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Ambient Intelligence System Enabling People With Blindness to Develop Electrotechnical Components and Their Drivers

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ABSTRACT Along with the development of new assistive technologies, including ambient intelligence (AmI) environments, new job opportunities are created for people with blindness or visual impairment. Whereas research on software development for people with blindness has been conducted since the 1960s, the design and development of electrotechnical equipment still lacks any way to compensate for the disability which would enable people with blindness to perform even the activities pertaining to this field. This article aims to introduce these new technological procedures enabling the compensation of the disability of people with blindness when designing and developing electrotechnical components (or prototypes) and their drivers by using the AmI system RUDO modules and other tools. This includes the modules enabling measuring electrotechnical quantities, tracing of oscilloscope curves, and ensuring a unified user interface for programming and operation of the devices connected. Other approaches are introduced herein that focused on the production of mechanical components for device construction. This article also contains an illustrative video of practical use of these technological procedures by a person with blindness. To assess the usability of the designed technological procedures to the work of a designer with blindness and one without visual impairment, the cognitive walkthrough method was used. The main contribution of this article is to broaden the knowledge base by the principles of involving people with blindness in the development and construction of electrotechnical components (or prototypes). These new possibilities can be used practically, for instance, in computer education, which can offer new curricula for visually impaired students and focused on more practical issues where hardware and software approaches meet.

INDEX TERMS Computer engineering, hardware, software driver, oscilloscope, multimeter, drilling and cutting, visually impaired people, education, informatics, ambient assisted working.

I. INTRODUCTION

Over the past decade, the popularity of assistive technologies [1], [2], concerning researchers as well as companies in the field of commercialisation of innovative solutions [3], has increased significantly. “Global disabled and elderly assistive technologies market was valued at \$22,466 million in 2016 and is anticipated to reach \$37,610 million by 2023” [4]. In addition to single-purpose tools, current technological approaches involving the assistance to peo-

ple with disabilities and the elderly also include ambient intelligence (AmI) environments or smart environments (SmE) [5]–[7]. The development of these systems is supported by research programmes of the European Commission [8], especially due to ageing of the European population and diseases associated therewith (e.g. visual impairment). It is currently assumed that by 2070, 50% of the European population will be at least 65 years of age [8]. The designed AmI environments or SmE aim to preserve or improve the quality of life of the elderly or those with certain impairment, such as people with blindness.

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Typically, the majority of current assistive technologies include single-purpose tools helping people with blindness read, write, find directions and support their everyday activities [9]–[12]. This article focuses on the compensation of visual impairment using an assistive system based on the AmI which can be installed in the household or workplace of the person with blindness [13], [14]. The aforementioned AmI system is called RUDO and consists of various hardware and software modules, the fundamental parts of which were described in detail in the article [13].

This article aims to introduce the designed technological procedures using, besides other things, software modules that form a part of the AmI system RUDO. The designed technological procedures enable people with blindness to carry out the following tasks concerning the development of electrotechnical components and their drivers:

1. connection of electrical circuits using miniature screw terminal blocks, WAGO terminal blocks, Faston connectors, and end sleeves used for cable termination.
2. technical preparation and machining of mechanical components for device construction using steel T-squares and models.
3. programming of software drivers in a unified user interface adjusted for people with blindness,
4. testing and debugging of the drivers and related hardware developed alongside using notification sounds,
5. measuring of electrical circuits of the developed hardware using a multimeter, mediation of the measured data by means of speech synthesis,
6. monitoring of the waveform of the electrical signal using an oscilloscope, recognition and description of the displayed curves by means of specially-designed notification sounds of speech synthesis.

As the assistive system helping the person with blindness perform the given tasks involves automated assistance with scientific as well as practical activities in the area of computer science and engineering (or informatics from a European perspective), its development must comply with a number of user requirements. The designed solution must be modifiable, enabling the addition of further functions. At the same time, the specialised user interface should not keep changing significantly, otherwise it would cause difficulties to the people with blindness in terms of their ability to perform the requested task in a fast and efficient manner to enable them to be market-competitive. However, single-purpose compensatory aids cannot easily fulfil these requirements.

In this article, the compensation of the visual impairment in connection with the development of electrotechnical components and their software drivers is performed by means of the assistive environment using modules of the AmI system RUDO with a unified user interface. Computer stations at the workplace or household have an identical user interface which is modifiable dynamically directly by the person with blindness. Software modules may be modified or new modules created, however, the overall system user interface

remains unaffected. This article describes, in particular, the way how the people with blindness can design and construct electronic circuits while using common electrotechnical components, single-purpose tools and the relevant modules of the AmI system RUDO.

From a methodological perspective, the article is based on the design science methodology, as defined in more detail in Section II. The main output hereof is an artefact in the form of design principles [15], which are introduced in this article in practice as technological procedures. These are the core principles and concepts enabling the design and development of electrotechnical components by designers with blindness. The following main implication for science is attached to the aforementioned output: Introduction of general principles usable by other researchers for the design of their own AmI environments, aids or technological procedures supporting the work of people with blindness. This extends the knowledge base concerning the design of the solution of assistive technologies for people with blindness.

The research question and connected technical research issue is: how to design a technological procedure (supported by the AmI system RUDO and other tools) that would satisfy the needs of people with blindness in their work environment so that they would be able to develop electrotechnical components and their drivers?

There are mainly two purposes of the designed artefact for people with blindness. The first one is to provide people with blindness with learning opportunities in the area of computer-focused study programmes. However, such programmes deal with hardware aspects theoretically rather than practically. With the presented technological procedures, even students with blindness may be involved in the design of hardware components, which provides better understanding of issues such as cyber-physical systems from the perspective of software and hardware components interconnection. The authors consider the aforementioned as particularly important due to the current development in ubiquitous technologies, i.e. internet of things and the general Industry 4.0 concept. The second purpose is associated with the construction of basic electrotechnical prototypes in the area of scientific IT work performed by a researcher with blindness.

In association with the topic of this article, it must be noted that there are no sources available dealing with the possibilities of involving people with blindness in the area of design and development of electrotechnical components. The authors of this article have found no scientific source that would deal with this issue in the past. For this purpose, the citation databases Web of Science and Scopus have been searched. This fact creates a research gap which may now be filled thanks to the long-term development of the AmI system RUDO for people with blindness [13], because the core principles presented in this article were tested during the development of the RUDO system (hardware components). Nevertheless, no article previously published by the authors in English provided more details on the technological procedures described in Section IV of this article.

On the other hand, many scientific sources can be found with respect to the possibilities of involving people with blindness (and the visually-impaired in general) in software programming [16]–[20].

This article is structured as follows: Section II presents, in particular, the methodological issues of the research introduced in this article and the evaluation of limitations associated therewith. Referring to the relevant sources of literature, Section III presents briefly the AmI system RUDO. Section IV presents assistive approaches and procedures for the development of electrotechnical components using the modules of the AmI system RUDO. The subsequent Section V presents the evaluation of the purposefulness of the designed approach from the perspective of people with blindness, and Section VI provides a discussion on further development possibilities.

II. METHODOLOGY

The research and development of new artefacts (e.g. methods, models, frameworks, instance) is associated with broad engineering area with design science (DS) methodology [21], [22]. DS research, based on DS methods, is typically iterative and in the form of a design cycle or engineering cycle [23]. The design cycle is associated with validation (ex-ante evaluation) without the need for implementation. The engineering cycle expands the design cycle by the implementation of the designed solution and its ex-post evaluation. During the development and continuous improvement of the designed artefact, the aforementioned cycles are repeated. The development of the RUDO system was performed in accordance with the engineering cycle which, according to the DS methodology, consists of five fundamental stages [23]: problem investigation, artefact design, design validation, implementation, implementation evaluation.

This article aims to present the technological procedures usable by a designer with blindness during the design and development of electrotechnical components and their drivers. Modules of the RUDO system, which provide assistance to people with blindness during their work performance, constitute a part of these procedures. Due to the fact that the iterative development of the RUDO system has been ongoing for over 20 years, including the implementation of modules used by people with blindness during the development of electrotechnical components and their drivers, this article focuses solely on three selected stages of the DS methodology: problem investigation, artefact design, and implementation evaluation. The reason why the undermentioned description excludes the stage of design validation and implementation is that they are closely associated with the development of the RUDO system carried out in the past and the details of the stages are provided in the articles [13], [24]. Pursuant to the DS methodology, this article is focused on three stages:

- **Problem investigation:** Introduction of the problem context, its particularities and targets of the design intro-

duced herein. An important prerequisite of the technological procedures introduced below is also the RUDO system, providing assistance to people with blindness. A summary of the aforementioned is presented in Sections I–III.

- **Artefact design:** Introduction of the actual solution which is also based on the current modules of the RUDO system. A summary of the aforementioned is presented in Section IV.
- **Implementation evaluation:** A practical assessment of the introduced technological procedures using the RUDO system in the problem context presented in this article. A summary of the qualitative evaluation is presented in Section V.

Due to the three stages used within the DS methodology, the primary purposes of the DS research can be accomplished. The primary purpose of the DS research is to introduce the general design principles of a solution to a specific problem, usable even for other similar problem contexts (conditions). A secondary result is the instance of the solution by which the technological procedures had been tested.

Regarding to the fact that the designed solution is very specific and designed only for the globally-limited number of users with blindness working in the field of computer science and engineering (or informatics from a European perspective), the implementation evaluation is performed using the technical action research (TAR) methodology [25]. The TAR methodology is based on the DS principles and shows the advantages of involving a designer in the process of evaluation of the designed solution in a specific context.

The TAR methodology is often applied in the area of information systems dealing with the organisational research level. The most commonly used methods of data collection thus include, e.g. the researcher's diary, interviews or logs of tools [25]. However, the research presented in this article is focused on the personal level typical for the design of tools for people with disabilities involved in health informatics (or medical engineering). Due to that, the data collection and evaluation will be carried out using the cognitive walkthrough method, typically used in health informatics.

Furthermore, a methodological issue has been identified with respect to the target group of users of the designed solution and to their use for the evaluation. In particular, this includes a very low number of suitable participants for the evaluation within the region where the prototype is applied. Sections II.A and II.B are dedicated to this methodological issue concerning the artefact evaluation.

To summarise, the qualitative single-subject research [26], based on the TAR methodology, was selected to evaluate the designed solution; the cognitive walkthrough method was used as the qualitative method of data collection and evaluation, as defined in more details in Section II.C.

A. METHODOLOGICAL ISSUE AND LIMITED EVALUATION OPTIONS ASSOCIATED WITH POTENTIAL USERS OF THE SOLUTION

The qualitative approach of evaluation of the situated artefact [25], [27], also involving the designer with blindness, is used to evaluate the designed solution. The quantitative approach to evaluate the solution is not suitable for the solution enabling people with blindness to develop electrotechnical components and their drivers presented in this article. As Goodman *et al.* [28] pointed out, the quantitative approach is not applicable in this case, because quite a large group of people with blindness (having specific skills) would need to be gathered to perform the evaluation.

As for the case presented in this article, the demands placed on people with blindness subject to the testing are already quite high, which would make it very difficult to gather the required number of participants within the state or the region. The participant subject to evaluation of the presented solution must be a person with blindness with a university degree from computer-related area. Such participants are also expected to have a theoretical background in the area of electrotechnics. Due to the fact that the authors intend to create conditions for the people with blindness to develop new electronic circuits, the aforementioned is also associated with the process of testing where the people with blindness would be connecting electronic circuits exceeding the scope of high-school education.

Based on the estimated number of 49.1 million people with blindness worldwide [29] and the constantly increasing number of people focused on specialised work of people with blindness using computer technology, e.g. [30]–[32], one may suppose that a sufficiently large group of people with blindness motivated and capable of using the outcome of the presented solution can be found worldwide. It may thus be assumed that, on a global scale, the presented solution brings interesting insights for hundreds or even a few thousands of users with blindness. Nevertheless, the number of potential participants meeting the aforementioned attributes within the authors' region is very low (individuals). It would thus be way too difficult to find a larger group of people with blindness having the attributes defined above and being motivated to participate in the experiment within a single state or region for the purposes of quantitative research.

Due to that, rather than the quantitative approach, the authors preferred using the qualitative approach to evaluation. That is why the evaluation of the designed technological procedures is based on the cognitive walkthrough method described in Section II.C. Qualitative evaluation is an important and, most frequently, the only possible means for such cases where there is a sufficiently large number of users worldwide, yet the regional number is very low. A typical example is the design of compensatory aids for a highly specific disability. Methods, such as the heuristic analysis [33]–[35] or the cognitive walkthrough method [36]–[38], are used precisely for such cases involving the design of disability solutions and medical equipment. The use of such

methods is also recommended in the area of health informatics [39]. Both methods are cost-effective and suitable for basic usability inspection. Unfortunately, due to the application of the TAR approach, where the solution designer takes an active part in the evaluation as well, the heuristic analysis is not suitable for the case presented in this article. The one suitable for this case is the cognitive walkthrough method.

The selected methodological approach is suitable and applied within the DS research for where there is quick feedback required [33], or for where it is impossible to gather a sufficiently large group of participants for quantitative evaluation who would have the required attributes suitable for the given type of evaluation [34], [35]. Section II.B presents a detailed profile of the participant involved in the evaluation according to the TAR methodology, within which the cognitive walkthrough method is used for data collection and evaluation.

B. PARTICIPANT IN THE SINGLE-SUBJECT QUALITATIVE RESEARCH

In connection with the design presented in this article, the fundamental question must be raised: Is a person with blindness capable of performing the research and development of hardware in the fields of computer science and engineering (or informatics from a European perspective) at the required professional level (e.g. as a hardware developer or researcher)? From this perspective, it should be demonstrated that such activities do not exceed the motoric skills and cognitive abilities of people with blindness.

Whereas there is no doubt that people with blindness were already able to become programmers even in the 60s of the 20th century — see e.g. [18]–[20], [40], [41] — the situation concerning the hardware design and development is quite different. The Web of Science and Scopus databases do not offer even a single article dealing with this matter. The reason why no one has studied this issue yet may be the fact that the required means of technology are available to us only now. Thanks to these new technologies and their miniaturisation and connectivity (see e.g. concept of ubiquitous computing) and the easier sociotechnical interaction, the cognitive abilities and motoric skills of people with blindness can be improved even further. New career options will thus be available to people with blindness.

In this subsection, the authors want to show that people with blindness can design and develop hardware solutions at a scientific level by means of various aids and software modules of the RUDO system. The authors assume that if the aforementioned activities can be performed by a single person with blindness, other people with blindness with the relevant background and support (e.g. aids, Aml environment) will be capable of doing the same. As a matter of course, the authors are aware of the fact that such generalisation would concern certain simplification of the statement. However, as mentioned in Section II.A, such generalisation is acceptable in cases where there is an insufficient number of potential users of the designed solution, or where the solution is highly

specialised. A similar approach including a very low number of respondents can be found, e.g. in [12], [42], [43].

First of all, a presentation should be made with respect to the designer of the RUDO system who, according to the TAR methodology, participated in the evaluation of the solution enabling people with blindness to develop electrotechnical components and their drivers. Not only did this participant design the entire RUDO system – he also created all the software and hardware components comprising the system. The participant is with blindness and a user of ocular prostheses. Besides this main disability, the participant has reduced sensibility and fine motor skills in the right hand. At a later age, the participant had to undergo a surgery: myringoplasty in both ears in the treatment of myringitis resulting in reduced sense of orientation. Despite these disabilities, the participant managed to obtain a doctoral degree in informatics (or computer science from a US perspective).

The RUDO system prototype is installed at the participant's household and workplace (at the university). The participant is accustomed to the daily interaction with this AmI system. First of all, the participant with blindness had to design and develop certain software modules which helped him with the practical design of other electrotechnical devices. This involves the following two software modules using speech synthesis:

- a module for measuring electrical quantities and working with a multimeter, which enables the measurement of other electrical quantities; the module currently allows the measurement of: voltage, current, resistance, capacity, frequency, diodes – threshold voltage, short-circuit measuring device – resistance measurement in milliohms;
- a module for work with oscilloscope and focused on curves description (recognising special shapes of curves).

Within constructing the RUDO system prototype, the designer with blindness designed and constructed:

1. boiler room equipment control electronics:
 - control of two electromotive valves,
 - control of the stepper motor of the four-way mixing valve with temperature feedback,
 - data collection from seven temperature sensors,
 - control of water pumps for boiler and heating circuit,
2. taxonomic system electronics:
 - data collection from motion sensors,
 - data collection from door switches,
 - connection of doorbells to the AmI system,
 - control of routing of household notification,
 - audio signal filter,
3. electronics of the connection of household photovoltaic power plant equipment to the AmI system:
 - collection of boiler power input data for water heating using solar energy,
 - battery condition check data collection,

- control of intelligent battery charging with a capacity of 10 kWh,
- hardware and control software of cascaded addition of appliances to the load of a photovoltaic power plant during its increasing summer output.

It must be noted that the research and development was long-term and experimental (since 1997 and still in progress) and leading to the current sixth versions of the AmI system RUDO. During this entire period of the continuous development, the RUDO system was being designed and continuously improved within the design and engineering cycles following the DS methodology. This task is associated with the improvement of the ways how the designer with blindness designed and developed the hardware and software components, and with the improvement of the practices supported by the RUDO system and other tools into the version presented in this article. Based on the aforementioned, it may be stated that the participant whose skills and services were used for the evaluation of the designed solution has the required education background and experience, and his characteristics are thus suitable for the fundamental assessment of the purposefulness of the solution.

This subsection presented that a person with blindness having a sufficient education background and being supported appropriately by means of tools and the AmI environment is capable of independent design and development of electrotechnical components. It may thus be assumed that even other people with blindness will be capable of achieving similar results if supported by similar tools.

C. COGNITIVE WALKTHROUGH METHOD

Cognitive walkthrough [33], [44] is a research method used for the verification of usability of designed technological procedures, especially at the level of sociotechnical interaction. In other words, it must be ascertained whether all the technological approaches stated in Section IV are realisable by a person with blindness; any limitations or issues should be identified. Along with the cognitive walkthrough, a comparison is also carried out with respect to the work of a designer with blindness and one without visual impairment.

The cognitive walkthrough is focused on tasks and the ability to identify problems by means of action sequences required for the provision of a solution to the assignment. The cognitive walkthrough method requires the design of simple tasks. Based on the theory of cognitive exploratory learning [45], it may be expected that an identical and basically a simple approach can be performed even by other solvers in other locations while maintaining the required conditions of the experiment. In this case, the solvers are people with blindness with a background in the computer-related area.

An integral part of the tasks design is the qualitative valuation. For this purpose, an evaluation question is set out for each of the tasks. Such questions differ with respect to each of the performed activities; however, they correspond to the general category of the problem context (e.g. they are

related to the course of the activity or the result achieved). While evaluating the individual tasks, emphasis is laid on the comparison of time and quality of work of a person without visual impairment and a person with a disability.

The results of the qualitative evaluation are based on the presentation of arguments from the area of cognitive psychology theory and of principles of user-focused design. The results indicate that the evaluation of the user interface and the system functioning even using a limited sample of participants serves as a useful tool for the provision of a quick output for further improvements [33], [34]. The evaluation details along with the individual tasks, categories of the problem context, and evaluation questions, are presented in Section V and Appendix F.

III. BRIEF PRESENTATION OF AmI SYSTEM RUDO FOR PEOPLE WITH BLINDNESS

The main problem concerning the development of extensive AmI systems for people with blindness is the fact that the design, realisation and testing of such systems is highly demanding in terms of time, technology as well as funding. This is also the reason why there has not been much progress with respect to research concerning people with blindness [46]. Only a few articles have been published in the past decade mentioning AmI systems in connection with people with blindness, see [5], [13], [47], [48].

This section provides a brief presentation of the RUDO system prototype for people with blindness, designed and developed by a person with blindness, and tested and evaluated in practice [13], [14]. The iterative development of this system is being carried out at the Matej Bel University in Slovakia. From the very beginning, the RUDO system was being developed for Slovak users, and thus the synthesiser and all the related texts are in Slovak. In 2016, the development of the fourth version of the RUDO system for people with blindness was completed and a comprehensive overview was presented in the article [13]. The aforementioned article also provides further reference concerning the details on some of the specific parts of the RUDO system.

Software modules are programmed in the Free Pascal language. The RUDO AmI system is currently compiled using the Free Pascal 3.04 version with the overall scope of the programmed code of 170,000 programme lines. The integrity of the RUDO AmI system is regulated automatically by means of an automated database that forms a part of this system. All the software modules are operated and debugged on Linux operation platforms (Debian and Ubuntu). The RUDO software installation package is available from [49] free of charge.

The prototype of the RUDO system is implemented in a two-floor family house occupied by the person with blindness and his family. The second part of the RUDO system is implemented at the Matej Bel University where the researcher works as a researcher. Both instances of the RUDO system, installed at the workplace as well as the household, are interconnected by means of a web server.

The sixth version of the RUDO system prototype is currently being tested – the details on the iterative improvement of the individual versions are available in [50]. This version contains taxonomic services focused on the care for the ill and elderly, and a more developed system of people recognition in the interior/exterior [14]. What constitutes an important part of the current version is the user interface called HANIBAL, securing the unification of the user interface. The HANIBAL user interface is briefly presented in Appendix A.

From the perspective of technological procedures presented in Section IV, only certain software modules are used from the RUDO system that can be installed and, to a limited extent, used even on a standard personal computer (PC). This includes software modules ensuring a unified user interface, assistance with measuring electrotechnical quantities and tracing of oscilloscope curves. These modules serve as a prerequisite of the technological procedures presented in Section IV. The majority of development of electrotechnical components performed by person with blindness and the evaluation stated in this article have been performed in an intelligent building equipped with the full version of the RUDO system.

The installation of these modules is available upon the download and installation of the RUDO software package from [49]. This way, all the necessary software components of the current version of the RUDO system can be installed. When running the RUDO system software package, should the system detect the availability of hardware components of the RUDO system (via LAN or the Internet), the user will be offered all relevant components related even to the equipment of the intelligent building where the hardware components are installed. Should the system detect that no hardware components of the RUDO system are available, only such components called the ROWS system in this article will be functional. Such software components or modules support the person with blindness when using the computer. More information on the RUDO software package and its components can be found in Appendix A.

All components are based on the unified HANIBAL user interface. The user may use software components without the user interface being changed, thus the user can still benefit from being able to work in this user interface skilfully.

IV. ASSISTANCE WITH USING ELECTROTECHNICAL MEASURING EQUIPMENT AND CONSTRUCTION OF ELECTROTECHNICAL DEVICES

This section presents the technological approaches or procedures based on the RUDO system which provide people with blindness with new opportunities when using the electrotechnical measuring equipment within the scope of professional development of hardware and the development of its software drivers. Although it may seem that such professional work exceeds the possibilities of people with blindness entirely, Section III presents a long-term research project concerning the RUDO system development within which the developer with blindness was able to produce

all the hardware and software components of the system independently. The following subsections present the partial technological procedures. For better illustration and understanding of the presented approaches, a video has been elaborated, see Appendix E.

A. ASSISTANCE WITH THE IDENTIFICATION OF COMPONENTS AND THE USE OF SELECTED TECHNOLOGIES FOR THE CONNECTION OF CIRCUITS BY DESIGNERS WITH BLINDNESS

A person with blindness using the electrotechnical components keeps such elements in small drawers labelled in Braille, see Figure 1. The selection of the individual resistors, condensers, etc., is thus very quick and simple.

Despite the aforementioned, in practice, it happens during the development of electronic circuits that a small pile of such components is assembled on the desk, where the person with blindness is not able to identify the components perfectly even by touch. In such case, there is a risk that the designer will need the assistance of a person without visual impairment, which will decrease the performance level of the worker with blindness and his or her work independence.

For this purpose, what is recommended is the use of a multimeter connected to the RUDO system to ensure the reproduction of the measured values. A multimeter is capable of providing assistance to the person with blindness by measuring the resistance as well as the capacity of the relevant components. Thanks to that, the person with blindness can sort the components correctly into drawers marked in Braille.

As for the sorting of certain types of diodes, e.g. DIAC (diode for alternating current) and the Zener diode, special hardware was created for the RUDO system (see Figure 2), which gets connected to the electrical network $220\text{ V}\sim$, creating phantom voltage of $600\text{V}\approx$ with galvanic isolation from the network. In the event of complete short circuit, the maximum current will be 0.5mA , which cannot cause harm to the measured semi-conductors. Phantom voltage is switched on or off by an easily-touchable lever. Due to the significant power supply limitation, when connecting clamps by hands while the power supply is on, the person touching the clamps might only feel slight discomfort. By such action, the health of the person with blindness is not put at risk.

This device is to be connected to the multimeter measuring the voltage of the clamps. After connecting the diode to the terminals in the reverse direction, the RUDO system reads the breakdown voltage or, in the case of Zener diodes, the Zener voltage to the person with blindness using speech synthesis.

To continue with other components, the person with blindness must remember what has been placed on the table. In the event of risk that the components could be confused with one another by their shape or quantity, the person with blindness should be disciplined enough to place such components back in the marked drawers. However, it must be noted that, from the perspective of the shape and quantity, the resistors, condensers and diodes constitute the most critical components for people with blindness. As for the other components, it is



FIGURE 1. Small drawers with electrotechnical elements labelled in Braille.

not as difficult to be disciplined about placing them back in the drawers or to remember the small number of remaining components on the desk or the components that can be distinguished easily by their shape.

If a developer without visual impairment is to connect the relevant circuits, a schematic drawing of the circuits is displayed on a screen or in a paper template. For people with blindness, graphic information is not available. People with blindness involved in the development design their individual connection schemes which they must remember. People without visual impairment often find it difficult to imagine what is associated with such an approach. For people with blindness, remembering things is the crucial component of the mobility and ability to work, see e.g. [51]. Even in the event of development of hardware components for the RUDO



FIGURE 2. Aid used for measuring diodes. The aid has been created by a developer with blindness. Its internal connection is realised using a miniature screw terminal block.



FIGURE 3. Sound measuring equipment for resistance estimation, diode testing, voltage identification and signal monitoring.

system, the memory and visualisation ability of the designer with blindness was of crucial importance.

To allow their colleagues without visual impairment to mediate the visualization of the schemes of the designed circuits by a person with blindness, this may be done by means of a textual description of the scheme by connecting the individual knots, see Appendix B. Similarly, to make it possible for a person with blindness to visualise an existing scheme, a colleague without visual impairment may read to the person with blindness how the individual knots are connected. This way, the person with blindness can memorise the entire scheme and use such visualisation for the construction or development as required.

Furthermore, attention is paid to the possibility of practical connection of circuits by a person with blindness, possibly raising questions concerning the ability of the person with blindness to use the provided assistance and designed technological approaches. The authors thus focus on a brief description of the construction part of the design and the connection of circuits by a person with blindness.

People with blindness are able to detect tactile information very well [52], for instance, they are often able to thread a needle or untangle a necklace independently. It is thus not a problem for them to distinguish resistor contacts from condensers, transistors, diodes, etc., by touch and to push them into the contacts of a tiny screw terminal block. The person with blindness can design and connect even quite complex circuits using such blocks. Hardware electronic devices of the RUDO system are connected precisely this way (see [13]).

The equipment in Figure 3 was constructed by a designer with blindness without the assistance of another person. Electrotechnical components are connected there using miniature

screw terminal blocks. Hardware adjustment was performed by the person with blindness using metal models/T-squares (see Section IV.B), enabling the drilling of the holes in a regular and symmetrical way. When connecting the electronic devices, the RUDO system was used along with a multimeter connected thereto. The measured data was mediated using speech synthesis.

Figure 4 illustrates the way of connecting electrical circuits by a person with blindness without the need of assistance. Electrotechnical components are connected into miniature screw terminal block, commonly available in electrotechnical equipment stores.

As this article is focused on the research and development of electrotechnical systems (e.g. prototype development), the miniaturisation of the product is not requested to such an extent as within commercial mass production. The stability of electronic devices in screw terminal blocks is, however, very good. Several tested products were functioning flawlessly for over ten years. This is also why the RUDO system prototype was designed this way, despite the fact that it operates by means of functions requiring reliability, such as the automation of heating and zone regulation [13].

Furthermore, the current electrotechnical market offers input/output devices with a connector of computer network soldered onto a small flat panel, integrated circuits and other electronic surface-mount devices as well as tiny screw terminal blocks to be connected to other developed circuits. Such devices are also perfectly usable by people with blindness. The RUDO system uses such devices for measuring the temperatures and for data connection and transfer. These devices perform galvanic separation of the computer network from other developed circuits connected to the screw terminal blocks using optocouplers and open emitters or collectors.

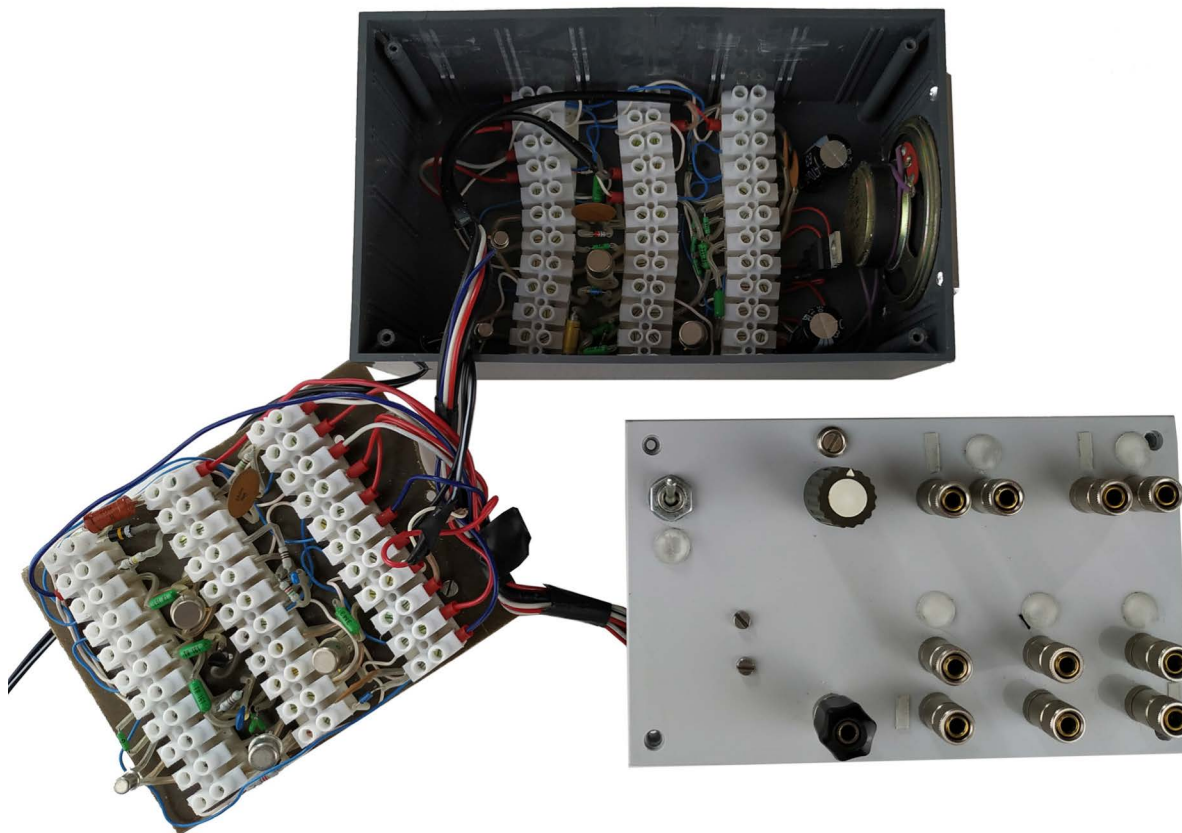


FIGURE 4. The disassembled sound measuring equipment of Figure 3.

From the software perspective, these devices have their own IP address, and communication with them within the RUDO system takes place via network programme interface called MODBUS. The authors of this article describe work using low-current devices that do not pose a risk of electric shock.

Within the current version of the RUDO system, the designer with blindness also connects photovoltaic power plant devices that connect common appliances to a photovoltaic energy system. The construction of devices thus uses voltage of 230V ~. In this case, the contacts must be very well insulated to prevent any safety risk for the designer during the manipulation. When connecting high-current circuits, WAGO terminal blocks, Faston connectors and bootlace ferrules are therefore very effective for designers with blindness. Figure 5 illustrates the device connecting other appliances to the photovoltaic energy system. For the connection of high-current circuits, the designer with blindness used solely the WAGO terminal blocks, Faston connectors and bootlace ferrules.

A brief description was provided with respect to the way how the designer with blindness performs the construction of electrical circuits in practice. The mechanical components of the construction of the developed devices are defined in more detail in the following subsection.

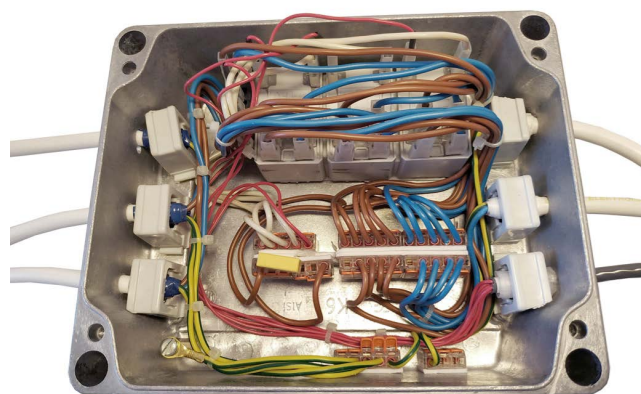


FIGURE 5. Equipment for the cascaded connection of appliances to the photovoltaic energy system. Relays and WAGO terminals used for the device are placed next to it.

B. USING MECHANICAL COMPONENTS FOR DEVICE CONSTRUCTION

Regarding the mechanical adjustment of the supporting structures by a person with blindness, two major questions may be raised:

- In which way does a person with blindness measure distances accurately?

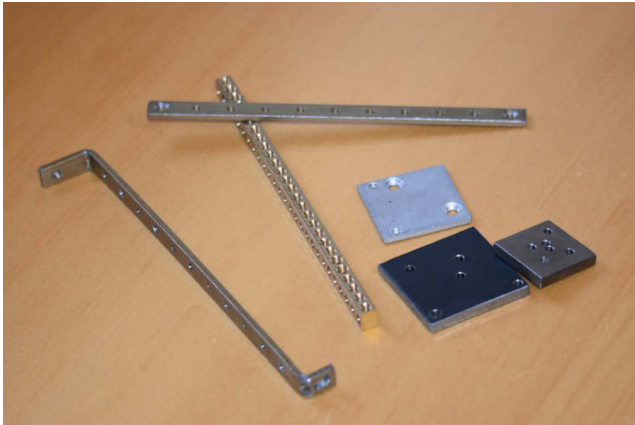


FIGURE 6. Sample of steel stencils.

- Isn't the use of certain equipment, such as a miter saw or a drill, dangerous for people with blindness?

A constructor without visual impairment uses a calliper to carry out the measurements, and a pencil or a steel point to mark the distances. Such an approach is common for those without visual impairment, however, unacceptable for people with blindness. A designer with blindness must use steel stencils with tiny holes pre-drilled at regular intervals. The stencils can be in the form of a strip, a strip bent at a right angle, a strip with a curved stopper at the end, or in the form of a square or a rectangle with holes in the corners, see Figure 6. The diameter of the holes in the stencils is the smallest diameter that the designer with blindness will be drilling. The designer can touch the holes on the stencils easily and, using the stencils, he or she can pre-drill them onto the given material. The holes can then be enlarged to the required size.

Similarly, when using a miter saw to cut materials at the required angles, the designer will measure the material on the saw stands using a special T-square, see video presented in Appendix E. The material is then clamped to the stand and when the designer proceeds finally with the actual cutting, he or she only operates the cutting blade lever with the hands at a safe distance from the cutting line.

When drilling, safety is guaranteed by the fact that the drill is switched off when placing it in the required location. At the same time, iron drill bits, which do not hurt when in contact with the skin from the side or when turning, are used for the drilling. Their drill blade operates in the drilling direction.

Most tools can be used in a similar way, where the person with blindness uses these tools in connection with simple steel T-squares and models. Since 1997, the designer with blindness has been able to work with no harm caused. When working with electric tools, even a person without visual impairment is expected to have a certain level of dexterity, caution and talent for doing so. For people with blindness, these requirements are very important from the work safety perspective.

C. PROGRAMMING OF SOFTWARE DRIVERS

The RUDO system may provide assistance to people with blindness even with writing source programming codes. It provides extensive support within the unified HANIBAL user interface. The user interface is presented in Appendix A in detail.

An editor, programmed for people with blindness specifically, serves as an important programming tool. This editor cooperates directly with the synthesiser and generator of notification sounds which serve to people with blindness in the same way as graphic icons to the ones without visual impairment, see [13].

The editor also cooperates with system compilers of programming languages used by the given person with blindness. Information concerning the successful or unsuccessful compilation is provided by the editor by means of a notification sound. In the event of a syntax error, the cursor points directly on the given error in the source code text, so that there is no need for the user with blindness to search for it. As a priority, the first identified syntax error is displayed.

The RUDO system allows the concurrent use of speech synthesiser and tactile touchscreen, which is absolutely crucial for professional programming. Certain characters, such as “{”, “}”, “[”, etc. are explained by the speech synthesis using two or three words. Using the tactile touchscreen, the person with blindness can read the characters immediately upon touching them. On the other hand, it takes longer to read common text by touch than by means of speech synthesis.

Working with a text using the RUDO system makes the person with blindness use both of these information sources methods concurrently – hearing and touching. In a relatively short time, the person with blindness gains the ability of perception by touch and hearing and is able to control the tactile touchscreen and synthesiser in such a way that is faster for acquiring the given source of information. The authors intend not only to enable people with blindness to work as professional programmers, they also intend for them to be successful on the labour market even compared to people without visual impairment. The ability to work fast is thus of great importance.

At the same time, the tactile touchscreen offers a very comfortable solution. Once the person with blindness reads a text and aims to carry out a change (edit) at a given place, all that needs to be done is to push a micro-switch above the given letter on the tactile touchscreen and the cursor moves to the required place in the text. This function is very important, as people without visual impairment need to check visually on the movements of the mouse cursor.

Using the aforementioned technologies, editing procedures as well as other common editing functions, such as chain search, etc., a person with blindness can work with the text highly efficiently. Combined to the programming and compatibility of a special editor with compilers, the person with blindness has a very powerful programming tool available – see also Appendix A.

At the very beginning of the RUDO system development, it was necessary to create special editing services using a synthesiser and a tactile touchscreen. At the same time, these services form a part of the designed RUDO system. This contributed to the increase of the productivity of the given person with blindness, especially in the area of programming. The RUDO system currently has approximately 160,000 programme lines which the programmer with blindness programmed entirely independently. It may seem that the extent of the developed system exceeds the possibilities of a single person, however, the authors' development in this area has taken over 20 years and, at the very beginning, the modular architecture was designed in such a way that the other software products followed the ones introduced previously. In the course of time, a very extensive system was created.

D. HARDWARE TESTING AND SOFTWARE DRIVER DEBUGGING

Software debugging constitutes an important part of hardware development. As for the software drivers of hardware installed in an intelligent building [53], that is a specific task that must be manageable even by a developer with blindness. The assistive environment thus offers a work desk with internet connection where the hardware development is enabled; the desk beside can serve for modifications of software drivers for this hardware. The work desk offers a LAN and USB connection through which a multimeter or an oscilloscope is connected. The RUDO system passes information from these measuring devices onto the person with blindness by means of speech synthesis using a speaker which also constitutes a part of the work desk.

Whenever the designer needs to reach the already installed hardware that cannot be laid on a work desk, the RUDO system also offers transmitters that can be switched on by means of a sound. Notifications from the speakers can be transmitted this way to the testing place of the installed hardware to be debugged. The RUDO system also offers measuring electrotechnical quantities even beyond the laboratory desk. Multimeters and oscilloscopes can be connected to the laptop with the necessary modules of the RUDO system directly and carry out the measuring at the required place.

During the hardware debugging, the programmer can select certain notification sounds in the system to warn him or her of any risk status or errors occurring. Similarly, the programmers can perform their own specific notification sounds and have them produced by means of the synthesiser. All such notifications can be received through the transmitter in any part of an intelligent building.

The RUDO system also contains a case with a speaker where a transmitter or an intercom can be plugged. A small speaker is also located close to the transmitter microphone, enabling the voice-sensor to get connected to it immediately upon the notification by the given sound. Another transmitter is placed at the developer's belt, thanks to which all the notifications are available to the developer regardless of his or her workplace location within the intelligent building or outside.

During the design of the case with the speaker, a problem was caused by the transmission interference. Due to this, it was necessary to separate the speaker located in the case from the RUDO system by two speech transformers, separating it from the system galvanically, with 150V in the mains to the case. This measure allows the developer to carry out the case sufficiently far away from the sensitive parts of the system.

Sections IV.A–D provided a presentation of the work of a person with blindness in the area of development of hardware and software drivers. The sections below offer the description of the actual mediation of data pertaining to the measuring technology, including a multimeter or an oscilloscope.

E. MEASURING ELECTRICAL CIRCUITS USING A MULTIMETER

The RUDO system provides testing of USB ports at regular intervals of 0.5 seconds. Provided that a cable with a galvanic distributor identified as a device offering connection to measuring technologies is connected to the USB port, by means of speech synthesis, the RUDO system reports being ready to providing assistance with electrotechnical data measuring. Upon connecting and switching on the multimeter, the following notification is made: "Multimeter switched on". Similarly, upon disconnecting or switching off the measuring devices, the person with blindness receives a sound notification. The examples of notifications for using the multimeter and switching to an oscilloscope are presented in Appendix C.

Upon a change to the measured value, the person with blindness receives a new sound notification along with the selected dimensions of the measured values. Due to the fact that certain measured values keep changing constantly, the RUDO system responds to the measuring suspension button that can be found directly on most multimeters. The person with blindness will be notified of suspension of the measurements and of the last measured value. This way the user with blindness avoids disruptive sound notifications without having to get up from his or her work desk. Pressing the measuring suspension button repeatedly allows the measuring to continue.

What constitutes an important measuring assistance element is the system of notification of statuses with respect to the measuring device. A dominant control element of the multimeter is a switch of the measured values including resistance, capacity, current, voltage, etc. In order to prevent various disruptive data being transmitted by sound notifications, the status report concerning the measuring device is reported only upon the change of such status, e.g. notification: "Resistance measuring". The person with blindness is likely to be able to remember such notifications. What also helps him or her is the reading of the measured value dimensions and units of measurement, e.g. notification: "9.302 kilo ohms". "Dimensions" are understood as the prefixes micro, milli, kilo, mega, etc. To summarise the aforementioned, if the measured value gets switched using the switch, the RUDO

system first reads the selected value, only then followed by the sound report of the measured data collection.

Once the button is pressed to switch on the relative measuring against an existing value, the RUDO system, to conclude each reading of the data, provides a sound notification using the word “Relative“. For instance, if intending to measure the increase in voltage, leaving aside the original value, the designer should press the “Relative” button. The display will be reset and it will start measuring only the increase in the given value. Similarly, during the automated identification of the value dimensions, the word “Automatic” will be pronounced. Let’s say, the user wishes to not have to choose the dimensions individually (e.g. micro, milli, kilo, mega), he or she presses the “Automatic” button and the multimeter will find the dimensions of the measured value automatically to have the given number displayed in the easiest way (36.9 Volts will not be displayed as 36900.00 milli Volts).

Speech synthesis of the RUDO system notification is designed in such a way that provides unequivocal information as requested, yet avoiding any disruptive lengthy or excessive use of words. Three examples of approaches to producing voice outputs can be found below:

- An identical value is not repeated during the measuring unless the number on the display is changed.
- If the measured value changes, it is possible to use a button to pause the reading. Upon pressing the button repeatedly, the reading of the displayed values will continue.
- The speed of the talking can be adjusted; faster production of words is required when reading fast-changing data. Medium speed of reading is the most preferred one, including spaces between the individual sound outputs.

F. MONITORING OF THE WAVEFORM OF THE ELECTRICAL SIGNAL USING AN OSCILLOSCOPE

An oscilloscope is connected to the RUDO system in the same way as the multimeter, see Section IV.E. Even using an oscilloscope requires assistance for setting the switches or buttons functioning identically, however, there are more driver components used with an oscilloscope. As for combining a multimeter with an oscilloscope in a single device, the device must be switched into the oscilloscope or multimeter mode, of which the RUDO system informs the person with blindness by means of sound notification. The examples of notifications for using the oscilloscope are presented in Appendix D.

What’s important with respect to using an oscilloscope is the fact that the measuring device must enable automated setting of display values of the curve on the display, which enables the enlargement of the curve, location on the display, period density, and so on. An electrotechnical engineer without visual impairment can set these values even manually to be able to visualise the required part of the curve clearly. The manual setting of the display values requires visual feedback which, obviously, is unavailable for a person with blindness.

To perform the automated calibration of the curve display, the measuring device sets the required parameters in such a way that will display the curve accurately. Using a USB interface, the RUDO system provides an output of the graphic raster of the curve, i.e. the displayed curve. The RUDO system must generate its description by means of recognition algorithms which provide the curve specification in the graphic raster and generate its description by speech synthesis.

When pressing the automated calibration button on the oscilloscope display, the assistive system informs the given person of being prepared to copy the monitored signal and to activate the recognition algorithms. The text below presents the algorithm used for curve recognition.

The curve concerning the measured electrical voltage is in the form of visual information that can be of various shapes. That is why its description by means of speech synthesis can only be solved by a relatively complicated method consisting of two main tasks:

- algorithm of measured electrical voltage recognition (or oscilloscope curve recognition algorithm),
- way of interpreting the voltage waveform by means of speech synthesis.

The graphic raster of the curve, which is received from the oscilloscope via a USB data connection, is not recognised by the RUDO system as normal computer graphics. The measured voltage curve has its specifics, essentially similar to sound recording. The graphic raster of the oscilloscope curve can therefore be perceived as a sequence of pulse code modulation samples (PCM), see e.g. [54], [55], used for digitalisation and processing of sound records:

- the image of the curve is monochromatic, e.g. a black curve appears on a white background,
- a perpendicular guided across the time axis, or more precisely across the X axis, intersects the curve only at one point in time.

PCM is the sequence of integers expressing the height of a signal at a given point in time. In the case of an oscilloscope curve, these numbers determine the position of the point in the vertical direction. The number of pixels of the graphic raster in the vertical direction of the Y axis determines the maximum value of the integer in the PCM sequence. The number of pixels of the graphics raster in the horizontal direction of the X axis expresses the number of available PCM samples that the recognition algorithm will work with. Therefore, upon receiving the graphic data from the oscilloscope, the raster of the computer graphics with the measured curve is first converted to a sequence of PCM integers. Once the curve is already converted to the PCM form, all known short-term signal processing algorithms and Fast Fourier transform for spectral analysis of the measured curve can be used to recognise its shape [56]. The oscilloscope curve recognition algorithm can then be expressed in six steps:

1. Raster conversion to PCM,
2. Basic classification:

- a) zero signal (horizontal line),
 - b) noise,
 - c) non-periodic signal,
 - d) periodic signal (this is further recognised),
3. If the signal is periodic, the system looks for the:
 - a) sine,
 - b) rectangle,
 - c) sawtooth,
 4. If 3a, 3b, 3c are not found, search for the following deformities is carried out:
 - a) sinus deformity with the description of quadrants,
 - b) deformity of the rectangle with the description of quadrants,
 - c) deformity of the sawtooth with the description of quadrants,
 5. If no deformities are found, troubleshooting and special
 - a) signal types are sought:
 - i) positive / negative sine / rectangle / sawtooth half-wave,
 - ii) positive / negative sine (ripple),
 6. In the event of non-recognition of the curve, the possibility of programming the recognition of a new wavelength of the curve is offered, so that this specific course can be recognised in the future.

Examples of notifications are provided in Appendix D. At the beginning of the notification, the basic distinction of curve 2a, 2b, 2c or 2d is voice-specified. In the case of a periodic signal, the frequency is specified and, provided that the amplitudes of one period in the absolute value are equal the amplitude in Volts is specified as well. In the case of a periodic signal, the type of curve or the similarity to the type of curve – the sine, rectangle, and the sawtooth wave, followed by two numbers:

1. phase ratio in the period,
2. ratio of amplitudes in the period.

Based on this information, the person with blindness can have a basic idea of the waveform of the electrical signal. If there are deformities in the signal against the three curves, the deformities for the given quadrants in the period are also expressed, for example:

1. positive mean deformity in the first quadrant,
2. negative major deformity in the third quadrant.

The term positive / negative expresses the direction of the deformity with respect to the classical sine, rectangle and sawtooth wave. The term smaller / medium / large expresses three estimated sizes of deviations. The quadrant numbers indicate the location in the period where the given deviation occurred.

In the case of a periodic signal that cannot be compared to the sine, rectangle and sawtooth wave signals, the expression of the frequency is followed by a description of the specific signal. At present, the RUDO system has five other predefined recognition signals, while at this point it allows the extension of the recognition algorithm depending on which

signals the person with blindness wishes to use and which he or she wants to have described automatically.

V. EVALUATION

Section I presented six tasks which the RUDO system and other tools enable people with blindness to perform during the course of development of electrotechnical components and their drivers. Section IV provided a detailed description of technological solutions including the relevant hardware, software, and approaches. This section is to focus on the evaluation of the designed solutions according to the DS methodology. This involves the use of the cognitive walk-through method [57]. The evaluation was carried out with the participation of the person with blindness characterised in Section II.B. Furthermore, in order to carry out comparison of the speed and quality of work of a designer with blindness and a designer without visual impairment, a university worker participated in the project with an assignment to perform the same tasks, however, in his own way. The detailed evaluation is presented in Appendix F (A–F) and corresponds to designed technological solutions defined in Sections IV.A–F. The evaluation was carried out in an intelligent building equipped with a full version of the RUDO system.

Due to the fact that the evaluation using cognitive walk-through includes vary distinctive activities (such as drilling or using an oscilloscope), the authors decided to define three general categories common for various kinds of problem context presented in Section IV. What served as an inspiration for their definition was the focus of evaluation questions and the approach stated in studies [38], [58]. These categories refer to the stage prior to commencing the work, the actual course of the work, and the completion of the work with the expected outcome. The three categories common for all problem contexts are as follows:

1. Prior to commencing work, the designer with blindness realises his or her capability of performing the relevant work using other tools, including the support provided by the RUDO system.
2. The designer with blindness is able to select (repeat, combine) the individual steps of the technological procedure in such a way that would contribute to achieving the expected outcome or solution.
3. The designer with blindness has completed the work and he or she is certain of having achieved the expected outcome or solution.

Based on the aforementioned three general categories, Appendix F presents the evaluation questions (EQ) associated with the given work-related context and tasks. In this case, due to the distinctive character of the individual tasks, general questions may not be applied.

From the perspective of the individual activities described in Appendix F, emphasis is laid on two levels associated with the work efficiency of a person with blindness in a mixed team including workers without visual impairment. Work efficiency in this case is perceived as work productivity

compared to the productivity of a worker without visual impairment. Work efficiency of a person with blindness will be presented on two levels:

- qualitative evaluation compared to the work efficiency of a person without visual impairment (who may use other approaches to achieve the same result as the person with blindness);
- time evaluation in comparison with a person without visual impairment.

Section IV presents certain designed solutions supported by a link to a video in Appendix E concerning a person with blindness, which may help the readers of this section visualise the relevant tasks to be performed by people with blindness. This includes, in particular, the demands and difficulty of their work.

VI. DISCUSSION AND CONCLUSION

In this article, the authors intended to demonstrate other self-realisation options of talented people with blindness in the computer-related area. Technological possibilities these days offer the possibility to use the existing components to assemble single-purpose tools as well as entire intelligent environments. This can help compensate for a number of disabilities which used to limit the activities of persons with blindness until recently [46]–[48]. The main benefit of technologies should be the improvement of a person's well-being [59]. The aforementioned should also concern all people with certain disabilities, such as people with blindness. What can serve as a great source of inspiration for the creation of assistive technologies for the scientific activities of people with visual impairment is the story of the well-known scientist Stephen William Hawking (1942–2018). Although he dealt with a different kind of disability, his life refers to the new opportunities offered precisely by the development of assistive technologies.

Even in the context of this article, the need to deal with the design and construction of electrotechnical components by people with blindness came soon after the appointment of a person with such impairment (see Section II.B) as a researcher at the university. The target of the designer with blindness was to create an Aml system that would help him at his workplace at the university as well as in his household. For this purpose, a series of software tools had to be created in the first place, as the designer needed them to provide the necessary information via the computer.

At the early stages of the RUDO system development, the designer with blindness had to deal with the fact that no assistive technology was available that would enable people with blindness to measure electrotechnical quantities. Therefore, the task of the highest priority was firstly to ensure that the designer with blindness was able to programme the most important parts of the software by himself, using the tools enabling people with blindness to work using a computer. In this way, a software package was first created, providing document printing, a programmable calculator, and a special

way of operating the keyboard and the tactile touchscreen for the Free DOS operating system. Subsequently, based on these instruments, a programme capable of communicating with the multimeter using the RS232 series interface was created, which enabled its operation and read the measured values. Despite the fact that this first version was very simple and could not entirely cover the needs of a designer with blindness, its functions were sufficient for the designer to start working on the development in the area of preparation of hardware and electrical circuits.

Firstly, however, long-term testing had to be carried out to determine whether the constructed electrotechnical components were reliable enough and whether it was possible to use this technology even in the development of more complex devices serving, for example, to operate heating, zone control and domestic photovoltaic power plants. In other words, by gradual iterations, the development of the partial tools (many of which became one of the modules of the future RUDO system) and the findings of the basic principles how to have the required task performed by a person with blindness have led to the creation of the current version of the RUDO system, see Section III.

The authors of this article aim to motivate the scientific public to the development of new approaches which could be implemented in the future assistive tools and systems. A talented designer with a disability can reach a brand new level of education and skills, which may enable him or her to become a professional in the given field whose work opportunities will be comparable to a person with no disability. Such progress will benefit to the entire society. The following subsections present the implications for science and for practice as well as the possibilities for the future development of the designed technological procedures.

A. IMPLICATION FOR SCIENCE

Obviously, every kind of disability requires special adaptation of the systems corresponding to the need of compensation. However, it must be noted that the compensation of the given disability should also involve the compensation in various contexts depending on the activities performed by the person with blindness. Therefore, the developed ambient environments must not only be tailored to the given person and her or his disability, but also to the activity performed by the person. Since there is no universal possibility available to compensate for the vision impairment of people with blindness, designers need to focus on the expansion of cognitive abilities of the given person with blindness, see [14]. It is important to use the abilities and knowledge of the person with blindness and not to overwhelm him with information that is far from her or his intrinsic model of the world, but close to a similar model of a person without visual impairment. This is also what the RUDO system is focused on. The designers of assistive technologies for people with blindness can lower the risk of rejection of the proposed solution by the people with blindness in practice when using this approach.

According to the DS methodology, what constitutes the main benefit is not the proposed and situated artefact, but the specified principles or approaches behind the proposed solution. Such principles can be re-used for other future solutions, which can expand the knowledge base by the design of solutions of assistive technologies for people with blindness. This article is focused precisely on the presentation of the basic technological procedures concerning the way the people with blindness can develop electrotechnical components, including the construction of prototypes of more complex devices.

The aforementioned principles in Section IV are usable and tried-and-tested by a person with blindness. The aforementioned is also illustrated by a video capturing the work of the person with blindness, see Appendix E. The authors are thus convinced that people with blindness worldwide, using the similar tools and technological procedures, will be able to achieve similar work outcomes. From the perspective of the DS methodology, these fundamental principles and presented ways of use of the partial tools required for the development of electrotechnical components and their drivers using the relevant modules of the RUDO system are considered as the main scientific benefit of this article. This benefit might have a positive impact on the future DS research in the area of design of assistive technologies for people with blindness.

From the scientific perspective, it must be noted that there are certain limitations to this article, as set forth in Section II. The evaluation of the designed solution using qualitative research was performed only with a single participant who also participated in the system development. This approach is understandable and applicable for the development of aids for people with a specific disability, as illustrated by Section II. Another possible limitation of the solution is associated with knowledge of basic electrotechnics and some dexterity of the given person with blindness.

B. CONTRIBUTION FOR PRACTICE

The main contribution for practice is the situated RUDO system prototype used to support the development and construction of electrotechnical components. The main technological procedures are documented by means of the figures in the individual sections as well as the video, see Appendix E. Furthermore, the complete programme packages used by the RUDO system are also available [49]. However, the packages are in Slovak, which constitutes a disadvantage.

From the practical point of view, the evaluation of the designed solution concerning a participant with blindness should be highlighted. There is a bigger chance for the designed solution (or technological procedures) being accepted even by other people with blindness worldwide. The authors also assume that it will be possible to apply the principles during the course of performing similar activities of a person with blindness even during the proposal of the assistive technologies to support the work of people with blindness in the area of electrotechnics.

Secondary contribution for practice can also be found in the area of education. The new opportunities for people with blindness to design and construct electrotechnical components enable the expansion of the curriculum of visually impaired students, e.g. in the area of information and computer sciences. This can also affect the professional training of dozens of thousands of visually impaired students at higher education institutions, see [60].

C. POSSIBILITIES FOR FUTURE DEVELOPMENT

In conclusion, several ideas are presented which could contribute to the improvement of the proposed technological procedures. The greatest improvement of the solution in terms of construction, debugging and servicing of the designed electrotechnical components in the place of their implementation would be the transition to mobile technologies and wireless communication. For instance, if a designer with blindness wishes to move around a building and use a multimeter and an oscilloscope, he or she must be equipped with at least a laptop with the installed software modules of the RUDO system (see sections IV.E, IV.F and Appendix A). Both tools are connected with the laptop via the Universal Serial Bus (USB). It should be noted that an intelligent building with the RUDO system installed has a work desk available equipped with USB connectors to relevant devices. From the perspective of the previous experience, for the purposes of a better overview of the work desk and its surroundings, work performed in a laboratory equipped with the full version of the RUDO system is preferred by the person with blindness over the work outside an intelligent building.

This current solution enabling the person's mobility should be replaced by a mobile phone with pre-installed modules of the RUDO system (which would need to be adjusted to the relevant operating system of the mobile phone) that would offer wireless communication with the multimeter and the oscilloscope. The designer with blindness could move around the interior of the intelligent building and measure electrotechnical quantities without limitations presented by the current solution.

From the perspective of cooperation of the person with blindness with other electrotechnical engineers, an easier way of sharing the schemes of circuit connections would constitute another benefit expanding the current solution. If a person with blindness wishes to have the schemes of the designed circuits mediated by a co-worker without visual impairment, this can be done by means of text description of the scheme by connections in the individual nodes. In this sense, an interesting expansion of the RUDO system could be software converting such a text file into a graphically expressed circuit scheme with a possible design of a printed circuit board. The issues concerning the collaboration of people with and without blindness using the assistive and collaborative technologies is, however, more complex, and further research is required for the future, see also e.g. [12].

APPENDIX A

BRIEF PRESENTATION OF THE HANIBAL USER INTERFACE

For the installation of any software modules which constitute a part of the RUDO system, all that needs to be done is to download and install the RUDO software package from [49]. When running the RUDO software package, should the system detect the availability of hardware components of the RUDO system (via LAN or the Internet), the user will be offered all relevant components related even to the equipment of the intelligent building where the hardware components are installed. Should the system detect that no hardware components of the RUDO system are available, only such components called the ROWS system in this article will be functional. Such software components or modules support the person with blindness when using the computer (turning a common PC into a compensatory aid for people with blindness).

Provided that hardware components of the RUDO system are available, all services are mediated through the ROWS system, as it involves HANIBAL, the unified user interface. A part of the ROWS system is the HANIBAL interface, programmed with the intention to make the work of a person with blindness more efficient up to the degree to make it possible for the person to compete on the common labour market. The HANIBAL user interface has a semi-graphic character, it mediates all user inputs and outputs. To do that, the sense of hearing and touch of the person with blindness is used. The interface transmits information via a synthesizer and a tactile touchscreen in such a way that these two sources of information complement the work of the person with blindness, which leads to increased efficiency of his or her activities.

When using common graphic environments, the person with blindness is delayed by the retrospective interpretation of graphics and is often confused by the number of functions on offer. Using the HANIBAL interface, the user with blindness is capable of creating a tree structure of windows independently and of choosing the name and menu of functions for each window.

The person with blindness chooses the structure of the windows and their content using a definition in a text editor. If the person with blindness is not skilled enough to use the computer to do so, the window structure can be created by a technical assistant during the installation of the RUDO system or to make changes at any time afterwards by remote administration via the Internet. This way, the HANIBAL interface offers the comfort and possibility of full operation of the computer. One of the goals of this development was to ensure that the computer does not discourage users with blindness who are less-skilled from working and, at the same time, to prevent any obstructions for more advanced users.

The last-mentioned feature of the ROWS system is command line assistance. This system is intended to support the person with blindness even in the field of professional informatics or computing, where work on the text console of the operating system is required. The command line is read

Asistent HANIBAL

A Komandér	Práca so súbormi a adresármi
B Texty a poznámky	Práca s textami - súbory, poznámky, plánovač práce
D Dokumenty	Spracovanie dokumentov s formátom HPR
C Prehliadať texty	Prehliadanie textových súborov a dokumentov
T Tlač	Tlač textov a dokumentov
P Pomoc	Návody na obsluhu systémov ROWS, RUDO, HANIBAL a LINUX
G Gramatiky	Editácia gramatiky - pravopis, výslovnosť a iné
F Slovníky	Anglický, nemecký, synonymický a cudzie výrazy
H Vyhľadávanie dát	Vyhľadávanie, prehliadanie a editácia dát na disku
I Internet	Internetové prehliadače
L LAN/WIFI siete	Pripájanie, odpájanie a práca s počítačovými sieťami
J Konverzie	Konverzie textových formátov dokumentov
R Napaľovanie CD	Napaľovanie CD a DVD nosičov
S Skenovanie a OCR	Skenovanie textov a obrázkov, OCR systém
U Ukončiť prácu	Vypnutie počítača, reštart, ukončenie HANIBAL
Z Vykurovací systém	Obsluha vykurovacieho systému a zónovej regulácie
O Programy	Ďalšie programové nástroje
Q Predpoveď počasia	Internetová predpoveď počasia
K Kalkulátor	Programovateľný kalkulátor
N Nastavenia RUDO	Nastavenia systému RUDO, ROWS a prostredia HANIBAL
V Vývojové nástroje	Aplikácie podporujúce vývoj v oblasti informatiky
W Zvuk wav/mp3	Prehrávanie a nahrávanie zvukových záznamov
M Programovanie	Editácia programov, kompilácia, tvorba systému
X Dátové zariadenia	Pripájanie/odpájanie USB, DVD a pamätových kariet

ESC/LF=naspäť; UP/DN/PGUD=vyber; ENTER/RG/PÍSMENÁ=zvoI; F2=pomoc; F10=ďalej;

FIGURE 7. Printscreens of the initial window of the HANIBAL interface. The top line contains the window name in the HANIBAL interface. Information on the active hot keys is displayed in the last line. For better orientation of the developer with blindness, the menu items in the left column of the window are arranged below each other. The function description is provided next to the items. HANIBAL informs the user with blindness about the selected item and its function using speech synthesis and a tactile touchscreen. The item selection is either followed by starting the programme application or by opening of a similar window with other functions. The window structure as well as contents can be defined by the person with blindness directly in the HANIBAL interface.

by the synthesiser offering the control elements to specify the text to be read. An important assistive component in such work is the proposed set of pre-programmed scripts, which can be entered as abbreviated commands of the operating system with simplified choice of their parameters.

A. BASIC PRINCIPLES OF THE HANIBAL USER INTERFACE

The current version of the HANIBAL interface has a predefined user menu with a tree structure. The user interface is only in Slovak. Figure 7 shows a root window from which the user can click on all functions of the RUDO system, or more precisely use all ROWS software modules.

The person with blindness is most efficient at work when there is no need to move his or her hands over the keyboard too much and look for the individual functional and control elements. Therefore, HANIBAL is operated in two alternative ways:

1. The left hand is on the CTRL and SHIFT keys, the right hand is on the four arrows.
2. Both hands are on the “asdf”, “jkl;” keys expressing the symbols of the Braille system used as a typewriter for the people with blindness, see [13].

In both cases, the person with blindness does not need to move the hands over the keyboard, he or she only uses the fingers. In the first case, the person with blindness uses the vertical arrows to select a function within the window. The horizontal arrows are used to select the parent or child window. Horizontal arrows can be replaced with ESC or ENTER. The combination of CTRL or SHIFT and vertical arrows

Spracovanie	Záznam	Font	Neurogen	Gramatika	Hlas
Alofóny	Fonémy	Difóny	Trifóny	Zvuky	GKPsynt
				vyvoj	Jan WAW
Text : Ahoj "Text pre umelú produkciu reči"					
Bricks : a;1 b;1 c;1 d;1 "Stavebné kamene reči "TalkBricks"					
Vzorka : <--395 1r 215: 1r					
Nábeh : <--57 1r1					
1stacio : <--37 1r2					
L-koar : <--20 1r3					
S-koar : <--30 1r4					
P-koar : <--45 1r5					
2stacio : <--0 1r6					
Koniec : <--204 1r7					
Popis: Spracovanie databázy stavebných kameňov reči.					
C+ENTER=povedz fragment	C+S+ENTER=vrav fragment	F5=vzorky pre načítavanie			
SPACE=povedz text	S+SPACE=vrav text	C+SPACE=hláskuj mediálne			
A+SPACE=hláskuj maxi	C+A+SPACE=hláskuj mini	C+S+SPACE=hláskuj med.			
A+S+SPACE=hláskuj max.	C+A+S+SPACE=hláskuj min.	F4=gramatika prepisov			
F1=jazyk TalkBricks	S+ENTER=plný preklad	A+ENTER=fonet. preklad			
PGUP/PGDN=objektová DB	A+PGUP/PGDN=celková	C+PGUP/PGDN=fonémová DB			
C+A+PGUP/PGDN=zvuky	C+S+PGUP/PGDN=tóny	C+HOME/END=rýchlosť PHN			
C+S+HOME/END=výška PHN	C+INS/DEL=bass PHN	S+HOME/END=výška obj			
S+INS/DEL=bass obj	S+F1=prečíta pomoc				
ENTER=zvoI	LF/RG=výber	ESC=koniec			

FIGURE 8. Printscreen of the initial window of the application for the development of voice synthesis. The top part contains a basic menu for the selection and recording of the speech corpus and the definitions of the language grammar rules. The lower part provides information on the active hot keys. The second menu from the top allows the person with blindness to select the processing of the required components of the voice, e.g. phonemes, diphones, triphones, allophone strings, and particles used in spelling. In the column menu on the left, the person with blindness works with the given selected voice particle using the sense of hearing, partial synthesis, and a tactile touchscreen. In this menu, the designer also selects the synthesised part of the sentence and defines prosody on the right. The synthesis of the speech corpus may be incomplete, which provides the person with blindness with qualitative feedback on the developed speech corpus.

allows the synthesizer to read to the user with blindness the following information:

- the name of the selected item,
- brief help for the selected item,
- the name of the entire work window,
- information on whether the selected item constitutes another HANIBAL window or a software application.

In the second case, with both hands placed on the “asdf”, “jkl;” keys while the person with blindness types letters of the alphabet in Braille, he or she can choose individual items of the window using the first character in their name. Once the person with blindness gets used to the predefined structure of the windows and starts to remember the most frequently used functions, he or she can select the functions in the parent window with a single keystroke; two keystrokes are required for all the child windows, and so on.

In this way, the person can benefit from a huge structure of a number of functions, which can be scrolled through using the arrows, however, the person with blindness can enter some of the functions by pressing a small number of characters. For instance, to select a function from the number $24^2 = 576$, only two letters are required. The maximum number of functions for one window is 24. However, when creating a tree structure of user windows, the emphasis is laid on this structure being unbalanced. Frequently used functions must be selectable by a shorter character sequence; rarely used functions must be selected by a longer sequence.

Editor	Kompilátor	Adaptácia	Vektor	Optimalizátor	Generátor	Disk	Spočítat
A> Hranica dospelosti	- 400 promile	=	0 jednotiek				NLG 64
B: Dĺžka manželstva	- 0 promile	=	0 jednotiek				ALPHA-2.
C: Rozsah šľachtenia	- 15 promile	=	0 jedincov				2021
D: Počet bodov križenia	- 20 promile	=	1 bod				----
E: Deštruktivita mutácie	- 2 promile	=	1 chyba				FPV UMB
F: Obnova šľachtenia	- 15 priechodov						
G: Opakovanie šľachtenia	- 3 krát						
H: Hromadné dospievanie	- VVP						
I: Hromadné rozváždzanie	- VVP	F-1 Chyba:	?				
J: Početnosť mutácie	- 2	F-2 Iterácia:	?				
K: Stupne starnutia	- 8	F-3 Priebek:	?				
L: Váha starnutia	- 0.10	F-4 Čas adaptácie:	?				
M: Celočíselný generátor	- 250	F-5 Počet neurónov:	?				
N: Excitačný generátor	- 9900	F-6 Počet synapsí:	?				
O: Excitačný posun	- 0.5	F-7 Dĺžka jedinca:	?				
P: Nulová početnosť	- 0	F-8 Veľkosť populácie:	?				
Q: Entropia selektora	- 0.13	F-9 Sieť:	18rudo01				
R: Inhibičný generátor	- 0.90	F10 Priechok:	/milan/rows/ngs				
S: Inhibičný posun	- 0.01						
		ESC=koniec					

FIGURE 9. Printscreen of the initial window of the application for the development of neural networks. In the upper menu, the user with blindness selects either the processing of the text definition of the neural network, or its compilation, adaptation or change of the name of the network definition file. Depending on the selection, the desktop is dominated by either the neural network source code, which is modifiable and contains a special compiler enabling the person with blindness to determine the correct notation syntax, or by a vector setting the parameters of the genetic algorithm, e.g. rate of mutations, maturity age of genetic individuals, featured in the adaptation process. In this case, the current statistical information concerning the adaptation progress is displayed on the right side of the screen. The environment informs the person with blindness about all states and values through speech synthesis, notification sounds, and tactile touchscreen.

A very important feature of the HANIBAL interface is the fact that it is available to a user with blindness on five consoles at the same time. Each console allows the person to work independently of the others. Each HANIBAL window remembers the last selected item; the fields for entering character strings have their own input history. Over some time, the user makes a simple selection from the relevant options without the need to rewrite all the data. Figures 8 and 9 show examples of the structure of commands used by the user in applications for the development of voice synthesis and neural networks.

APPENDIX B SAMPLE TEXT DESCRIPTION OF THE SCHEME AND ASTABLE MULTIVIBRATOR

V+ power supply:

R1/1, R2/1, R3/1, R4/1 (resistors, contact 1)

V- power supply:

T1/e, T2/e (emitters or transistors)

Node 1:

R1/2, C1/1, T1/c

(resistor 1 / contact 2, condenser 1 / contact 1, transistor collector 1)

Node 2:

R4/2, C2/1, T2/c

(resistor 4 / contact 2, condenser 2 / contact 1, transistor collector 2)

Node 3:

R2/2, C1/2, T2/b

(resistor 2 / contact 2, condenser 1 / contact 2, transistor collector 2)

Node 4:

R3/2, C2/2, T1/b

(resistor 3 / contact 2, condenser 2 / contact 2, transistor collector 1)

APPENDIX C

EXAMPLES OF RUDO SYSTEM MESSAGES WHEN USING A MULTIMETER (AND SWITCHING TO AN OSCILLOSCOPE)

Messages (originally in Slovak) of the RUDO system are in italics.

Connecting a multimeter/oscilloscope to a computer USB

- *Uni-Té connectivity* (a cable with a galvanic separator by the Uni-Trend manufacturer was recognised).

Turning on the combined multimeter and oscilloscope device

- *Switched on, multimeter mode, voltage* (the device was switched on, the multimeter mode is selected, voltage is the selected measured quantity).

Switching to the oscilloscope mode

- *Oscilloscope mode*

Voltage measuring

- *3.6 Volts, 3.611 Volts,...* (upon connecting the measuring leads to the measured nodes, the message concerning the measured quantity is repeated).

Measurement suspension

- *Measurement suspended* (upon pressing the “stop” button, the measurement is paused, no messages will be generated).

Switching off the oscilloscope

- *Oscilloscope switched off. Multimeter disconnected.* (USB multimeter cable disconnection from the computer).

APPENDIX D

EXAMPLES OF MEASUREMENT USING AN OSCILLOSCOPE

A. EXAMPLE 1

The oscilloscope was connected to the USB connector at the desk, turned on, switched to oscilloscope mode; AC voltage measurement. See also Appendix C for an explanation of some terms.

Messages (originally in Slovak) of the RUDO system are in italics:

- *Uni-Té connectivity,*
- *oscilloscope switched on,*
- *oscilloscope mode,*
- *AC voltage.*

230V AC/8V AC adapter was connected to the 230V~ mains socket. The oscilloscope leads were connected to its output and the automatic calibration was turned on.

Messages (originally in Slovak) of the RUDO system are in italics and explanations in parentheses:

- *automatic calibration,*

- *7.97 Volts,*
- *50.08 Hz,*
- *sine,*
- *amplitudes -1.03* (ratio of positive and negative amplitude),
- *phase 1.05* (ratio of amplitude distances),
- *alternating course* (it can, for example, also be positive pulsating).

B. EXAMPLE 2

The output contacts of the adapter were connected with a diode and a resistor connected in a series. The oscilloscope leads were connected to a resistor.

Messages (originally in Slovak) of the RUDO system are in italics:

- *4.08 Volts,*
- *50.05 Hz,*
- *positive half-waves* (negative half-waves are also possible).

A semiconductor in a series – a diode – transmits the current in only one direction, negative half-waves did not flow through the circuit. Such a course can no longer be called alternating, which is why the RUDO system described it as “positive half-waves”.

C. EXAMPLE 3

A capacitor and a larger resistor were connected in a series to the two contacts of the adapter. The oscilloscope leads were connected to the resistor, which also affected changes caused by interference. The measured values kept changing, the authors present one of the measured variants.

Messages (originally in Slovak) of the RUDO system are in italics and explanations in parentheses:

- *1.659 Volts,*
- *49.96 Hz,*
- *deformed sine* (expressed similarity of the displayed curve),
- *amplitudes -1.00* (ratio of amplitude size),
- *phase 1.00* (ratio of amplitude distances),
- *alternating course,*
- *1st quadrant – positive minor deviation*
- *2nd quadrant – negative mean deviation,*
- *3rd quadrant – negative mean deviation.*

The measured signal resembled a sine, and in contrast to the sine, it was on average above the notional sine in the first quadrant, and on average below the notional sine in the second and third quadrants. The RUDO system provides information on the small, medium or large deviation in the given quadrants. In the fourth quadrant, the signal matched the notional sine, so the deviation was not expressed.

APPENDIX E

DESCRIPTION OF THE ILLUSTRATIVE VIDEO

The video is part of the online version of this article and is available in IEEE Xplore Digital Library. The video

is also supplementary downloadable material available at <https://doi.org/10.5281/zenodo.5878546>, provided by the authors. The activities performed by a person with blindness in this video are described in more detail in this appendix. The video is divided into two parts.

A. PART 1: THE WAY OF CONNECTING ELECTRICAL CIRCUITS BY A PERSON WITH BLINDNESS WITHOUT THE NEED OF ASSISTANCE

The example includes the connection of a DC/DC converter to a miniature screw terminal block and testing its functionality in a designed device. DC/DC converter is connected into miniature screw terminal block, commonly available in electrotechnical equipment stores. The DC/DC converter has six contacts, which means that in two cases two contacts are connected at the same time to one socket. After connecting the DC/DC converter, the laboratory power supply is switched on to keep the device energized. Person with blindness measures the voltage at the input and also at the output of the DC/DC converter. This will ensure that it works correctly in the given connection.

A power switcher is connected to the constructed device. In our case, the power switcher should switch the power supply of the appliances to either photovoltaics or the mains. The device with DC/DC converter is connected to the LAN and via the second wire is connected to the power switcher, i.e.:

- the software on the home server will control this device with a DC/DC converter via LAN,
- a device with a DC/DC converter will command the power switcher to switch the power current.

The power switcher is turned on and the person with blindness goes to the computer, where he runs a test program to test the entire connection. The test program taps the relay three times and waits a while. The test program repeats this sequence until it is interrupted. In the end, the contacts of the power relay were measured with an audible short-circuit meter, which always started to emit a whistling tone when the state was switched on. This debugged the functionality of the hardware and its data connection to the home server.

B. PART 2: PREPARATION OF MECHANICAL COMPONENTS FOR DEVICE CONSTRUCTION

The example includes cutting a board made of pertinax material on miter saw and its further modification. This modification involves grinding the edge of the cut board and drilling holes for further assembly of the board using a steel stencil and a meter marked in Braille. Finally, two miniature screw terminal blocks can be glued to the board prepared in this way.

APPENDIX F DETAILED DESCRIPTION OF THE QUALITATIVE EVALUATION

The qualitative research is based on the rigorous performance and detailed description of the individual steps. That's why

the realised procedure is presented in this Appendix along with the findings of the qualitative evaluation using the cognitive walkthrough method.

A. ASSISTANCE WITH THE IDENTIFICATION OF COMPONENTS AND THE USE OF SELECTED TECHNOLOGIES FOR THE CONNECTION OF CIRCUITS BY DESIGNERS WITH BLINDNESS

The first prerequisite of designing the task to connect circuits by a designer with blindness is the existence of electrotechnical components which are sorted into small drawers labelled in Braille. When purchasing such components, it must be noted that their contacts need to be long enough for the connection into screw terminals. The second prerequisite is the literacy of the person with blindness concerning the Braille system.

The basic order for the task involving the connection of circuits by a designer with blindness is divided into four steps presented in Task A.

Task A:

1. to find the electrotechnical component in the drawers,
2. to insulate the part of the contact using insulation sleeving.
3. to plug the uninsulated parts of the contacts into the screw terminal blocks,
4. to screw the contacts into the blocks.

Three EQs were formulated in connection with the evaluation:

EQ1: Is the designer with blindness, prior to commencing the work, aware of his or her ability to connect electronic circuits using the tools set forth in Task A (or Section IV.A)?

EQ2: Is the designer with blindness able to select (repeat, combine) individual steps of the technological procedure according to Task A in such a way that would contribute to achieving the expected outcome or solution?

EQ3: At the end of the process, is the designer with blindness certain of having achieved the expected outcome?

First of all, the answers to the three EQs are provided; subsequently, the specific manner of connecting the individual components is assessed along with the work efficiency of the designer with blindness. The answer to **EQ 1 and 2** is linked to the dexterity of the given designer, in particular. Task A can be performed in practice by every person with blindness capable of doing basic personal self-care tasks and of using the Braille system. However, the development of electrotechnical devices is also associated with the person's education background (knowledge of electrotechnics). As for the case presented in this article, the dexterity of the person with blindness is of a really high level, as the designer had constructed various devices using this method.

Therefore, **EQ3** constitutes the question related to Task A of higher importance. The expected solution in this case is a contact with low transient resistance, which can be stressed mechanically without changing the quality of the contact. Provided that the component contact is plugged in correctly under the lamella under the screw and screwed tightly, the designer can try mechanically whether the con-

tact can be easily removed from the screw terminal block. If the screw is tightened sufficiently in the component contact, the construction of screw terminal block with lamellas ensures that the requested transition resistance is sufficiently low. The accuracy of the solution can be verified by the person with blindness by simply pulling the component contact.

Connecting complex circuits only involves the repeating of the aforementioned basic steps. Complexity of circuits does not place higher demands on using the sense of touch, however, higher demands are placed on the talent, education background and skills of the designer in this area. This is the way the authors decided to divide their experiment, concerning the construction of repeated simple basic steps, which serves as a proof that this solution is of significance to the entire target group of people with blindness, see Section II.B. Moreover, as for the labelling of the drawers, the authors used the common standard of the Braille system used in the community of people with blindness worldwide.

From the perspective of the qualitative evaluation of the connected circuits, upon several years of testing, the authors can state that, in general, the circuits connected this way worked flawlessly for over 10 years. In certain cases, the connections worked even for twenty years. From the perspective of repairs and improvement, the terminal system had very satisfactory outcomes, as it enables the performance of modifications as necessary.

The terminal circuits can thus compete with the flat board, or the circuitry connected to the bootlace ferrules, which would be used by designers without visual impairment. The disadvantage of the terminal block solution is the fact that the product is physically larger, which is not as big of a problem during the development stage. In the production of consumer electronics, this solution is unusable.

From the perspective of time, the comparison between a designer with blindness and a designer without visual impairment is problematic, as the latter uses a soldering iron and flat boards or insulated crimp bootlace ferrules.

Generally, one could say that the construction time required by a person with blindness and a person without visual impairment is very similar. However, the designer with blindness loses approximately 20% of time by finding the components or acquiring information from the electrotechnical components catalogues. Working without visual impairment helps obtain information very quickly.

On rare occasions, certain situations may occur during the construction that are even much more time-demanding. A component falling on the floor, looking for information on the Internet, availability of the construction place only using the sense of touch, etc. Work efficiency of the person with blindness would be much better at a workplace where also people without visual impairment could be found who would be willing to help the designer with blindness if need be. To avoid burdening the person without visual impairment with excessive supporting tasks, such assistance should only be demanded on very rare occasions. Assistance to people

with blindness could thus be compared to mutual assistance of colleagues without visual impairment.

The connection of high-current circuits using WAGO terminals, Faston connectors and end sleeves was not included in the evaluation, since a person with blindness takes identical actions during the performance of this activity as a person without visual impairment. The performance of this activity does not require any great challenges with respect to the sense of touch, dexterity or intellectual capacity. This way of connecting high-current circuits was mentioned in the article just for the sake of completeness concerning the work performed by a designer with blindness.

B. WORK WITH MECHANICAL COMPONENTS FOR DEVICE CONSTRUCTION

Various products are being manufactured these days which are designed for the encapsulation of electrical circuits. In order to fulfil the required purpose, the boxes sold only need minimum adaptation. Such adaptation can be performed even by a person with blindness. For this purpose, 2 tasks comprising four steps are presented below.

Task B:

1. to fix the deck to the vice,
2. to attach a steel model to the edge of the deck and making a hole,
3. to insert the drill into the hole,
4. to perform the drilling.

Task C:

1. to measure the distance on the material using a steel T-square and a meter marked in Braille, laid directly on the miter saw stand,
2. to fasten the material to the saw stand using bolts,
3. to grip the lever with the saw switch with two hands to prevent any harm (the hands are thus out of the cutting level),
4. to saw the material to the required length.

Tasks B and C involve the preparation and machining of mechanical components for the device construction. Although these tasks only constitute a supportive activity in hardware development, they are significant when evaluating the overall independence of a designer with blindness. As for the machining of materials, the activities are highly variable; for the purposes of this article, all such activities can be performed by repeating the basic steps.

Three EQs were formulated in connection with the evaluation:

EQ1: Is the designer with blindness, prior to commencing the work, aware of his or her ability to prepare and machine the mechanical components for device construction using the tools set forth in Task B and C (or Section IV.B)?

EQ2: Is the designer with blindness able to select (repeat, combine) the individual steps of the technological procedure according to Tasks B and C in such a way that would contribute to achieving the expected outcome or solution?

EQ3: At the end of the process, is the designer with blindness certain of having achieved the expected outcome?

Prior to answering the three EQs, it must be noted that these are only related to those people with blindness who have natural technical talent and dexterity, i.e. who are capable of performing technical tasks. Hardware encapsulation machining can also be performed by a technical assistant at the given workplace. First of all, the answers to the three EQs are provided; subsequently, the work efficiency of the designer with blindness is evaluated.

The positive answer to **EQ1** is associated with the training and technical dexterity of the designer with blindness. To be certain of being capable of performing the required procedure successfully, the designer with blindness needs to use the sense of touch to become familiar with all possible T-squares, models, and tools, and he or she must be informed of the possibility to use such technical aids and tools. As for the **EQ2**, the positive answer is given only by the technical dexterity of the designer with blindness. To provide an answer to **EQ3**, the purpose of the activity is to verify the accuracy of the procedure and the details of technical work performed by the designer. When the designer with blindness drills two holes through which the screws securing the hardware component are to pass, the designer can verify the correctness and accuracy of the procedure by screwing this component. If the hole is moved improperly, making it impossible to screw to component into it, additional adjustments are required, where more dexterity and estimation might be needed. Therefore, it may sometimes be better to use the given hardware component directly instead of a T-square or a model and to pre-drill holes using this component. However, this option is not available for soft-material components or components consisting of fine electronics.

It must be noted that a person with blindness may drill or mark out certain distance only by using steel T-squares. Distance variability is thus lower than if a designer without visual impairment marks out precisely as many millimetres as designated for the given purpose. As this particular task concerns development hardware (prototype), that detail can be considered as insignificant.

When comparing the time demands of the work performed by a designer without visual impairment and a designer with blindness with respect to the two examples of the basic procedures of Task B and C set above, as for Task B, the latter is faster by 50%; as for Task C, the latter is slower by 60%. As for the first case, the designer without visual impairment is slower due to the fact that, firstly, he or she must measure the distance using a measuring scale (designers without visual impairment do not use steel models for their work), mark out the distance and, only then, the drilling can be performed. The designer with blindness only attaches the steel T-square and performs the drilling right away. In the second case, the designer with blindness gets delayed by measuring the distance only by touch and also due to the need to use the T-square.

The preparation of the materials requires drilling and sawing of all sorts of combinations. Since a person with blindness carries out certain activities sooner and some of the others later on, the overall preparation time is comparable with the time demands on the work of a designer without visual impairment. The authors based this comparison on the use of semi-finished decks which can commonly be purchased, provided that the designer with blindness has experience with the aforementioned activities.

C. PROGRAMMING OF SOFTWARE DRIVERS

The evaluation of the purposefulness and efficiency of programming software, which provides assistance to designers with blindness, should be based on certain standards. These standards have been tried and tested by people with blindness when using compensatory aids or when using common assistance software of computer workstations. Software modules of the RUDO system used for programming are based on the undermentioned implicit standards shared with other software programmes to support the work of people with blindness:

- selection menu items arranged one below another to enable easy orientation of the person with blindness, selection by means of vertical arrows, selection and exit by means of horizontal arrows, or more precisely using the ENTER and ESC keys,
- work with data exclusively in the text mode directly displayed on the tactile touchscreen or expressed using speech synthesis,
- using the system cursor for text editing and orientation in dialogues,
- using speech synthesis,
- using the tactile touchscreen,
- automatic movement of the cursor to a place in the text read by touch,
- uppercase / lowercase lettering by changing the colour of tone of speech synthesis or on the tactile touchscreen by means of the seventh dot of the Braille system.

The basic sequence of operations in coding and debugging programmes for designers with blindness is given by six steps.

Task D:

1. initialisation of the programming environment,
2. programme coding,
3. syntax error detection,
4. syntax error fixes,
5. search for runtime errors and incorrect codes,
6. runtime error and incorrect codes fixes.

This procedure or its part is repeated by the programmer until reaching the required purposefulness of the created programme. Three EQs were formulated in connection with the evaluation:

EQ1: Is the designer with blindness, prior to commencing the work, aware of his or her ability to do programming using the tools set forth in Section IV.C?

EQ2: Is the designer with blindness able to select (repeat, combine) individual steps of the technological procedure according to Task D in such a way that would contribute to achieving the expected outcome or solution?

EQ3: At the end of the process, is the designer with blindness certain of having achieved the expected outcome?

First of all, the answers to the three EQs are provided; subsequently, the work efficiency of the designer with blindness is evaluated. The positive answer to **EQ1** is associated with the experience of using the HANIBAL user interface. Upon switching on the computer, the screen of the HANIBAL interface is displayed (Appendix A). This special interface enables the person with blindness to go through the screen structure and to listen to what is said with respect to each of the items or to read a short text aid while using some of the aforementioned seven standards. Even during the first use of this interface, the person with blindness can thus easily find the programming screen. If using the HANIBAL interface for a longer period of time, the programming screen can be selected by a single keystroke of the character (in Braille) designated for the programming item. In the pre-defined screen structure, it is the character “m”.

When finding the answer to **EQ2**, one must assume that the user with blindness has reasonable experience and education background in the area of programming. The degree of correctness of selecting the next step is thus given by the education background, experience and abilities of the programmer with blindness.

As for the programmer’s direction to the expected solution, the following features of the development environment must be taken into consideration.

- a) During the initialisation of the programming screen, the HANIBAL interface informs the person with blindness of the fact that the screen has been opened and is thus ready for work.
- b) While performing the coding, a special editor informs the programmer with blindness of the number of lines and of the cursor coordinates. At the same time, the editor allows editing text using the aforementioned seven standards.
- c) When detecting syntax errors automatically by compiler, the cursor is placed by the interface on the first syntax error and informs the person with blindness of its character and coordinates of the cursor. The editor is switched automatically to the edit mode. When the error is fixed, the progress is reflected either on the basis of the new cursor coordinates or on the fact that no further syntax errors are found in the programme code.
- d) When detecting the runtime errors, the system communicates with the person with blindness in a similar way; if the person with blindness needs to improve the code, he or she uses the aforementioned standards for text editing.

Based on the properties of the interface (a) to (d), the user realises the progress and is able to determine even the precise degree of approaching the correct solution. This is also related to the positive answer to **EQ3**. The programming interface

informs the user with blindness of whether all the syntax errors or runtime errors have been fixed. The functioning of the programme being developed by the designer with blindness is assessed based on meeting the set requirements.

Programming complex and vast programmes only involves the repeating of the aforementioned sequence of basic steps. The complexity of the programmed software systems does not place higher demands on the sense of touch, but it places demands on the talent, education background and experience in this field, manifested, for example, by the right degree of modularity of the developed software.

From the perspective of further evaluation of the developed software, there is no reason why software programmed by a person with blindness should be of poorer quality than software programmed by a programmer without visual impairment. The only exception to this is the programming of graphic user interfaces or the display of any other graphics where the programmer with blindness cannot achieve the adequate visual feedback. In terms of time, the comparison with a programmer without visual impairment can be divided into three levels that take turns during text editing:

- a) writing text,
- b) orientation in text,
- c) reading text.

When writing text, the person with blindness may acquire an equal degree of dexterity and speed as a person without visual impairment who can type with 10 fingers. In order to find bearings in the text, a person with blindness uses the aforementioned seven implicit standards in combination with compiling adjustment for people with blindness described above. Based on these special adjustments, on average, a person with blindness can work faster than a person without visual impairment by 20%. However, the talent and experience of the given programmer with blindness or without visual impairment needs to be considered. The work of a programmer who has more talent and experience is always performed at a faster pace.

In certain cases, the reading of programme texts by speech synthesis prevents the programmer from working at his or her standard speed. For example, the reading of characters such as “(){}[]”, and so on, takes a long time since they require even up to three words to explain the given symbol. When there is a large number of such characters per programming line, the person with blindness combines the speech synthesis and tactile touchscreen, by means of which reading of the given characters is much faster. The characters are written in Braille and they only require one character position.

On the other hand, reading of other texts by means of touch can take longer than by means of speech synthesis, as the person with blindness can switch to a faster mode of reading by speech synthesis and become accustomed to reading at such a pace that a person without practice would no longer be able to perceive the contents of the text.

On average, reading programming text takes longer to a person with blindness than to people without visual

impairment. In certain cases, the delay can be even of up 30% of time. This is where the dexterity of the reading skills of the person with blindness must be taken into consideration. A person with blindness finds obtaining information as the most difficult part of this kind of work.

Programming is associated with the combination of writing, reading and orientation in text, and that's why the speed of work can be hardly generalised. However, the slow-down during the reading process is compensated for by the significantly fast orientation of the person with blindness which, in association with fast typing, can often lead even to a faster pace of work of a person with blindness compared to a person without visual impairment. Generally, one could thus say that the programming speed of performance of people with blindness is comparable with the speed of programmers without visual impairment. What could take longer for a person with blindness is, however, the seeking of information or browsing libraries via the Internet. This is where a colleague without visual impairment can be of great assistance.

D. HARDWARE TESTING AND SOFTWARE DRIVER DEBUGGING

Driver debugging in this subsection is not identical to the software programming in Section V.C, which concerned software exclusively. A driver is a specific kind of software closely linked to hardware. Speaking of development, hardware is developed concurrently with its software driver. Debugging is thus associated with the correct functioning of the hardware and with the communication between the hardware and its software driver.

Hardware testing and driver debugging with respect to the hardware consists of repeating and rotation of the procedures for hardware construction and software programming. These procedures are evaluated in the subsections above. This subsection will thus provide the specification of two basic tasks, the repeating of which is performed for hardware testing in connection with software driver debugging.

In the first case, the task is divided into six steps, assuming that the relevant hardware is already installed in the place of use (e.g. intelligent building).

Task E:

1. software driver coding, hardware construction,
2. software driver compilation and installation,
3. initialisation of a new service and client application,
4. movement throughout the building interior in connection with the possibility of adjustment of the hardware connection and location,
5. monitoring of notification sounds and announcements using the house speakers, transmitter or the speaker of the computer station,
6. alternative adjustment of software or hardware.

In the second case, the task is divided into five steps, assuming that the relevant hardware is tested on a work desk in a laboratory and is to be installed in the place of use only in the future.

Task F:

1. software driver coding, hardware construction,
2. software driver compilation and installation,
3. initialisation of a new service and client application,
4. monitoring of notification sounds and announcements using the laboratory speakers and the speaker of the computer station,
5. alternative adjustment of software or hardware.

Some of the aforementioned steps in Task E and F are non-trivial and thus evaluated separately in the appendix subsections A, C, E and F (hardware construction, software programming, using a multimeter or an oscilloscope). By means of that, the authors show that all non-trivial steps can be divided according to the sequence of other activities. Hardware testing along with the driver debugging is then comprised of repeating the sequences of Tasks E and F.

Three EQs were formulated in connection with the evaluation:

EQ1: Is the designer with blindness, prior to commencing the work, aware of his or her ability to debug hardware driver using the tools set forth in Section IV.A, IV.C, IV.E, IV.F?

EQ2: Is the designer with blindness able to select (repeat, combine) the individual steps of the technological procedure according to Task E and F in such a way that would contribute to achieving the expected outcome or solution?

EQ3: At the end of the process, is the designer with blindness certain of having achieved the expected outcome?

First of all, the answers to the three EQs are provided; subsequently, the work efficiency of the designer with blindness is evaluated. The answer to **EQ1** is positive and arises to a certain extent from the aforementioned outcomes presented in appendix subsections A–C. The installation and initialisation of the service can be performed by the user with blindness using the command line by means of the HANIBAL interface (Appendix A).

Provided that the designer with blindness is in a well-known environment, moving around the building does not constitute a problem for him or her. A problem arises in a situation where the hardware is located beside other unrelated devices which may also be stored in a special locked room or a box. In such case, the person with blindness needs to be assisted by the relevant technical assistant. Due to this, it is better to organise hardware storage in such a way that would make the designer with blindness independent even in this case.

As for the answer to the **EQ2**, one must realise that the step that makes the person with blindness approach the solution is given exclusively by his or her professional capacity and it is unrelated to the visual impairment. A positive answer can also be provided with respect to **EQ3**. The correct solution for this case is the accomplishment of the purpose for which the relevant hardware and software driver is developed. The accomplishment of the purpose can also be tested either by a test programming application or directly by using the hardware and its driver for the purpose for which it has been

designed. A programmer with blindness is capable of performing such purpose testing. Appendix subsection C proved that a designer with blindness is capable of creating general programme applications.

Evaluation in terms of time and quality was performed by the authors in this subsection solely with respect to Step 4 of Task E, which the person with blindness may perceive as challenging. If situated in a well-known environment, the speed and quality of the work can be compared to the speed and quality of work of a person without visual impairment. However, in the event of an unknown location, the performance of a person with blindness can take up to several times longer than the work of a person without visual impairment. Moreover, if the tested hardware is also installed in other devices within the building, handling it may even cause damage to the hardware. That's why it is very important that in the event of location in an unknown environment, within Step 4 of Task E, enough time should be spent by familiarising the person with blindness with the environment and the place of installation of the tested hardware. This task would best be performed by a technical assistant or a colleague willing to provide such one-off assistance.

E. MEASURING ELECTRICAL CIRCUITS USING A MULTIMETER

In appendix subsection A, the authors focused on the construction of electrotechnical devices from the perspective of physical connection of the individual electrotechnical components. However, the development of functional electrotechnical devices requires measuring even them, i.e. measuring the components and electrotechnical quantities in the parts of the circuits that are physically connected. Due to that, this activity is evaluated separately in appendix subsections E and F.

Measuring electrotechnical quantities by a person with visual impairment must be divided into two types of activities which will be evaluated separately,

- a) operation of measuring equipment,
- b) acquisition and understanding of measured data.

The operation of measuring technology is similar to the operation of single-purpose aids for people with blindness, which have already been tested in practice and accepted by the users with blindness. Therefore, the conclusions of the authors are based on the tried-and-tested implicit standards:

- when using the control, the device announces a change of status using speech synthesis,
- the device enables the acquisition of information about the current state using speech synthesis,
- the device reports a change of status separately, provided that the change occurred on the basis of automation, without user intervention,
- the device informs the user about the states in an easy and understandable way.

When measuring electrical quantities using a multimeter, the RUDO system, or its modules installed in a laptop, provide the person with blindness with assistance. From the

perspective of comfort of work of the person with blindness, work in a laboratory equipped with the full version of the RUDO system is preferred, as the person with blindness has a better overview of the work desk and its surroundings. In the laboratory, notifications are made by means of a speaker that constitutes a part of the RUDO system. To generate reports, the RUDO system software module used all of the above tested standards. The basic task for operating a multimeter by a user with blindness is given in seven steps.

Task G:

1. connecting the device,
2. switching on the device
3. setting the required value,
4. additional settings,
5. suspension and resumption of measurement,
6. switching off the device,
7. disconnecting the appliance.

From the perspective of understanding and acquiring the measured data, the authors divided the measurement into the repeating of the basic sequences of the four steps set forth below.

Task H:

- 1) connection, switching on and setting up the device,
- 2) connection of leads to the measured circuit nodes,
- 3) listening to speech synthesis that conveys data from a multimeter or an oscilloscope display,
- 4) switching off and disconnecting the device from the assistive AmI system.

All required measurements of electrotechnical quantities are feasible by repeating the aforementioned Tasks G and H or their parts. Three EQs were formulated in connection with the evaluation:

EQ1: Is the designer with blindness, prior to commencing the work, aware of his or her ability to do the measurement by means of a multimeter using the tools set forth in Section IV.E (including the assistance provided by the RUDO system)?

EQ2: Is the designer with blindness able to select (repeat, combine) the individual steps of the technological procedure according to Task G and H in such a way that would contribute to achieving the expected outcome or solution?

EQ3: At the end of the process, is the designer with blindness certain of having achieved the expected outcome?

First of all, the answers to the three EQs are provided; subsequently, the work efficiency of the designer with blindness is evaluated. The user with blindness must be aware of having available the measuring technology, however, this information can also be found separately using the auxiliary window of the HANIBAL interface in the part called "Electrotechnics". The user must be familiarised with the technical manual of the relevant measuring technology to prevent any harm of the technology or the measured circuits. Once the user with blindness becomes familiarised with the technical equipment, he or she can make the connections independently and test all the setting options; the RUDO system provides

voice guidance. Under such circumstances, the answer to **EQ1** is positive.

The answer to **EQ2** can be formulated as follows: When encountering any change to the measuring technology settings, the user with blindness gets feedback by means of a short notification of the new settings. Such notification can be acquired by the repeated use of the control on the measuring device, which is placed directly on the worktable (multimeter or oscilloscope). Other steps helping the person with blindness approach the solution are, in this case, given solely by his or her professional capacity and are unrelated to the visual impairment of the person.

As for the answer to the **EQ3**, the correct solution is given exclusively by the person's professional capacity and it is unrelated to the visual impairment. However, in order to be able to use his or her expertise, the person with blindness must understand correctly the measured data reported by the speakers during the course of the measurements. That's why the notifications are designed in such a way that provides the shortest, yet understandable reports on the measured values and quantities. When changing the measured data, the notifications are repeated automatically.

During the qualitative comparison of data acquisition performed by a person without visual impairment, the quality is equal with the exception to very fast changes of the measured data. If several other changes take place on the display during one course of notification, the person with blindness might miss a piece of data which could be of importance. However, most measurements do not require fast data monitoring. If the person with blindness needs to read data quickly, this insufficiency can be compensated for in two ways:

- by longer measuring period (compared to a person without visual impairment),
- by measuring the maximum or minimum of the given value.

In the first case, data loss may be encountered; in the second case, when it comes to acquiring the minimum or maximum values, the values are produced quickly and accurately. The construction of the RUDO system by the person with blindness did not require fast data reading due to the fast changes of the measured values (e.g. three times per second). Due to this, it can be assessed that a designer with blindness can perform the measurements as quickly and accurately as a designer without visual impairment. The person with blindness can adjust the speed of the speech synthesis and often uses speed unacceptable for audience without practice.

F. MONITORING OF THE WAVEFORM OF THE ELECTRICAL SIGNAL USING AN OSCILLOSCOPE

Evaluation of the operation of an oscilloscope is not presented in this subsection, since it is practically identical to the operation of a multimeter evaluated in appendix subsection E above. Furthermore, the basic sequence of steps of Task I is proposed, which the authors use in evaluation of the collection of graphic data and in evaluation of the automated

description of the course of the monitored waveform of the electrical signal.

Task I:

1. connection of the oscilloscope to the assisting AmI system, switching it on,
2. setting the measured quantity using control elements,
3. connection of leads to the measured circuit nodes,
4. turning on the automatic calibration of the curve on the display,
5. listening to speech synthesis that conveys the shape of the curve on the oscilloscope display,
6. switching off and disconnection of the oscilloscope from the assistive AmI system.

All measurements on the oscilloscope can be performed by repeating the steps above using the RUDO system. Three EQs were formulated in connection with the evaluation:

EQ1: Is the designer with blindness, prior to commencing the work, aware of his or her ability to use the oscilloscope using the tools set forth in Section IV.E and IV.F (including the assistance provided by the RUDO system)?

EQ2: Is the designer with blindness able to select (repeat, combine) the individual steps of the technological procedure according to Task I in such a way that would contribute to achieving the expected outcome or solution?

EQ3: At the end of the process, is the designer with blindness certain of having achieved the expected outcome?

First of all, the answers to the three EQs are provided; subsequently, the work efficiency of the designer with blindness is evaluated. Under the following circumstances, the answer to **EQ1** is positive. The user with blindness must be aware of having available an oscilloscope, however, this information can also be found separately using the auxiliary window of the HANIBAL interface in the part called "Electrotechnics". The user must be familiarised with the technical manual of the oscilloscope to prevent any harm of the technology or the measured circuits. Once the user with blindness becomes familiarised with the technical equipment, he or she can make the connections independently and test all the setting options; the RUDO system provides voice guidance.

The answer to **EQ2** can be formulated as follows: When encountering any change to the oscilloscope settings, the user with blindness gets feedback by means of a short notification of the new settings. Such notification can be acquired by the repeated use of the control on the oscilloscope. Other steps which help the person with blindness approach the solution are, in this case, given solely by his or her professional capacity and are unrelated to the visual impairment of the person.

As for the answer to the **EQ3**, the correct solution is given exclusively by the person's professional capacity and it is unrelated to the visual impairment. However, in order to be able to use his or her expertise, the person with blindness must understand correctly the formulations of the automated description of the curve, which is of the highest importance when using an oscilloscope by a person with blindness. The curve description method is defined in more detail in Section IV.F.

When comparing the speed and quality of work with a designer without visual impairment, at this point, the evaluation of the work performed by people with blindness being supported by an assistant is poorer. From a qualitative point of view, a person without visual impairment can see a number of details on the curve, which can be available to the person with blindness only in general or if a special recognition algorithm is programmed for the given specific curve. Despite the fact that such algorithms can be programmed by the person with blindness additionally, such situation constitutes such a disadvantage that the quality of the measurement can easily be affected. An oscilloscope can provide the person with blindness with very much assistance, but this assistive system cannot fully substitute the advantage of being able to visualise the details.

In terms of time, the description of the curve is quite lengthy, what the person with blindness needs to hear within a medium-long notifications (4–8 sec), a person without visual impairment can see the description immediately. If an oscilloscope should constitute the dominant measuring device used by the person with blindness during the development, even in the case of a high-quality description of the curves, the designer with blindness will be significantly slower than his or her colleague without visual impairment. Nevertheless, if an oscilloscope is only a supplementary tool used on rare occasions, the automated assistance in this area helps improve the independence of the designer with blindness to a reasonable extent.

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