A Real-Time Physical Therapy Visualization Strategy to Improve Unsupervised Patient Rehabilitation

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1 Introduction

Rehabilitation is a lengthy and difficult process. Despite the speed with which physicians can diagnose an injury, for full recovery patients must regularly meet with their physical therapist (PT) as well as daily perform their prescribed, unsupervised exercise routine. PTs usually give their patient simple diagrams, sketches, and text-based instructions to assist them in recalling and correctly executing each exercise. With these limited tools, patients often rely on memory to recall complex sets of exercises. If an exercise is remembered incorrectly, months may pass before an appointment with the PT corrects the motion. This process results in significantly longer recovery times, taxing both the health care system and the patient's motivation to recover.

Interactive visualization tools can fill a current need for providing real-time corrective feedback to patients as they exercise, however, several research challenges remain in designing effective motion tracking and visual feedback strategies for these tools. This poster presents the design, implementation, and lessons learned in developing a real-time feedback visualization for squat exercises, which are commonly used in a variety of rehabilitation settings.

2 Previous Work

The state of exercise has changed universally as a result of advances in the gaming industry, which has begun to incorporate interactive exercise games. Products such as Konami's Dance Dance Revolution, Playstation's EyeToy Kinetic, the Wii Fit, and Expresso bikes can motivate and entertain patients to the degree that they no longer differentiate playing and exercising. Physical therapists have also begun incorporating these elements into their practice, though primarily during supervised training sessions.

Academic research has focused largely on increasing or returning movement in post-stroke patients using innovative, interactive, gaming solutions. Jack et al. [1] use a glove-based solution to increase wrist movement, while White et al. [2] and Yeh et al. [3] both use a variety of input devices to increase upper extremity movement. Our work expands on these rehabilitation frameworks to treat larger muscles groups in the lower extremities, where wired input devices can no longer support the large torso and leg movements.

3 Real-time physical therapy visualization

In collaboration with Dr. David Nuckley, a bioengineer at the University of Minnesota Medical School, we designed and developed a prototype feedback application. We chose to address the specific needs of an anterior cruciate ligament (ACL) tear, a common knee ligament injury. Physical therapy for ACL tears

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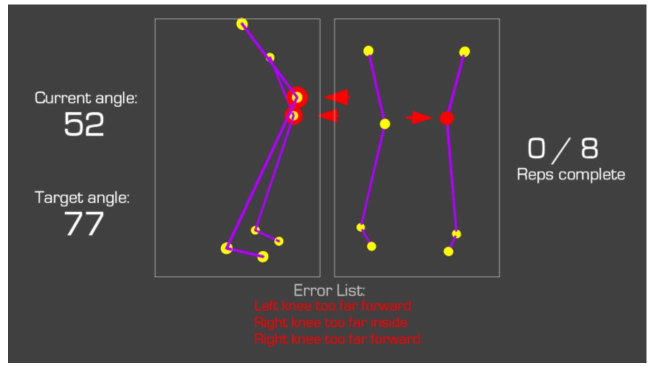

Figure 1. Application interface

focuses on strengthening large muscle groups close to the torso like the quadriceps, hamstrings, and calves. We chose to focus on a single exercise, the squat, which has the simple constraint of bending both knees while preventing them from passing or moving far to the side of the toes. Thus, the majority of user feedback should focus on the knee's trajectory. The squat exercise has different levels of complexity, entirely determined by the maximum angle reached by the knee during the exercise, with 90, 75, and 50 degrees corresponding to high, medium, and low difficulties respectively.

We used a minimal version of the Helen Hayes marker set, commonly used for gait analysis, consisting of four markers placed just below the small toe, below the ankle, at the outer knee joint, and outside the thigh. A six infrared camera configuration was used to record the individual position of each of the eight markers.

3.1 Design

Our design goals were simple: 1. Demonstrate the target motion. 2. Dynamically show the user when they have made an error performing the target motion and how to correct it. 3. Allow for variance in marker placement. 4. Support interaction at a range of distances from the screen.

The visualization displays the markers as spheres connected by a stick figure representation for the legs. When the knee is incorrectly positioned, the size of the sphere representing the knee is increased, the color is changed from yellow to red, and a red arrow is drawn next to the knee pointing in the direction to move the knee to resolve the error (Figure 1).

In addition to these graphical elements, we included some text to assist new users. The visualization displays the target angle and current average angle of the legs, the number of exercise repetitions complete, and the number remaining for set completion. An error list compliments the graphics by textually explaining the reason for the appearance of the arrows. Example errors are: "knee too far inside" and "knee too far forward."

3.2 Implementation and Example Exercise Session

When an exercise session begins, the visualization displays an ideal example of the squat motion. Following this animation, the patient is calibrated in resting position, with legs straight and feet forward, by calculating the angle between the lower and upper leg. The slope of the lines connecting the ankle and knee and the thigh and knee are used to calculate the resting angle at the knee. This calibration step allows a very loose placement of the thigh and ankle markers (Figure 2a). Regardless of how far up or down the leg they are placed, the calculation will result in virtually the same knee angle. This initial knee angle is normalized with the 0 degree line where the ankle, knee, and thigh line up, where the positive direction is in the direction of the knee bend (Figure 2b).

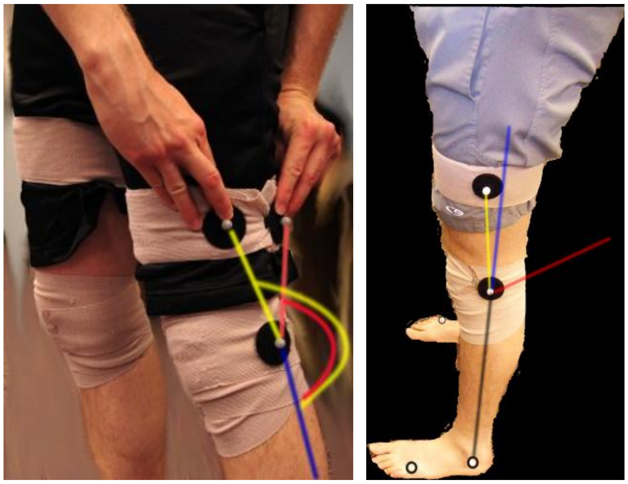

Figure 1. a) Marker Placement:.1) -15º; 2) +10º b) Leg angle examples: 1) Resting; 2) Starting Position; 3) Ending Position

At this point the feedback loop begins by showing the user a target angle and their current knee angle. The squat starts with the knees slightly bent, thus, the starting angle is calculated by adding 15 degrees to the average of the knee angles. Once this position is assumed, the target angle changes to the squat end angle, which is 50 degrees plus the starting angle. At each point in the session, the target angle is either the start or end squat angle. The user must complete 8 repetitions to end the set. New users are expected to make errors as some strength and balance training is necessary to learn to complete the squat correctly. Thus, the program still counts reps that were made incorrectly.

Maintaining the same visual presentation of the legs regardless of changes in the patient's distance from the screen is important. The user may lose balance and re-start from another position or simply find a more comfortable distance from the screen. In order to achieve this consistency, the right ankle marker is anchored to a position on screen and the rest of the markers are drawn relative to that position. Although walking will make the avatar appear to be rotating in place, doing a squat, which is preformed with the feet planted, moves the stick figure avatar as expected.

4 DISCUSSION

The current design is a result of several visual iterations. One version included an abstract representation of the leg silhouettes drawn around the stick figure. The silhouette lines moved along with the patient's markers until they aligned vertically with the toe marker position, which bounds the correct knee movement. At this point, they stopped moving, indicating that the knee should not move beyond this point.

This initial design proved to be too cluttered and confusing. Since the boundaries moved initially with the patient, but then eventually stopped, their sudden change in behavior was confusing and unclear. The final visualization provides fewer visual cues, but is more effective because the visual language is readily understood.

During the design, a number of our discussions centered on the relative merits of presenting positive versus negative feedback. Aside from the initial target motion animation, our program does not present positive targets or motions that the user must mimic. Instead, we present negative feedback when the user moves outside the boundaries of the exercise constraints. The lack of positive feedback requires the user to recall the correct trajectory of the exercise, much as the diagrams and sketches do that the PT provides. In the future, additional, complimentary feedback mechanisms may address these concerns.

5 CONCLUSION AND FUTURE WORK

Our prototype application is a first step towards dynamically visualizing exercise performance. Future work includes creating a more realistic avatar, adding support for the full set of ACL physical therapy exercises and conducting user studies. If our studies provide positive findings, we could then create a hardware solution that patients would purchase for their homes.

We plan to complete our work by including a motivational gaming framework. These games may provide appropriate positive feedback to compliment our current approach. Our working design for a game that would support a diverse set of exercises is based upon the TV program, "Hole in the Wall", where contestants must assume the correct position to fit through a hole made in the shape of a human silhouette in a wall as the wall moves toward them. The wall will push incorrectly positioned participants into a pool of water waiting below, while correctly positioned participants will pass through the hole unhindered.

In this design, the pace of the game could easily be set by the speed with which walls approach, and a variety of exercises could be expressed through designing a series of appropriate silhouette-shaped holes. A preview window that presents the next approaching wall, similar to the Tetris interface, would allow the walls to approach continuously without obscuring each other. This gaming framework would change the slow, repetitive nature of physical therapy, to a far more interactive experience.

The initial investigations reported in this poster indicate that whole body exercises can be reliably integrated into rehabilitation applications and suggest a number of exciting future directions for real-time exercise motivation and feedback for virtually any exercise.

REFERENCES

[1] Jack, D., Boian, R., Merians, A., Adamovich, S. V., Tremaine, M., Recce, M., Burdea, G. C., and Poizner, H. A virtual reality-based exercise program for stroke rehabilitation. *Proceedings of the Fourth international ACM Conference on Assistive Technologies* (Arlington, Virginia, United States, November 13 - 15, 2000). Assets '00 pages 56-63, 2000.

[2] White, D., Burdick, G., Fulk, G, Searleman, J., Carroll, J. Virtual Reality Application for Stroke Patient Rehabilitation. *Proceedings of the IEEE International Conference on Mechatronics and Automation* (Niagara Falls, Canada, July 2005). Vol 2, pages 1081 - 1086, 2005.

[3] Yeh, S., Rizzo, A., Zhu, W., Stewart, J., McLaughlin, M., Cohen, I., Jung, Y., and Peng, W. An integrated system: virtual reality, haptics and modern sensing technique (VHS) for post-stroke rehabilitation. *Proceedings of the ACM Symposium on Virtual Reality Software and Technology* (Monterey, CA, USA, November 07 - 09, 2005). VRST '05 pages 59-62, 2005.