

High Fidelity Prototype Design for Gamified Telerehabilitation Platform for Older Adults with Upper Limb Impairments

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Abstract—This report is meant to outline the development of high-fidelity prototypes for a gamified telerehabilitation system designed for older adults with upper-limb impairments. It is built upon the low-fidelity concepts and validated user requirements as presented in our previous assignment; the high-fidelity prototype delivers refined game interactions, a more polished visual interface as well as a functional dashboard flow for the patients, caregivers and clinicians. Our system will integrate responsive webcam-based motion tracking and each game is designed to target specific movement categories. This stage focuses on visual refinement, interaction detailing and preparing the system for usability testing and the final evaluation.

Index Terms—Telerehabilitation, Upper-limb impairments, Gamified therapy, Motion tracking, Rehabilitation games, High-fidelity prototype, Older adults, HCI.

I. INTRODUCTION

The high-fidelity prototyping stage marks for us a significant progression in the development of our gamified telerehabilitation system for older adults with upper-limb motor impairments. While our earlier stages focused on identifying user needs, mapping clinical requirements and sketching conceptual interactions, this phase translates those foundations into a fully realised and refined, interaction-ready digital experience. The high fidelity prototype aims to simulate the final product as closely as possible.

The system is to incorporate three therapy based games, a patient focused rehabilitation interface as well as dedicated dashboards for the caretakers as well as clinicians. Unlike that of the low fidelity prototype which emphasized more on the structure and functionality, our high fidelity version brings in the aspect of the implementation of our action plan. It is a critical bridge between that of design exploration as well as user evaluation which enables us to test not only how users interact but also how they feel while using it.

II. SYSTEM DESIGN & SYSTEM ARCHITECTURE

A. Overview of the System Architecture

Our high-fidelity prototype builds upon our previous low-fidelity design and implements a functional software for our gamified telerehabilitation platform for older adults with

upper-limb impairments. To summarize, the system architecture will consist of four interconnected modules:

- **User Interface Layer:** It will vary for the patient, caregiver and clinician. It also includes the game interfaces, calibration and notification panels.
- **Webcam Motion-Tracking Layer:** It involves real time joint detection using the web camera feed.
- **Game Engine Layer:** This involves the moment verification, scoring, difficulty as well as the point XP system.
- **Data & Monitoring Layer:** This includes the session data logging, performance summaries, appointment scheduling and so on.

These modules communicate through a simulated internal API, mimicking how a real-world telerehabilitation system would store, process and present data.

B. Game Engine Logic

TABLE I: Shared Logic Pipeline across game prototypes

Stage	Description
Calibration Phase	Users position their body within the camera frame as the system detects major joints such as shoulders, elbows, wrists and fingers.
Instruction Phase	The game presents a set of instructions for the user to follow accordingly.
Tracking Phase	Continuous joint and limb movement capture.
Verification Phase	Movement compared with target trajectories and templates.
Reward Phase	Users receive motivational reinforcement such as XP points or sound cues.
Summary Phase	Session data including score, accuracy, repetitions, range of motions is updated.

Each game uses a shared logic pipeline, apart from Game 2 which does not use the web camera but requires physical touch and interaction with the system.

C. Data Flow and System Interactions

The system follows a structured data pipeline:

- The user logs into the dashboard
- Choice of Game
- Calibration initiated

- Motion Data capture/physical interaction input
- Game verification engine checks gesture correctness
- XP and streaks uploaded and updated
- Session report automatically uploaded
- Dashboards get reports and charts accordingly
- Adherence and consistencies are monitored

D. Role-Based Dashboards

The system supports three user types:

- **Patient Dashboard:** Daily session, weekly report/goal, XP progress, streaks, reminders, messages and an emergency contact.
- **Caregiver Dashboard:** Tracks patient attendance, medication, alerts for skipped sessions and simplified progress graphs.
- **Clinician Dashboard:** Manage patients, map performance, configure therapy plans, adjust levels and communicate.

III. PROTOTYPING CONSIDERATIONS & COMPROMISES

A. Horizontal vs Vertical Fidelity

In order to maximize coverage especially when it came to various types of upper limb mobility issues, we decided to go for a high horizontal fidelity rather than a vertical fidelity system. Our high horizontal fidelity focused on three navigation systems for the dashboards, multiple games as well as reports for users, notifications and other functionalities. There was however, moderate vertical fidelity which focused on tracking simulation using mock joint movement, calibration system, a simplified scoring engine and results/outputs.

B. Visual Compromises

The colour palette remained limited. Icons were reused across screens to maintain consistency. Simple interaction system and game design due to time constraints.

C. Functional Compromises

Difficulty is pre-programmed and not dynamically computed. Feedback is text based instead of animated overlays. Lag in real time projection (minor). Inability to implement proper Action Research Arm Test.

IV. CONCEPTUAL DESIGN

A. Metaphors and Interactions

Rehabilitation as Gameplay: Users are to perceive therapy as not a medical task but rather a rewarding challenge.

Arm Orchard (Game 1) – "Garden Exercise": Picking fruit from a tree.

Piano Tiles (Game 2) – "Music Practice": Playing a simplified piano keyboard.

Shape Tracer (Game 3) – "Drawing Sheet": Tracing outlines of drawings.

Result dashboard – "A personal progress board": Similar to a bulletin board.

In this way our system becomes a Visual Therapy Studio with three game stations along with a progress board.

B. Design Principles Used

- 1) **Simplicity and Learnability:** Older adults benefit from shallow navigation, that is, one function per screen, large buttons and no hidden menus.
- 2) **Feedback and Visibility:** Real time scores increase along with movement detection and auditory cues.
- 3) **Consistency:** The games use similar simplistic designs and layout.
- 4) **Motivation:** We incorporated the use of streaks, XP points and goals to help motivate users.

C. Action Research Arm Test Integration

TABLE II: Game mapping alignment with the ARAT Domains

ARAT Domain	Game Correspondence
Grasp	Arm Orchard and Piano Therapy
Grip	Piano Therapy
Gross Movement	Arm Orchard and Shape Tracer

D. Design Space

The design space for our telerehabilitation system emerges at the intersection of various gesture based interaction, game based motivation, clinical reporting as well as accessibility. Since the objective is to help older adult users to perform structured upper-limb rehabilitation at home, the design space is shaped by three key components which includes: Interaction modalities, feedback mechanism and stakeholder needs. Together these elements determined how each prototype supports encouragement, therapeutic accuracy as well as remote monitoring.

- 1) **Interaction modalities:** The three games explore different forms of interaction to accommodate varying motor abilities and hardware constraints.
 - **Motion-tracked interaction (Game 1 and 3):** These games rely on webcam-based body tracking which focuses on joint detection (shoulder, elbow, wrist and fingers) to interpret various motions like reach, grasp and tracing movements.
 - **Hybrid Interaction (Game 2):** This prototype expands the design space beyond motion tracking by allowing direct keyboard or touchscreen input. It captures fine-motor inputs rather than gross motor movements.

This mix allows the system to support a wide variety of rehabilitation needs within a consistent interface.

- 2) **Feedback and motivation layer:** A large portion revolves around how the system keeps users motivated. This includes real-time visual feedback (joint highlights, tracking lines and correctness), reward systems (XP points, streaks, auditory cues and scores) and simple explanations.
- 3) **Multi-stakeholder requirements:** The design also extends to how various stakeholders can use the same ecosystem. For instance, patients require clear guidance, fun tasks and assurance in movements. Clinicians

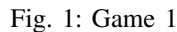
is holistic design space ensures that the system is not a collection of mini-games but rather a more unified rehabilitation ecosystem that can be used in order to support learning, motivation as well as long term clinical insights.

V. PROTOTYPE DESCRIPTION AND FUNCTIONALITIES

Please refer to the demo video to understand the gameplay of our prototypes.

This game is created to stimulate a simplified reach to grasp tasks using colourful fruit as the interaction object. The patient is instructed to reach towards the apple and pick them by mimicking the grasp movement. The system then recognizes the movement and registers it to move according to the hand and when the hand is released, so is the apple.

Visually, the game emphasises encouragement rather than clinical severity.



This game is a music-inspired exercise aimed at improving coordination. The interface resembles that of a simplified piano keyboard with keys that light up according to the exercise rhythm. The patients are then instructed to use their fingers to perform the action accordingly. When performed correctly and within the desired time range, the movement is registered as correct and adds onto the existing score board.

The screenshot shows the 'Piano Reaction Game' interface. At the top, a status bar displays 'Attempts: 1', 'Correct: 0', 'Incorrect: 0', and 'Not Done: 0'. A 'Save' button is located in the top right corner. The main game area consists of seven columns labeled A through J. Column F is black, and column H is grey. Below the columns, a row of buttons shows the sequence: A, S, D, F, G, H, J.

C. Game 3: Shape Tracer

TABLE III: Game to goal relationship

Game	Functional Goal	Rehabilitation Goal
Arm Orchard	Grab apples and place it into the basket	Improve reach, shoulder stabilization and arm movement
Piano Therapy	Press keys in timed sequence	Improve fine motor precision of fingers
Shape Tracer	Trace shapes	Enhance range of motion and coordination of movement

While the games form the core therapeutic experience, the dashboards establish the scaffolding which then connects patients, caretakers as well as clinicians. We had each of the dashboards reworked to reflect our perceived requirements for each user type.

Please refer to the application for more detailed overview.

Patient Dashboard: The user is greeted with warm colour, readable fonts and a focus on efficacy.

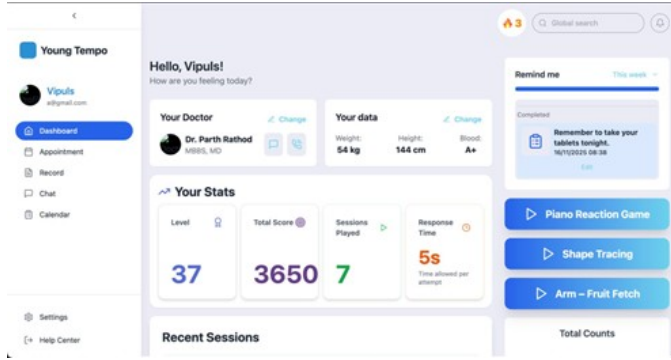


Fig. 4: Patient dashboard

Caregiver Dashboard: This dashboard is designed with simplicity in mind. It reframes rehabilitation as a family-supported activity.

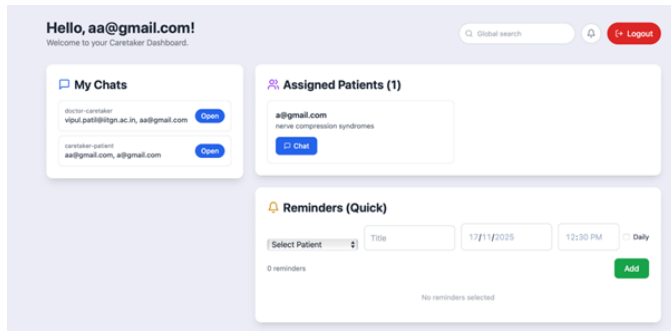


Fig. 5: Caretaker dashboard

Clinician Dashboard: This dashboard embraces a more data-dense layout, with charts, accuracy graphs and session logs.

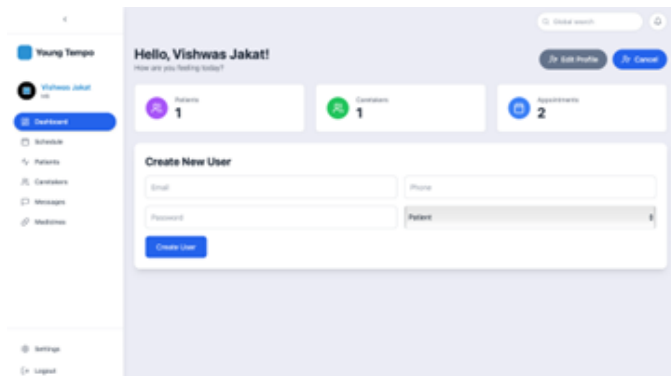


Fig. 6: Clinician dashboard

VI. USER EVALUATION AND RESULTS

Before evaluating the system with users, we needed to ensure that our design had a solid clinical foundation up

to an extent. For this reason, we first consulted a physiotherapist to understand traditional rehabilitation challenges, essential movement parameters, and the practical difficulties faced during home-based therapy. His inputs helped us refine our game mechanics, choose meaningful metrics, and identify potential risks. Once the expert evaluation gave us clarity on the therapeutic direction, we proceeded to test the system with users, gather their experiences, and assess its effectiveness in a realistic environment.

We have filtered some of the important details and consolidated all the required points in our project report.

A. How Upper-Limb Rehabilitation Was Traditionally Done

Before introducing digital or game-based tools, the physiotherapist explained that upper-limb rehabilitation mostly depended on manual exercises and one-on-one guidance. Treatment involved a combination of passive and active range-of-motion exercises, strengthening routines using elastic bands or weights, and repeated task-based activities like pegboards and object transfers. Fine motor tasks such as using beads or clips were also part of the routine.

These sessions required close supervision to correct posture, prevent compensatory movements, and ensure the movements were performed safely. Progress was usually monitored with simple tools like goniometers, manual muscle testing, and general observation. Although these methods worked, they were highly subjective and depended heavily on the therapist's judgement.

B. Issues Doctors Faced With Traditional Rehabilitation

The physiotherapist explained that traditional rehabilitation often struggled because the exercises felt repetitive, which made many people lose motivation and stop following their routines regularly. At home, there was no supervision, so exercises were often forgotten, done incorrectly, or skipped altogether. This made it hard for therapists to know what was really happening outside the clinic. They couldn't see if someone was moving properly, using harmful compensations, or getting tired too quickly. Overall, there was a clear gap between what happened during therapy sessions and what happened at home, which affected recovery.

C. Previous Experience With Gamified Rehabilitation

We were told by the physio that even though gamified rehabilitation tools like VR or Kinect systems exist, they are rarely used in real clinical settings. The biggest obstacles are high cost, complicated setup, the need for technical support, and calibration problems with older technology. Previously they have experimented with simple mobile or smartwatch-based exercise apps, and while these tools made sessions more engaging, they lacked the clinical accuracy and meaningful metrics needed for serious, long-term rehabilitation.

D. Doctor's Feedback on Our Web-App

After we explained our system, the physiotherapist provided both positive feedback and suggestions for improvement.

Positive Points

- The idea of blending therapy with simple games felt practical and motivating.
- The app attempts to record measurable aspects such as accuracy and response time.
- Camera-based calibration is seen as a strong feature if made smooth.
- The movements in our games match actual therapy goals.
- A guided system could improve at-home compliance.
- Detecting compensatory movements would be clinically valuable.

Recommended Improvements

- More accurate joint angle tracking.
- Clinically meaningful metrics like fatigue curves.
- Adaptive difficulty.
- Customization options (speed, range, repetitions).
- Integration into clinic workflows with report export.

E. Evaluation Metrics for Our Games

Game 1 – Arm Orchard: reach accuracy, range of motion, grip quality, completion time, fatigue. Game 2 – Piano Tiles: reaction time, accuracy, motor control, rhythm, bilateral use. Game 3 – Shape Tracing: path accuracy, smoothness, completion time, error rate.

F. Broader User Feedback

A. Concerns about accuracy in different lighting and environments. B. Practical issues: space, webcam quality, standing posture. C. Usability friction if gestures fail to register. D. Safety concerns regarding fast or unsafe movements. E. Inclusivity issues for users with tremors or cognitive issues.

G. Types of Observations Conducted

Expert Observation, Usability Observation, Think-Aloud Observation, Behavioral Observation, Contextual Observation, Non-Expert Observation, Caretaker Observation.

VII. ETHICS AND RISK ASSESSMENT

A. Ethical Design Considerations and Risk Management

Ensuring ethical integrity is crucial when it comes to designing and evaluating digital rehabilitation systems especially in our case where we work with older adults with physical impairments and possible reduced cognitive capacity. It goes beyond just formal consent but rather emotional well being, safety and access as well as a responsible representation of user needs.

Although our evaluation did not involve the target population, we stimulated ethical protocols that would be required in a real world deployment. We had informed the participants the purpose of the evaluation, the voluntary nature of participation as well as their right to withdraw at any given time. They were encouraged to express any sort of discomfort, confusion or frustration openly so that we can use their feedback in the future.

We also believe that ethics must be integrated into the system and we do this at broadly three various levels. They are:

Privacy: Only essential tracking data is collected, no facial recognition or identity markers are stored.

Transparency: Users are informed each time data uploads or is shared. They are allowed to withdraw and delete their account.

Autonomy: Users can pause or exit the game at any given point without penalty, supporting personal agency.

Additionally, one of the highest risks in rehabilitation systems is in terms of physical harm. Our prototypes mitigate these risks by incorporating slow guided movements to prevent strain, fatigue or injury. The system also flags incorrect posture patterns and provides a calibration phase to ensure safe running. There also exists an emergency contact button that alerts clinicians and authorities in case of any accidents.

Telerehabilitation systems usually involve users with diverse physical, cognitive and emotional states. Therefore our high fidelity design explicitly addresses these needs by prioritising clarity, safety and dignity.

Physical accessibility: Each game has been designed to accommodate various levels of motor function. Game 1: supports slow-motion reach; Game 2: tempo adjustment; Camera-based exercise supports seated posture, reducing fall risk.

Cognitive accessibility: Instructions appear in short segments. Colour coding: green = correct, red = incorrect. Icons based on familiar metaphors.

Emotional and motivational accessibility: Warm colours, soft transitions and encouragement-focused wording. XP points and streak indicators support adherence.

B. Limitations

Despite the strengths of our prototype, several methodological and technical limitations exist.

The motion-tracking system is simulated and not clinically validated. It does not employ medical-grade depth sensors. Calibration uses simplified posture measures and may be difficult for users with restricted mobility. Lighting variation might reduce accuracy.

The prototype was tested through user walkthroughs but the sample did not represent the true target population (older adults with upper-limb impairment), limiting generalizability.

While exercise movements were informed by physiotherapy principles, no licensed clinician supervised the prototype development.

Game difficulty, pacing and fatigue handling are limited. The system assumes access to webcam, stable internet, and a device capable of rendering graphics, which may exclude some users.

Nevertheless, the prototype provides a strong conceptual foundation for a full telerehabilitation system.

VIII. CONCLUSION

The development of this high-fidelity telerehabilitation system is a representation of our team's attempt to explore how

digital technologies can be meaningfully integrated into upper limb motor recovery. Through an extensive multi-stage design process—beginning with user research and literature review to personas and low fidelity sketching—the project evolved into a coherent and functional system encompassing three rehabilitation games, user-specific dashboards and interfaces.

Although conceptual and simulation-based, it successfully demonstrates how rehabilitation tasks can be gamified, structured and interpreted within a unified ecosystem.

We believe the key achievement lies in its user-centered design approach, ensuring that the system addresses needs of patients, clinicians and caretakers. The three games illustrate how diverse rehabilitation movements can be embedded within approachable gameplay metaphors. Visual cues, feedback and motivational framing help bridge challenges commonly associated with home-based therapy.

We acknowledge technical and methodological limitations due to time constraints, but the prototype succeeds as a “proof of concept,” demonstrating a unified system integrating rehabilitation, feedback and oversight, outlining a path for future hybrid systems.

In summary, this project offers a compelling starting point for future work in digital rehabilitation. It articulates the design space, establishes interaction flows and reveals critical opportunities for refinement through real-world testing.

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Finally we also would like to acknowledge the dedication and collaborative spirit of our project team. Each member’s effort and commitment to bring together this multi-stage design over the semester. This project is a reflection of our shared hard work and collective learning during the course - “Human Computer Interaction”.

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