INDYvr: Towards an Ergonomics-based Framework for Inclusive and Dynamic Personalizations of Virtual Reality Environments

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Abstract

As Virtual Reality (VR) gains prominence, the need for inclusive experiences becomes essential, particularly for users with physical impairments. Current VR development often caters to a exclusive demographic, excluding diverse populations. This paper introduces INDYvr, an ergonomics-based framework that dynamically adjusts the VR environment, fostering a personalized and inclusive experience. INDYvr will acquire the user's physical attributes and capabilities and translate them into a parametric model, which is then used to dynamically adjust the VR environment to improve the user's reachability and walkability. The framework consists of six interconnected modules: User Profiling and Environment Profiling, Coverage Calculation, Architectural Constraints, Object Repositioning and Environment Modification. INDYvr represents a shift towards a user-centered VR paradigm, striving for a future where VR is accessible to all users, irrespective of their physical abilities.

Index Terms: Human-centered computing [Accessibility]: Accessibility systems and tools—; Social and professional topics [User characteristics]: People with disabilities—; Human-centered computing [Human computer interaction (HCI)]: Interaction paradigms—Virtual reality;

1 Introduction

As users increasingly engage with Virtual Reality (VR) environments, the need for tailored and inclusive virtual experiences becomes of great importance [3, 4]. Specifically, the current landscape often falls short in terms of representation and inclusion of users with physical impairments, e.g. missing limbs, limited mobility. This exclusion happens because most VR development predominantly caters to a segment of the population known as M-WEIRD (Male, White, Educated, Industrialized, Rich and Democratic) [9, 21]. As such, a challenge lies in adapting VR environments to match the range of diverse physical characteristics of users [20]. Moreover, these adaptations need to be performed dynamically for each user, instead of having predefined general personas [15].

This research explores the relationship between users' physical capabilities and VR personalization, focusing on users with upper-limb amputations and upper-limb reduced motion. The primary goal is to define a framework capable of modifying the position and size of elements in a VR environment based on the users' reach envelope. To do this, INDYvr will acquire the user's physical attributes and capabilities, translating them into a parametric model to dynamically adjust the VR environment and improve the user's reachability and walkability. By addressing these goals, this research paves the way for customized and inclusive VR experiences across a wider spectrum of users' physical attributes.

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2 Literature Review

VR has proved effective to address the digital divide for individuals with disabilities [12]. Albeit research initiatives have aimed at enhancing accessibility within VR [6], a significant gap remains in achieving inclusion. An in-depth analysis reveals a predominant focus on the M-WEIRD population [9]. While this approach has led to advancements in VR applications, it excludes a substantial portion of the global population [21]. For instance, researchers have consistently highlighted the underrepresentation in VR studies of women, individuals from diverse cultural backgrounds, varying age groups, and those with different abilities [16, 21, 22]. This underrepresentation emphasizes the urgent need for more inclusive and diverse perspectives in the development and utilization of VR technology. Addressing this challenge stands as a pivotal step in ensuring that the potential of VR is accessible to a broader spectrum of users.

In the pursuit of inclusion, researchers have explored adaptive VR systems, focusing on personalized interfaces and environments [1, 27]. These systems aim to go beyond static applications, where the system configuration is arranged for a single type of user, catering to individual variations in user's needs. Nonetheless, there is a deficiency of dynamic adaptations over the environment based on the user's physical characteristics [30]. As such, these efforts are insufficient to provide a more inclusive VR experience.

Recognizing this gap, we propose the development of INDYvr, an ergonomics-based framework that will consider the user's capabilities to perform dynamic modifications on the VR environment.

3 Overview of the INDYvr Framework

The INDYvr framework embraces user-centered and ability-based [28] design by adapting the VR experience for each user. By dynamically adjusting the environment, a more personalized and inclusive virtual experience can be fostered.

Consider two individuals using a VR headset to evaluate the design of a space to be used as kitchen, as seen in Figure 1. Andrew is a 35 year-old male with no physical impairments (Fig. 1, A). Conversely, Diane is a 28 year-old female that has an upper-limb amputation (Fig. 1, D). Prior to wearing the headset, their physical attributes and capabilities, such as height, both arm's length, and both hand's size, were acquired. In turn, INDYvr used this information to dynamically modify the environment of the VR kitchen application. In the case of Andrew, the framework detected that no adaptations were needed; the environment remained the same (Fig. 1, B-C). Contrarily, INDYvr detected that several changes were required to elevate Diane's VR experience. For instance, the height of cabinets, counter space, and spacing of storage, should be modified to account for the mobility and interaction afforded by an amputee (Fig. 1, F). These environment modifications could provide Diane with both a VR experience that more closely resembles how she would perform the task in real-life, and inform how the real-world should be modified to fit Diane's requirements better.

INDYvr will be comprised by six interconnected modules. First, an **User Profiling** module will acquire the users' physical data, e.g., their height, arms length, and hands size. AI profiling modules, such as OpenPose [2] and MediaPipe [8], can be leveraged to detect the

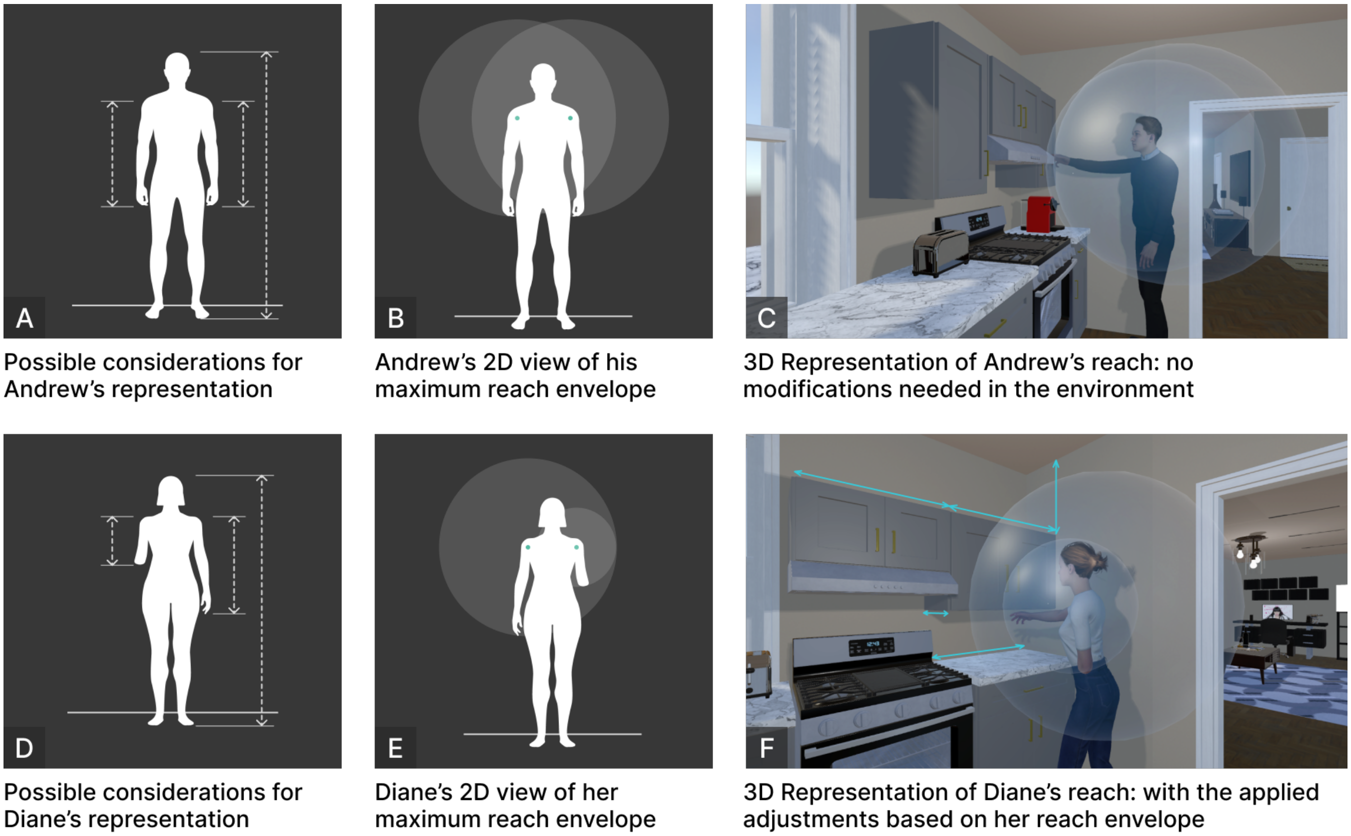

Figure 1: Comparison between users Andrew and Diane and the modifications to the VR environment: A) Andrew's physical data, B) 2D view of Andrew's reach envelope, C) 3D view of Andrew in a VR kitchen, no modifications were applied, D) Diane's physical data, E) 2D view of Diane's reach envelope, and F) 3D view of Diane in a VR kitchen: INDYvr lowered the cabinets, adjusted their size, and added counter space.

users' height, joints locations, and distances between them to output an approximation of their reach envelope [10]. Similarly, an **Environment Profiling** module will receive an existing VR environment and will obtain the spatial and scale information (position, width, length, and depth) of all the elements within the space.

Subsequently, the output of both profiling modules will be sent to the **Coverage Calculation** module. This module will intersect the maximum reach envelope with the position of all the elements in the VR environment to obtain an index of coverage. The index will function as an indication of how reachable or unreachable each object is. For instance, if an object's index of coverage is 50%, only half of it will be reachable by the user. The output of this module will detail the coverage percentage of all the objects in the VR environment. Alongside, an **Architectural Constraints** module will provide a set of guidelines and restrictions regarding placement and dimensions of the space and objects within it. The guidelines will be extracted from sources such as the American Institute of Architects' Architectural Graphic Standards [19]. These constraints will ensure that the suggested dynamic modifications can be recreated in a real-world environment.

The outputs from the previous modules will be fed into an **Object Repositioning** module, which will calculate a set of adjustments to be performed over the environment and its objects to maximize the user's reachability [7, 29] and walkability [11, 17]. For instance, if a set of shelves only has an index of coverage of 10%, they should be repositioned, considering the architectural constraints, to have a larger coverage based on the user's reach envelope. The aim is to optimize the user's interaction with the space by maximizing each object's index of coverage. This calculation will be done by solving a maximization problem for each object [23]. Through such optimizations, INDYvr could find that by lowering the shelves 30cm and reducing their depth 5cm, their index of coverage would increase to 70% without affecting other objects' index of coverage.

Finally, the required adjustments over the environments will be performed during the **Environment Modification** module, either automatically by solving a discrete multivariate optimization problem [26] or manually through user's input with the VR controllers.

4 Future Work and Challenges

The INDYvr framework will require access to the users' physical and information, e.g., height, arm's length, hand's size, and how they contribute to user comfort, interaction efficiency and immersion. Such data needs to be acquired from diverse population to guarantee generalization to the varied range of users. As such, acquiring this data poses an ethical challenge; working with underrepresented groups requires strong ethical safeguards of the users' rights, privacy, and well-being [13]. This challenge will be constant throughout the research to adhere to the most rigorous ethical approvals to avoid a bias in participant recruitment [14].

Furthermore, formulating the calculation of the best reach coverage as a continuous multivariate maximization problem introduces both time and computational power constraints [5, 18]. As such, research will be done to approximate these computations as discrete optimization problems [25, 31]. Such simplification would increase the amount of available machine learning optimization solvers [24], which in turn could increase INDYvr's generalizability.

5 CONCLUSION

This paper introduced INDYvr, a framework to dynamically modify a VR environment to better suit individual physical characteristics, specifically for users with upper-limb amputations and upper-limb reduced motion. INDYvr will achieve this by acquiring the user's physical attributes and capabilities and translating them into a parametric model, which is then used to dynamically adjust the VR environment to improve the user's reachability and walkability. Through these modifications, INDYvr represents an improvement from traditional adaptive VR systems that require users to conform to standard personas. As such, INDYvr strives for a future where VR is accessible to all users, irrespective of their physical abilities.

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