# Hybrid Workflow Process for Home Based Rehabilitation Movement Capture

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## ABSTRACT

Telehealth rehabilitation systems aimed at providing physical and occupational therapy in the home face considerable challenges in terms of clinician and therapist buy-in, system and training costs, and patient and caregiver acceptance. Understanding the optimal workflow process to support practitioners in delivering quality care in partnership with assistive technologies is significant. We describe the iterative co-development of our hybrid physical/digital workflow process for assisting therapists with the setup and calibration of a computer vision based system for remote rehabilitation. Through an interdisciplinary collaboration, we present promising preliminary concepts for streamlining the translation of research outcomes into everyday healthcare experiences.

## CCS CONCEPTS

• **Human-centered computing** → *Empirical studies in HCI*; *Accessibility technologies*; • **General and reference** → **Design**.

## KEYWORDS

calibration; co-design; computer vision; service design


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## 1 INTRODUCTION

The global COVID-19 pandemic has accelerated efforts worldwide to create home and community based healthcare mechanisms and services to deliver effective and accessible care to diverse and dispersed populations. As the world population also continues to age, there is a growing need for increased rehabilitation services for common debilitating illnesses and injuries such as stroke and arthritis [12, 20]. Applying a telemedicine approach to physical rehabilitation at the home is not yet possible, owing to the challenges in capturing data and the complexity of the therapy structuring and adaptation process. For upper extremity rehabilitation for stroke survivors, which is the focus of our work, over 30 low-level movement features need to be tracked as the patient performs functional tasks in order to precisely and computationally characterize movement impairment [7]. In addition, detailed activity documentation during daily life is needed to understand the effect of therapy on functional recovery [18]. Although high-end sensing technologies can provide some of the necessary detailed tracking, these technologies are cumbersome even in the clinic and certainly not yet feasible for the home. The physical homes of many stroke survivors are also often constrained and cannot easily accommodate the type of technology typically used in rehabilitation systems in hospitals and clinics [3]. Even small systems, if they are intrusive or perceived negatively, will be rejected by the stroke survivor and/or their caregiver or partner [3].

Technological systems aiming to assist the therapist in delivering remote rehabilitation may not be adopted by therapists if they are incompatible with the therapists' approaches or introduce steep learning curves. As noted in our recent prior work, therapists have limited training time to learn, troubleshoot, and maintain complex new systems, particularly as part of their compensated work [9]. From the patients perspective, they rely greatly on their one-to-one interactions with the therapist to motivate and structure their continuous engagement with therapy. Without continuous and effective training monitoring accompanied by feedback on their immediate performance and long term progress, and without customization of therapy to their needs and learning styles, patients will likely not adopt home-based rehabilitation systems [21].

In this paper, we present our human movement capture workflow in setting up, calibrating, and capturing video using a low-cost camera based system for Semi Automated Rehabilitation At Home (SARAH) [16]. We describe our iterative design process in developing unique physical components and novel software interfaces aimed at ultimately supporting non-expert users (e.g. therapist, caregiver, patient) with everyday use.

## 2 PRIOR WORK

Our approach builds on insights from extensive prior work, including our own, in the development of home based rehabilitation systems, computer vision systems for accurately capturing human movement, and the design of accessible interfaces.

Technology-assisted rehabilitation in the home is considered a key avenue for improving health and wellness outcomes with the potential also for reducing costs [1, 20]. Smart rehabilitation in the home can provide evidence-based customization of therapy, together with the increased intensity necessary for better functional outcomes over a shorter duration. Over the past twenty years, researchers have proposed simple wire transducer systems [24], augmented reality tools [2], virtual coaches [14], customized one-off systems [3], depth camera systems [7], and telerobotics [5]. However, the scaling of technology-assisted rehabilitation in the home faces significant challenges [3, 21], ranging from automating the role and activities of the therapist, system cost, insurance coverage, and ultimate trust and acceptance of such systems by patients, caregivers, and clinicians.

Our current approach is informed by our previous work developing marker and camera based systems for the clinic [4, 6] and our expanded work aimed at a cost effective camera system for the home [17]. Additional work by other researchers has shown that performing analysis on low level kinematics during rehabilitation training can result in automated performance analysis [8, 23, 25]. Using an array of low cost video cameras can help achieve the required kinematics data using computer vision techniques [17]. The end goal of the proposed movement capture workflow in this work is to have a camera setup that allows for consistent and invariant video capture and data collection. The camera placement problem has been studied previously [11, 13] while prior work in this area also suggest the productive use of motion sensors and omnidirectional cameras [11]. We propose here that all the requirements can be met using two low cost video cameras and fiducial markers in combination with a calibration interface.

Making interfaces and systems more accessible is necessary in the design of systems targeted at impaired users. Older adults, who are more likely to have experienced stroke, often have vision impairments in the form of color-blindness, making it difficult for them to distinguish between various color combinations [26, 27]. Feedback from participants in prior studies and analysis from research also indicate the need to employ large text in sans-serif fonts to make things as clear as possible for people with vision impairments [19]. All text should be high contrast at a minimum of 70% compared to the background, to improve readability for vision impaired users. Finally, the use of touchscreen tablets tend to be the best form of input for older or impaired adults, especially when compared to a touch pad or mouse on a traditional computer screen [19].

## 3 DESIGN PROCESS

Developing a movement capture workflow process for diverse stakeholders requires committed collaborations between all involved parties, which for our team includes UI/UX designers, industrial designers, occupational therapists, computer vision/machine learning experts, and computer scientists. The potential success of our approach requires considerable trade-offs and/or handshakes between and physical and virtual components in our system, in conjunction with the need to create a straightforward interaction experience for the ultimate users of our system. For example, the unique design of the rehabilitation objects [15] are tailored to maximize patient perception of the possible affordances [10] of the artifacts, while also supporting the computer vision detection algorithm through the different sizes, shapes, and colors of the objects. Figure 1a depicts the seven modular rehabilitation objects in our system that can be grasped, manipulated, and combined in a variety of ways to support therapeutic activities related to activities of daily living. Similarly, the screen printed staging mat used in our tabletop system (seen in Fig. 1b) assists the patient in determining where to place the objects, while the markings also function to help automatically calibrate the correct location of the patient and the staging mat itself. In the next section, we discuss the iterative process engaged in by our team, surfacing lessons learned as we refined our system and evaluated the efficacy of the approach through a small pilot study.

## 4 MOVEMENT CAPTURE WORKFLOW

Our movement capture workflow for setting up, calibrating, and capturing videos combines screen based interfaces for the patient and the therapist. The goal of our system is to support remote monitoring of patient activities by the therapist as part of a regular therapy protocol (typically two visits in person by the therapist per week). On non-visit days, the patient will complete their therapy activities using the system with summary information sent to the therapist. A key issue here is minimizing the technical burden on both the therapist and patient. Our workflow process is designed to assist the therapist with initial system setup and calibration, while patient specific software ensures the efficient delivery of the

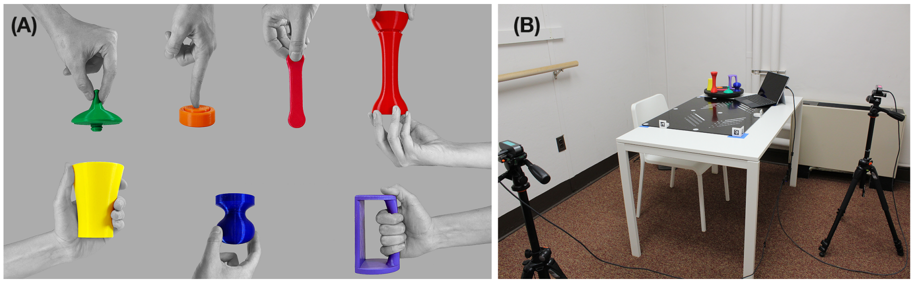


**Figure 1: (A) The seven objects used in our SARAH system as props for upper extremity stroke rehabilitation activities; (B) The physical setup of the SARAH system**

therapy protocol. We focus here primarily on the therapist interface for assisting with system setup and calibration.

## 4.1 System Setup and Calibration

The key motivation of the occupational or physical therapist is typically to spend as much time as possible engaging with the patient during therapy [9]. This means that any assistive technology designed for placement in the home needs to accommodate to the therapist's typical routine and require minimal setup and maintenance events. Our prior experience with motion tracking [7] and depth camera systems [22] emphasized the amount of time needed and the presence of experts required to correctly install and calibrate such systems. We needed to develop a much simpler approach to create a system that might realistically work for therapists and patients alike. The user experience designers on our team organized three, one-hour long design sessions with the two occupational therapists collaborating with our team. The first design session was an interview focused on understanding each of the therapists' experiences, their general impressions of system use and system calibration as a topic, and their perceptions of the feasibility of technology in the lives of stroke patients. The second design session consisted of a card-sorting activity where the therapists were asked to sort cards containing the tasks required to setup and calibrate the system into an order that they considered to be most intuitive and feasible. Finally, the third design session entailed a group discussion about the prototype interfaces for the proposed setup sequence with detailed review and feedback of the diagrams and videos created for users' reference.

The therapists in the design sessions emphasized several key points to consider when creating our system. They believed it imperative to reduce the amount of physical and/or mental toll on the patient by minimizing their involvement in as much of the setup and calibration processes as possible. They insisted that it would be less distressing to the patients if we did not move their own furniture or home furnishings to accommodate our system, but rather we should ensure that our system (i.e. cameras and tripods) could fit around the patient's home setup. The therapists directed that all components of the calibration process that did not absolutely require the patient should be performed first, and the patient should only be invited to participate for any last final stages before therapy began. Finally, they noted that foreknowledge of the calibration process would be important for all parties to be aware of, especially in instances where the user carrying out the process is in a transactional relationship with another party present. The therapists indicated that they would like to be able to easily review the process ahead of time (e.g. through shortcut instruction cards) before a home visit, in order to maintain the professional nature of the visit while also ensuring the accuracy of the session.

For the focus group activity with the therapists, we prepared a series of interface prototypes for them to move through as if they were setting up and calibrating the system. Both of the therapists agreed on the effectiveness of the diagrams and videos in conveying necessary information, but each indicated a different preference as to which to rely on. The resulting group discussion revealed the necessity of having both available when carrying out early setup and calibration processes as each relate to different styles of problem solving. Subsequent customization of the setup and instruction interface could ensure that therapists are provided with their preferred approach without encountering redundant information.

Armed with the therapist insights, we next integrated our findings with the needs of the industrial design and computer vision members of our team in developing the interactive calibration components of our project. From a computer vision perspective, standardizing the captured video frame through the reduction of frame invariance is significant. Here, the design of the staging mat for the therapy activities assists with ensuring the correct placement of the two cameras with respect to the patient. The industrial designers on our team laser cut and screenprinted a high contrast staging mat with guidance lines for the patient indicating the four therapy activity performance spaces through increasingly colored lines. For the computer vision approach, three fiducial markers attached to the mat are used to assist with mat detection, while four rows of circles printed on the mat assist the two cameras with boundary detection for the anticipated patient activity performances (the activities are described more fully in [16]. Using algorithms based on opencv and aruco libraries, the calibration software interface detects the markers: the first marker on the saggital side of the patient needs to be aligned with the center of the frame along the X-axis and at a certain offset below the center along the Y-axis. The second marker is placed at the top-right corner of the mat to ensure that the mat is not crooked on the table. Once detected by the calibration software, the tablet interface provides feedback to the therapists via commands such as "Move the camera to the left" and "Move the camera forward" in order to properly align the

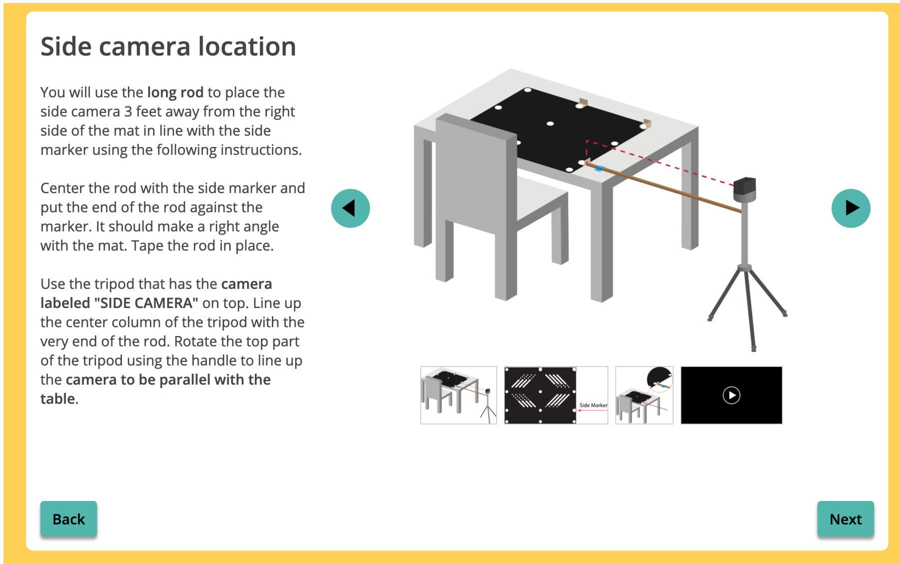


**Figure 2: Calibration interface displayed to the therapist to assist with camera setup**

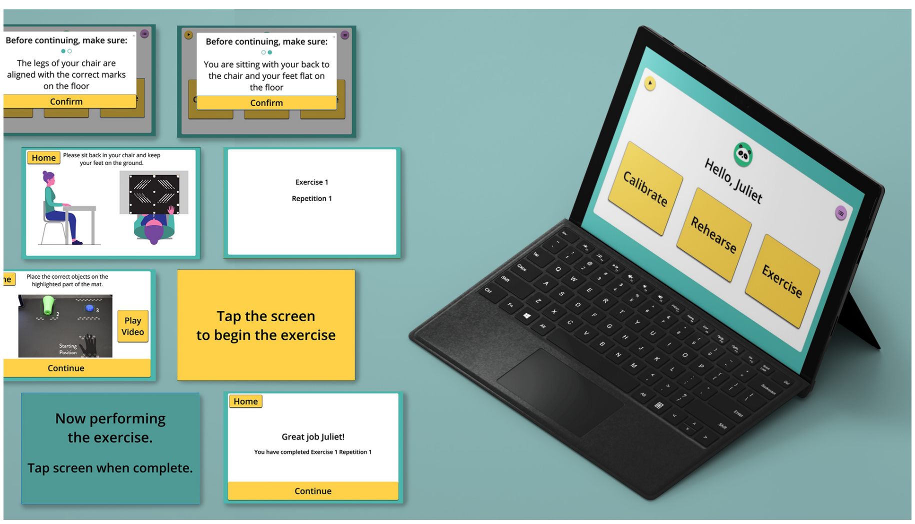


**Figure 3: Screens from the calibration sequence that directs the therapist through initial system setup**

cameras. The cameras must be positioned such that the patient and activity mat can be captured in the frame with minimal deviation across varying users, setup equipment, and physical environments. Then the activity space is recognized by detecting 5 bounding boxes on the mat bounded by the rows of circles as shown in Fig. x. The circles displayed on the mat are detected using computer vision techniques and the resulting coordinates are used to generate the bounding boxes. These boxes are the key components for the system to run the analysis of the patient performance in the back-end. In the last step, the location of the patient is determined. In all these steps, continuous feedback is sent to the therapist so that they can adjust the camera setup accordingly.

## 4.2 Preliminary Pilot Study

We conducted a preliminary stress-test of our system by recording one member of our team and two members of our extended team who were unfamiliar with the calibration and setup process attempting to complete the full setup using only the tablet interface software for guidance. The two primary issues encountered were challenges with making minor adjustments to the camera position, where the direction from the system was to move left or right, but even slight over-correction resulted in an error message. The second was that the participants were instructed to place tape markings on the floor as they went along to assist with subsequent re-setups. This process took over a quarter of the time for each run-through, despite it being anticipated as a relatively trivial task to do. Each of the participants were able to complete the full setup, but took varying times to do so (10 minutes; 25 minutes; and 32 minutes). Current adjustments to our system to reduce these times include using warehouse style pre-made markings for easy attachment to the floor, better refinement of the calibration process with regards to projected extent of necessary camera movement, and use of larger circular markings on the mat to deal with foreshortening issues from the camera placed to the side of the patient.

## 5 CONCLUSION

Developing telehealth technologies requires consideration of the perspectives of multiple stakeholders, including endusers, developers, and designers. In crafting a hybrid workflow process, our work aims to center the needs and values of the therapists on our team, and to use their input to direct our development work in both the physical and digital realms. While the pandemic has hindered our ability to work with patients directly in their homes, the contributions of therapists with considerable expertise with home based therapy has allowed our workflow process to continue to develop. Next steps in our work include evaluating the system with therapists who are unfamiliar with our system in the clinic, and then testing the system under the supervision of a therapist in the homes of three patients. Findings from this work will enable us to refine our process and better understand the potential impact of our system on patients, therapists, and caregivers as a clinical assistive tool.

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