On-Body e-Hub: Accessibility Technology for People with Disabilities

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***Abstract*—This paper presents an innovative approach to adapting the Next Generation First Responder (NGFR) communication platform for two critical applications: day-to-day care of individuals with disabilities and disaster management scenarios. The NGFR system, currently under Research and Development (R&D) by the US Department of Homeland Security, shows promising potential for extension beyond its original scope. This study outlines three key R&D adaptation paths: a new taxonomical view of assistive technologies; architecture modification of the existing NGFR framework to accommodate new use cases; and elicitation process protocols for gathering user requirements and preferences. This adaptation incorporates compact, energy-efficient, and cost-effective devices in wearable format for seamless integration. These devices provide comprehensive on-body sensing capabilities for physiological metrics monitoring as well as environmental condition assessment, supported by a robust infrastructure that includes cloud computing and other external resources. This research provides a roadmap for improving assistive technologies for individuals with disabilities, focusing on optimal selection of tools tailored to individual needs. The optimization is achieved by using a unique expert elicitation mechanism known as the *reference protocol*, which is proposed as a crucial step toward the practical design of customized on-body e-hubs. The proposed roadmap is directed at both technology developers and users, as well as at care providers, including emergency responders, social workers, and healthcare professionals.**

***Index Terms*—disability, assistive technologies, on-body communication hub, emergency management, e-health, expert elicitation.**

I. Introduction

This paper addresses one of the most pressing issues in human society: the care of people with disabilities. According to the World Health Organization (WHO), disability is defined as “an umbrella term, covering impairments, activity limitations, and participation restrictions. Disability is a part of being human. Almost everyone temporarily or permanently experiences disability at some point in their life. An estimated 1.3 billion people – about 16% of the global population – currently experience significant disability. This number is increasing, partly due to population aging and the rising prevalence of noncommunicable diseases [1]. Recent scoping review [2] highlights a significant gap in the coverage and accessibility of Assistive Technology (AT), particularly in relation to health equity for people with disabilities.

AT encompass a range of devices, including personal emergency alarm systems, fall detectors, smart watches, screen readers, gesture-to-voice converters, and communication devices [3]. Each of these technologies presents unique challenges related to design, deployment, updating, upgrading, energy consumption, cybersecurity, and communication protocols [4]. The development of these tools as wearable, on-body devices can be costly and may exacerbate socio-economic disparities, potentially undermining efforts to achieve health equity [2].

The study of assisting people with disabilities during emergencies and disasters reveals multiple challenges, particularly for marginalized groups that do not conform to typical ability norms influencing emergency management procedures [5]. It has been observed that current emergency management technologies often do not address the specific needs of these marginalized groups, highlighting a significant gap that cannot be bridged without a deeper understanding of the ’social’ dimensions involved [6].

In our recent paper [7], we introduced an innovative extension of the on-body communication e-hub concept, originally designed for the Next Generation First Responder (NGFR) [8]. Our approach emphasizes on the primary advantage of offloading data processing to a cloud platform, which significantly reduces the need for bulky on-body equipment. This results in a compact, energy-efficient, portable, and cost-effective solution, embodied in wearable forms such as belts, wristbands, or vests. By minimizing on-body equipment, our solution not only lowers costs but also enables interoperability across various standards and integrates seamlessly with citizens’ digital records within smart city and e-health frameworks.

This study’s results are introduced as follows. In Section II, technology adaptation strategy is introduced. A modified NGFR e-hub architecture is described in Section III. Expert elicitation process is introduced in Section IV. The overall results, conclusions, and future works are given in Section V.

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$$\underbrace{\left\{\begin{array}{c}\texttt{International Classification of Functioning}\\ \texttt{(ICF) taxonomy of disability}\end{array}\right\}}_{\text{Given}} \Rightarrow \underbrace{\left\{\begin{array}{c}\texttt{Disabled Person}\\ \texttt{Profile (DPP)}\end{array}\right\}}_{\text{On-body e-hub (proposed)}} \Leftarrow \underbrace{\left\{\begin{array}{c}\texttt{Assistive}\\ \texttt{technologies}\end{array}\right\}}_{\text{Given}}$$

Fig. 1. On-body e-hub delivers personalized assistive technologies to individuals with disabilities.

II. Technology adaptation strategy

We propose to adapt the NGFR communication platform for day-to-day care for people with disabilities using a 3-tier Research and Development (R&D) strategy.

A. 3-tier R&D strategy

Proposed technology adaptation strategy includes the following R&D tiers:

1) Formulation of a new taxonomical view of assistive technologies (requirements, distinguishing features, beneficial features, e.g., energy- and cost-efficient, formalization, criteria of similarity);
2) Architecture modification of the NGFR on-body computational platform (re-scheduling tasks and re-distribution of data sources while keeping the concept unchanged); and
3) Specification of expert elicitation process (requirements for experts, protocols, argument selection and marginalization mechanism, and transparency of decision-making).

B. Formalization

The challenge of developing an on-body e-hub for individuals with disabilities is formulated the problem as follows. Let $I \in \{I_1, I_2, \ldots, I_m\}$ be a set of disabilities, $T \in \{T_1, T_2, \ldots, T_n\}$, $n > m$, along with their implementation costs and deployment scenarios (such as power consumption, battery life, size, environmental constraints, and usability). The task is to optimally select assistive tools tailored to the specific needs of an individual. This task involves cost-benefit-driven decision-making, wherein the relationships between disabilities $I_i, i = 1, 2, ..., m$ and assistive tools $T_j, j = 1, 2, ..., n$ must be determined.

C. Taxonomy of disability and impairment models

Accordingly to the taxonomy of disabilities by International Classification of Functioning, Disability and Health (ICF), there are approximately 1400 impairment categories corresponding to body functions and structures, activities, functioning of a person as a member of society, and environmental factors (facilitators or barriers) [9]. This ICF taxonomy is used to create a Disabled Person Profile (DPP), which collects operating instructions (e.g., warnings, procedures, and recommendations) for first responders. In our study, the available AT are considered in relation to the ICF and DPP:

The scheme in Fig. 1 illustrates the potential for optimal selection of assistive tools for a given disability or impairment category, assuming that the ICF, DPP, and assistive tools are provided. Specifically, this scheme reflects the well-identified problem of the next generation of ICF-DPP scenarios – the accessibility of assistive tools for a given individual, independent of geographic location, country, and income. We propose the 'key' to the solution: an on-body communication hub that is a modification of the NGFR on-body hub.

D. Example: assistive communication technology

Most speech recognition systems designed to assist individuals with speech disorders have focused on dysarthria, a motor speech disorder resulting from damage to the nervous system that affects the control of the tongue, larynx, and jaw. In contrast, aphasia is an acquired language disorder caused by damage to specific areas of the brain responsible for language function. Individuals with aphasia often know what they want to say but struggle to find the right words; their issue is not related to motor control. The converters and systems developed to address these speech disorders can be costly, and their deployment is often constrained by various requirements [4].

Gestures are frequently used for communication by individuals with various types of disabilities. For example, they serve as a crucial communication tool for people with speech impairments [11]. Additionally, gestures can be employed by stroke patients to aid in both the rehabilitation of dysfunctional fingers and to facilitate communication. To bridge the gap between these gestures and other forms of communication, converters are necessary to translate gestures into alternative communication signals.

$$\begin{array}{c}\texttt{Voice}\\ \texttt{(speech)}\end{array} \Leftrightarrow \begin{array}{c}\texttt{Gestures}\\ \texttt{(visual)}\end{array} \Leftrightarrow \begin{array}{c}\texttt{Text}\\ \texttt{(avatar)}\end{array} \quad (1)$$

For example, a webcam or a cellphone camera equipped with gesture recognition software can serve as an effective assistive tool to recognize gestures and translate them into text or speech. This solution involves processing video footage of a person performing a hand gesture, extracting the hand joints from the video, and using this data for gesture recognition. The recognized gestures can then be converted into corresponding text or speech outputs, facilitating communication for individuals with disabilities.

Various converters of behavioral biometrics in Scheme (1) include gesture-to-text, text-to-gesture, gesture-to-voice, and voice-to-gesture [3]. Also avatar-based techniques are found useful, e.g., visualization gestures and emotional state. A well-identified trend is multi-modal system development, e.g., the composed speech analyzing system and facial expression recognition [11].

Similar converters such as text-to-voice are used in case of visually impaired people [12]. For example, a screen reader allows people who are blind or have low vision to use their computer or device; the AI "read out loud" the text on a screen, using a synthesised voice. A different type of devices include AT that enable person's orientation and position location.

III. E-HUB ARCHITECTURE

The cutting-edge AT based on mobile, wearable and distributed resources, as discussed in [4], [12], [13], have not yet been fully integrated into the next-generation human-machine interfaces such as on-body communication and computing hubs. In a recent paper [7], we proposed adopting an on-body e-hub designed initially for first responders for these purposes.

The e-hub architecture functions as an open communication and computing platform for distributed on-body resources. This includes a wearable network of wireless sensors, preliminary processing units for physiological signals, environmental cameras, portable devices, and external cloud-based resources, Internet of Things and distributed ledger as needed. The e-hub facilitates seamless integration and management of these components, aiming to enhance the efficiency and effectiveness of AT.

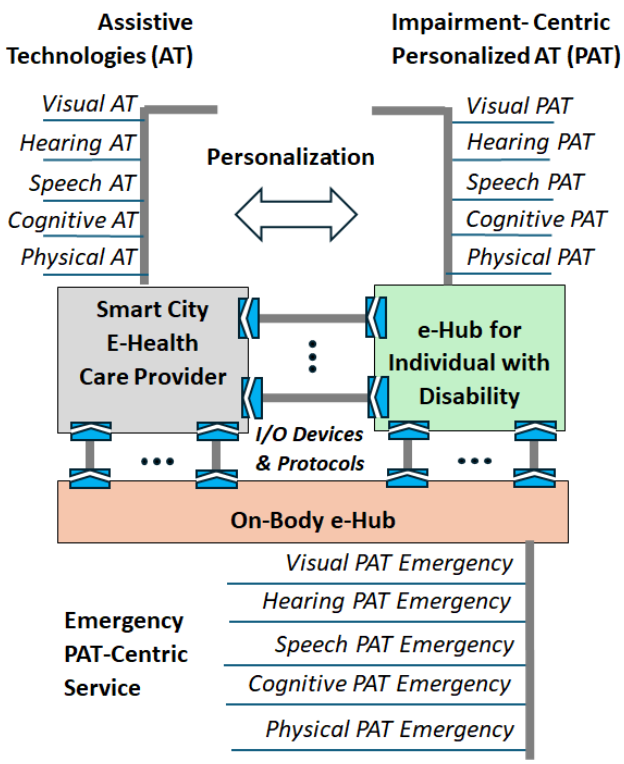

Fig. 2. Concept of an on-body e-hub for people with disabilities. The tasks of the on-body mobile computing tools are delegated to the city infrastructure and cloud platform, leaving only energy-saving pre-processing computing.

An example concept of on-body e-hub for people with motor-function disability, such as stroke survivors, is provided in Fig. 2. The three components: a healthcare provider within a smart city, an on-body e-hub, and an emergency service via a new-generation fist responder hub on a cloud, – are connected using the standard Input/Output (I/O) devices and protocols. Each e-hub user has an access to AT of the smart city technology provider. These technologies include visual, hearing, speech, cognitive, and physical ATs. Their personalized versions, i.e. impairment-centric Personalized AT (PAT), are enabled by the e-hub facilities. The smart city emergency services have access to all healthcare resources of smart city in order to provide personalized help to individuals, including the guidance to interacting with people with disabilities [14]. This is an example of an emergency PAT-centric service.

Fig. 3 provides additional details: how the on-body e-hub (down plane) is embedded into the smart city technology infrastructure (upper plane) using I/O devices (heads-up displays, wrist-worn displays, microphone/earphone headsets, hand-held touchscreen displays, voice-activated commands, etc.) The e-hub contains a Controller Module, Power Module, Communication Module, Sensor modules, and Operator I/O Devices. The Controller Module has internal capabilities such as communications, audio/video recording, and data storage. The Communications Module provides an interface between the Controller Module and external communications devices. The Sensor Modules include physiological sensors, thermal sensors and other devices.

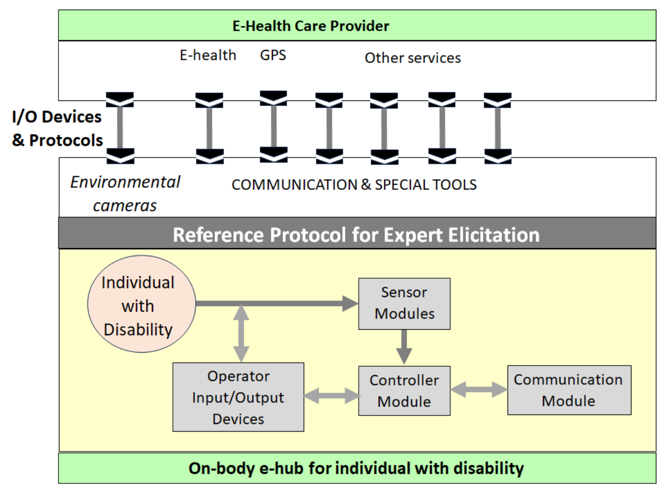

Fig. 3. Architecture of the on-body e-hub for individuals with disabilities. Miniature energy-saving, portable, comfortable, and low-cost on- body sensing and communication tools are embodied into belt, wristband, or a jacket.

IV. EXPERT ELICITATION AND REFERENCE PROTOCOL

Communication and computing functions of on-body e-hub must be framed by a group of experts from various fields of expertise. This collective knowledge provides the key parameters for configuring the e-hub.

A. *Reference protocol for expert elicitation*

The reference protocol manifests in various forms, such as computer templates or benchmarks for best practices and reporting, serving as "standard tools that allow valuating and comparing different systems or components according to specific characteristics such as performance, dependability, and

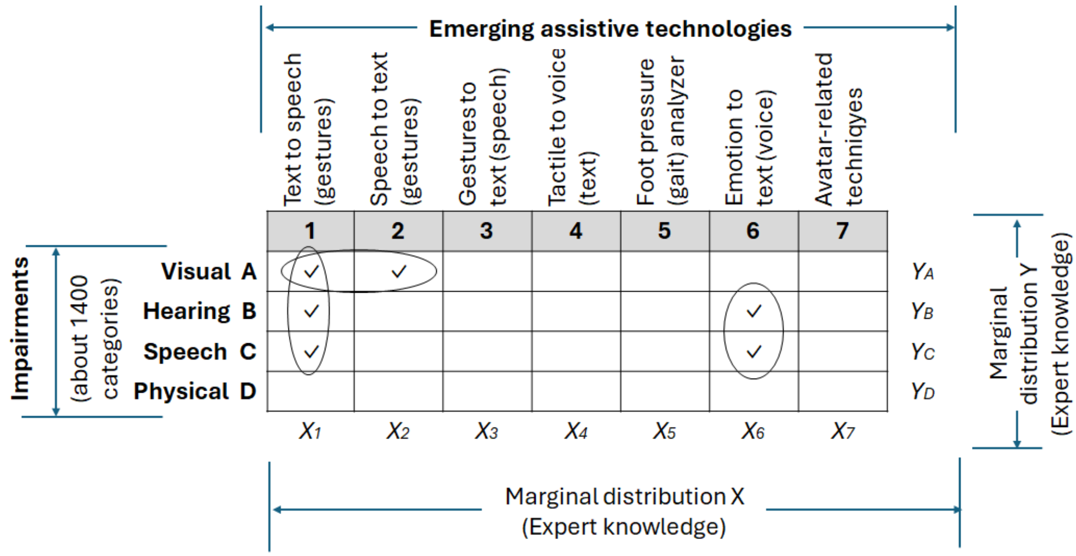

Fig. 4. Reference protocol for expert elicitation of AT. Each cell represents an expert judgment on the recommended assistive tools. The clusters represent collective expert judgments; the transparency of the judgments is visualized using the dimensions of the disability type and the assistive technologies.

security" [10]. The work [10] proposes a set of requirements (principles) for effective elicitation. Based on this work, we emphasize, in particular, on the following requirements to experts:

- Transparency in elicitation (ensuring that the process is open and understandable);
- Usefulness (the protocol must be relevant and applicable to the specific decision-making context, such as AT for people with disabilities);
- Inclusion of Constraints (addressing relevant constraints and limitations in the elicitation process);
- Reflection of Imperfect Knowledge (acknowledging that individual experts may have incomplete or uncertain knowledge);
- Recognition of Cognitive Biases (identifying and mitigating biases that may affect expert judgment);
- Suitability for professionals in the field; and
- Adaptivity of Expert Skills (allowing for adjustments based on the expertise and skills of the individuals involved).

These principles aim to enhance the effectiveness and reliability of the reference protocol in evaluating and comparing different systems and components.

B. Configuration

In this paper, a sample of seven emerging assistive technology are specified (Fig. 4):

- Text-to-speech and vice versa activated by gesture signs;
- Gesture-to-text and vice versa;
- Gesture-to-voice and vice versa;
- Tactile-to-voice;
- Foot pressure (gait) analyzer;
- Emotion-to-text activated by voice or gestures;
- Avatar related rehabilitation techniques.

These technologies are represented in conjunction with four sets of impairments: Visual (A), Hearing (B), Speech (C), and Physical (D).

An example of aggregation of four technologies based on interoperability is given in Fig. 5. The lip movements are detected and recognized, then converted to text. The avatar incorporates both the text and its audio representation of the lip movements.

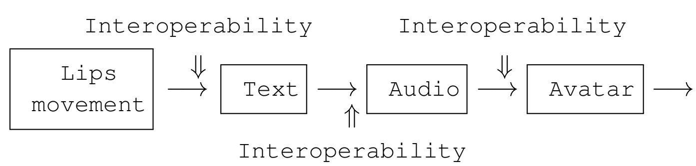

Fig. 5. Example of interoperable assistive technologies.

C. Clustering

The key mechanism of data manipulation in this protocol is clustering. Each cluster organizes and associates the accountability for delivering services, based on different levels of impairment mitigation. For example, consider the cluster $\{A1, A2\}$. This cluster represents scenarios where text-to-speech technologies are employed to address both visual and hearing impairments. By grouping these scenarios, the protocol links specific AT to their corresponding impairment, facilitating targeted and efficient service delivery.

D. Marginalization

Marginalization is a mechanism for the decomposition of the expert elicitation in dimension X of AT for a given set of impairments and dimension Y of impairments for a given AT;

these are the arguments, or variables in the decision support model. For example, marginal distribution X conveys the expert recommendations on systems and devices to have use a given individual, while marginal distribution Y introduces a set of impairments of a given individual. For example, given an individual with hearing (B) and speech (C) impairments, recommendations of an experts are introduced by cluster $\{B1, CI\}$ (text-to-speech and gesture-to-speech technology) and cluster $\{B6, C6\}$ (emotion visualization technology).

V. Summary, conclusions and future work

This work can be recognized as a call to the R&D community developing the NGFR computing and communication on-body hub [8]. We found that this on-body hub is related to emerging problems of assistive technologies for people with disabilities, formulated under the following principles: accessibility, adaptability, acceptability, affordability, availability, and quality [15]. Specifically, we tackle a classical optimization problem: mapping impairment categories by combining existing and new AT. For any given impairment, the challenge is to select the appropriate assistive device(s) from available resources, ensuring that these choices align with the individual's specific needs. The on-body communication hub aims to balance the cost-benefit ratio between individual needs and available AT. This paper focuses on creating conditions for effective expert elicitation to facilitate this selection process. Conceptually, this paper aims to answer two research questions:

- How to provide an individual with access to acceptable AT?
- How to minimize the cost of a such access?

The key conclusion is that adaptation of the on-body NGFR computing and communication platform is a feasible, timely, and beneficial solution to the aforementioned emerging problems. The developed three R&D paths represent a rational approach for implementing this strategy.

The focus of our future work is an on-body hub's *digital twin*. Briefly, a "human digital twin is defined as a pairing of a real-world human twin and a human digital twin which includes a model of physical appearance, physiology, personality, perception, cognitive performance, emotion, or ethics of a human; where the real-world human and human digital twin are integrated such that a change in the real-world human or its digital representation produces change(s) in the other" [16]. The application of a human digital twin given a specific impairment or impairments requires [16], [17]: 1) a digital model of impairment (i.e. impairment taxonomy [9] and aggregative learning model); 2) an evolving set of data relating to the impairment (i.e. continuous monitoring [18]); and 3) a bidirectional communication between the system and its digital representation for dynamically updating or adjusting the model using the continuously monitored data (i.e. mechanism of perception-action cycle).

The proposed e-hub provides the necessary conditions for bidirectional communication between the person with a given impairment and the model. The expected benefit of such digital twin is an adaption of an assistive tool for the personalized needs.

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