluded that the same, essentially simple procedure can also be performed by other people in other places if the required conditions are maintained. The progress of the execution of individual tasks is then qualitatively assessed as answers to evaluation questions (EQ).

The mentioned evaluation of the UI and functionality of the system, even on a limited sample of participants, is a valuable approach for providing quick feedback and for subsequent improvements to the solution within the engineering cycle of DS research [26]. The evaluation procedures are presented in Section V in more detail. Below is an overview of the thematic focus of the four tasks that are addressed as part of the research in this article:

1. heating application UI,
2. zoning application UI,
3. photovoltaic application UI,
4. energy redirection application UI.

To summarize the above, TAR is used to evaluate the designed and implemented UI for the administration of energy systems in IB. The research approach is therefore equivalent to the study [4], which dealt with the professional work of people with blindness in electrical engineering and informatics.

IV. DESCRIPTION OF IMPLEMENTED SOLUTION

In this article, we deal with a new extension of the long developed and tested RUDO AmI system for people with blindness (see Section II). The extension of the AmI system includes, from the point of view of the user with blindness, the following functions related to the administration module of ecologically oriented energy systems in IB:

- control of the photovoltaic power plant operation;
- the possibility of redirecting photovoltaic energy to the seven load branches of the IB;
- assisted AmI environment with an extended interface for people with blindness, which enables full technical and user service;
- remote administration allowing people with blindness full service via the Internet;
- heating control with extension to multiple energy sources;
- zonal regulation with extension to multiple energy sources;
- the possibility of using backup energy solutions;
- the possibility of choosing the use of alternative energy sources (photovoltaics and storage batteries with a capacity of 10 kWh, conventional electrical grid and heat pump, gas, solid fuel).

Individual parts of the AmI energy subsystem of the RUDO system were put into practice gradually between 2014 and 2020 because a scholar with blindness ensured the entire development: first-phase regulation of heating (2014), second-phase zonal regulation (2015), solid fuel backup source (2017), heat pump with air conditioning (2018), photovoltaic power plant (2020).

The purpose of this article is not to present in detail the energy subsystem solution itself at the software and hardware level, which may differ in practice for individual implementations of IB; instead, the goal is to present the space where interactions between humans and IB occur. Therefore, the article focuses only on the UI of the energy subsystem, which follows up with the unified HANIBAL UI used in the RUDO system. The general principles of interaction and administration of the energy subsystem can also be used in other solutions. HANIBAL has a modular character and a uniform menu structuring logic and can be adapted to the needs of people with blindness (e.g., hiding unused modules, adding and configuring a new module or system function). Figure 2 shows the main menu with the basic modules offered by the RUDO system. Simultaneously, the sub-screen (available after pressing the E key) of the basic menu of the energy subsystem is shown here. The highest degree of certainty when pressing the keys by a person with blindness is using Braille on an ordinary keyboard as described in [7] or using Braille keyboard.

The menu has a tree structure, which a person with blindness can remember during frequent work and reach the desired function quickly. For example, by successively pressing the letters E, F, and A (see the keyboard shortcuts shown in Figures 2 and 5), the user can very quickly get information about the current photovoltaic energy production in Watts. The structure of menu items can be easily adjusted, so functions that are often used can be accessed more quickly.

Each module is thematically focused and offers specific functions (e.g., programming module, weather forecast module). HANIBAL makes full use of the possibilities of interaction with the user with blindness, which the RUDO system enables, i.e., use of a keyboard (with Braille support), Braille display and notifications (i.e., use of orientational sounds and voice synthesis) for interaction with the user. Menus are presented in text and semigraphical form, thanks to which even sighted users can control the given system; see Figure 2.

The RUDO AmI system presented in Section II and the implemented functions of the energy subsystem are quite robust and complicated, placing considerable demands on people with blindness regarding UI complexity. The intention is that the research regarding the RUDO system broadly covers most situations from practice and, at the same time, requires a degree of technical skill, which, however, generally does not exceed the capabilities of people with blindness [4]. Partial solutions designed for the RUDO system can also be used in other AmI systems connected with IBs. This opens a new way to create life and work possibilities for people with blindness without geographical or ethnic restrictions.

In the following subsections, the article will focus on the following four UI of the energy subsystem for people with blindness:

```
                    HANIBAL Assistant

  A Command line       Working with files and directories
  B Notepad            Work with texts - files, notes, work planner
  D Documents          Processing documents in HPR format
  C Search texts       Search text files and documents
  T Print              Print of texts and documents
  P Help               User manuals for  ROWS, RUDO, HANIBAL and LINUX
  G Grammar            Grammar editing - spelling, pronunciation
  F Dictionaries       English, German and synonymy dictionary
  H Search data        Search, view and edit data on disk
  I Internet           Internet browser
  L LAN/WIFI network   Connecting, disconnecting, working with comp. networks
  J Conversion         Conversion of text document formats
  R CD burning         DVD and CD burning
  S Scanning and OCR   Scanning of texts and images, OCR
  U Quit working       Shut down the computer, restart, HANIBAL exit
  E Energy system      Photovoltaics, heating and zones
  O Programs           Other software tools
  Q Weather forecast   Weather forecast
  K Calculator         Programmable calculator
  N RUDO settings      Settings of RUDO system, ROWS and HANIBAL
  V Development tools  Development of software applications
  W Sound wav/mp3      Playback and recording of audio recordings
  M Programming        Editing and compilation of programs
  X Data devices       Connecting/disconnecting USB, DVD, memory cards

ESC/LF=back; UP/DN/PGUD=select; ENTER/RG/CHAR=choose; F2=help; F10=next;

                      Energy system

  V Heating system     Heating and water heating service
  0 Ground floor zone  Zonal regulation - ground floor
  1 First floor zone   Zonal regulation - first floor
  F Photovoltaics      Photovoltaic power plant, data collection
  2 Ground floor menu  Zone name editing - ground floor
  3 First floor menu   Zone name editing - first floor
  K Configuration      Configuration of ROWS, RUDO, and HANIBAL systems
  U Leakage function   Calculation of radiator temperatures
  N Manual for users   Instructions for using heating and zonal regulation

ESC/LF=back; UP/DN/PGUD=select; ENTER/RG/CHAR=choose; F2=help; F10=next;
```

FIGURE 2. The top screen is the main screen with an overview of the main thematic modules offered by the RUDO system. The bottom screen is a sub-screen (accessible from the main screen by pressing the E key) with an overview of the main functions offered by the energy subsystem administration module. All text is translated from Slovak.

- heating operator interface for people with blindness, Section IV-A.2,
- zone control operator interface for people with blindness, Section IV-B.2,
- photovoltaic data browsing interface for people with blindness, Section IV-C.2,
- photovoltaic energy redirecting interface for people with blindness, Section IV-C.2.

The following subsections introduce the technological solution of the energy system and the basic UI principles for their control. Because the control description is closely related to the solution design and its evaluation, we decided to describe the controlling method in Section V to understand how administrators with blindness control the energy system using the proposed UI. For illustrative purposes, the article includes Appendix, which contains a video where a person with blindness shows how working with the presented solution looks like in practice.

A. HEATING REGULATION

1) BASIC DESCRIPTION OF IMPLEMENTATION IN RUDO PROTOTYPE

Gas is the primary energy source for heating in the described energy system. The electronics of gas boilers require power from the grid during their operation. The consumption of boiler electronics is minimal; it can be covered by photovoltaic electricity production even in winter. Therefore, all the boiler room equipment is primarily powered by the photovoltaic power plant. A second solid fuel boiler is a backup energy solution. Combined heating in both boilers at the same time is also supported. In the case of exclusive heating with solid fuel, the system enables self-sustaining operation without requiring support from electrical energy.

The water in the boiler is primarily heated by photovoltaics; in cloudy weather the heating is automatically switched to gas or it can be manually switched to solid fuel heating. All electronic and manual equipment in the boiler room is fully operable by an administrator with blindness. The second backup energy source for heating the two thermal zones in the building is an air-to-air heat pump with a small output. In transition seasons, it can be powered by photovoltaics or permanently from the regular electrical grid.

All the equipment in the boiler room (gas boiler, pumps, temperature sensors, electric valves and climate control valve) has data connection to the RUDO AmI system via the control electronics. The gas boiler heats the water in the primary circuit, where technical water is at a relatively high temperature. The technical water is mixed from the primary circuit through the climate control valve into the radiator circuit. A regulation method with temperature feedback is used for heating the technical water. One temperature sensor must therefore measure the temperature in the primary circuit and one in the radiator circuit.

Each building has a specified energy leakage, which is based on the degree of insulation. In an AmI system, leakage is given by determining the leakage curve. The AmI system calculates the required temperature of technical water in the radiator circuit based on the following: determination of leakage curve, measurements from the exterior temperature sensor, and setting of the desired average interior temperature. The implemented heating regulation and zonal regulation are described in more detail in [7].

2) HEATING OPERATOR INTERFACE FOR PEOPLE WITH BLINDNESS

Before introducing the heating administration client application and its UI, it is necessary to introduce the associated communication interfaces that allow a user with blindness to obtain heating information (even outside the computer station) and respond to this information via the client application. These associated communication interfaces are characteristic of AmI systems, which use sensors to capture and evaluate, e.g., the movement of people around the building or changes in the internal and external environment, and make the necessary information available to system users in various forms.

Such a communication interface is a light and voice beacon of the heating status, which contains a device with three LED light indicators for three possible heating statuses (for sighted users in the house):

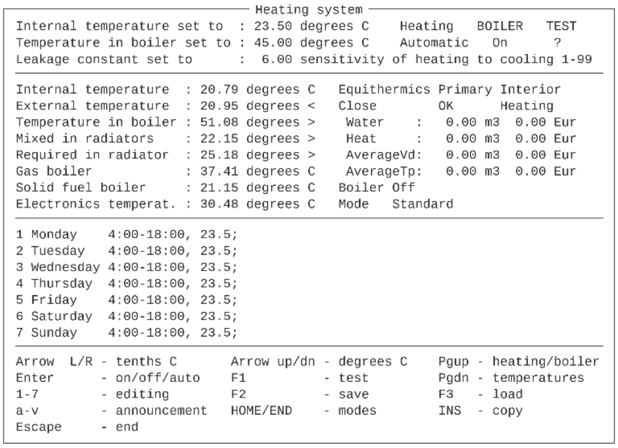
- not heating (green);
- heating (red);
- heating break in the transition season, ventilation is possible (blue).

One beacon is located on the ground floor, and one on the first floor. This status information is made available to the administrator with blindness by notification in the speakers when the status changes (see Section II). Furthermore, it is repeated once upon a motion sensor stimulus if the administrator with blindness was not near the speaker at the time of the state change. In addition to speech synthesis, when information is reported via the home speaker(s), the RUDO system also uses the so-called orientational sounds [6]. They can introduce the message using speech synthesis or independently communicate frequently transmitted information so as not to disturb the people in the building too much. An example of a notification message is the orientational sound of the locomotive horn followed by the message: "The heating is on." People with blindness know that windows should be closed for ventilation.

Additional options for advanced settings via the configuration file can also be provided by a user with blindness in the client application (example in Section IV-C.2). The heating administration client application enables the user with blindness to:

- view the set average interior temperature,
- set the required average interior temperature,
- set the steepness coefficient of the leakage curve,
- view measured and statistical data,
- view and set time-temperature profiles.

The client application for heating administration consists of several parts; see Figure 3. In the uppermost first part, the required average interior temperature, water temperature in the boiler and the steepness coefficient of the leakage curve can be set. In addition, it displays data on the status of the space heating and water heating service (on, off, automatic). The second part displays current technical and statistical data readings. In the third part, the time-temperature profile is shown either for space heating or for water heating. The last part is an auxiliary information window.



```
                           Heating system
Internal temperature set to  : 23.50 degrees C    Heating   BOILER   TEST
Temperature in boiler set to : 45.00 degrees C    Automatic   On      ?
Leakage constant set to      :  6.00 sensitivity of heating to cooling 1-99

Internal temperature  : 20.79 degrees C   Equithermics Primary Interior
External temperature  : 20.95 degrees <   Close        OK      Heating
Temperature in boiler : 51.08 degrees >    Water    :   0.00 m3  0.00 Eur
Mixed in radiators    : 22.15 degrees >    Heat     :   0.00 m3  0.00 Eur
Required in radiator  : 25.18 degrees >    AverageVd:   0.00 m3  0.00 Eur
Gas boiler            : 37.41 degrees C    AverageTp:   0.00 m3  0.00 Eur
Solid fuel boiler     : 21.15 degrees C   Boiler Off
Electronics temperat. : 30.48 degrees C   Mode   Standard

1 Monday    4:00-18:00, 23.5;
2 Tuesday   4:00-18:00, 23.5;
3 Wednesday 4:00-18:00, 23.5;
4 Thursday  4:00-18:00, 23.5;
5 Friday    4:00-18:00, 23.5;
6 Saturday  4:00-18:00, 23.5;
7 Sunday    4:00-18:00, 23.5;

Arrow  L/R - tenths C      Arrow up/dn - degrees C    Pgup - heating/boiler
Enter      - on/off/auto   F1          - test         Pgdn - temperatures
1-7        - editing       F2          - save         F3   - load
a-v        - announcement  HOME/END    - modes        INS  - copy
Escape     - end
```

FIGURE 3. Heating operator interface for people with blindness – example of semigraphical interface. All text is translated from Slovak.

B. ZONAL REGULATION

1) BASIC DESCRIPTION OF IMPLEMENTATION IN RUDO PROTOTYPE

The zonal regulation is divided into two separate services for the flat on the ground floor and the flat on the first floor. As this is a test prototype of an AmI system subject to engineering development cycles [26], it was intended that improvements related to services for the residents of one flat would not affect the environment of the residents of the other flat. A separate heating zone was defined for each room of the building. The zonal regulation system can thus best respond to the sun's movement in the sky and appropriately adapt the heating performance for each part of the building to the strength of the solar radiation.

Individual zones are created by wireless Z-Wave radiator valves that communicate with a controller connected via USB to the home miniserver (see Section II). Radiator valves are supplied with energy from batteries, which will last approximately one heating season for a given valve.

The prototype of the RUDO system installed in a two-storey family house uses two-phase heating regulation. The first phase is heating regulation (see also Section IV-A) and the second is zonal regulation. The first level of regulation heats the technical water in the entire radiator distribution. The water temperature must be approximately two degrees higher than that required for the coldest room in the building. The second level of regulation is implemented by Z-Wave radiator heads for each zone (room) separately. This is a regulation with temperature feedback, in which the radiator heads measure the temperature in individual zones and, based on this, regulate the flow of heated technical water to the radiators.

The highest temperature comfort is achieved when the temperature of the radiators does not oscillate between minimum and maximum but changes continuously and smoothly based on the interior temperature in the given zone. In order to prevent the temperature of individual radiators from oscillating, the technical water in the radiator distribution must not be heated excessively. If, on the other hand, the technical water in the radiator distribution is heated insufficiently, the coldest rooms of the building will begin to experience a lack of heat by recording temperature below the required minimum limit. An important advantage of the two-stage regulation is that during brief ventilation in the heating period, there will be no excessive heat leakage.

2) ZONE CONTROL OPERATOR INTERFACE FOR PEOPLE WITH BLINDNESS

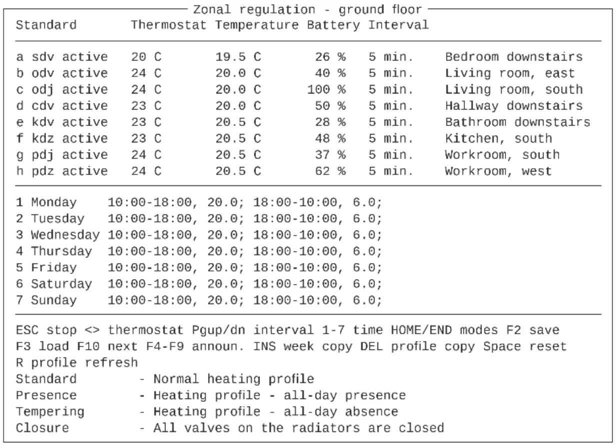
Similar to what was mentioned in Section IV-A.2, it is appropriate first to introduce the associated communication interfaces that allow a user with blindness to obtain information about heating (even outside the computer station). Through the speakers installed in the building with the RUDO system, information is transmitted to the person with blindness using notification messages. We can present at least two examples:

- The first example contains the orientational sound of a jingle bell followed by the message: "Bathroom radiator head batteries are dying." There is still energy left in the batteries for approximately two weeks of operation.
- The second example contains the orientational sound of a jingle bell and two swings of the sword, followed by the message: "The batteries of the radiator head in the kitchen are completely discharged."

Additional options for advanced settings can be made via the configuration file (example in Section IV-C.2). The client application providing zonal regulation enables the user with blindness to:

- view the set temperatures in individual zones,
- set the required temperatures in individual zones,
- browse the measured temperatures in individual zones,
- view the battery status in Z-Wave heads,
- view and set time-temperature profiles.

The client application for the administration of zonal regulation consists of several parts; see Figure 4. In the uppermost first part on the left is the name of the current user profile. By user profile, we mean all weekly time schedules for individual heating zones. The names of the table columns are listed in the uppermost part. The heating zones are listed line by line in the second part with the corresponding values. Values can be changed by an administrator with blindness in three ways: selection from history, writing new values or editing existing ones using Braille display, keyboard, voice synthesis and syntax checking. The third part shows the weekly time heating schedule of the selected zone. The last bottom part is a help information window. It is also worth mentioning that applications of zonal regulation for individual floors (flats) are available in user mode (not administrator mode) and to individual residents of the IB. With it, they can adjust the temperatures in their flat according to their personal needs.



```
                     Zonal regulation - ground floor
Standard       Thermostat Temperature Battery Interval

a sdv active   20 C       19.5 C        26 %   5 min.    Bedroom downstairs
b odv active   24 C       20.0 C        40 %   5 min.    Living room, east
c odj active   24 C       20.0 C       100 %   5 min.    Living room, south
d cdv active   23 C       20.0 C        50 %   5 min.    Hallway downstairs
e kdv active   23 C       20.5 C        28 %   5 min.    Bathroom downstairs
f kdz active   23 C       20.5 C        48 %   5 min.    Kitchen, south
g pdj active   24 C       20.5 C        37 %   5 min.    Workroom, south
h pdz active   24 C       20.5 C        62 %   5 min.    Workroom, west

1 Monday    10:00-18:00, 20.0; 18:00-10:00, 6.0;
2 Tuesday   10:00-18:00, 20.0; 18:00-10:00, 6.0;
3 Wednesday 10:00-18:00, 20.0; 18:00-10:00, 6.0;
4 Thursday  10:00-18:00, 20.0; 18:00-10:00, 6.0;
5 Friday    10:00-18:00, 20.0; 18:00-10:00, 6.0;
6 Saturday  10:00-18:00, 20.0; 18:00-10:00, 6.0;
7 Sunday    10:00-18:00, 20.0; 18:00-10:00, 6.0;

ESC stop <> thermostat Pgup/dn interval 1-7 time HOME/END modes F2 save
F3 load F10 next F4-F9 announ. INS week copy DEL profile copy Space reset
R profile refresh
Standard          - Normal heating profile
Presence          - Heating profile - all-day presence
Tempering         - Heating profile - all-day absence
Closure           - All valves on the radiators are closed
```

FIGURE 4. Zone control operator interface for people with blindness – example of semigraphical interface. All text is translated from Slovak.

C. PHOTOVOLTAIC POWER PLANT

1) BASIC DESCRIPTION OF IMPLEMENTATION IN RUDO PROTOTYPE

The total output of the active area of the photovoltaic power plant installed in the building with the RUDO system is 6 kWP (kilowatt-peak). 2.4 kWP is used for water heating and 3.6 kWP for producing 230 V AC electricity (parameters of the standard electrical grid in continental Europe).

The produced electrical energy is distributed into seven load branches within the IB. The power plant is equipped with storage batteries with a total capacity of 15 kWh (kilowatt-hour).

The zero branch is continuously powered by photovoltaics. It switches to the regular electrical grid automatically only if it is entirely cloudy outside for a long time and the whole capacity of the electrical energy stored in the storage batteries is consumed. The zero branch is connected to:

- computer network,
- home server,
- boiler room equipment,
- audio/video information consoles,
- taxonometry sensors,
- AmI system electronics,
- computers used to operate and administrate the AmI system,
- battery chargers for lawn mowers and electric hand tools.

Load branches 1-6 are automatically connected to the photovoltaic plant based on the amount of electricity produced. However, it is possible for the user to forcibly connect or disconnect any of branches 1-6 from the photovoltaic system. The branch is automatically connected to the regular electrical grid when disconnected from the photovoltaic system. The above-mentioned distribution of photovoltaic energy is calculated to charge the storage batteries during the day entirely, and the remaining power is consumed utilizing connected appliances. During the night, in summer, the consumption mode from the storage batteries is automatically selected; in winter, the energy in the storage batteries is perceived as a backup solution in the event of a power outage.

A modern ecologically oriented energy system that includes photovoltaics must have an alternative energy source available. The reason is the possibility of long-term cloudy weather, during which the acquisition of photovoltaic energy is reduced to a minimum. Our tested prototype automatically switches electricity production to the electrical grid during long-term cloudy weather without short-term outages. In this case, there is no need to deal with the interface for administrators with blindness. Water heating is automatically switched from photovoltaics to gas heating in long-term cloudy weather; see Section IV-A.

In case of long-term cloudy weather, gas failure or a long-term power failure, it is possible to manually switch the water heating to heating using solid fuel. In this case, it is necessary to manually open the lever valve on the solid fuel boiler and heat it conventionally. Under these conditions, the ordinary skills of an operator with blindness are sufficient for heating with solid fuel [50], [51], [52].

2) PHOTOVOLTAIC DATA BROWSING INTERFACE FOR PEOPLE WITH BLINDNESS AND PHOTOVOLTAIC ENERGY REDIRECTING INTERFACE FOR PEOPLE WITH BLINDNESS

Similar to what was mentioned in Section IV-A.2, it is appropriate first to introduce the associated communication interfaces that allow a user with blindness to obtain information related to the production and distribution of electricity (even outside the computer station). Such a communication interface is the light and voice indicator of the electricity branching. It consists of one device with three LED light indicators for the three load branches on the first floor and another one for the other three load branches on the ground floor. These LED indicators light up when the given load branch is automatically or manually connected to photovoltaic energy. The LED indicator does not light up if the given branch is connected to a regular electrical grid.

This status information is made available to the administrator with blindness by a notification message in the speakers when the status changes (see Section II). We can mention at least two examples of notification messages:

- The first example contains the orientational sound of three drops of water followed by the message: “Battery status 100 percent.”
- The second example contains the orientational sound of a machine followed by the message: “Excess solar energy.”

Advanced settings of the photovoltaic power plant can be adjusted through the configuration file, which in the current version has 96 items and includes basic and advanced settings of all modules of the RUDO system. An example of a few lines of the configuration file is given in Source code 1.

```
heat=on #Heating service, on/off
zonreg0=on #Ground floor zonal regulation
service, on/off
zonreg1=on #Floor zonal regulation service,
on/off
powerstation=on #Photovoltaic service,
on/off
taxonometry=on #Taxonometry service, on/off
klingon=on #Web server service, remote
control, on/off
summercascades=20-30,30-40 #Summer intervals
of adding consumption indicated in the
percentage of battery charge - switching
off, switching on
wintercascades=70-80,90-100 #Winter
consumption addition intervals indicated in
the percentage of battery charge - switching
off, switching on
tuningsounds=off #Extended debugging
notification messages
```

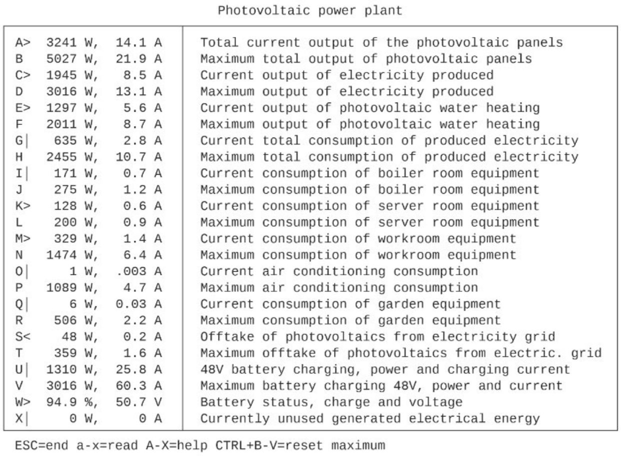
SOURCE CODE 1. Example configuration file.

The client application for the photovoltaic power plant is divided into two user windows. The first user window deals with current data on the state of the power plant, and the second one enables branching of electricity and redirection of the photovoltaic source.

The client window of current data (see Figure 5) allows administrators with blindness to browse:

- the current consumption on load branches,
- the current output of produced photovoltaic energy,
- the current battery charging status,
- the current output of unused energy.

When using this application, it is not possible to make a false step during administration, which enables the administration to be carried out at a lower professional level.



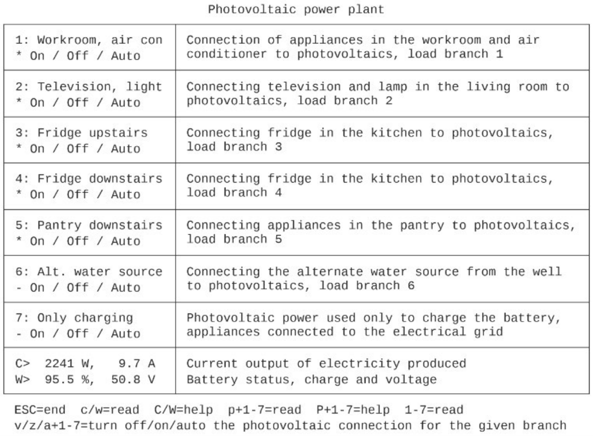
```
                         Photovoltaic power plant

A>  3241 W,   14.1 A    Total current output of the photovoltaic panels
B   5027 W,   21.9 A    Maximum total output of photovoltaic panels
C>  1945 W,    8.5 A    Current output of electricity produced
D   3016 W,   13.1 A    Maximum output of electricity produced
E>  1297 W,    5.6 A    Current output of photovoltaic water heating
F   2011 W,    8.7 A    Maximum output of photovoltaic water heating
G|   635 W,    2.8 A    Current total consumption of produced electricity
H   2455 W,   10.7 A    Maximum total consumption of produced electricity
I|   171 W,    0.7 A    Current consumption of boiler room equipment
J    275 W,    1.2 A    Maximum consumption of boiler room equipment
K>   128 W,    0.6 A    Current consumption of server room equipment
L    200 W,    0.9 A    Maximum consumption of server room equipment
M>   329 W,    1.4 A    Current consumption of workroom equipment
N   1474 W,    6.4 A    Maximum consumption of workroom equipment
O|     1 W,   .003 A    Current air conditioning consumption
P   1089 W,    4.7 A    Maximum air conditioning consumption
Q|     6 W,   0.03 A    Current consumption of garden equipment
R    506 W,    2.2 A    Maximum consumption of garden equipment
S<    48 W,    0.2 A    Offtake of photovoltaics from electricity grid
T    359 W,    1.6 A    Maximum offtake of photovoltaics from electric. grid
U|  1310 W,   25.8 A    48V battery charging, power and charging current
V   3016 W,   60.3 A    Maximum battery charging 48V, power and current
W>  94.9 %,   50.7 V    Battery status, charge and voltage
X|     0 W,      0 A    Currently unused generated electrical energy

ESC=end a-x=read A-X=help CTRL+B-V=reset maximum
```

FIGURE 5. **Photovoltaic data browsing interface for people with blindness – example of semigraphical interface. All text is translated from Slovak.**

Figure 6 shows the client application of branching the electricity and redirecting the photovoltaic source to the exclusive charging of the storage battery. This application requires higher expertise in administration, as it enables switching between automatic and manual redirection of electricity to individual load branches. It also allows direct manual electricity redirection. At the same time, the application contains protections to prevent the photovoltaic system from malfunctioning during its use and to prevent any danger to the residents of the IB. Incompetence or a mistake in its use can only be manifested by the inefficient use of the produced electricity or a slight reduction in the life of the storage batteries.



```
                       Photovoltaic power plant

1: Workroom, air con    Connection of appliances in the workroom and air
* On / Off / Auto       conditioner to photovoltaics, load branch 1

2: Television, light    Connecting television and lamp in the living room to
* On / Off / Auto       photovoltaics, load branch 2

3: Fridge upstairs      Connecting fridge in the kitchen to photovoltaics,
* On / Off / Auto       load branch 3

4: Fridge downstairs    Connecting fridge in the kitchen to photovoltaics,
* On / Off / Auto       load branch 4

5: Pantry downstairs    Connecting appliances in the pantry to photovoltaics,
* On / Off / Auto       load branch 5

6: Alt. water source    Connecting the alternate water source from the well
- On / Off / Auto       to photovoltaics, load branch 6

7: Only charging        Photovoltaic power used only to charge the battery,
- On / Off / Auto       appliances connected to the electrical grid

C>  2241 W,    9.7 A    Current output of electricity produced
W>  95.5 %,   50.8 V    Battery status, charge and voltage

ESC=end  c/w=read  C/W=help  p+1-7=read  P+1-7=help  1-7=read
v/z/a+1-7=turn off/on/auto the photovoltaic connection for the given branch
```

FIGURE 6. **Photovoltaic energy redirecting interface for people with blindness – example of semigraphical interface. All text is translated from Slovak.**

V. EVALUATION

This section presents the evaluation of the UI of the energy subsystem (part of the RUDO AmI system), which was summarized in Sections II and IV, according to the DS methodology. The evaluation was carried out in an IB, where the RUDO system is installed by a participant with blindness who, according to TAR, acted as a designer and scholar participating in the evaluation [33]. The evaluation consists of three perspectives corresponding to three subsections: qualitative solution evaluation based on CW method (Section V-A), evaluation of work speed based on measurement (Section V-B), and conclusions from long-term development and testing based on observation and experiences (Section V-C).

For qualitative evaluation, we chose TAR to evaluate the usefulness of the proposed solution for a narrow group of potential users. The TAR includes three different approaches for data collection. The first is CW method [39], [40], [42], [53] for feedback on the design of the UI. In addition to verifying the proposed solution's effectiveness, this evaluation aims to show that the proposed assistance environment and UI are usable for administrators with blindness regardless of geographic location or ethnicity. Details on the involvement of the participant with blindness in the CW are given in Section III. Based on previous research [4] and the approaches presented in [42] and [54], we defined three evaluation questions (EQ) concerning CW:

- **EQ1:** Is the administrator with blindness, prior to commencing the work, aware of his or her capability of performing the relevant work with the UI of the energy subsystem?
- **EQ2:** Is the administrator with blindness able to select (repeat, combine) individual steps of the procedure in such a way that would contribute to achieving the expected outcome or solution?
- **EQ3:** At the end of the process, is the administrator with blindness certain of having achieved the expected outcome (i.e., required energy subsystem settings)?

Individual qualitative evaluation tasks were performed within one day and assessed first by the participant with blindness. Then, possible issues were discussed with a sighted scholar who supervised the carrying out of CW. Subsequently, responses to the EQs were formulated by the participant with blindness.

The second is the work speed measurement of an administrator with blindness and a sighted technician, which was evaluated on four other tasks with several breaks. The third is conclusions from long-term development and testing, which were formulated based on the notes and reflections of the designer with blindness who developed the proposed solution and improved it over the years. The improvement of the UI was carried out based on partial conclusions from testing, which has been iterative since 2014 and connected with developing the RUDO system's new functionalities.

A. EVALUATION USING COGNITIVE WALKTHROUGH

This subsection presents a description of the steps in four tasks used for the qualitative evaluation of the UI described in Section IV based on CW. Qualitative evaluation is based on rigorous performance. Each task should comprise a small number of simple steps. The EQs 1–3 are applied to evaluating all the tasks. In the following subsections, the UI elements are presented first, followed by the steps in a task.

1) EVALUATION TASK DESIGN FOR HEATING OPERATOR INTERFACE FOR PEOPLE WITH BLINDNESS

a: BASIC DESCRIPTION OF CONTROL USING THE USER INTERFACE

Before introducing the steps in this task, it is essential to present the elements of the user interface mentioned in Section IV-A, which will also be the focus of the evaluation. The most frequently used keys of the heating control console are arrows, alphabetic characters, numbers and the ENTER, PGUP/PGDN, and HOME/END keys. Using the arrows, the administrator sets the required temperatures and the steepness coefficient of the leakage curve. The ENTER, PGUP/PGDN keys are used to turn on, turn off or switch to automatic activation of the space heating and water heating service.

Time-temperature profiles are switched by the administrator using the HOME/END keys. Profile settings are initialized with a number key representing the day of the week. Standard editing functions (known from the HANIBAL user interface) are used when entering time data, just as with zonal regulation.

The AmI system transmits information to an administrator with blindness using artificially produced speech. The application output is in a semigraphical form on the console, so the person with blindness can read it line by line with the help of a synthesizer or Braille display for people with blindness. The heating application is initialized in the AmI system through the unified HANIBAL UI.

The evaluation task for heating operator interface for people with blindness has seven steps:

1. Opening the application via the unified UI HANIBAL.
2. Parameter selection using the up/down arrows; announcements using voice synthesis.
3. Setting with the left/right arrows; announcements using voice synthesis.
4. Pressing function keys; announcements using voice synthesis.
5. Pressing character keys; announcements using voice synthesis.
6. Pressing the number keys; editing the user profile.
7. Closing the application.

2) EVALUATION TASK DESIGN FOR ZONE CONTROL OPERATOR INTERFACE FOR PEOPLE WITH BLINDNESS

a: BASIC DESCRIPTION OF CONTROL USING THE USER INTERFACE

First, the UI elements mentioned in Section IV-B are presented, which will also be the focus of the evaluation. The arrow keys are the most frequently used in the zonal control console. With the up/down arrows, the administrator selects the console line – temperature zone. The line with the selected zone is marked with the system cursor. The administrator sets the required temperature for the given zone (room) with the right/left arrows. The administrator can obtain data for the selected zone – set temperature, measured temperature and battery status – by pressing one of the three function keys.

An essential and very effective function is the change of user profiles, which is done by pressing the HOME/END key. There are ten profiles available for each floor, such as "presence", "standard", "do not heat" and so on. When changing the profile, the zone control system changes the settings on all thermostatic valves within one floor.

Let us mention one more function. When the number keys are pressed, the administrator enters the profile editing mode, where he or she can set the heating schedule for each zone separately. When editing, standard editing functions, editing history and copy commands are available, which facilitate the creation of time schedules.

The AmI system transmits information to an administrator with blindness using artificially produced speech. The application output is in a semigraphical form on the console so that the administrator can read it line by line with the help of a synthesizer or Braille display for people with blindness. The zone control application is initialized in the AmI system through the unified HANIBAL user environment.

The evaluation task for zone control operator interface for people with blindness has seven steps:

1. Opening the application via the unified UI HANIBAL.
2. Zone selection using the up/down arrows; announcement of the selected zone using voice synthesis.
3. Setting the desired temperature with the right/left arrows; announcement of the set temperature using voice synthesis.
4. Pressing function keys; listening to data on temperatures and battery states.
5. Selecting a user profile using the HOME/END key; announcement of the selected profile using voice synthesis.
6. Pressing the number keys; editing the user profile.
7. Closing the application.

3) EVALUATION TASK DESIGN FOR PHOTOVOLTAIC DATA BROWSING INTERFACE FOR PEOPLE WITH BLINDNESS

a: BASIC DESCRIPTION OF CONTROL USING THE USER INTERFACE

First, the UI elements mentioned in Section IV-C are presented, which will also be the focus of the evaluation. The information console contains current data in the left column and a short comment in the right column; see Figure 5. By directly pressing a small character, the AmI system reads the current status of the given item, which changes over time, in a synthetic voice. After the first letter in the menu are the characters "< | >", meaning the values are decreasing, constant, or increasing. The synthesizer reads the values, the units, and finally either says the word "decrease" or "increase". If it makes no comment, it means that the value does not change in a fundamental way.

A short comment is read when a capital character is pressed. Characters can be pressed by the person with blindness on the keyboard in the normal way or in the form of Braille for people with blindness, see also [7].

The application output is in a semigraphical form on the console, so the person with blindness can read it line by line with the help of a synthesizer or Braille display for people with blindness. For sighted administrators, the information is also separated in colour for clarity. All applications are initialized in the AmI system through the unified HANIBAL UI, which does not require administrators with blindness to make fundamental changes in data acquisition and control of IB devices.

The evaluation task for photovoltaic data browsing interface for people with blindness has four steps:

1. Opening the application via the unified UI HANIBAL.
2. Pressing a key with an alphabet character or a combination of Braille dots.
3. Listening to a short report with data.
4. Closing the application.

4) EVALUATION TASK DESIGN FOR PHOTOVOLTAIC ENERGY REDIRECTING INTERFACE FOR PEOPLE WITH BLINDNESS

a: BASIC DESCRIPTION OF CONTROL USING THE USER INTERFACE

First, the UI elements mentioned in Section IV-C are presented, which will also be the focus of the evaluation. The energy redirection application console also has two columns displayed in semigraphical mode. It is initialized in the HANIBAL environment; the difference is that by pressing two characters, the person with blindness can manually redirect the electricity for the given branch from photovoltaics or the regular electrical grid. The third option is the "automatic" option, in which the redirection is performed automatically by the AmI system according to how much energy is available.

The AmI system is primarily built for fully automatic operation. With backup solutions, a situation may arise when electrical energy is required in some branches and expendable in the rest. In this case, the consumption profile is set by the administrator with blindness according to the needs of the residents of the IB.

The "$*$" or "-" character is indicated under the load branch number. In the first case, it is information that the branch is powered by photovoltaics; in the second case, the regular electrical grid powers it. After the administrator presses the number of the branch, the AmI system reads all the information in a short and concise message.

The evaluation task for photovoltaic energy redirecting interface for people with blindness has five steps:

1. Opening the application via the unified UI HANIBAL.
2. Pressing a key with an alphabet character or a combination of Braille dot; selection of an operation on the load branch.
3. Pressing a key with a number or a combination of Braille dots; selection of the load branch.
4. Listening to a short report on the progress of the power redirection operation or a report on the status of the redirection.
5. Closing the application.

5) ANSWERS TO EVALUATION QUESTIONS

The involved participant with blindness performed the steps in the individual tasks. During this activity, he was observed by a sighted scholar, who then discussed individual procedures and potential problems with the participant with blindness. The person with blindness summarized his feedback in answers to the three EQ.

a: THE ANSWER TO EQ1

The positive answer is related to the participant's experience with the HANIBAL UI, which is used for the entire operation of the RUDO AmI system. After turning on the computer, the opening window of the HANIBAL environment is on the screen. This environment allows people with blindness to navigate through the window structure and listen to or read a short help for each item. A user with blindness can find a menu related to the energy subsystem here, which contains the four windows of the UI described in Section IV. Therefore, even when using this environment for the first time for energy subsystem administration, the person with blindness can easily find the window intended for her or his activity. However, if the user has been using the HANIBAL environment for a long time, she or he will select the desired window with a single hotkey press.

b: THE ANSWER TO EQ2

A positive answer is again related to the ability to use the HANIBAL UI. At the same time, it is an assumption that the user with blindness has completed energy subsystem administration training. The degree of correctness of choosing the next step is therefore determined by education or course completion and experience. In the administration of the energy subsystem, however, successful completion of the course is a necessary basic education.

c: THE ANSWER TO EQ3

A positive answer is associated with the user's ability to read the current state of individual parts of the energy subsystem using speech synthesis (e.g., after changes have been made). At the same time, the aforementioned is related to the completion of energy subsystem administration training and its understanding by the given user.

B. EVALUATION OF WORK SPEED

From the point of view of ensuring the competitiveness of a person with blindness in the labor market, it is crucial to ensure his or her work speed, which should be as fast as the speed of work of a sighted worker. Although the solution presented in this article for people with blindness can be controlled by the sighted (see the semigraphical interface in this article), it is only an additional control option. The proposed solution is not primarily intended for the professional work of a sighted technician. Therefore, we decided to measure the work speed of an administrator with blindness on four tasks connected with using the proposed UI and compare it with the work speed of a sighted technician using a smartphone with a special application.

Both applications are optimized and purpose-designed for professional work with the energy system, thus enabling comparison. However, the above evaluation has its limits. The first is that the application for the administration of the energy system for people with blindness also provides other functions that the sighted technician application does not allow, and vice versa. The second limitation is related to the design of similar tasks for sighted and blind participants in connection with the photovoltaic power plant. The speed of the work had to be measured on a functional photovoltaic power plant, which carries with it the risk that a sighted technician, in particular, could make a mistake (with such a large number of attempts), which could lead to irreversible damage to partial parts of the photovoltaic power plant, e.g. dramatically reduce battery life. Therefore, the tasks of the sighted technician were chosen in such a way as to threaten the IB energy system as little as possible. Only under these conditions did the technician agree to participate in the research. Some tasks for a sighted technician consist of simpler steps that, in summary, imitate the same task (e.g. in terms of physical execution) as if a sighted technician performed the same settings as a participant with blindness and at the same time, the given task is as complex as what a participant with blindness does.

1) DESCRIPTION OF THE MEASUREMENTS

All tasks take place on the same IB. We asked for the cooperation of the company that installed photovoltaics on the roof of the building for the given measurement. Two different applications were used for the measurement, which was designed for professional use by the administration of energy systems. The first is a presented solution for people with blindness, and the second is smartphone application, which comes from a photovoltaic manufacturer and uses its own graphical UI. Because both participants use different applications, we tried to design similar tasks. For each task, we performed 50 measurements (a total of 200 measurements on participant) and calculated the average speed and standard deviation (SD). During the measurement, time ran until the participant correctly performed the required settings, so it was pointless to calculate the error rate. Both participants are approximately the same age and use the application for the administration of energy system on a daily basis.

Description of equipment and tasks for person with blindness

The participant is the same person with blindness as in the case of TAR. For individual tasks, he uses a designed solution for the blind, which is available on a personal computer (Linux) equipped with HANIBAL unified UI (as a part of RUDO system) with voice synthesis, and for control he uses a keyboard and Braille display, see video presented in Appendix. The procedure for each task is given below. The participant with blindness used the keyboard shortcuts as he was used to for control.

Task 1: Information obtaining

1. HANIBAL opening window, click on the Energy system window (shortcut "E");
2. in Energy system window of the HANIBAL environment, click on the Photovoltaics application (shortcut "F");
3. selecting a window focused on Photovoltaic data browsing;
4. click on the Battery status (shortcut "W"), which is reported by an optimized announcement;
5. the participant hears only the first number (charge status), and the units are not necessary, so he interrupts the announcement and returns to the initial window of HANNIBAL by double-clicking ESC.

Task 2: Simple value setting

1. HANIBAL opening window, click on the Energy system window (shortcut "E");
2. in Energy system window of the HANIBAL environment, click on the First floor zone application (shortcut "1");
3. information about the current settings is available to the participant on the Braille display; the cursor is by default on the first item (Bedroom downstairs), see Figure 4, where we change the temperature by one degree by clicking on the arrow key;
4. the participant hears only the first number (the newly set temperature), and the units are not important, so he interrupts the announcement and returns to the initial window of HANIBAL by double-clicking ESC.

Task 3: Switching the states of photovoltaics in protection mode (more complex action)

1. HANIBAL opening window, click on the Energy system window (shortcut "E");
2. in Energy system window of the HANIBAL environment, click on the Photovoltaics application (shortcut "F");
3. selection of a window focused on Photovoltaic energy redirecting;
4. participant writes by Braille "z3" on the keyboard, which means that the energy branch three will be forced to switch to photovoltaic energy;
5. a short notification sound will sound, return to the initial window of HANIBAL by double-clicking on ESC.

Task 4: Time-temperature schedule setting (with text search and editing)

1. HANIBAL opening window, click on the Energy system window (shortcut "E");
2. in Energy system window of the HANIBAL environment, click on the First floor zone application (shortcut "1");
3. click on the zone selection key, e.g. "g" for kitchen;
4. click on the number key of the day of the week, e.g. "2" for Tuesday;
5. searching in the text, adjusting the time and temperature in the room and at the end, click on ENTER for confirmation;

6. return to the initial window of HANIBAL by double-clicking on ESC.

Description of equipment and tasks for sighted technician

The participant is a technician who assembles photovoltaic systems. For their administration, he uses the VRM Victron application supplied by the manufacturer (version 2.9.3), which he uses on his OnePlus 9 Pro (Android) smartphone. The procedure for each task is given below. The sighted participant used the touch controls as he was used to.

Task 1: Information obtaining

1. click on the application icon on the desktop and the VRM Victron application will start;
2. in the menu, open the battery capacity setting;
3. reading data (battery capacity);
4. closing the application.

Task 2: Simple value setting

1. click on the application icon on the desktop and the VRM Victron application will start;
2. in the menu, open the battery capacity settings;
3. setting the lower voltage limit for charging the accumulator;
4. closing the application.

Task 3: Switching the states of photovoltaics in protection mode (more complex action)

In order to ensure the safety of the IB, a different procedure had to be designed to provide the equivalence of the participant with blindness and sighted technician tasks. The sighted technician proposed a procedure where he switches two values in one window, which is equivalent to execution (on a physical level) to what a participant with blindness does. Therefore, this task has the following form.

1. click on the application icon on the desktop and the VRM Victron application will start;
2. in the menu, open the battery capacity setting;
3. finding and setting the first value;
4. finding and setting the second value;
5. closing the application.

Task 4: Time-temperature schedule setting (with text search and editing)

The application of the sighted technician does not offer the given function, which is connected to heating. The sighted technician chose a similar task he does regularly, where he has to edit a text field in the application.

1. click on the application icon on the desktop and the VRM Victron application will start;
2. opening the console in the application (console for adjusting the battery charging criteria);
3. searching for a text field (searching for an item with a corresponding text field, there are many elements in the window);
4. opening the text correction (editing in the text field);
5. saving text (saving changes);
6. closing the application.

TABLE 1. **The speed of work of the administrator with blindness who regularly uses the proposed UI for administration of energy system in IB and sighted technician who use smartphone with special application for administration of energy system in IB.**

	Administrator with blindness		Sighted technician	
Task	Average value [s]	Standard deviation [s]	Average value [s]	Standard deviation [s]
Task 1	2.66	0.55	12.47	1.11
Task 2	5.95	0.53	23.58	5.34
Task 3	4.58	0.76	47.55	3.76
Task 4	17.18	4.36	71.23	2.79

Notes: s = second. Each task is described in detail in the text above.

2) RESULTS AND CONCLUSIONS

The results are summarized in Table 1. It can be concluded that the speed of displaying data and setting up the energy system by a person with blindness is faster than a sighted worker would do it via a graphical UI. Although the application is intended for professional work in both cases, it should be taken into account that other applications for the sighted can offer a better UI and, therefore, also control speed related to these tasks. However, this is an application from a manufacturer of photovoltaic systems. Therefore, we can consider the given application as default and suitable for comparison. It should also be taken into account that a sighted layperson would be even slower using the VRM Victron application, and the same is true of the application for people with blindness.

The sighted technician stated that he uses Victron's VRM smartphone app most often in his work. However, he also has a laptop with a web application that offers the same functions. When using a laptop, he thinks that his work speed is 20 percent faster than that of a smartphone, but the disadvantage is that it is not as compact as a smartphone when used in a limited space during photovoltaic power assembly.

In the case of the solution presented in this article, it should be emphasized that it offers high variability for its users. People with blindness can set the menu structure to speed up their work, which the application for the sighted does not provide. For example, a tree menu can be adapted to the user's needs, so frequently used items can have a shorter path from the root to the leaves.

In addition to variability, the proposed solution is optimized so that the work of a person with blindness is as easy as possible and can be performed in different ways. For example, Task 4 can be accelerated. Task 4 in Table 1 is associated with the most challenging way of doing it: searching in a short text and editing it. This task can be faster if a person with blindness only writes text (avg. value = 9.98s, SD = 2.17s) whose syntax is checked or uses contextual help based on the history of previously entered values (avg. value = 5.33s, SD = 0.87s). Similarly, other applications designed specifically for zonal regulation can help sighted users. Still, even so, we believe that an administrator with blindness would be fast enough and competitive with a sighted one when using the proposed solution.

In conclusion, several assumptions can be stated that were supported by illustrative measurements. In the Introduction section, the mentioned articles [11], [12], [14], [15] present a solution using the UI for mobile phones with assistance for people with blindness, which is offered by the iOS and Android operating systems. These articles do not deal with work speed but with the ability of a person with blindness to work with a given solution intended for ordinary users. It can be assumed that even a blind user using Victron's VRM application for professional work with assistance for people with blindness will, at best, be as fast and rather slower than a sighted user of the application. It can be concluded that even the presented solution for people with blindness would be faster than if a person with blindness uses an application for a sighted user on a smartphone with assistance for people with blindness.

These illustrative measurements support our claim that the proposed UI principles allow designing UI that is sufficient for the professional work of people with blindness. For a better idea of the work speed of a person with blindness, see an illustrative video in Appendix.

C. CONCLUSIONS FROM LONG-TERM DEVELOPMENT AND TESTING

As mentioned in Section IV, the described energy subsystem has been developed for almost ten years. During that time, it has undergone several engineering cycles within the framework of DS research, in which various approaches to solving the UI were tested. We will briefly describe the reflection and main conclusions focused on the complexity of the UI and the possibilities of its control by a person with blindness.

The oldest and simplest UI focused on heating regulation (see Section IV-A.2) displays the necessary data, which are conveyed to the person with blindness by speech synthesis (A-V keys). Settings are adjusted by individual keys (e.g., keys 1-7 for individual days), with each key allowing a specific selection. Then person with blindness can, for example, increase the temperature by up/down arrows. This solution is similar to physical button control on a device, as the person with blindness does not select individual items in the menu using the cursor (e.g., arrow keys), which he or she could subsequently edit. It is a ''single screen with data'' where the editing mode can be started only with specific buttons.

The given UI solution for heating regulation does not provide complex functions (e.g., compared to zonal regulation or the photovoltaic power plant). Therefore, the given solution, which does not use a cursor to select an item in the menu, is sufficient. In addition, the work of a person with blindness speeds up with practice, as there is no need to click through menu items. In the case of the UI for zonal regulation (see Section IV-B.2), this interface already has the possibility to click between menu items by arrow keys. Such a solution is easier for a person with blindness to adopt.

In terms of recommendations for the designing of more robust UI providing more complex functions, it is appropriate to start from the principles presented for the UI for the photovoltaic power plant (see Section IV-C.2). Here, the UI is divided into two parts – one for the safe display of some basic data and the other one for more advanced data editing (i.e., separation of information from the possibility of actively changing settings). Main principles for creating a UI for people with blindness and their prioritization are given in Section VI.

VI. GENERALIZED PRINCIPLES OF USER INTERFACE DESIGN AND THEIR PRIORITIZATION

Based on the long-term testing of the UI presented in Section IV over several years and other experiences with the development of the UI, see Section V-C, we can present ten generalized principles for the design of an interface for IB energy systems for people with blindness. The presented principles can help UI designers to design UI for people with blindness, which will ensure their job competitiveness with sighted workers. These principles were ordered from most important (1) to least important (10) in the following text. This prioritization should be taken into account by designers when designing UIs.

The principle of browsing the tree menu is based on the unified HANIBAL UI used in the whole RUDO system, which was described in the introduction of Section IV. Therefore, it was not included in the principles below.

A. THE UI HAS A TEXTUAL AND SEMIGRAPHICAL CHARACTER

All information must be in text form. Textual information is directly accessible to a person with blindness via tactile output (Braille display) or a synthesizer. There is no need to additionally determine the status of the UI control, e.g. by hovering over the given element when controlling via a mobile phone. Unsuitable are, for example, UI controls that use graphic information and different types of range sliders. There is no need to interpret UI elements. Thanks to it, no interpretation errors are created, and there is no effect or feeling of slow information transfer at the output of the user interface.

B. UNIFIED UI SHOULD BE USED IN ALL IB SUBSYSTEMS

The UI is designed for people with blindness, and its control should be the same or very similar to the entire IB – including the use of a speech synthesizer and Braille display. It is an inappropriate and not recommended principle to make the original graphical user interface available using other software that will convert it in real-time into a form for people with blindness because, in this case, problems may arise during updates (incompatibility, new layout of UI controls). Two examples: (1) In the case of a UI change, a user with blindness must get used to the new work environment, which will have a negative impact on his performance. (2) Switching between different ways of controlling different IB subsystems can be confusing and cognitively exhausting for a person with blindness.

C. THE UI ALLOWS READING THE CONTENTS OF DIFFERENT PARTS OF THE WINDOW (PARALLEL READING OF DIFFERENT TEXT OUTPUTS)

An important element in the fast work of a person with blindness is the possibility of receiving information in several ways. A person with blindness chooses the currently fastest output or uses two methods in parallel (synthesizer and Braille display). Therefore, the special UI must first provide the most important information to the person with blindness, including the options for further selection. It is also very useful for a person with blindness if the synthesizer reads entire lines from beginning to end. This reading is important when correcting text or working in parallel in two parts of the window when the cursor of the synthesizer reads one part of the window and the cursor for the Braille display allows the user to read another part of the window.

D. THE UI OFFERS UP-TO-DATE HELP USING THE SPEECH SYNTHESIZER IN EVERY STATE OF THE APPLICATION

Up-to-date help refers to the operation of special navigation and selection functions that convey relevant information to the person with blindness. See, e.g. Figure 2, where the second column is the help text for each item.

E. THE UI PREFERS FOLLOWING NATURE OF DATA

The interface prefers:

(a) priority columnar nature of data,
(b) secondary tabular nature of data,
(c) in a critical case, also the nature of data outside of columns and tables.

The terminal for people with blindness should preferably have a column layout (a). It is ideal if its length does not exceed the number of monitor lines. From our experience, the virtual monitor should have the following dimensions: a width of 80 characters per line, as the connected Braille display has the same number of characters, and a height of 28 lines, see Figure 2. It is possible to access the items with the direction keys or directly through the first letters or numbers (keyboard shortcut). This approach is the most suitable in terms of simplicity and clarity. A long menu can be divided into sub-menus, creating a tree structure that is suitable for many cases but not for data to be perceived two-dimensionally.

Therefore, when it comes to more complicated data, where the column form cannot contain the required context, the tabular menu (b) is chosen. An example can be the measurement of energy consumption on one of several hot water stacks on a given floor. Administrator with blindness uses arrow keys in the sense of two dimensions – vertical and horizontal.

If the data cannot simply be offered in the above forms, it can be displayed differently (c). An example is the IB population census, which comprises a range of data. Such a list is very extensive, and therefore, it is not advisable to go through it and search it by individual items but use the text string search.

If the UI designer chooses options (a) or (b), the person with blindness will, over time, create a cognitive model of the individual menus and quickly work with them. This is not the case with option (c).

F. THE UI ENABLES OBTAINING OF INFORMATION WITHOUT THE POSSIBILITY OF USER CHANGES IN THE DATA

The UI's combined input/output windows can cause errors to be introduced into the system when reading information. This is particularly dangerous for critical systems. Therefore, it is advisable that when reading, the user cannot inadvertently change the parameters of the energy system. In the case of exclusive reading, the interface always disables the input (possibility of direct editing of energy system parameters) to eliminate errors.

G. THE UI ALLOWS CHANGES TO DATA WITH FULL USER FEEDBACK USING THE SPEECH SYNTHESIZER

With the input enabled, when a user with blindness changes energy system parameters, the UI comments on the changes. In this case, it is advisable to choose a longer form of communication through the synthesizer, so the user is completely confident that the changed settings are correct.

H. THE UI OFFERS UNIFIED EDITING TOOL FOR TEXTS

Any writing or processing of texts is done only in text mode and using unified editing tool (one tool for all subsystems of IB). This enables the fastest form of writing and encourages skill with a single editing tool adapted to the needs of people with blindness.

I. THE UI OFFERS A SINGLE RETURN KEY IN EVERY STATE OF THE APPLICATION AND THE SAME THROUGHOUT THE SYSTEM (UNIFIED UI) WITHOUT MAKING ANY CHANGES

The user's need to return to the previous window of the UI without making changes is an essential function for the fast work of a user with blindness. This key should be universal for the entire UI (or a group of keys for quickly returning to higher menu levels). Otherwise, the user's work could slow down, or errors could occur.

J. THE UI ALLOWS CHANGES TO BE MADE AND THEN SAVED TO DISK IN A SECOND STEP, USING THE SAME KEYS THROUGHOUT THE SYSTEM FOR SAVING TO DISK AND RELOADING

When changing the settings (e.g. overwriting a value), the values stored on the disk do not change immediately. Permanent changes can only be made by choosing the particular function to save to disk. The above also applies to the functions of loading data from disk or backing up data. The functions for saving to disk, reloading, and backing up have the same call form throughout the IB system (always the same keys in all editing menus).

With the priorities mentioned above, it should be emphasized that this prioritization is not intended for the use of ordinary computers by people with blindness. It is about the administration of energy systems in IB, where the emphasis is placed on safety, speed and minimization of errors. With this in mind, the commonly used design approaches for UI for computer control in common computer systems are insufficient.

VII. DISCUSSION

This article presented a UI for people with blindness to administrate the energy subsystem in an IB based on many years of continuous development of the RUDO system. This solution was deployed and evaluated in an IB equipped with an energy subsystem that allows the use of gas heating, photovoltaics, zonal regulation, gas water heating, photovoltaic water heating, solid fuel space heating, solid fuel water heating, air conditioning and additional heat pump space heating. The assistance environment and UI for people with blindness is built on the basis of the RUDO AmI system. Based on the presented solution and experiences from its long-term development and testing, principles of UI design were generalized, which can be used by a designer in a similar problem context.

The main contributions of the presented solution are twofold: scientific and practical. From a scientific point of view, the main contribution is the presentation of a useful solution to the problem context of people with blindness. This means a contribution to the knowledge base of proposed solutions in the field of UI for people with blindness [26], [55]. The gradual development from a simple interface based on push-button control to a more complex approach to the safe administration of the energy subsystem of an IB was presented in Section V-C. Generalized principles for creating a UI for people with blindness for IB energy systems are introduced in Section VI in more detail.

The proposed solution and the related UI design principles solve the problem context associated with the work activity, where speed, accuracy (or small error rate of settings) and reliability are necessary. The mentioned problems are not solved very well by older UI solutions [11], [12], [14], [15], which are suitable for personal use (e.g., household) but not very suitable for work activities, where competitiveness with a sighted worker must also be ensured. More complex setups can be slow as a person with blindness does not use other aids besides the smartphone, the smartphone is less reliable (e.g. dead battery, losing orientation in a complicated menu), and errors can occur when recognizing speech or clicking on a touchscreen smartphone display [16], [17], [19].

From a practical point of view, this article offers a summary of best practices in UI implementation for people with blindness, emphasizing the control of energy systems of IB. The proposed UI principles enable the solution of more complex tasks, reduce the possibility of incorrect settings and ensure a competitive speed with a sighted worker. Companies worldwide can be inspired by the proposed solution when developing their solutions for users with blindness. According to our findings, this is the first proposal of this kind. Another practical benefit is increasing the independence of people with blindness when living in IB and their administration. This is a socially oriented contribution of this research; see also articles on increasing social inclusion [3], [56], [57]. From the point of view of the future development of the information society, another possible future benefit is the development of work opportunities for people with blindness. We discuss this in more detail in Section VII-B.

With current building energy systems, more and more emphasis are placed on ecology in terms of the types of energy sources used and their savings. The administrator with blindness must be able to set time schedules in the thermal zones, have an overview of the current consumption, and the possibility of choosing an energy source so that the operation is the most acceptable from an ecological point of view. The described prototype enables such activity for an administrator with blindness. However, its shortcoming is that it does not contain information on pollution levels when using individual energy sources. It also does not include an adaptive habitability mechanism of zones. The administrator must orient himself in this area and choose the optimal solution.

High energy requirements usually require concessions in ecology. The discussed energy system points to using such a type of energy input, which simultaneously creates a problematic situation for a person. In this context, we use the term Ecological Triple Sun or Eco3S, where the "3S" refer to:

- S1 – when the sun is warm, let it power the air conditioning as well;
- S2 – when the sun makes the grass grow, let it also power the robotic lawnmower;
- S3 – when the sun dries the soil, let it supply energy to the domestic water plant connected to the well that irrigates the soil.

The essential meaning of the term Eco3S does not lie in the fact that the sun powers three types of appliances. Excessive solar radiation, in this case, causes three kinds of problems that can be eliminated by the same solar energy, which is in excess at a given time. Such a concept of the energy system saves energy from other sources, thus actively contributing to current trends in nature protection.

A. GUIDELINES AND STANDARDS FOR ENSURING USER ACCESSIBILITY FOR PEOPLE WITH BLINDNESS

Accessible design for people with blindness is indeed supported by standardization in ICT but to a lesser extent than for the numerically more significant group of partially sighted people. International manufacturers of ICT solutions (e.g. Apple, Google, Microsoft) try to ensure the accessibility of their solutions for visually impaired people, while in addition to standards, they also build on their own or good practice approaches, see [58]. The International Organization for Standardization (ISO) and the World Wide Web Consortium (W3C) provide several general standards and guidelines to support information acquisition by people with blindness. An example can be ISO 19029:2016 for auditory guiding signals in public facilities or ISO 19028:2016 for display methods of tactile guide maps. Other standards deal with making available information that is not directly available to disadvantaged people. An example can be ISO/IEC TS 20071-15:2017 focused on scanning visual information for presentation as text, ISO/IEC TS 20071-25:2017 focused on audio presentation of text in videos, ISO/IEC TS 20071-21:2015 focused on audio descriptions, or ISO/IEC 20071-5:2022 presents accessible user interfaces for accessibility settings on information devices.

In terms of accessibility of information content on computers and smartphones, the W3C Web Content Accessibility Guidelines (WCAG) [59] or ISO/IEC 40500:2012 are mentioned in the scientific literature [16], whose principles can also be applied outside of web content, as web control elements tend to be similar to smartphone operating systems control elements [60]. In the case of people with low vision, it can be found a more detailed document W3C Accessibility Requirements for People with Low Vision [61], which ensures the accessibility of electronic content, tools, and technologies for people with low vision. The WCAG standard offers four broad principles [59]:

- Perceivability – Information and user interface components must be presentable to users in ways they can perceive.
- Operability – User interface components and navigation must be operable.
- Understandability – Information and the operation of user interface must be understandable.
- Robustness – Content must be robust enough that it can be interpreted reliably by a wide variety of user agents, including assistive technologies.

The presented UI for people with blindness fulfils these four principles only in relation to users with blindness. This solution is only aimed at the work of a person with blindness on a personal computer; it is not intended or suitable for the work of people with low vision or sighted people, and it is not intended for smartphones (but it can be installed on a notebook). To support a user with blindness, the proposed solution uses commonly available hardware aids (e.g. Braille display, keyboard) and special software aids assisting work (e.g. HANIBAL unified UI with speech synthesis and notifications), ensuring access to information and enabling easy energy system administration.

Although standardization offers best practice approaches, there is still room for improvement even in the case of established standards, as mentioned in [16] and [60]. This applies especially to users with blindness.

B. POSSIBILITIES OF FUTURE DEVELOPMENT OF EMPLOYMENT OPPORTUNITIES FOR PEOPLE WITH BLINDNESS

Employment is a difficult problem for people with blindness [62], [63]. They often find only occasional and short-term jobs. If they have a permanent job, losing it threatens to destroy their social status, especially in developing countries. In the Central European region, workers with blindness hold, for example, the following jobs that require special primary or secondary education for people with blindness and partially sighted [64]:

- masseur,
- translator and interpreter,
- sound designer,
- worker in information technology,
- telemarketing worker,
- operator and dispatcher.

Before the digitization of telephone exchanges, people with blindness often worked as telephone operators in switchboards, of which there used to be a large number. On the other hand, currently, people with blindness are very often employed as masseurs. In the field of computer and information technologies, people with blindness have been employed since the 1960s, most often as programmers [65], [66], [67], [68].

With the development of remote monitoring and administration come new work opportunities for people with blindness. An example can be the development of IB and their administration, where these people can act as administrators. This article compared the speed of work of an administrator with blindness with that of a sighted technician, considering the speed of the person with blindness to be fully competitive with the sighted.

The numbers of such buildings are expected to proliferate in the coming years [10]. Despite all the automation, active human intervention will be required in many areas – for example, in the area of building energy systems. Monitoring and administration of large complexes of IB is also an opportunity for the employment of people with blindness on the labour market. During remote operation, the administrator only adjusts the settings, checks the functionality of the operation, and in the event of a malfunction, specifies the problem and calls technical support. Remote access also solves the problem of going to work, which can sometimes be very problematic for a person with blindness. In this context, it is worth noting that the remote access is also a new option for people with other health disabilities, such as deaf people or people with a health physical disability of the locomotor system.

At the same time, for all differently disadvantaged people, additional support for their work activities is essential, for example, with the use of ambient assisted environments or SmE. This brings us back to the support of AmI systems in IB, which would facilitate the stay of disadvantaged people in these buildings. For this purpose, it is important to introduce standards connected with SmE that would also require relevant assistance services for disadvantaged people from the manufacturers of tools or whole environments or systems. An example can be the Active Assisted Living Program supported by the European Commission since 2008 focused on a ‘‘European framework that supports the development of standardised solutions and facilitates their adaptation to local, regional and national levels to account for varying social preferences and regulatory requirements’’ [69]. This technological shift and the associated creation of new work roles will enable increased social and work inclusion of people with blindness (and disadvantaged people generally) in society.

C. POSSIBILITIES OF FUTURE TECHNOLOGICAL DEVELOPMENT OF THE PROPOSED SOLUTION

Essential for the employment of people with blindness is their competitiveness against sighted workers, especially with regard to the speed of work activities. Although there are several proposed UI for people with blindness [11], [12], [14], [15], such solutions are of limited use if we consider them as part of a working tool for professional work. These solutions are intended for a different problem context, most often the household. However, our main goal of the presented UI solution and UI design principles is in professional work and work activities related to remote control. For this purpose, an administrator with blindness accesses individual functions via a console on a computer equipped with additional aids. In the future, we plan to provide access to the modules of the RUDO system via a smartphone, but from the point of view of ensuring speed, accuracy and reliability in professional work, this method of control should be complementary.

VIII. CONCLUSION

The article presents the results of long-term applied research in the field of UI design for people with blindness (2014–2023), thanks to which people with blindness would be competitive with sighted workers in the selected work type. Therefore, contribution of this article is technologically and socially oriented.

The main scientific contribution of this article is to broaden the knowledge base with the principles of more complicated UI design for people with blindness useful in professional work, where they must be competitive with the sighted workers. The main practical contribution of this article is to provide recommendations for designing UI for people with blindness, emphasizing the speed, reliability, and accuracy of control. Furthermore, the article discusses new job opportunities for people with blindness in connection with the remote administration of IB, the number of which will increase.

Ensuring the competitiveness of workers with blindness with sighted workers in computer-oriented areas is not a topic that has yet been addressed in the scientific literature. Ensuring work competitiveness is closely related to developing new and complex ambient technologies or SmE, but such research is very expensive, and the target group of users is not commercially interesting enough for research in this area to be carried out on a larger scale. Therefore, most researchers currently focus on single-purpose aids or solutions rather than large-scale intelligent systems implemented in buildings. Available articles only deal with increasing (and not ensuring) competitiveness or enabling new abilities for people with blindness.

This also applies to the area of smart homes, which is the closest to our problem context, and relevant articles [11], [12], [13], [14], [15] can be found. Aspects such as speed, accuracy (or small error rate of settings) and solution reliability are not important in these articles because what is important is that a person with blindness is able to perform a particular activity at all. This is also confirmed by the literature review in Section I, where the proposed solutions for the administration of a smart home most often use smartphones with assistance for people with blindness, which is offered by the iOS and Android operating systems. However, people with blindness themselves complain about the shortcomings of smartphone control, where, for example, speed and accuracy decrease with increasing complexity of the controlled application (or the range of edited text). In addition, solution reliability can change (e.g. signal fluctuations, battery discharge, touchscreen use). On the other hand, using a personal computer brings advantages in terms of speed and accuracy of control. For example, other aids such as input/output devices can be connected, which brings to the work of people with blindness the certainty of control (keys versus touchscreen) and the possibility of parallel reception of information. Our proposed solution for professional work also goes in this direction.

Besides the solution's usefulness in the presented problem context, the proposed UI is relevant for all people with blindness, thanks to different control approaches. This can be mentioned as an important benefit. The UI has three possible approaches how to work with it (see video in Appendix): only synthesizer without Braille (using only arrows and enter); Braille only without synthesizer (Braille for reading and writing); parallel use of synthesizer and Braille. Such a solution is effective for the entire social category of people with blindness and is therefore not intended only for the significantly smaller social subcategory of Braille-literate people [70]. Other benefits of this research include the usability of the presented outputs in other domain areas than intelligent buildings, or increasing the independence of people with blindness when living in IB.

Unfortunately, even our solution and related research have weaknesses or limitations in addition to their benefits. The weakness of the presented research is the evaluation of the solution carried out on a small sample of people with blindness. Although a similarly small number of participants is used in other studies focused on people with blindness [45], [46], [47], evaluating the solution on a higher number of participants would be more appropriate. In our case, this is not possible, and the reasons for this limitation of our research are discussed in Section III. Another weakness is the narrow focus of research on intelligent buildings and their remote administration. Nevertheless, the authors believe that the advantages and benefits of this article for scholars and practitioners outweigh its limitations.

APPENDIX

ILLUSTRATIVE VIDEO PRESENTS THE WORK OF A PERSON WITH BLINDNESS USING HANIBAL UNIFIED UI

The video is part of the online version of this article and is available in IEEE Xplore Digital Library. The video aims to show the fast work of a user with blindness.

REFERENCES

[1] Y. Klopota, O. Klopota, and V. Gudonis, "Socio-psychological training for readiness for interaction in professional activity of employers and specialists with blindness," *Pedagogika*, vol. 134, no. 2, pp. 224–236, Oct. 2019, doi: 10.15823/p.2019.134.14.

[2] A. Armaly, P. Rodeghero, and C. McMillan, "AudioHighlight: Code skimming for blind programmers," in *Proc. IEEE Int. Conf. Softw. Maintenance Evol. (ICSME)*, Sep. 2018, pp. 206–216, doi: 10.1109/ICSME.2018.00030.

[3] I. D. Shadrick, "Social and community inclusion of people with blindness, low vision, and deafblindness," *J. Appl. Rehabil. Counseling*, vol. 51, no. 4, pp. 290–294, Dec. 2020, doi: 10.1891/jarc-d-20-00026.

[4] M. Hudec and Z. Smutny, "Ambient intelligence system enabling people with blindness to develop electrotechnical components and their drivers," *IEEE Access*, vol. 10, pp. 8539–8565, 2022, doi: 10.1109/ACCESS.2022.3144109.

[5] V. Dyzel, R. Oosterom-Calo, M. Worm, and P. S. Sterkenburg, "Assistive technology to promote communication and social interaction for people with deafblindness: A systematic review," *Frontiers Educ.*, vol. 5, Sep. 2020, Art. no. 578389, doi: 10.3389/feduc.2020.578389.

[6] M. Hudec and Z. Smutny, "Advanced scene recognition system for blind people in household: The use of notification sounds in spatial and social context of blind people," in *Proc. 2nd Int. Conf. Comput. Sci. Appl. Eng.*, Oct. 2018, pp. 1–5, doi: 10.1145/3207677.3278101.

[7] M. Hudec and Z. Smutny, "RUDO: A home ambient intelligence system for blind people," *Sensors*, vol. 17, no. 8, Aug. 2017, Art. no. 1926, doi: 10.3390/s17081926.

[8] M. Darwish, E. Senn, C. Lohr, and Y. Kermarrec, "A comparison between ambient assisted living systems," in *Smart Homes and Health Telematics* (Lecture Notes in Computer Science), vol. 8456, C. Bodine, S. Helal, T. Gu, and M. Mokhtari, Eds., Cham, Switzerland: Springer, 2015, doi: 10.1007/978-3-319-14424-5_26.

[9] G. Qiao, "Intelligent building with multi-energy system planning method considering energy supply reliability," *J. Interconnection Netw.*, vol. 22, Jun. 2022, Art. no. 2146007, doi: 10.1142/s0219265921460075.

[10] Juniper Research. (2022). *Smart Building Deployments to Exceed 115 Million Globally in 2026, With Efficiency Savings Driving Demand*. [Online]. Available: https://www.juniperresearch.com/pressreleases/smart-building-deployments-to-exceed-115mn

[11] G. D. Z. Villegas, V. E. B. García, and R. N. E. Chávez, "ROSmotic: A scalable smart home for blind people controlled with an app," in *Proc. Int. Conf. Comput. Sci. Comput. Intell. (CSCI)*, Dec. 2017, pp. 1365–1370, doi: 10.1109/CSCI.2017.238.

[12] S. Rizvi, I. Sohail, M. M. Saleem, A. Irtaza, M. Zafar, and M. Syed, "A smart home appliances power management system for handicapped, elder and blind people," in *Proc. 4th Int. Conf. Comput. Inf. Sci. (ICCOINS)*, Aug. 2018, pp. 1–4, doi: 10.1109/ICCOINS.2018.8510595.

[13] P. Akkapusit and I.-Y. Ko, "Task-oriented approach to guide visually impaired people during smart device usage," in *Proc. IEEE Int. Conf. Big Data Smart Comput. (BigComp)*, Jan. 2021, pp. 28–35, doi: 10.1109/BigComp51126.2021.00015.

[14] M. Buzzi, F. Gennai, and B. Leporini, "How blind people can manage a remote control system: A case study," in *Smart Objects and Technologies for Social Good*. Cham, Switzerland: Springer, 2018, pp. 71–81, doi: 10.1007/978-3-319-76111-4_8.

[15] H.-D. Jeong, S.-K. Ye, J. Lim, I. You, and W. Hyun, "A computer remote control system based on speech recognition technologies of mobile devices and wireless communication technologies," *Comput. Sci. Inf. Syst.*, vol. 11, no. 3, pp. 1001–1016, 2014, doi: 10.2298/csis130915061j.

[16] M. Jain, N. Diwakar, and M. Swaminathan, "Smartphone usage by expert blind users," in *Proc. CHI Conf. Hum. Factors Comput. Syst.*, May 2021, pp. 1–15, doi: 10.1145/3411764.3445074.

[17] A. Rodrigues, H. Nicolau, K. Montague, J. Guerreiro, and T. Guerreiro, "Open challenges of blind people using smartphones," *Int. J. Hum.-Comput. Interact.*, vol. 36, no. 17, pp. 1605–1622, Oct. 2020, doi: 10.1080/10447318.2020.1768672.

[18] S. Azenkot and N. B. Lee, "Exploring the use of speech input by blind people on mobile devices," in *Proc. 15th Int. ACM SIGACCESS Conf. Comput. Accessibility*, Oct. 2013, pp. 1–8.

[19] A. Khan and S. Khusro, "An insight into smartphone-based assistive solutions for visually impaired and blind people: Issues, challenges and opportunities," *Universal Access Inf. Soc.*, vol. 20, no. 2, pp. 265–298, 2020, doi: 10.1007/s10209-020-00733-8.

[20] C. H. Abraham, B. Boadi-Kusi, E. K. A. Morny, and P. Agyekum, "Smartphone usage among people living with severe visual impairment and blindness," *Assistive Technol.*, vol. 34, no. 5, pp. 611–618, Sep. 2022, doi: 10.1080/10400435.2021.1907485.

[21] B. Rudinger, "Bridge or barrier: Technology, well-being, and blindness," *Disab. Rehabil., Assistive Technol.*, vol. 18, no. 6, pp. 904–912, Aug. 2023, doi: 10.1080/17483107.2021.1937342.

[22] S. Millar, *Reading by Touch*. Evanston, IL, USA: Routledge, 2003.

[23] A. Khan and S. Khusro, "A mechanism for blind-friendly user interface adaptation of mobile apps: A case study for improving the user experience of the blind people," *J. Ambient Intell. Humanized Comput.*, vol. 13, no. 5, pp. 2841–2871, May 2022, doi: 10.1007/s12652-021-03393-5.

[24] A. Frattari and M. Dalprà, "The intelligent buildings: The case study of the residence for elderly people," *Int. J. Housing Sci. Appl.*, vol. 27, no. 4, pp. 259–267, 2003.

[25] C. Ma, O. Guerra-Santin, and M. Mohammadi, "Smart home modification design strategies for ageing in place: A systematic review," *J. Housing Built Environ.*, vol. 37, no. 2, pp. 625–651, Jun. 2022, doi: 10.1007/s10901-021-09888-z.

[26] R. J. Wieringa, *Design Science Methodology for Information Systems and Software Engineering*. Berlin, Germany: Springer, 2014.

[27] J. Mariani, *Language and Speech Processing*. London, U.K.: Wiley, 2009.

[28] Y. Shimomura, E. T. Hvannberg, and H. Hafsteinsson, "Accessibility of audio and tactile interfaces for young blind people performing everyday tasks," *Universal Access Inf. Soc.*, vol. 9, no. 4, pp. 297–310, Nov. 2010, doi: 10.1007/s10209-009-0183-y.

[29] P. L. Emiliani and C. Stephanidis, "Universal access to ambient intelligence environments: Opportunities and challenges for people with disabilities," *IBM Syst. J.*, vol. 44, no. 3, pp. 605–618, 2005.

[30] A. Dresch, D. P. Lacerda, and J. Antunes, *Design Science Research: A Method for Science and Technology Advancement*. New York, NY, USA: Springer, 2015.

[31] A. Hevner and S. Chatterjee, "Design science research in information systems," in *Design Research in Information Systems* (Integrated Series in Information Systems), vol. 22. Boston, MA, USA: Springer, 2010, doi: 10.1007/978-1-4419-5653-8_2.

[32] M. Hudec. (2024). *Log of Updates*. [Online]. Available: https://systemrows.eu/drive/verzie.txt

[33] R. Wieringa and A. Morali, "Technical action research as a validation method in information systems design science," in *Design Science Research in Information Systems. Advances in Theory and Practice*. Berlin, Germany: Springer, pp. 220–238, doi: 10.1007/978-3-642-29863-9_17.

[34] T. Götzelmann and J. Kreimeier, "Optimization of navigation considerations of people with visual impairments through ambient intelligence: A case study," in *Proc. 13th ACM Int. Conf. Pervasive Technol. Related Assistive Environ.*, 2020, pp. 1–6, doi: 10.1145/3389189.3398009.

[35] P. Bate and G. Robert, *Bringing User Experience to Healthcare Improvement: The Concepts, Methods and Practices of Experience-Based Design*. London, U.K.: Radcliffe Publishing, 2007.

[36] A. Cherns, "Principles of sociotechnical design revisted," *Hum. Relations*, vol. 40, no. 3, pp. 153–161, Mar. 1987, doi: 10.1177/001872678704000303.

[37] T. Greenhalgh, C. Jackson, S. Shaw, and T. Janamian, "Achieving research impact through co-creation in community-based health services: Literature review and case study," *Milbank Quart.*, vol. 94, no. 2, pp. 392–429, Jun. 2016, doi: 10.1111/1468-0009.12197.

[38] M. Choras, R. Kozik, S. D'Antonio, G. Iannello, A. Jedlitschka, K. Miesenberger, L. Vollero, and A. Wołoszczuk, "Innovative solutions for inclusion of totally blind people," in *Ambient Assisted Living*, N. M. Garcia and J. J. P. C. Rodrigues, Eds., Boca Raton, FL, USA: CRC Press, 2015, pp. 401–434.

[39] M. Georgsson, N. Staggers, E. Årsand, and A. Kushniruk, "Employing a user-centered cognitive walkthrough to evaluate a mHealth diabetes self-management application: A case study and beginning method validation," *J. Biomed. Informat.*, vol. 91, Mar. 2019, Art. no. 103110, doi: 10.1016/j.jbi.2019.103110.

[40] Y. Liu, A.-L. Osvalder, and S. Dahlman, "Exploring user background settings in cognitive walkthrough evaluation of medical prototype interfaces: A case study," *Int. J. Ind. Ergonom.*, vol. 35, no. 4, pp. 379–390, Apr. 2005, doi: 10.1016/j.ergon.2004.10.004.

[41] WHO. *Visual Impairment and Blindness*. Accessed: 2023. [Online]. Available: https://www.who.int/en/news-room/fact-sheets/detail/blindness-and-visual-impairment

[42] E. Liljegren and A.-L. Osvalder, "Cognitive engineering methods as usability evaluation tools for medical equipment," *Int. J. Ind. Ergonom.*, vol. 34, no. 1, pp. 49–62, Jul. 2004, doi: 10.1016/j.ergon.2004.01.008.

[43] F. Arshad, N. Nnamoko, J. Wilson, B. Roy, and M. Taylor, ''Improving healthcare system usability without real users,'' *Int. J. Healthcare Inf. Syst. Informat.*, vol. 10, no. 1, pp. 67–81, Jan. 2015, doi: 10.4018/ijhisi.2015010104.

[44] H. M. Salman, A. Kamaruddin, L. S. Affendey, E. I. Mansor, R. W. O. K. Rahmat, and A. H. Jantan, ''Using heuristic evaluation to improve the usability of electronic medical record (EMR) mobile interface of the cardiothoracic surgery and anesthesia system (CSAS),'' *Jurnal Teknologi*, vol. 77, no. 7, pp. 91–96, Nov. 2015, doi: 10.11113/jt.v77.6254.

[45] B. Gamecho, R. Miñón, A. Aizpurua, I. Cearreta, M. Arrue, N. Garay-Vitoria, and J. Abascal, ''Automatic generation of tailored accessible user interfaces for ubiquitous services,'' *IEEE Trans. Human-Mach. Syst.*, vol. 45, no. 5, pp. 612–623, Oct. 2015, doi: 10.1109/THMS.2014.2384452.

[46] O. B. Kaul, M. Rohs, M. Mogalle, and B. Simon, ''Around-the-head tactile system for supporting micro navigation of people with visual impairments,'' *ACM Trans. Comput.-Hum. Interact.*, vol. 28, no. 4, pp. 1–35, Aug. 2021, doi: 10.1145/3458021.

[47] M. Al Zayer, S. Tregillus, J. Bhandari, D. Feil-Seifer, and E. Folmer, ''Exploring the use of a drone to guide blind runners,'' in *Proc. 18th Int. ACM SIGACCESS Conf. Comput. Accessibility*, Oct. 2016, pp. 263–264, doi: 10.1145/2982142.2982204.

[48] C. Lewis, P. G. Polson, C. Wharton, and J. Rieman, ''Testing a walkthrough methodology for theory-based design of walk-up-and-use interfaces,'' in *Proc. SIGCHI Conf. Hum. Factors Comput. Syst. Empowering People (CHI)*, 1990, pp. 235–242, doi: 10.1145/97243.97279.

[49] P. G. Polson and C. H. Lewis, ''Theory-based design for easily learned interfaces,'' *Hum.-Comput. Interact.*, vol. 5, nos. 2–3, pp. 191–220, Jun. 1990, doi: 10.1080/07370024.1990.9667154.

[50] R. D. A. Rangni and A. B. D. Costa, ''Altas habilidades/superdotação e deficiência visual: Duplicidade de necessidades educacionais especiais,'' *Revista Ibero-Americana de Estudos em Educação*, vol. 11, no. 4, pp. 1979–1993, Dec. 2016, doi: 10.21723/riaee.v11.n4.7387.

[51] S. Schmidt, C. Tinti, M. Fantino, I. C. Mammarella, and C. Cornoldi, ''Spatial representations in blind people: The role of strategies and mobility skills,'' *Acta Psychol.*, vol. 142, no. 1, pp. 43–50, Jan. 2013, doi: 10.1016/j.actpsy.2012.11.010.

[52] R. W. V. Boven, R. H. Hamilton, T. Kauffman, J. P. Keenan, and A. Pascual-Leone, ''Tactile spatial resolution in blind Braille readers,'' *Neurology*, vol. 54, no. 12, pp. 2230–2236, Jun. 2000, doi: 10.1212/wnl.54.12.2230.

[53] T. Beer, T. Anodenko, and A. Sears, ''A pair of techniques for effective interface evaluation: Cognitive walkthroughs and think-aloud evaluations,'' in *Proc. Hum. Factors Ergonom. Soc. Annu. Meeting*, 1997, vol. 41, no. 1, pp. 380–384, doi: 10.1177/107118139704100184.

[54] M. H. Blackmon, P. G. Polson, M. Kitajima, and C. Lewis, ''Cognitive walkthrough for the web,'' in *Proc. SIGCHI Conf. Hum. Factors Comput. Syst.*, Apr. 2002, pp. 463–470, doi: 10.1145/503376.503459.

[55] V. Hubka and W. E. Eder, *Design Science: Introduction to the Needs, Scope and Organization of Engineering Design Knowledge*. London, U.K.: Springer, 1996.

[56] F. Fuentes, A. Moreno, and F. Díez, ''The usability of ICTs in people with visual disabilities: A challenge in Spain,'' *Int. J. Environ. Res. Public Health*, vol. 19, no. 17, p. 10782, Aug. 2022, doi: 10.3390/ijerph191710782.

[57] M. D. P. Oviedo-Cáceres, K. N. Arias-Pineda, M. D. R. Yepes-Camacho, P. Montoya Falla, and L. Guisasola Valencia, '''My disability does not measure me: It is a way of living and being in the world' meanings of social inclusion from the perspective of people with visual impairment,'' *Brit. J. Vis. Impairment*, vol. 41, no. 1, pp. 181–194, Jan. 2023, doi: 10.1177/02646196211036403.

[58] AbilityNet. (2023). *Vision Impairment and Computing*. [Online]. Available: https://abilitynet.org.uk/factsheets/vision-impairment-and-computing

[59] A. Kirkpatrick, J. Connor, A. Campbell, and M. Cooper. (2023). *Web Content Accessibility Guidelines (WCAG) 2.1*. [Online]. Available: https://www.w3.org/TR/WCAG21/

[60] N. Alajarmeh, ''The extent of mobile accessibility coverage in WCAG 2.1: Sufficiency of success criteria and appropriateness of relevant conformance levels pertaining to accessibility problems encountered by users who are visually impaired,'' *Universal Access Inf. Soc.*, vol. 21, no. 2, pp. 507–532, Jun. 2022, doi: 10.1007/s10209-020-00785-w.

[61] J. Allan, A. Kirkpatrick, and S. L. Henry. (2016). *Accessibility Requirements for People With Low Vision*. [Online]. Available: http://www.w3.org/TR/low-vision-needs/

[62] K. E. Wolffe, R. T. Roessler, and K. F. Schriner, ''Employment concerns of people with blindness or visual impairments,'' *J. Vis. Impairment Blindness*, vol. 86, no. 4, pp. 185–187, Apr. 1992, doi: 10.1177/0145482x9208600407.

[63] M. A. Zapata, ''Disability affirmation predicts employment among adults with visual impairment and blindness,'' *Rehabil. Counseling Bull.*, vol. 65, no. 2, pp. 120–128, Jan. 2022, doi: 10.1177/0034355220957107.

[64] Praceprozp. (2019). *Zrakové Postižení*. [Online]. Available: https://praceprozp.cz/zrakove-postizeni/

[65] N. M. Al-Ratta and H. S. Al-Khalifa, ''Teaching programming for blinds: A review,'' in *Proc. 4th Int. Conf. Inf. Commun. Technol. Accessibility (ICTA)*, Oct. 2013, pp. 1–5, doi: 10.1109/ICTA.2013.6815285.

[66] P. W. F. Coleman, ''Status report on work for the British blind programmer,'' *ACM SIGCAPH Comput. Physically Handicapped*, vol. 3, no. 9, pp. 10–13, Oct. 1973, doi: 10.1145/964151.964153.

[67] J. DeRuyter, ''The training of blind computer programmers,'' *J. Vis. Impairment Blindness*, vol. 62, no. 1, pp. 7–24, Jan. 1968, doi: 10.1177/0145482x6806200102.

[68] T. D. Sterling, M. Lichstein, F. Scarpino, and D. Stuebing, ''Professional computer work for the blind,'' *Commun. ACM*, vol. 7, no. 4, pp. 228–230, Apr. 1964, doi: 10.1145/364005.364054.

[69] AAL. (2023). *Ageing Well in a Digital World*. [Online]. Available: http://www.aal-europe.eu/about/

[70] R. M. Sheffield, F. M. D'Andrea, V. Morash, and S. Chatfield, ''How many Braille readers? Policy, politics, and perception,'' *J. Vis. Impairment Blindness*, vol. 116, no. 1, pp. 14–25, Jan. 2022, doi: 10.1177/0145482x211071125.

MILAN HUDEC received the M.Sc. degree in cybernetics and informatics from the Faculty of Mathematics and Physics, Charles University, Czech Republic, in 1994, and the Ph.D. degree in information systems from the Faculty of Science, Pavol Jozef Šafárik University, Košice, Slovakia, in 2004. He is currently a Researcher with Matej Bel University, Banská Bystrica, Slovakia. He is a person with blindness. His main current research interests include the development of the ambient intelligence system RUDO and the synthesis and recognition of fluent speech, neural networks, and genetic algorithms in solutions for people with blindness.

ZDENEK SMUTNY received the B.Sc. degree in information systems from the Faculty of Science, Jan Evangelista Purkynš University, Ústí nad Labem, Czech Republic, in 2008, and the M.S.E. degree in cognitive informatics and the Ph.D. degree in applied informatics from the Faculty of Informatics and Statistics, Prague University of Economics and Business (formerly the University of Economics), Prague, Czech Republic, in 2010 and 2016, respectively. He is currently an Associate Professor of applied informatics with Prague University of Economics and Business. He is also the research and development project manager focused on intelligent transportation systems and services. He has 20 years of experience in research and development projects and has participated in more than 20 national or international research projects. His current research interests include social informatics, intelligent transportation systems and services, and advancement in informatics methodology.

• • •