# Augmented Reality-based Exergames for Rehabilitation

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# Stroke

- Interruption in the normal flow of blood or bleeding in the brain, damage the brain cells that start dying within minutes leading to a condition known as Stroke.
- Damage to the brain cells triggers symptoms in parts of the body they controlled, attention deficiency, long-term disability, weakness and partial paralysis on localized regions or even death.
- 80% of the stroke survivors suffer from upper limb impairments.
- More than 40% of the patients receiving lower limb rehabilitation therapy sessions are not able to walk freely even after completing therapy.
- Rehabilitation for stroke involves repetitive exercising of the affected parts. E.g. reaching, flexing and grasping objects of daily use, treadmill training with partial support of body weight, hip and knee extension.



# Exergaming

- In recent years, Exergaming (exercise and gaming), also known as Serious Gaming, has emerged as a cost effective rehabilitation tool, making repetitive exercising a fun and motivating task.
- Augmented Reality (AR) used to improve motion recovery using action observation.
- Mirror Therapy involves seeing oneself in a mirror, or on a display in an AR scenario, and then getting motivated by improvement in the tasks seen in virtual world which in reality would be difficult to achieve.
- Repetitive exercise performance which is a major concern for rehab is solved easily by using Exergames.
- The gaming aspect removes the boring and mundane parts of exercising.
- Being cost-effective and in-home setup improves the chances of patients actually taking the treatments regularly.



# Problems with current AR systems

- Majority of the AR systems need external devices or sensors to be worn by the person.
- Invasive in the sense that it inhibits the normal user movements making them uncomfortable, and hence cannot be used for in-home rehab.
- Some of the non-invasive systems use webcams restricting the movements in 2D space.
- Multiple devices make the system setup complex and also increases the overall cost making it ineffective.
- Virtual avatars can be used to model the human actions, but having live
  3D models of themselves increase the motivation and involvement.
- Generating live 3D models is non-invasive and also captures emotions.
- Obtaining, generating and rendering live 3D models in a nice augmented reality setup is not an easy task.



# **UT Dallas Immersive Rehab Facility**

#### Panoramic View of the 30' x 15' Immersive Facility @ UT Dallas





## **Skeleton Computation**





# **3D Model Generation**

- Kinect V2 used for capture using depth and color streams.
- Random decision forest used to track features and estimate skeleton.
- 25 skeleton joints are obtained by fitting a human skeleton on extracted features.
- Point cloud information obtained per frame from the depth image.
- Dense mesh generated on top of the human extracted point cloud.



# **3D Model Generation**

- Based on the enhancement ratio, a modified skeleton is obtained by changing the original skeleton using a virtual enhancement technique.
- Using the original mesh, original skeleton and modified skeleton, an animation based enhancement strategy incorporated to obtain a transformed/enhanced mesh.
- Voronoi based segmentation is performed on the original point cloud to obtain the corresponding regions which need modification based on the transformed skeleton.



### **Merged Mesh Computation**





# Holobubble Game





#### **Rendering in Collaborative Environments**

Vs

#### **Mirrored rendering**



#### Person sees oneself along with others

#### **First person rendering**



Person sees only the others

- Mirrored rendering : A participant is rendered in the scene along with the other participants in a 3<sup>rd</sup> person view.
- First person rendering : A participant only sees his environment (virtual and/or real) and the other participant in a 1<sup>st</sup> person view.



#### Soccer Game



# Voodooing





# Voodooing





### Virtual Enhancement Using Voodooing



#### **Patient Exercising Alone**

#### Patient Exercising with Therapist's Avatar and Virtual Enhancement





## Phantom Limb









## Session Storage & Retrieval





# Augmenting Therapy Sessions

#### Virtual Enhancement:

- Encourage the patient using virtual enhancement features.
- Work on the "live" 3D model of the patient captured in real-time using the Kinect cameras and virtually enhance the movements of the patients.
- <u>Real-time Anomalous Movement Detection</u>:
  - Compare skeletal movements of the patient and the therapist.
  - If the trajectories of the movements differ by more than a threshold (that will be decided by therapist in the clinic), give a real-time feedback about the anomalous movement to the patient.
  - Therapist's movements may be in real-time or from stored data.
- <u>Guidance Through "Voodooing":</u>
  - On detecting an anomalous movement, alert the patient by giving visual and audio feedback.
  - Use the therapist's skeleton and animate the patient's 3D model to demonstrate how s/he should be doing the movement correctly.



## In-clinic, In-home, Tele..





# **Exergames System**

- Microsoft Kinect V2 camera used for capture in realtime – low cost, off the shelf, depth sensing, noninvasive, markerless.
- Color, depth, skeleton streams obtained from Kinect.
- Points of the person are extracted from the entire captured scene.
- 3D model is generated by performing meshing on top of the points obtained.
- Augmented reality environments created and 3D model is put in it.



# Exergames System (Contd.)

- Animation based virtual enhancement performed on top of the skeleton obtained to provide positive reinforcement.
- Toolkit consisting of 4 immersive Exergames developed – ShotPut, Blowing, Balance, RehbaQuiz corresponding to 4 different rehab exercises - Elbow Flexion, Elbow Extension, Elbow Rotation and Hip Abduction.
- Additional features for game selection, session recording, and playback (for future reference and expert feedback), and user mode (physician vs. patient).







# System Schematic Diagram





# **Exergame Toolkit**

- Easy to use interface, browse and select games by name or the associated body joint e.g. elbow, hip.
- User profile generation for future reference or for physician review.
- Dropdown for selecting assistance ratio in terms of virtual enhancement.
- Recording facility to record entire live scene as a video.
- Recordings allow for feedback for the physician to understand the correctness of the performed actions along with the scoring mechanism which might be incorrect in some situations.



# **Exergame Toolkit**

- Physicians can record the correct movements for each game to act as reference for the patients.
- Exercises adapted from publicly available websites supervised or created by certified rehabilitation specialists http://www.stroke-rehab.com/ & http://www.hep2go.com/.







Elbow Flexion

Elbow Extension



Exergaming toolkit, showing game selection based on body part, user profile creation/loading and enhancement ratio selection



**Elbow Rotation** 





Recording system showing the person trying to record a game by selecting it.









Mesh generated on the original skeleton and captured point cloud





Mesh animated using the original mesh, original skeleton and enhanced skeleton



# Virtual Enhancement

- Virtual enhancement of the limb movements by animating the skeleton based on the previous skeleton and enhancing the movement.
- 25 skeletal joints refreshed at more than 30 frames per second.
- At any point in time, we maintain two skeleton structures: S<sub>t-1</sub> and S<sub>t</sub>.
- Displacement of any joint p is obtained using its position in skeleton at two time frames, p<sub>t-1</sub> and p<sub>t</sub>.
- The magnitude of displacement, along with an enhancement factor determined by the therapist, decides the actual enhancement applied.
- Modification in one joint applied to its child joints in the hierarchy.
- Two constraints provided for each bone describing a minimum angle and maximum angle of rotation between current bone and its parent bone.
- Though the proposed enhancement can be applied to any joint movement, we focus only on arm and leg.





Illustration of enhancement for a simple wrist movement (a)pose of skeletal joints at time instance t-1 and t and enhancement estimation for wrist joint without normalization shown with orange point and (b)with normalization shown with red point and (c)enhanced pose obtained with the proposed method



Illustration of enhancement of a complex movement involving multiple joints (a)Enhancement with normalization applied to elbow joint and its child join: wrist (b)Enhancement with normalization applied to wrist joint (c)Final enhanced pose



### Exergames

- 4 games ShotPut, Bowling, RehabQuiz and Balance each focusing on different exercise.
- Close fist to grab an object involved in the game e.g. ball.
- Open fist to release the object in the direction.
- Kinect V2 SDK used to detect open and close fist.
- A scoring module calculates the score for a particular game and updates it on the screen to provide a sense of challenge.
- All games require the person to be standing or sitting in front of the camera, which is put right under the 3D TV.
- Virtual enhancement is incorporated into the limb movements to assist and motivate the person and can be activated or deactivated at any moment during the game.



# ShotPut

- Elbow Flexion incorporated to improve the motion of bending and straightening of the elbow.
- The task is to throw the ball as far away as possible in the virtual world by taking the hand holding the ball as far back as possible and then bringing it forward and releasing the ball, making it travel in the direction of the motion with the velocity calculated using the change in the fist position with respect to the time taken.
- The further one can extend the arm, longer the distance the ball covers from the foul line and higher the score.
- A virtual camera tracks and follows ball once released.
- Olympic style shotput open stadium where the person is placed.





# Bowling

- Another important exercise for elbow rehabilitation is Elbow Extension.
- Keep elbow straight by stretching it as far back as possible and bringing it in front.
- A virtual 10-pin Bowling alley, similar to the real bowling game, is generated and the person is placed in it.
- Person either stands or sits and holds the ball on the side parallel to the body.
- The idea is to try and stretch the arm as far back as possible, bring it in front and release the ball by opening the fist to make it roll down the alley and hit the pins.
- Based on the pins hit, scoring mechanism as used in real bowling is used.
- For ease and motivation, side extensions are provided and one bowling set starts only if at least one pin is hit.
- Force based on ball release.





# RehabQuiz

- A trivia contest known as RehabQuiz to be performed along with Elbow Rotation.
- The participant places the elbow and the lower arm close to the body and rotates the elbow to make the hand go away from the body.
- Participant placed in a virtual room sitting on a chair.
- A virtual table consists of deck of cards, each card having a question for the quiz, along with 3 bins where the cards are to be dropped.
- Internal rotation to go near card and close fist to pick.
- External rotation to place the card in the correct bin.
- Correct or Wrong shown on table in front and score updated based on the answer bin selected.





#### Exergame Toolkit





# **Experimental Setup**

- One Kinect V2 capturing the person attached to computer using USB 3.0.
- Computer running GTX 970 graphics, Intel i7 2.4 GHz processor, 32 GB RAM.
- A 60" Samsung 3D LED TV as primary display.
- 30 fps motion capture for real-time rendering.
- Motion capture and enhancement in C++, game development in Unity3D game engine using OpenGL rendering and PhysX for physics.
- 3 games modes normal, enhanced and restrained.
- Restrained setup person tied with bungee cord to restrict arm movements and hence simulate a real world patient scenario for testing purposes.





# User Study

- Able-bodied people to test playability and usability of the toolkit in rehab.
- 10 healthy adults + 2 psychology experts + 2 Physical Medicine & Rehab Experts.
- 8 male + 6 female. Age group 23 50 with average 28 years.
- 10 people with experience playing video games and 4 having idea about VR for serious games.
- Questionnaire about different parameters used in the games, virtual environments used for immersion and exercise motivation for stroke patients.



# User Study (Contd.)

- Mostly objective questions with a 5 point Likert-type scale ranging from -2 to 2.
- Balance game best because of no picking or dropping objects interaction.
- Restrained setup really tough but helpful for pre-testing of system for post-stroke rehabilitation.
- Kinect open and closed fist detection had false positives and negatives.
- Artifacts shown in the mesh due to sudden movements leading to degradation in overall visual quality.



Question	<u>Avg Score</u>
Overall experience	1
Visual quality - Game environment and person	1.46
Ease of use	1.26
Correctness - How correct does game replicate user motion	1.14
Likely to play again	1.12
Fun to play	1.22
Motivating to exercise by engaging in game rather than focus on exercise	1.38
Hard work - does it feel that you exercised enough	1.04
Enhancement Mode	-
Visual quality - Game environment and person	0.1
Improved performance	0.5
Restrained Setup	-
Simulates handicap situation	1.25
Difficult than normal	1.63
Improved performance by enhancement	1



# **Results from User Study**

- <u>2 Psychology experts review</u> Camera tracking is not as fast as real world bowling scenario leading to bad performance.
- Enhancement is counter-intuitive for long trained muscles to slow down in compensation to the enhancement added but is useful in restricted mode.
- Using cognitive aspect along with rehab exercise is a good concept.
- <u>2 Physical Medicine and Rehab Experts</u> based on direct usage for patients.
- Exergames were intuitive for stroke patients, but they may have varying degrees of difficulty with the activity depending on the type of stroke and degree of physical impairment.



# Results from User Study (Contd.)

- Acceptability depends on patient preferences as well as on severity of stroke and corresponding level of impairment.
- Given that stroke patients are a heterogeneous group, it is difficult to extrapolate information from this study on able-bodied individuals and apply it to patients after stroke.
- This type of inter-disciplinary innovative system with customizable games is ripe for further evaluation with post-stroke patient populations.



# Contributions

- Cost effective, easy to use, non-invasive system for live 3D capture of a person and its use in various augmented reality settings.
- Mirrored view of participants help understand their emotional experience during the game-play, especially for physicians reviewing the recorded game sessions.
- Use of animation based virtual enhancement performed on the skeletal joints as well as mirror therapy to assist patient rehabilitation.
- Positive reinforcement by mirror therapy and virtual enhancement.



# Contributions (Contd.)

- Feedback from the 2 Physical Medicine and Rehab physicians and the 2 psychology experts, apart from 10 people with no known disabilities.
- Shows the augmented reality based exergaming system is enjoyable, engaging, assistive and motivating, having good potential in rehabilitation for stroke affected patients.



# Future Work

- Improve open and close fist detection algorithm.
- Get rid of mesh artifacts during fast movements and self-occlusion by improving the virtual enhancement and mesh prediction strategy.
- Include other body parts increasing the versatility of the toolkit.
- Study comparing 3D avatar vs live 3D human model planned.
- Preliminary positive findings for usability and satisfaction lead to research along with rehab experts to evaluate feasibility and effectiveness in stroke patient populations.
- According to rehab experts, this technology holds great promise and has potential to improve in-home rehab in several vulnerable populations, including patients affected with stroke as well as with chronic degenerative musculoskeletal pain conditions.



#### Questions



