

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.

1. 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.

2. System Design & System Architecture

2.1 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.

2.2 Game Engine Logic

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. This ensures initial adjustment and readiness for the tracking.
2. Instruction Phase	The game presents a set of instructions for the user to follow accordingly.
3. Tracking Phase	This involves continuous joint and limb movement capture, allowing real-time responsiveness.
4. Verification Phase	The system then compares captured movement patterns against predefined target trajectories, exercise templates or various gesture requirements as per the selected game.
5. Reward Phase	The users will also receive motivational reinforcement such as XP points or sound effect cues based on performances.
6. Summary Phase	This includes the session data like the scores, accuracy, repetitions, range of motions and completion times which is updated to the dashboard accordingly.

Table 1. Shared Logic Pipeline across game prototypes

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.

2.3 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 updates
- Session report automatically uploaded
- Dashboards gets reports and charts accordingly
- Adherence and consistencies are monitored

2.4 Role- Based Dashboards

The system supports three user types:

Patient Dashboard: This includes the daily session, view of weekly report/ goal, XP Progress, streaks and receiving reminders, messages as well as an emergency contact function.

Caregiver Dashboard: This includes tracking the patient attendance, medication, alerts for skipped sessions as well as a simplified progress graph.

Clinician Dashboard: This includes the function to manage patients, map performance, configure therapy plans as well as adjust levels accordingly and a communication function.

3. Prototyping Considerations & Compromises

3.1 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.

3.2 Visual compromises

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

3.3 Functional compromises

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

These constraints are acknowledged as part of our prototyping process.

4. Conceptual Design

4.1 Metaphors and interactions

- Rehabilitation as Gameplay: Users are to perceive therapy as not a medical task but rather as a rewarding challenge.
 - Arm Orchard (Game 1) - "Garden Exercise"
- Metaphor: Picking fruit from a garden tree

This involves studying the grasping and reaching motions naturally, gardens can also represent calm and familiar spaces for older adults with fruit baskets resembling real life tasks involving reaching for objects and placing them away.

- Piano Tiles (Game 2) - “Music Practice”

Metaphor: Playing a simplified piano keyboard

This involves pressing keys and it relates to fine motor tasks. The idea of “following notes” is familiar to those who have been exposed to music.

- Shape Tracer (Game 3) - “ Drawing sheet”

Metaphor: Tracing outlines of drawings onto a sheet of paper

This involves following a pattern and outlining it accordingly. Many users must have drawn or traced shapes in their childhood or at some point of time. The system then becomes a virtual drawing table where they can trace out the pattern using their arms.

- Result dashboard - “A personal progress board”

Just like in real physiotherapy or schools, there would be a bulletin board that tracks improvement using charts, XP points, Check marks, etc.

In this way, the metaphor helps users understand what the numbers mean, its not just “data” but rather “the user’s progress sheet.”

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

4.2 Design Principles Used

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

4.3 Action Research Arm Test integration into conceptual design

The ARAT assesses grasp, grip, pinch as well as gross motor movement. Although not perfectly implemented, our design takes inspiration from the same.

ARAT Domain	Game correspondence
• Grasp	Arm Orchard (Fruit pick up and drop) and Piano Therapy (One version required user to interact with their mobile device)
• Grip	Piano Therapy (Key pressing on the mobile device required wrist stability)
• Gross movement	Arm Orchard and Shape tracer requires movement including arm elevation and lateral reach

Table 2. Game mapping alignment with the ARAT Domains

4.4 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.

- 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 a 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.
- 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.
- Multi-stakeholder requirements: The design also extends to how various stakeholders can use the same ecosystem. For instance, patients would require clear guidance, fun tasks and assurance in movements. On the other hand, clinicians require a more structured reporting, progress summaries and adherence tracking as well as low-noise performance metrics. Caretakers require reminders, alerts and simple monitoring tools to support the patient.

This holistic design space ensures that the system is not just a collection of minin-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.

5. Prototype Description and functionalities

The three games represent distinct rehabilitative principles inspired by that of neurorehabilitation literature. Wherein each module addresses specific domains of motor recovery like reach accuracy, coordination, fine motor control and upper limb range of motion.

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

5.1 Game 1: Arm Orchard

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.

The interface provides to the patient a clear and corrective guidance. For instance, if the patient were to lift beyond the ideal range of angle, the system is to flag and register the

action as incorrect. The goal is to nudge the user towards healthier motor patterns. When the fruit is deposited correctly, it is reinforced by an increase in score and sound cue. Visually, the game emphasises encouragement rather than clinical severity.

Figure 1. Game 1

5.2 Game 2: Piano Therapy

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.

By grounding the game in familiar musical metaphors, it reduces anxiety associated with repetitive finger movements and transforms the experience.

Figure 2. Game 2

5.3 Game 3: Shape Tracer

This game is intentionally designed with those users with limited shoulder mobility and presents geometric shapes, with the users being asked to trace them by moving their arms according to the traced outline provided to them. If the tracing deviates, the system recognizes it accordingly and translates the same in the later results.

Figure 3. Game 3

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

Table 3. Game to goal relationship

5.4 Dashboard ecosystem

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.

Figure 4. Patient dashboard

- Caregiver Dashboard: This dashboard is designed with simplicity in our mind. It tries to reframe rehabilitation as not a clinical obligation but rather a family-supported activity.

Figure 5. Caretaker dashboard

- Clinician Dashboard: This dashboard stands in stark contrast wherein it embraces a more data-dense layout, it incorporates charts, movement accuracy graphs and session logs.

Given below are images of how the clinician dashboard looks like:

Figure 6. Clinician dashboard

6. 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 .

6.1 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.

6.2 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.

6.3 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.

6.4 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, which the doctor found promising.
 - Camera-based calibration is seen as a strong feature—if made smooth and easy to set up.
 - The specific movements in our games (reaching, grasping, tracing) match actual therapy goals.
 - A guided system could help improve at-home compliance.
 - Detecting compensatory movements would add significant clinical value.
- **Recommended Improvements**
 - **More accurate tracking** of joint angles, smoothness, trajectory, and alignment.
 - **Clinically meaningful metrics** like fatigue curves and range-of-motion utilization.
 - **Adaptive difficulty**, so the system doesn't overwhelm weaker users or bore stronger ones.
 - **Customization options** (speed, range, repetitions) for different physical conditions.
 - **Smooth integration** into clinic workflows, including report export and long-term tracking.

6.5 Evaluation Metrics for Our Games

We compiled evaluation metrics based on some of the clinical standards and the doctor's

recommendations.

Game 1 – Arm Orchard

Focuses on shoulder, elbow movement, and grip coordination.

Metrics include reach accuracy, range of motion used, grip detection quality, completion time, and signs of fatigue.

Game 2 – Piano Tiles

Focuses on hand-eye coordination, reaction time, and finger dexterity.

Metrics include reaction time, accuracy rate, fine motor control, rhythm maintenance, and bilateral use.

Game 3 – Shape Tracing

Focuses on controlled trajectory and stability.

Metrics include path accuracy, movement smoothness, completion time, error rate, and consistency.

6.6 Broader User Feedback (General Crowd & Non-Experts)

We also had informal conversations with peers, seniors, and family members. Their feedback helped us understand real-world usage concerns.

A. Concerns About Accuracy

Some people questioned whether the camera would detect gestures consistently in different lighting conditions or small rooms. Others doubted whether subtle movements would register reliably.

B. Practical Loopholes

Many pointed out that not everyone has the ideal setup; space, lighting, or a good webcam.

People may also stand incorrectly, move out of frame, or depend too much on network stability.

C. Usability Friction

If the app fails to detect a gesture, individuals may assume they did the movement

wrong, causing frustration.

D. Safety Concerns

Observers worried about the lack of automatic correction for unsafe movements or overly fast motions.

E. Inclusivity

Not everyone can form a perfect fist or follow fast instructions. People with tremors or cognitive difficulties may struggle without slower, more flexible instructions.

6.7 Types of Observations Conducted :

Types of Observation	Descriptions
Expert Observation (Doctor Evaluation)	<i>Assessed therapeutic relevance, accuracy of movement detection, safety, compensatory behaviors, and clinical usefulness of the system.</i>
Usability Observation (Task-Based Testing)	<i>Observed how individuals interacted with the system in a real-world setting without guidance, noting ease of use, understanding, and spontaneous behavior.</i>
Think-Aloud Observation	<i>Users performed specific tasks within each game; we observed errors, task completion time, confusion points, and overall task performance.</i>
Behavioral Observation	<i>Users verbalized their thoughts while using the system, helping us understand their reasoning, expectations, and confusion during interactions.</i>
Contextual/Environmental Observation	<i>Monitored users' body movements, posture, fatigue signs, hesitations, and any compensatory movements during gameplay.</i>
Non-Expert / General Crowd Observation	<i>Evaluated how physical environment factors lighting, space, camera position, background impacted usability and tracking accuracy.</i>
Caretaker Observation	<i>Noted caretaker involvement, challenges faced during assistance, and their perspective on setup, instructions, and usability.</i>

7. Ethics and Risk Assessment

7.1 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: Wherein only essential tracking data is collected, no facial recognition or identity markers are stored.
- Transparency: The users are also informed each time data uploads or is shared. They are allowed to withdraw and delete their account and in turn erasing data completely.
- Autonomy: The users can pause or exit the game at any given point of time without any penalty. We do this in order to support the personal agency of the patient in their rehabilitation journey.

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 any sort of strain, fatigue or injury. The system also flags incorrect posture patterns and provides a calibration phase to ensure safe and smooth running. There also exists an emergency contact button that alerts clinicians and authorities in case of any accidents or issues.

Telerehabilitation systems usually inherently involve the user possessing diverse physical, cognitive as well as emotional states. Therefore our high fidelity design explicitly addresses these needs and is done so by prioritising clarity, safety as well as dignity of the users.

- Physical accessibility
Each game has been designed to accommodate various levels of motor function:
Game 1 (Arm Orchard): Target with slow motion support with limited reach accuracy.
Game 2 (Piano Therapy): Task can be adjusted for tempo to accommodate range.
Moreover, camera-based exercises allow the user to remain seated which in turn prevents and reduces any fall risk which can be a major concern for home rehabilitation.
- Cognitive accessibility
Older adults or users with mild cognitive impairment may struggle with complex instructions. Hence, we have made certain adjustments to ensure smooth functioning. Instructions appear in short, step-by-step segments. There is simple color coding across modules (green=correct, red= incorrect). Icons also rely on familiar metaphors such as musical keyboard, shapes, etc rather than simply abstract symbols.
This therefore reduces cognitive load and also aids in the strengthening of comprehension.
- Emotional and motivational accessibility
As we already know, rehabilitation can be emotionally draining and so in order to

counter this we have incorporated certain elements into our high fidelity prototype. All modules incorporate warm colors and smooth transitions along with soft sound cues. The system avoids any sort of language that implies “failure or blame”, but rather encourages the user. Progress is also celebrated and this can be seen through XP points as well as streak indicators. Additionally the games are designed to feel playful rather than simply clinical.

In this way, we ensure our approach aligns with positive reinforcement which we believe will increase the user’s adherence dramatically especially when it comes to remote therapy.

7.2 Limitations

Despite the various strengths of our prototype and clarity in our design rationale, we do acknowledge that there are several methodological, technical as well as conceptual limitations. These limitations do not necessarily detract the value of our work but rather frame the boundaries within which our findings and design decisions should be interpreted.

One of the limitations would be that the motion-tracking system is simulated and may not be clinically validated. While the prototype models joint tracking and gesture detection, it does not employ real medical grade depth sensors. Our calibration module also uses oversimplified posture and forearm alignment however older adults with restricted mobility may struggle and the calibration requires repeated position sampling. There is also lighting variation that might affect the system and reduce accuracy.

Although the prototype was tested through user walkthroughs and heuristics, the sample did not represent the true target population, namely the older adults with upper limb mobility impairment. This limits the generalizability of usability findings.

While the exercise movements were informed by that of physiotherapy principles and ARAT relevant components, there was no licensed clinician who supervised the prototype development.

Our three games aimed to strike balance between that of motivation and therapeutic functions but they do still possess inherent limitations. For instance, movements lack adjustable intensity and pacing and do not account for fatigue accumulation or cognitive load. The system also requires a webcam, stable internet and a device that can render interactive graphics and therefore may unintentionally exclude certain users.

Nevertheless, the prototype still provides a strong conceptual foundation on which a fully functional telerehabilitation system can be built upon.

8. 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. It was through the extensive multi-stage design process, beginning with user research and literature review to the creation of personas and low fidelity sketching that the project eventually evolved into a coherent and functional system encompassing three

rehabilitation games, user specific dashboard and interfaces as well as tools. Although conceptual and stimulation-based, it can be seen that it successfully demonstrates how rehabilitation tasks can be gamified, structured and interpreted within a unified ecosystem.

We believe that a key achievement in our project lies in its user-centered design approach which ensures that the system addresses the needs of the various stakeholders: the patient, the clinician as well as that of the caretaker. When it comes to the three games, it further exemplified how diverse rehabilitation movement can be embedded within an approachable gameplay metaphor. We had integrated visual cues, feedback and framing to try and bridge the motivational gap that often challenges patient adherence when it came to traditional home-based exercises.

At the same time, we acknowledge the technical as well as methodological limitations. Given the short amount of time, there was much we would have liked to incorporate but were unable to do so. As mentioned, we believe there are various other possibilities to carry on the idea and project. Despite the constraints, the prototype succeeds in demonstrating what we call “proof of concept” wherein we have a system that unifies physical rehabilitation, meaningful feedback as well as reinforcement and oversight. It outlines a sort of realistic pathway for how further work can be done to evolve it into a hybrid system.

In summary, this project offers a compelling starting point for further work in the future when it comes to digital rehabilitation. The aim was to articulate the design space, establish core interaction flow and reveal critical opportunities for refinement through real-world testing.

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