Gait Analysis using a Single Depth Camera

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Motivation

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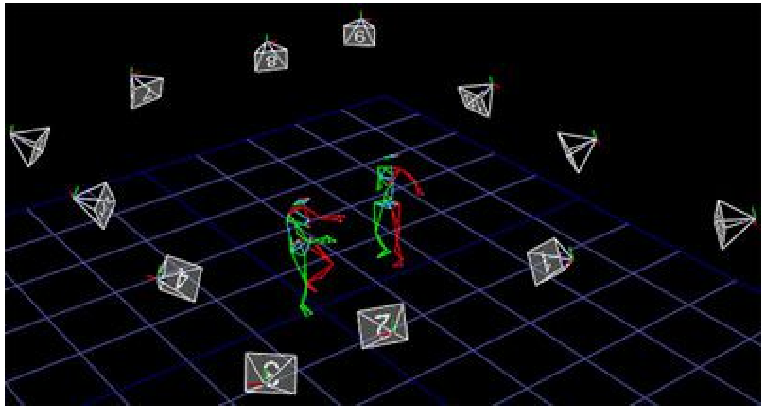
- Typical rehabilitation programs periodically assess recovery of stroke patients based on their walking patterns
- Optical **multi-camera** motion capture systems, such as VICON, are accurate, but expensive, require operational expertise and large dedicated labs

➢ Shift towards tele-rehabilitation: Provide rehabilitation services from home or local clinics using low-complexity, portable, and relatively cheap hardware

➢ Can we develop a system that matches VICON (performance-wise), but is cheaper and suitable for home use?

Optical Motion Capture for Rehabilitation Assessment

- VICON: industrial standard, 3D marker tracking via 12 infrared cameras → Expensive, not-portable, requires large rooms, expertise to handle



http://accad.osu.edu/~aprice/courses/BVE/joy.html

- Previous single- and stereo- camera solutions require manual processing, operation expertise, limited to specific colors of clothes *[Ugbolue-2013, Leu-2011, Liao-2010, Li-2011, Yang-2013, 2014]*

- Using Microsoft Kinect camera with skeleton tracking is not accurate enough for clinical use *[Jun, Nguyen-2014, Sarkar-2015]*

Proposed System: Main Features

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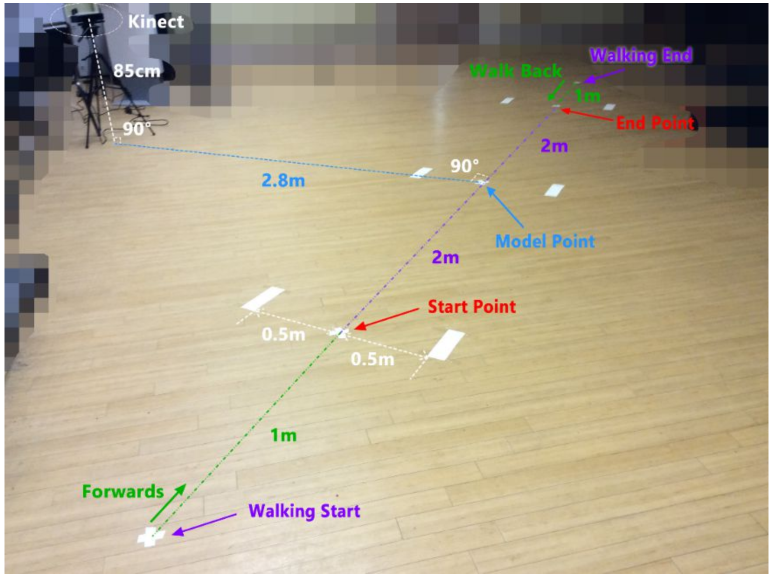
- Single camera (with infrared + depth outputs)
  - Implemented using Microsoft Kinect v2
- Tracking in 3D in real time of retro-reflective markers attached to a subject's joints
- Kinematics analysis in near real time based on the previous 3D marker trajectories
- User-friendly interface iteratively designed using clinicians' feedback
- Interactive tele-rehabilitation service via cloud
- Portable, cheap, simple to operate

Application Tasks

- Straight-line walking exercise from left to right and back

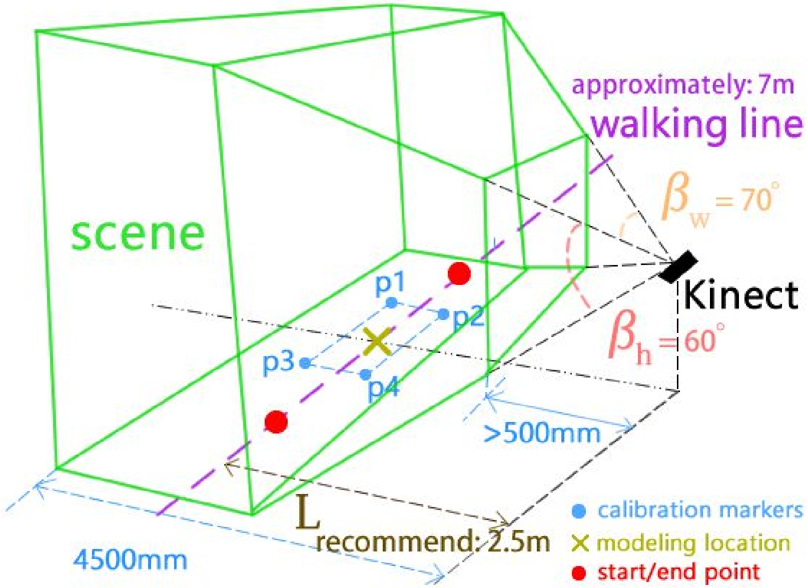


6m straight walking exercise

- Track positions of all 12 markers attached to joints
- Calculate and present clinical parameters using 3D trajectories

Pre-processing

- Scene-calibration
  - *Capture necessary dimensions to form the geometry of the scene*
  - *Define start and end points of walking line*

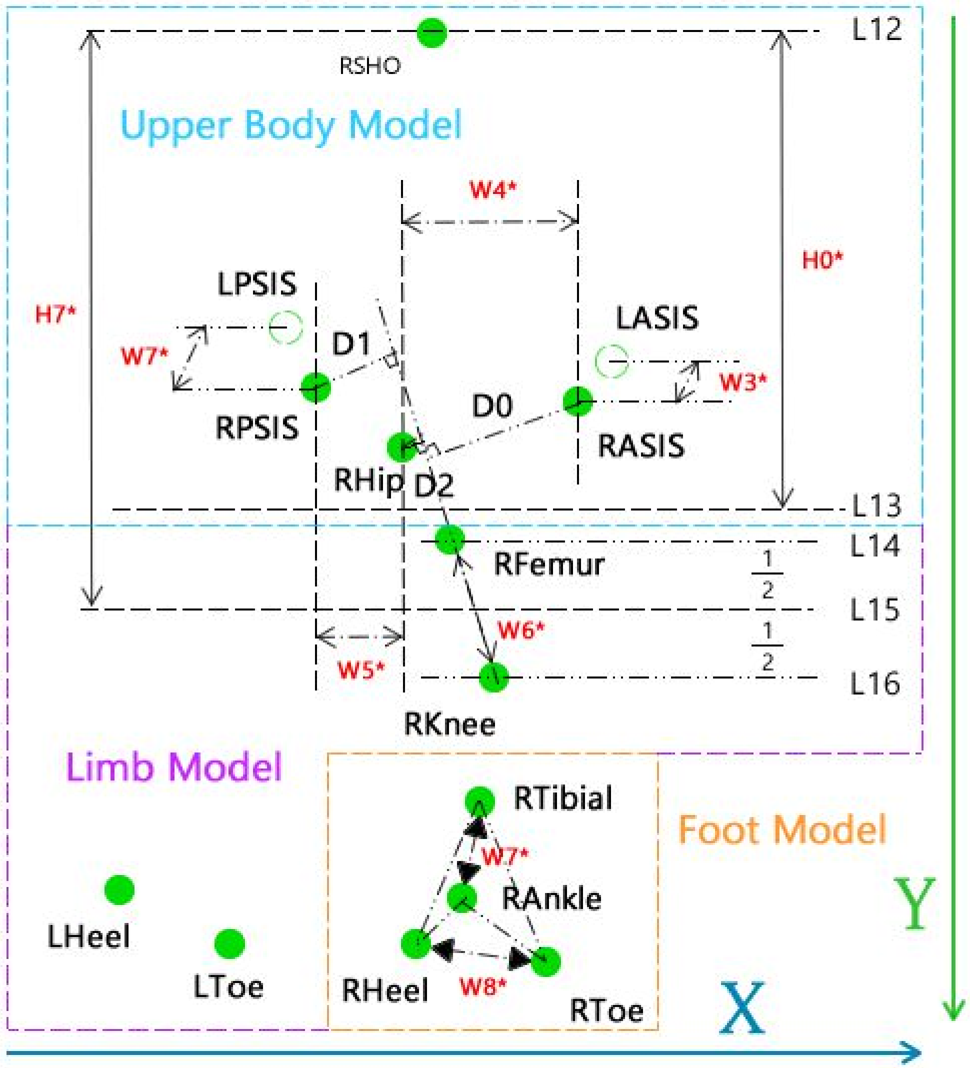


- Denoising of depth images

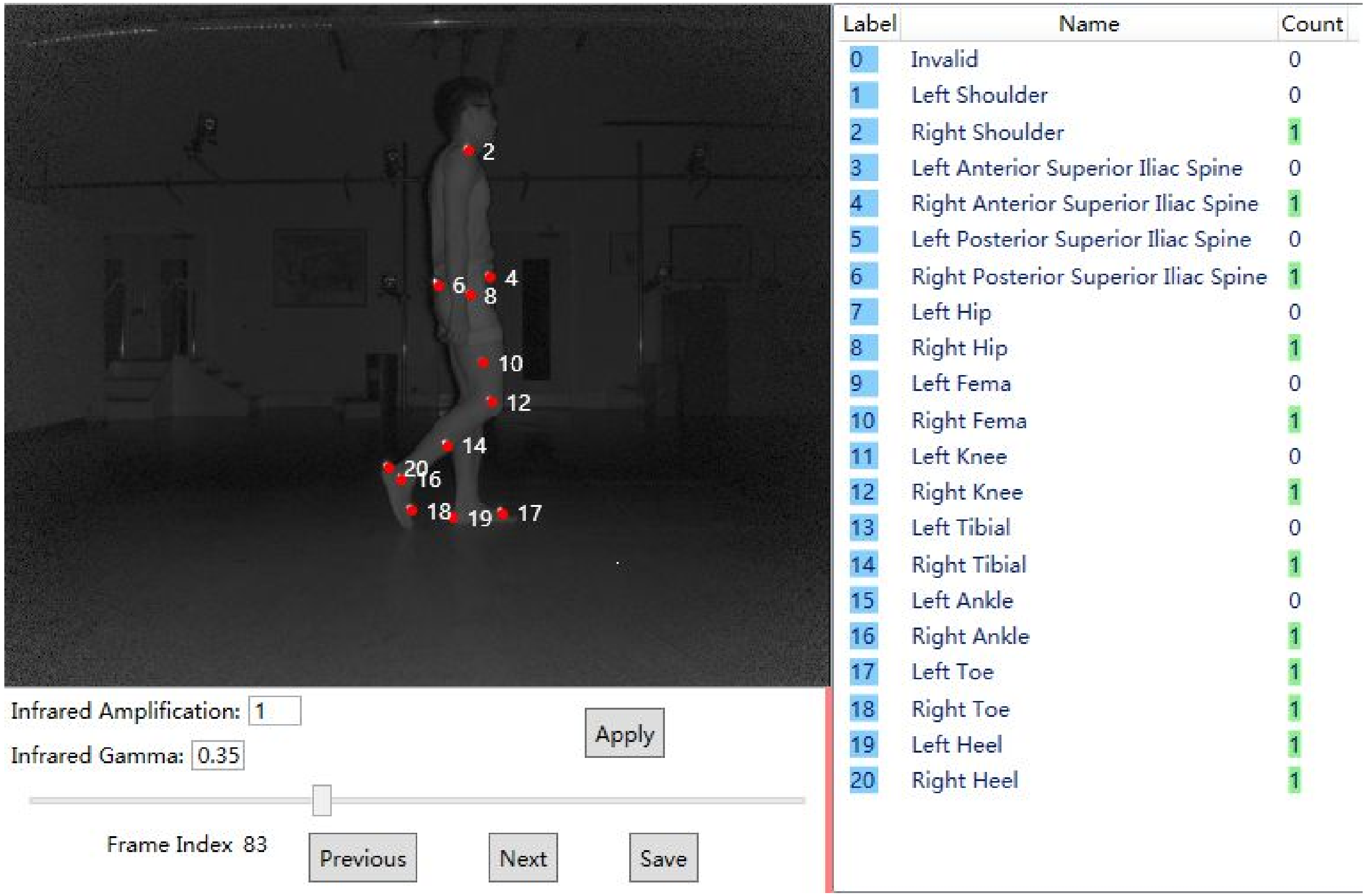
Pre-processing: Modelling

- Construct subject model
  Physically measure the subject standing at modeling location

- Sagittal subject model is then split into:
  - upper body model
  - limb model
  - foot model



Marker Detection

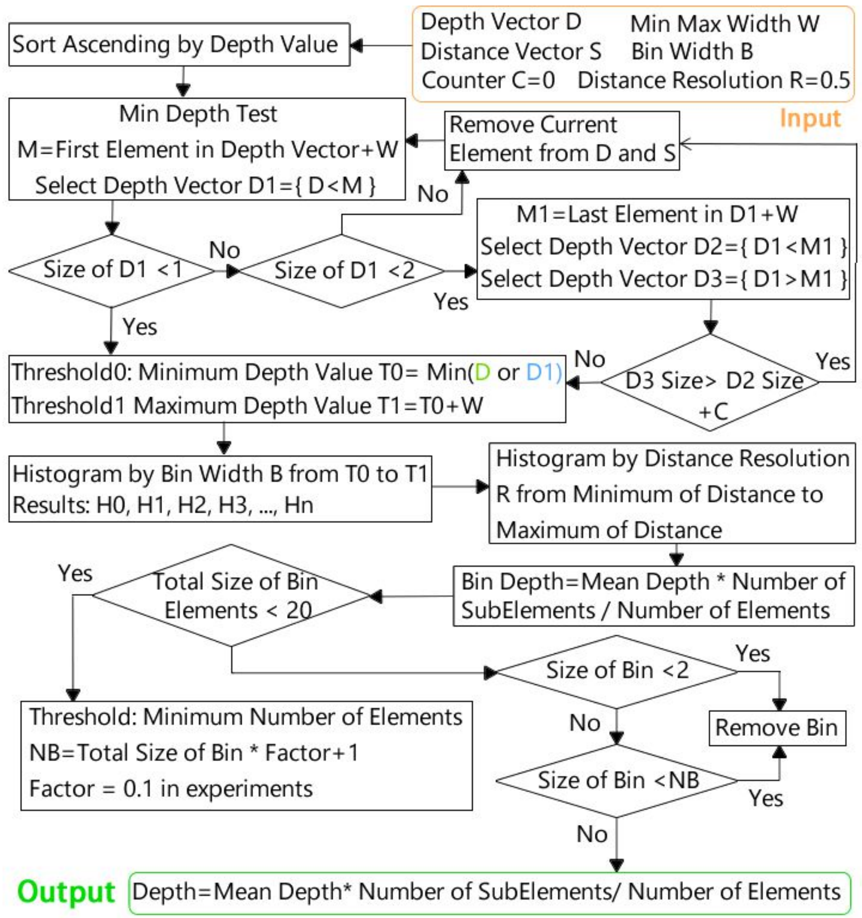


- *Blob detection through image binarization*
- *Contour finder* – to identify all valid contours [Suzuki et al.]
- Ellipse and minimum area rectangle fitter to extract blob information [Fitzgibbon et al., Toussaint]
- Proposed *kernel cluster filter* – identify (not label) all markers in 2D plane

Marker Mapping in 3D plane

- Task: Map markers from image space to camera space
- Retro-reflective markers: depth image value zero!

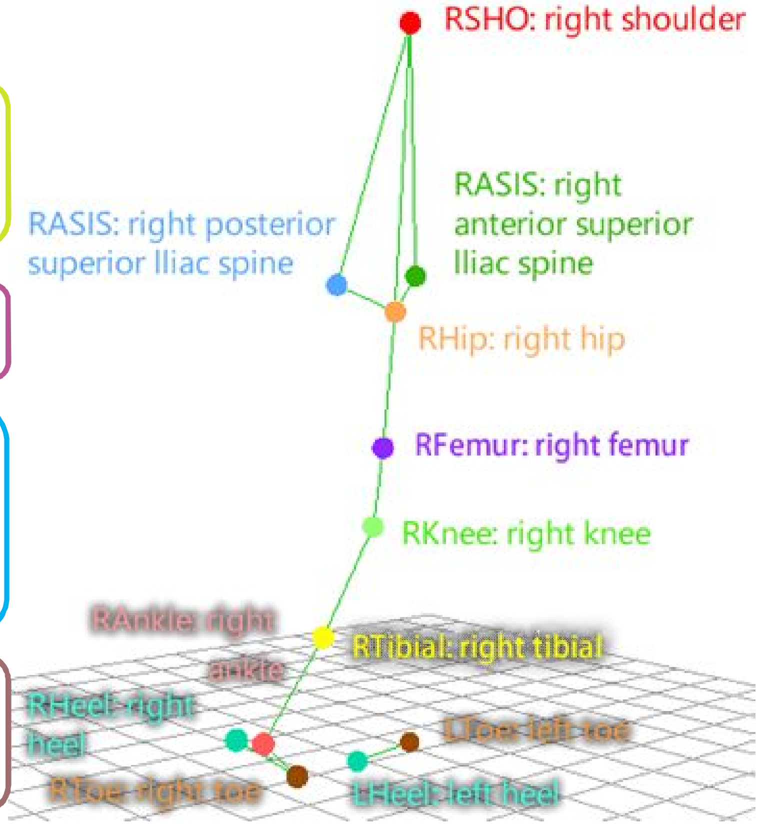
- Idea: Use weighted average from depth-map histogram statistics with appropriate heuristic adjustments in case of occlusion



Marker Labelling

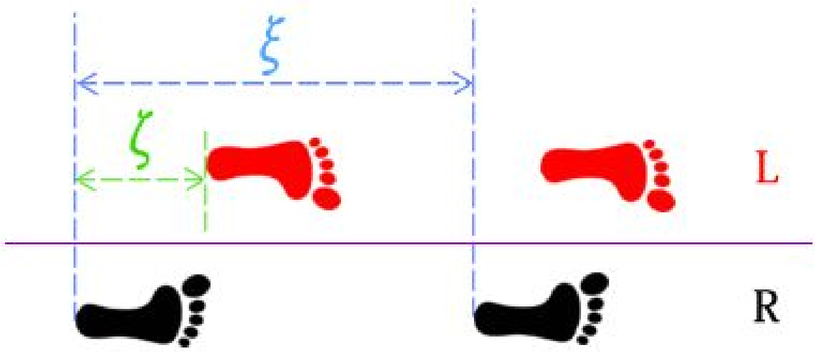
- Use the constructed subject model to label markers

1. Identify the shoulder marker based on the previous frame using Kalman filter to combat occlusion and fast motion
2. Predict current status of model parameters
3. Label other markers using their relative position w.r.t the shoulder marker and corresponding sub models in terms of predicted model parameters
4. Correct model parameters in terms of labeled markers

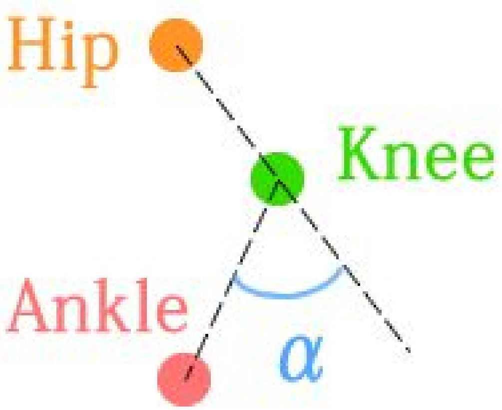


Kinematics Analysis

- Based on 3D marker trajectories:
  - Detect gait events: Heel strike, Toe off (step, stride length and stance, swing duration)



Step and stride length

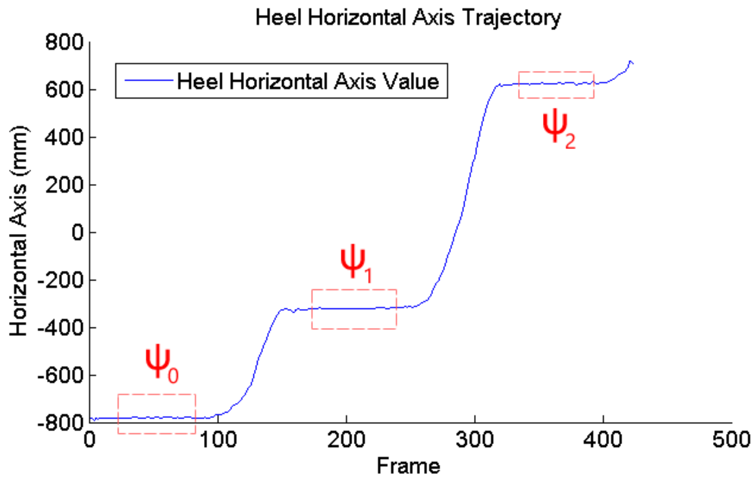


Knee Angle

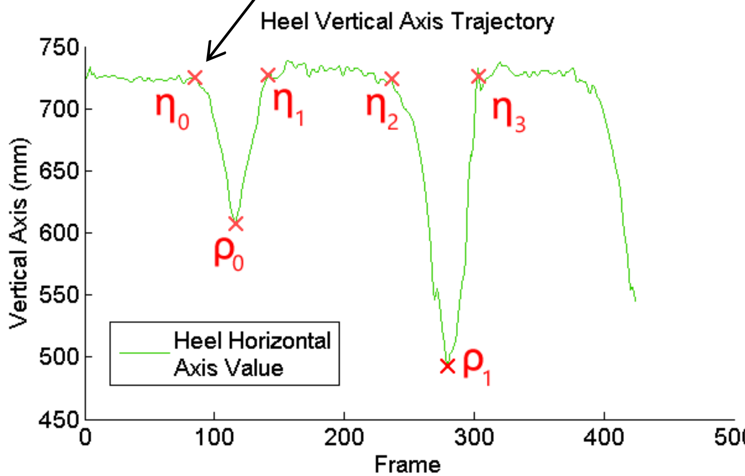
- Calculate relevant angles between markers and track the changes of these angles over time

Gait Event Detection

- Find inflection points and local peaks
  - ➢ Examine stable values ψ using window matching between inflection points
  - ➢ Iteratively search the region between inflection points and local min/max



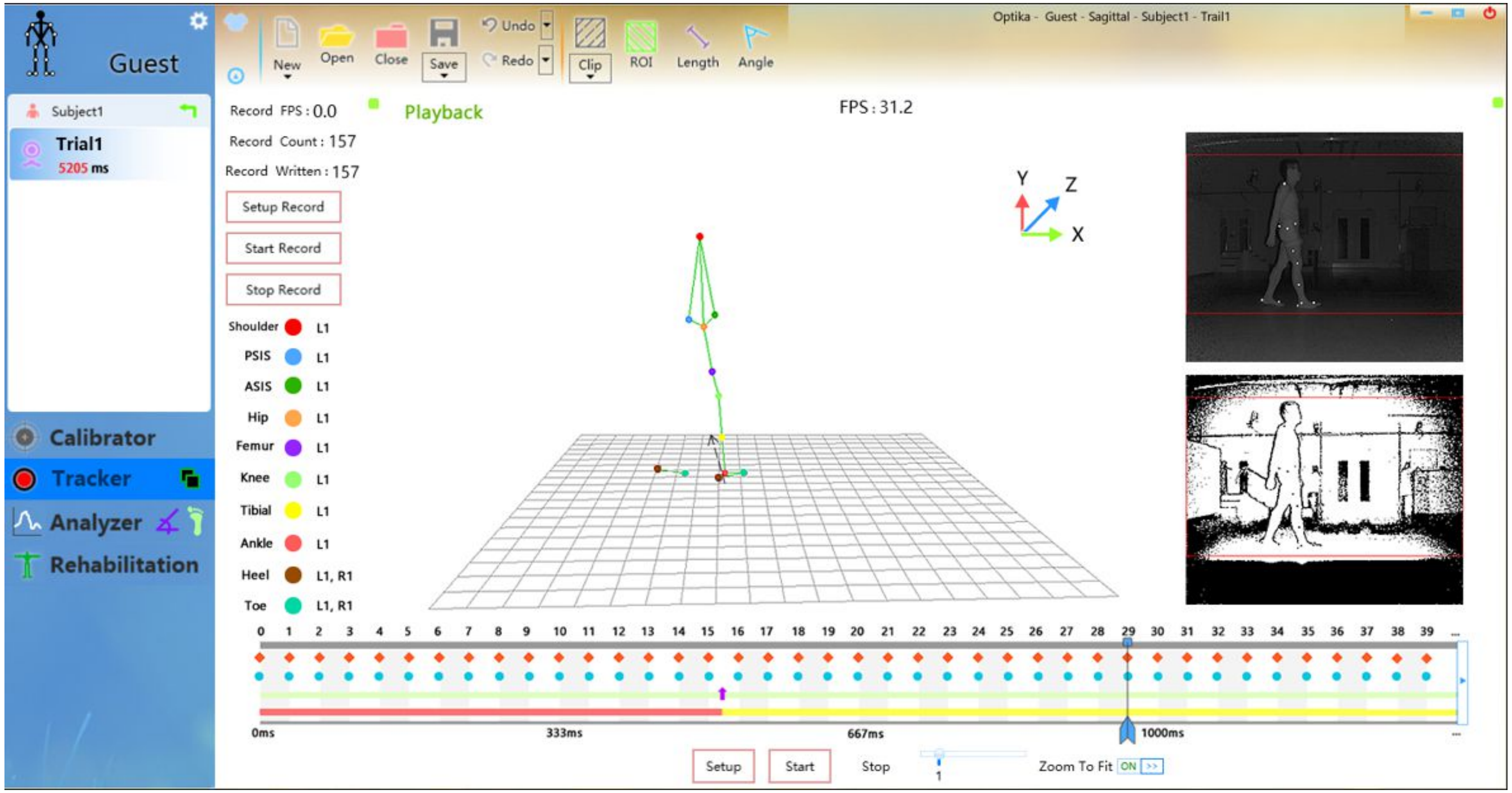
Step and stride measurement



Stance and swing phase measurement

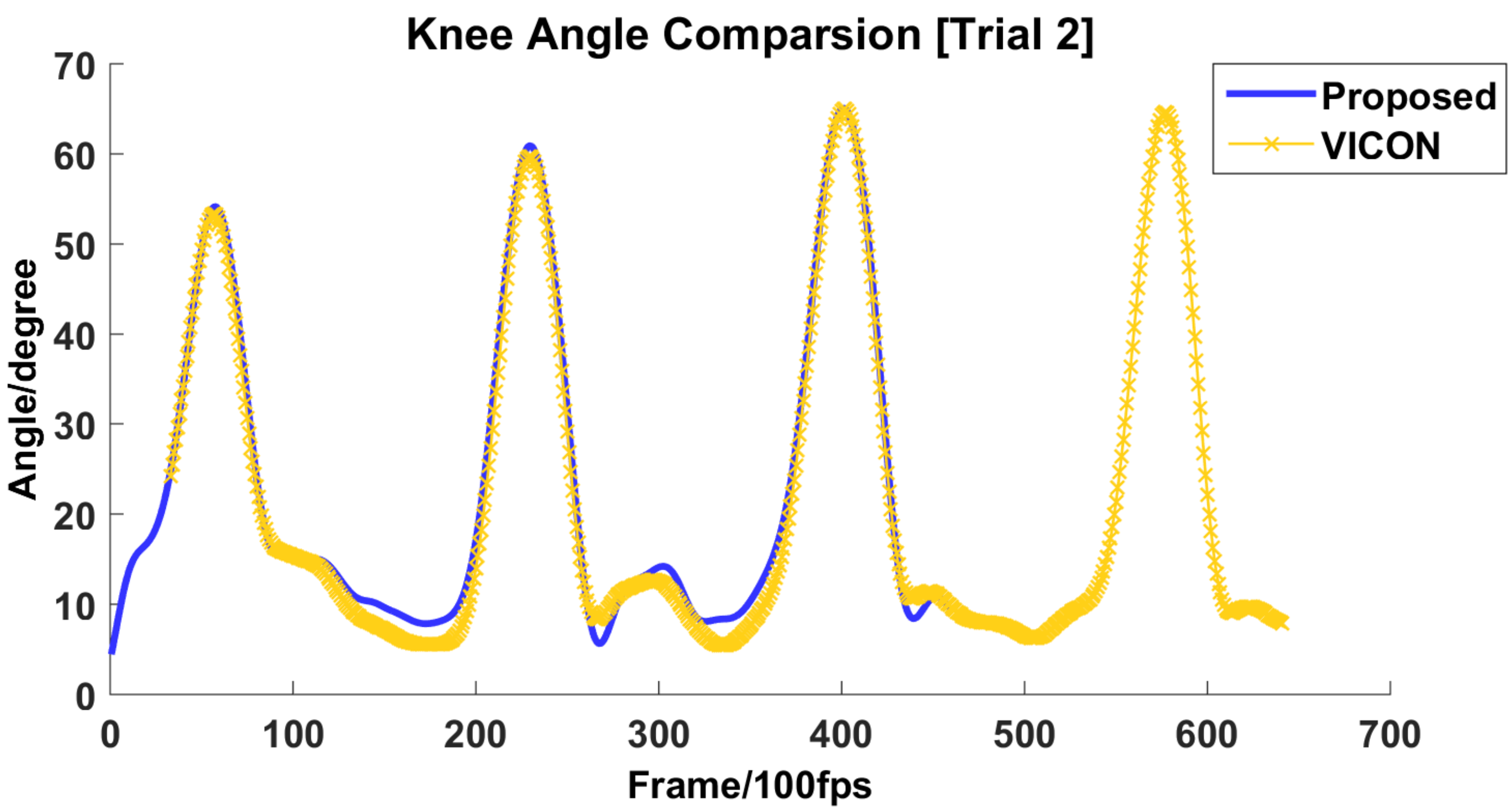
Visualisation

- Interactive multi-view scene manager
- Automatic reconstruction process or manual play-back
- Simple sharing of authorized content across platforms



Experimental Results: Angle

- 40 experiments with 6 different subjects (male and female)
- Close agreement with VICON results



Experimental Results: Gait Events

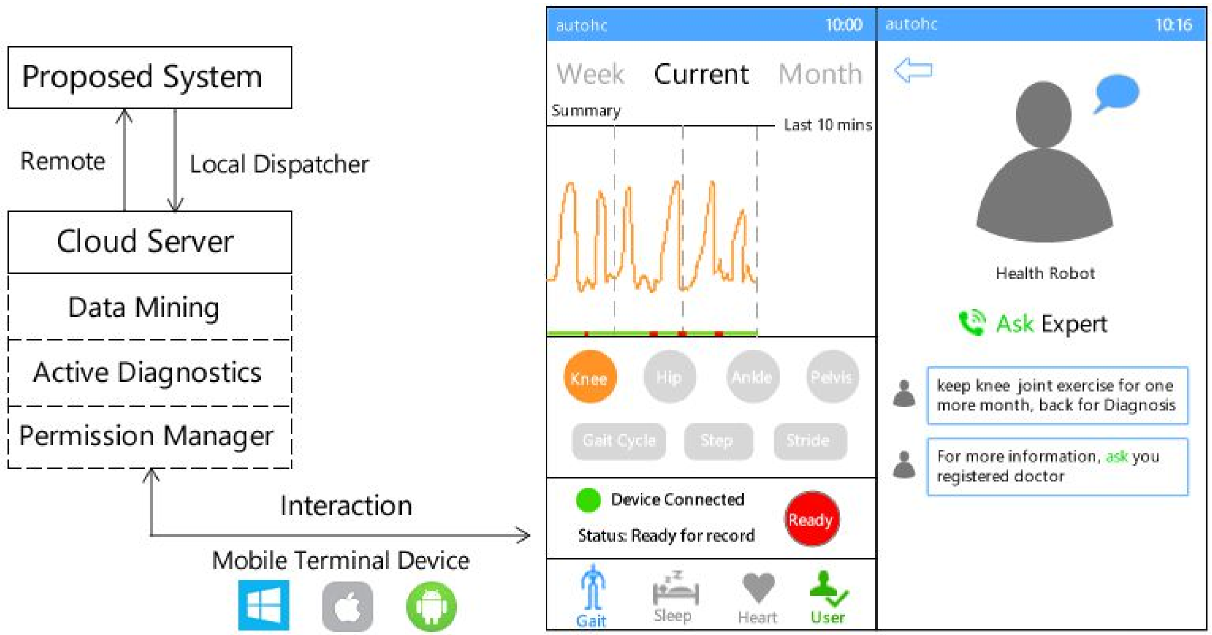
- 40 experiments with 6 different subjects
- Close agreement with VICON results

ERROR	Step	Stance	Stride	Swing
Mean [%]	1.05	1.82	1.17	1.10
Std [%]	5.33	5.83	4.76	4.37

Averaged over 40 experiments

Mobile Multimedia System

- Dispatch encrypted patient personal information and diagnostics reports to a cloud server for authorized direct inquiry or data mining to evaluate patient's rehabilitation conditions



Conclusions

- Portable, cheap and accurate solution
- Easy to operate with user-friendly interface
- Tested for accuracy and ease of use in UK hospitals with stroke patients

Future Work

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- Improved tracking and identification via adaptive blob thresholding [paper submitted]
- Better marker design
- Improve marker trajectory accuracy and stability via texture clustering (use point clouds in levelled region with centroid reconstruction to solve partial occlusion)