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Nancy L. Black · W. Patrick Neumann ·
Ian Noy *Editors*

Proceedings of the 21st Congress of the International Ergonomics Association (IEA 2021)

Volume II: Inclusive Design



Lecture Notes in Networks and Systems

Volume 220

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Nancy L. Black · W. Patrick Neumann ·
Ian Noy
Editors

Proceedings of the 21st Congress of the International Ergonomics Association (IEA 2021)

Volume II: Inclusive Design

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Preface

The International Ergonomics Association (IEA) is the organization that unites Human Factors and Ergonomics (HF/E) associations around the world. The mission of the IEA is “to elaborate and advance ergonomics science and practice, and to expand its scope of application and contribution to society to improve the quality of life, working closely with its constituent societies and related international organizations” (IEA, 2021). The IEA hosts a world congress every three years creating the single most important opportunity to exchange knowledge and ideas in the discipline with practitioners and researchers from across the planet. Like other IEA congresses, IEA2021 included an exciting range of research and professional practice cases in the broadest range of Human Factors and Ergonomics (HF/E) applications imaginable. While the conference was not able to host an in-person meeting in Vancouver, Canada, as planned by the host Association of Canadian Ergonomists/*Association canadienne d’ergonomie*, it still featured over 875 presentations and special events with the latest research and most innovative thinkers. For this congress, authors could prepare a chapter for publication, and 60% chose to do so. The breadth and quality of the work available at IEA2021 are second to none—and the research of all authors who prepared their publication for this congress is made available through the five volumes of these proceedings.

The International Ergonomics Association defines Human Factors and Ergonomics (HF/E) synonymously as being:

the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance.

Practitioners of ergonomics and ergonomists contribute to the design and evaluation of tasks, jobs, products, environments and systems in order to make them compatible with the needs, abilities and limitations of people.

Ergonomics helps harmonize things that interact with people in terms of people’s needs, abilities and limitations. (<https://iea.cc/definition-and-domains-of-ergonomics/>)

The breadth of issues and disciplines suggested by this definition gives one pause for thought: what aspect in our lives is not in some way affected by the design and application of HF/E? For designers and managers around the world, a similar realization is growing: every decision made in the design and application of technology has implications for the humans that will interact with that system across its lifecycle. While this can be daunting, the researchers and professionals who participated in IEA2021 understand that, by working together across our disciplines and roles, we can achieve these lofty ambitions. This is especially relevant as we continue our collective journey into an increasingly “interconnected world”—the theme for the 21st IEA Congress. With the rise of a myriad of technologies as promulgated by Industry 4.0 proponents, we need now, more than ever, the skills and knowledge of HF/E researchers and practitioners to ensure that these tools are applied in a human-centric way towards resilient and sustainable systems that provide an enduring and sustainable road to prosperity—as advocated in the new Industry 5.0 Paradigm (Breque et al. 2021). Where the trend of Industry 4.0 aims primarily at encouraging technology purchasing and application, Industry 5.0 includes goals of resiliency and sustainability for both humans and our planet. These proceedings provide examples of research and development projects that illustrate how this brighter, human-centred future can be pursued through “*Ergonomie 4.0*”, as stated in the French theme of the Congress.

While the theme of the Congress concerns human interactions within a rapidly evolving cyber-physical world, the devastating impact of the COVID-19 pandemic has given an added dimension to the Congress theme and its delivery model. As the pandemic began to engulf the world, the traditional in-person Congress became increasingly less viable and gave way to the creation of a hybrid model as a means to enhance international participation. In early 2021, it became clear that holding an in-person event would not be possible; hence, the Congress was converted to a fully virtual event. The uncertainty, mounting challenges and turbulent progression actually created new possibilities to engage the global HF/E community in ways that were never previously explored by the IEA. Indeed, one of the scientific tracks of the congress focuses explicitly on HF/E contributions to cope with COVID-19, and readers will find some submissions to other tracks similarly focus on what HF/E practitioners and researchers bring to the world during this pandemic period. This journey epitomizes broader transformative patterns now underway in society at large and accentuates the urgency for resilience, sustainability, and healthy workplaces. No doubt, the notion of globalization will be redefined in the wake of the pandemic and will have far-reaching implications for the connected world and for future society, and with new paradigms emerge a host of new human factors challenges. The breadth of topics and issues addressed in the proceedings suggests that the HF/E community is already mobilizing and rising to these emerging challenges in this, our connected world.

IEA2021 proceedings includes papers from 31 scientific tracks and includes participants from 74 countries across 5 continents. The proceedings of the 21st triennial congress of the IEA—IEA2021—exemplify the diversity of HF/E, and of the association, in terms of geography, disciplines represented, application

domains, and aspects of human life cycle and capability being considered. Our diversity mirrors the diversity of humans generally and is a strength as we learn to weave our knowledge, methods, and ideas together to create a more resilient and stronger approach to design than is achievable individually. This is the strength of the IEA congresses, in the past, in the current pandemic-affected 21st occasion, and in the future. There is no other meeting like it.

A substantial number of works were submitted for publication across the Scientific Tracks at IEA2021. This gave us the happy opportunity to group contents by common threads. Each volume presents contents in sections with papers within the track's section presented in alphabetical order by the first author's last name. These proceedings are divided into five volumes as follows:

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Activity Theories for Work Analysis and Design (ATWAD)
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Advanced Imaging
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Neuroergonomics
Working with Computer Systems

These volumes are the result of many hours of work, for authors, Scientific Track Managers and their reviewer teams, student volunteers, and editors. We are grateful to Springer for making it available to you in book form and are confident you will find these works informative and useful in your own efforts to create a better, more human-centred future.

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IEA2021 Acknowledgements

The IEA Congress organizing committee acknowledges many individuals whose contributions to the event have been invaluable to its success.

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The Organizing Committee is also indebted to those contributors who were instrumental in developing and promoting IEA2021. Joanne Bangs, our freelance Communications Specialist, provided engaging news blogs and other promotional collateral to help get the word out about the Congress. Sadeem Qureshi (Ryerson University), Elizabeth Georgiou, Elaine Fung, and Michelle Lam (Simon Fraser University) helped to create widespread awareness of the Congress as well as the HF/E field and profession through creative use of digital and social media. We are also grateful to those who worked diligently to ensure that the Congress provided meaningful opportunities for students and early career researchers, including Daniel P. Armstrong and Christopher A.B. Moore (University of Waterloo), Owen McCulloch (Simon Fraser University), Dora Hsiao (Galvion, Inc.), Chelsea DeGuzman and Joelle Girgis (University of Toronto), and Larissa Fedorowich (Associate Ergonomist, self-employed). The ePoster presentation option, new to IEA triennial congresses in 2021, was defined with care by Anne-Kristina Arnold (Simon Fraser University). Colleen Dewis (Dalhousie University) was key to

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The organizers are especially grateful to our sponsors, whose generous contributions made the Congress possible and readily accessible to the global HF/E community. Their recognition of the Congress as a valuable opportunity to advance the field of HF/E, as well as their steadfast support throughout a very trying planning period, was critical to the success of the Congress. The IEA 2021 sponsors include:

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**Part I: Ageing and Work (Edited by Jodi
Oakman)**



Designing Smart Ring for the Health of the Elderly: The CloudIA Project

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Abstract. This paper describes the design and development of a wearable device, able to monitor physiological data, movement and falls, for fragile older person who require health care. Some approaches of Universal Design and Human-Centred Design were used, which allowed to evaluate and design the interaction between the person and the system. From a design point of view, studies on wearability and the most appropriate landmarks of the human body were carried out, suitable for monitoring heartbeat, movement and falls. From an engineering point of view, the main challenge was the miniaturization of the electronic components for the development of a wearable device to be placed on a small surface of the body, able to allow the performance of daily activities without altering the natural movements of the user, also considering the physical limitations of older and fragile people. Our results indicate how digital technologies, specifically wearable, can be a resource to support the independence and psycho-physical well-being of old people. The next step of the research program concerns the experimentation with a significant sample of typical users (elderly and socio-health professionals), both in nursing home and at home.

Keywords: Wearable · Smart ring · Elderly · Human-Centred Design · Universal design · Multidisciplinary approach

1 Introduction

The process of population aging is occurring throughout the world and the number of older people is expected to grow steadily over the coming decades, both at European and global level [1, 2]. According to ARS Toscana [3], the Regional Health Agency that deals

with consulting and research for elderly in Tuscany, by 2060 almost a third of Europeans will be over 65 and demographic trends in Tuscany are even more pronounced. A study conducted by ARS in 2014 demonstrated that elderly in Tuscany were 916.640 and will increase up to 36% of the population in 2050.

Old people are more subject to illness and disability, in fact around 51% of the elderly in Tuscany declare to suffer from a chronic or long-term illness [3]. However, despite health problems, most of them hope to be able to live in their own home as long as possible. Although such desire can be interpreted as an improvement in the quality of life, it is strongly related to the risk of domestic accidents, such as falls, and social isolation, such as depression and loneliness. This condition often requires that the older persons should move from their home to the nursing home, radically changing their everyday life.

The demand for products and services dedicated to the care and support of the elderly at home is becoming increasingly high, especially for what concerns diagnostic, health monitoring and care devices.

Nowadays digital technologies represent a resource to support ageing at home since they can effectively monitor physiological data and support the elderly's performance of daily domestic activities promoting their own safety [4]. This condition offers new exciting challenges for designers, ergonomists and engineers, both from a technical/functional perspective as well as from an aesthetical and socio-emotional point of view.

The paper describes the methodology used and the results achieved by the *CloudIA* research program, a project co-funded by the *POR FESR Toscana 2014–2020* program, which involved a partnership of 5 social cooperatives and 2 university of Tuscany Region.

1.1 Digital Technologies for the Elderly

New digital products, objects connected to the network and to each other (IoT) and wearable technologies (wearable computers) are playing and may play a key role in the near future.

Compact and miniaturised health devices can be effective for monitoring physiological data and maintaining health status, but also for promoting the safety of the elderly at home and supporting the performance of daily and household activities.

Such devices have vast potential and can be applied in different areas, depending on the user's needs [5, 6]. Integrated into watches, shoes, socks, bracelets, necklaces etc., increasingly powerful wearable device that enhance human abilities are becoming an integral part of everyday life, blending into more traditional interactions with objects or generating new modes of action.

The challenges of wearable health devices to overcome demographic changes can be summarised as [4]:

- continuous sensor-based monitoring can bring new sources of information and insights to help care providers understand each individual's situation and needs and help researchers better understand diseases and their cures;
- monitoring and caring for elderly or frail users requiring long-term care, either at home or in nursing homes or hospitals;
- reduction of healthcare costs as on-site clinical monitoring.

2 Needs Study

2.1 Evaluation Phase

Thanks to Human-Centred Design (HCD) [7] methods, such as interviews [8–10], brainstorming sessions [10, 11] with facility managers and coordinators and social and health professional (social and health workers, caregivers, nurses and rehabilitation therapists), user observation [9, 10], Task Analysis [9, 10] and scenario-based design [8–12], it was possible to investigate the needs, expectations of each single operator, current or potential criticalities and problems during the implementation of the activities [13].

The interview and brainstorming sessions made it possible to discuss together with the facility managers (directors and social workers) each daily activity carried out in the nursing home and at home. A total of 10 operators participated in this phase. Questions have been raised over the tools commonly used for work management and over the improvements needed to make health care more efficient.

The observation of the users was useful to evaluate how the operators work and how the users behave in the real context of use.

The Task Analysis (TA) involved the breakdown of the actions necessary to achieve goals for each character involved in the pathway (elderly person) and in the care process (formal and/or informal caregiver, and health or social worker).

Following the evaluation phase, it was possible to identify the main criticalities felt by the people involved, the areas of intervention and the relative design solutions.

It is important to point out that the co-operatives involved expressed the need for a wearable device compatible with the users' lifestyles, i.e. simplified devices addressed to elderly with compromised abilities. Specifically, the need of a wearable device emerged, i.e. a ring which monitors physiological data, movement and possible falls of the elderly person.

Finally through the scenario-based design, it was possible to define the following functions of wearable devices suitable for the users and the contexts of use at issue:

- monitoring the patient's health status, in terms of heart rate and its variations, movements and falls;
- monitoring of the patient's sleep;
- and support to the health worker in control activities.

3 Smart Ring Description

To ensure that the wearable technology encounter the user's needs, the Universal Design (UD) approach was followed. The UD includes and recognizes the variety of abilities and circumstances of various users allowing to become aware of them and how to deal with them. The UD principles [14, 15] are strongly linked to usability, as good usability allows users to employ technology consistently and easily [15, 16].

Considering the UD principles, the HCD approach has been applied for the design of the new wearable device, based on the needs of the target users. This means that it has been designed considering two categories of users: health professional and elderly people.

The UD challenge, which also bases its effectiveness on the HCD approach, consists in the design and development of the product system, based on the real needs, expectations and aspirations of the users involved during the evaluation phase.

As a result, the new wearable has the function of supporting health professional in providing care services to the elderly, whilst, as far as the elderly are concerned, its purpose is monitoring their physiological parameters and movements, as well as eventual falls. The collected data will be sent to a cloud platform able to analyse them in real time. In case of detection of any abnormal event, a web interface will be able to communicate it to the social health professionals. The user interface on the Cloud platform is designed to facilitate and optimize the social health professionals workflow.

The wearable ring-shaped device has been defined starting from the development of a flexible electronic board, modeled on studies based on wearability [17] and on the most suitable landmarks of the human body, suitable to monitor heart rate, movements and falls. It has to be placed in contact with the first phalanx of the index finger to detect the signal of movement, HR, HRV and SpO₂.

From the design point of view, the main challenge was to ensure a product with high usability standards but not invasive from a morphological perspective and stigmatized from a perceptual viewpoint (see Fig. 1).

The ring is made of 2 covers, both printed in 3D in commercial material produced by Formlabs. One cover is made of Flexible resin material (flexible and compressible elastomer) inside which is inserted the flexible electronic board (see Fig. 2), whilst the other cover performs the function of closure and protection, and it is made of Tough Resin (elastomer with high resistance to stress) (see Fig. 3).

3.1 Flexible Electronic Board

The flexible printed circuit board (PCB) layout of the electronic board has been developed according to the requirements identified (mainly wearability, comfortability, ease of use). This type of circuit is very practical and suitable for applications where flexibility, space savings are required, as in the case of finger device. At the same time, they are also very expensive, easily damaged and requires a more difficult assembly process. A PCB consists of two basic parts: a substrate (the board) and printed wires (the copper traces). The substrate provides a structure that physically holds the circuit components and printed wires in place and provides electrical insulation between conductive parts. The PCB layout integrates all the main components of the ring-shaped device, i.e., microcontroller, Bluetooth module and Inertial Measurement Unit and physiological sensors.

The ring-shaped wearable device for psychophysical monitoring proposed in CLOUDIA has been developed based on an STM32-F103 controller (STMicroelectronics, Italy) that integrates ARM@Cortex™-M3 32-bit MCU technology and represents a good trade-off between power consumption and size. The system is equipped with the LSM9DS1 9-axis sensor, which is the latest generation of inertial MEMS (STMicroelectronics, Italy). The inertial sensor includes a 3D digital linear acceleration sensor (selectable full scale: $\pm 2/\pm 4/\pm 8/\pm 16$ g), a 3D digital angular rate sensor (selectable full scale: $\pm 245/\pm 500/\pm 2000$ dps), and a 3D digital magnetic sensor (selectable full scale: $\pm 4/\pm 8/\pm 12/\pm 16$ gauss). The system is also equipped with a Rigado BMD-350



Fig. 1. Some tests of formal study of the ring.

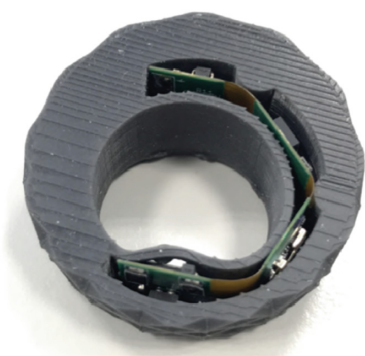


Fig. 2. Detail of the flexible electronic board inserted in the ring cover.



Fig. 3. The new smart ring.

Bluetooth serial device for wireless communication towards a generic control station and it is supplied by a rechargeable LiPo battery. The sampling rate for data acquisition is set at 50 Hz.

The system has been already preliminary validated comparing the accuracy of its measurements with those obtained from an optoelectronic system (i.e., Vicon system) as reported in [18].

Furthermore, the smart ring includes the MAX30102 (Maxim Integrated™, San Jose, CA, USA), a sensor for the measurement of physiological parameters. Indeed, it allows measuring heart rate (HR), heart rate variations (HRV) and blood oxygen saturation

(SpO₂) parameters based on the photoplethysmography (PPG) signal. The analysis of the PPG signal, by studying the diffusion of infrared rays in the tissues, makes it possible to study the blood supply. The very low energy consumption, miniaturisation and robustness with respect to motion artefacts with a high signal-to-noise ratio (SNR), were decisive aspects for the selection of this sensor. The placement of the device on the first phalanx of the index finger allows detecting HR, HRV and SpO₂ signals via peripheral blood flow. The sensor, indeed, works according to the reflective mode, i.e., the LED and the photodiode are on the same side of the finger. The accuracy of the physiological measurements has been already tested in lab environment involving healthy and young subjects as reported in [19].

4 Conclusion

The results presented in this article have relevance in the design and healthcare sectors. This research is particularly aimed at providing at designing and developing a novel ring solution that monitor the total movements and the physiological parameters of older adults over the day. This device has also an impact on the work of social and health professionals, for whom it is essential to improve health conditions – for the elderly – and working conditions – for health professionals.

Digital technologies represent a resource to support the independence and mental and physical well-being of old people and pose many challenges to design. The research presented in this article also highlights how UD and HCD approaches, in synergy with engineering expertise in the field of Ambient Assisted Living, can offer an important contribution to the identification and analysis of unspoken needs and expectations, in order to create truly useful and acceptable products. Design, when user-centred, can have disruptive results as well as incremental innovation [20], providing a concrete contribution in terms of product innovation and business competitiveness. On this basis, the purpose of design is the design of technologies based on usability, effective and intuitive interaction, absence of stigma, reliability and security to ensure a positive user experience both hedonic and functional.

The technical bench test performed on the flexible electronic board suggest a good accuracy in the measurements. However, the tests were conducted with healthy and young adults. Therefore, the next step of the research program concerns the experimentation with a significant sample of typical users (elderly and health professionals), both in nursing home and domiciliary environments.

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