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The development and evaluation of a sensor-fusion and adaptive algorithm for detecting real-time upper-trunk kinematics, phases and timing of the sit-to-stand movements in stroke survivors

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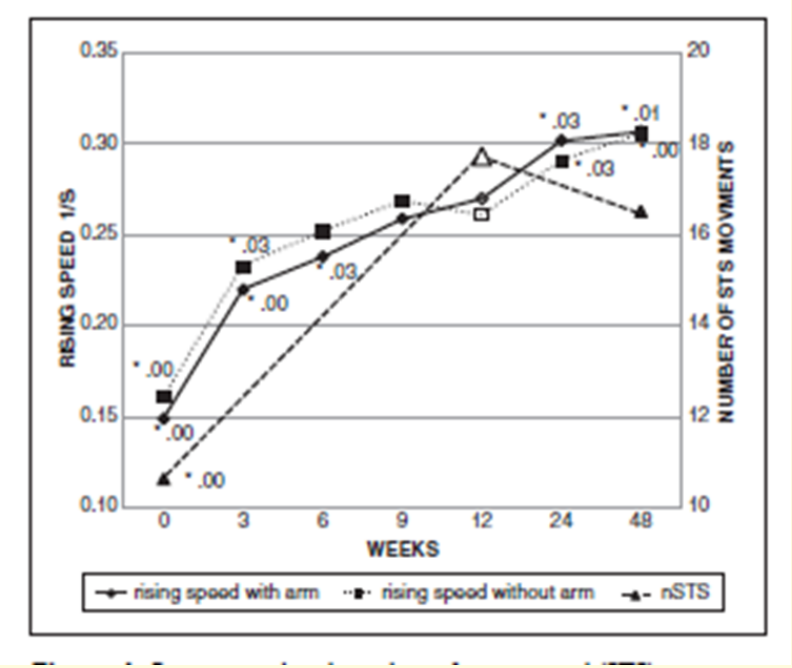
Background

- **Stroke**
  - The largest cause of complex disability in adults (Adamson, Beswick, & Ebrahim, 2004)
- **Sit-to-stand (STS)**
  - Critical to activities of daily living
- **Physical Rehabilitation**
  - Regain functional movement
- **Assign treatment plan**
- **Assess performance**



(Janssen et al, 2010)

Clinical assessments

- **Five times STS test (NHS)**
- **30 Seconds Chair Stand Test**
- **Timed Up and Go test**

  - **Visual Observations**

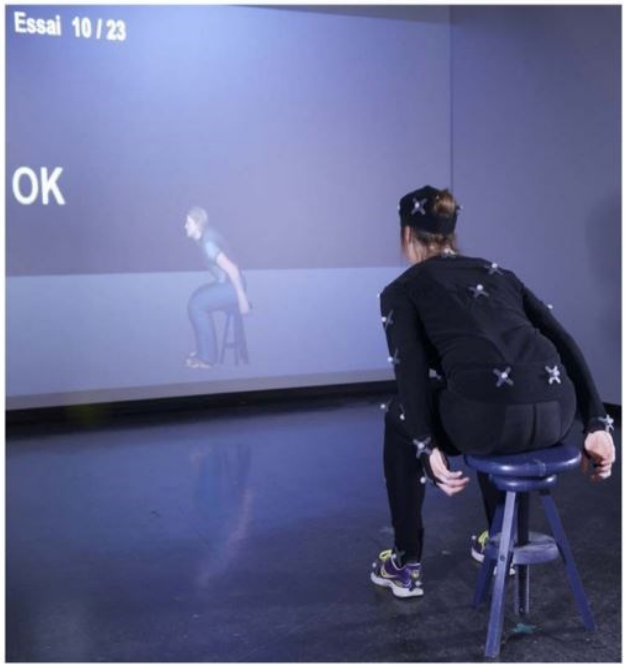
  - **Accurate to quantify**
    - Manually timed
    - Repetitions

  - **Inexact to characterise**
    - Biomechanical performance
    - Weight symmetry loading, velocity, angles

Adopting Technology

Analysis Performance

- **Vicon motion capture**
  - Markers + Large space for infrared red cameras
- **Kinect**
- **Fixed force plate**



(Roosink et al, 2015)

Problems

- Restricted to Lab
- Time consuming
- Set-up
- “Unobstructable”

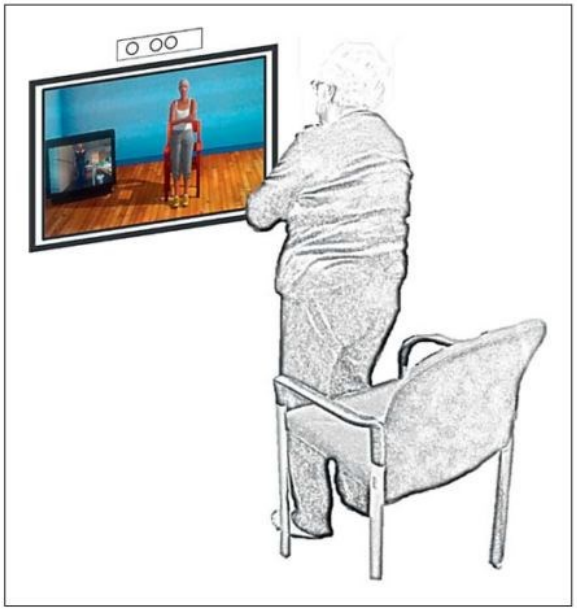


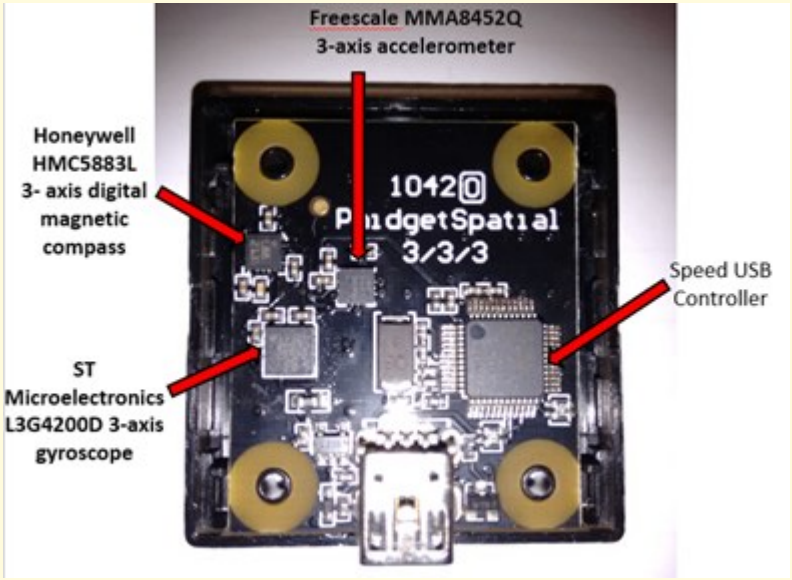
Fig. 1. Illustration of the Kinect-based 5STS.

(Ejupi et al, 2016)

Hypothesis

Wearable Technology

- Inertial Measurement Unit (IMU)
  - Low-cost
  - Mini-natured
  - Plug-and-Play
  - Low power and high performance



Developed Algorithm

- Healthy Individuals (Cerrito, Bichsel, Radlinger, & Schmid, 2014)
- Elderlies (Guimaraes, Ribeiro, & Rosado, 2013)
- Other disorders (Zijlstra, Mancini, Lindemann, Chiari, & Zijlstra, 2012) (Van Lummel et al., 2012)
- **No stroke**

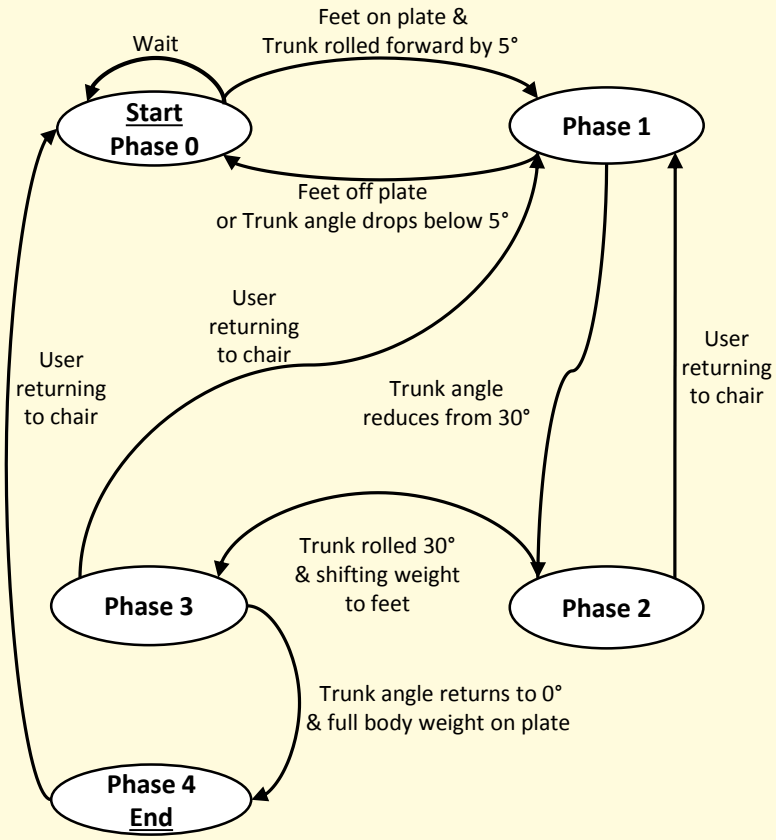
Sit-to-stand Event Detection

1. Initiation

2. Seat-off

3. Flexion

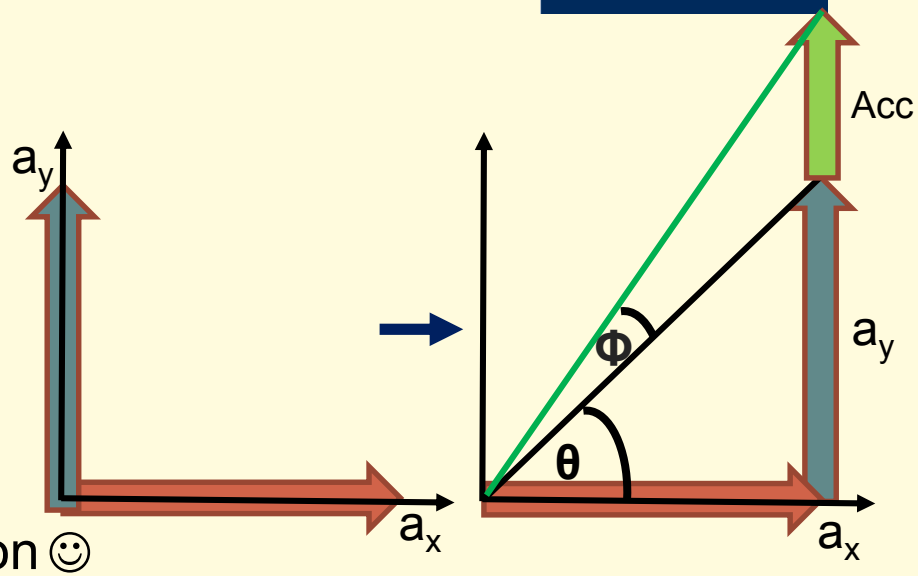
4. Stand



Orientation Estimation

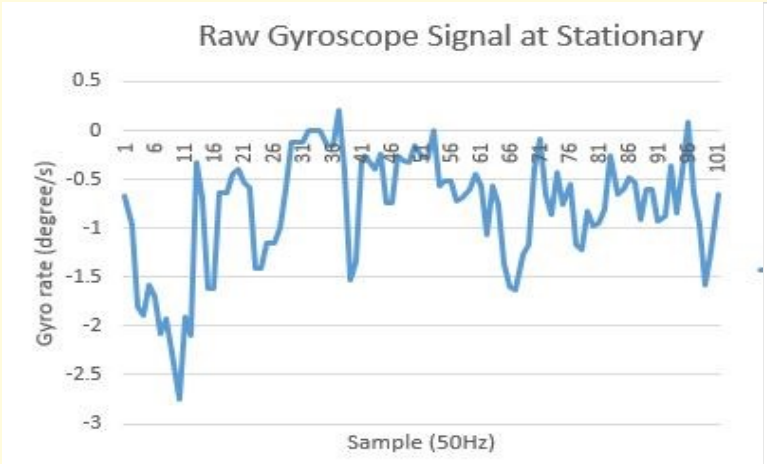
Accelerometer

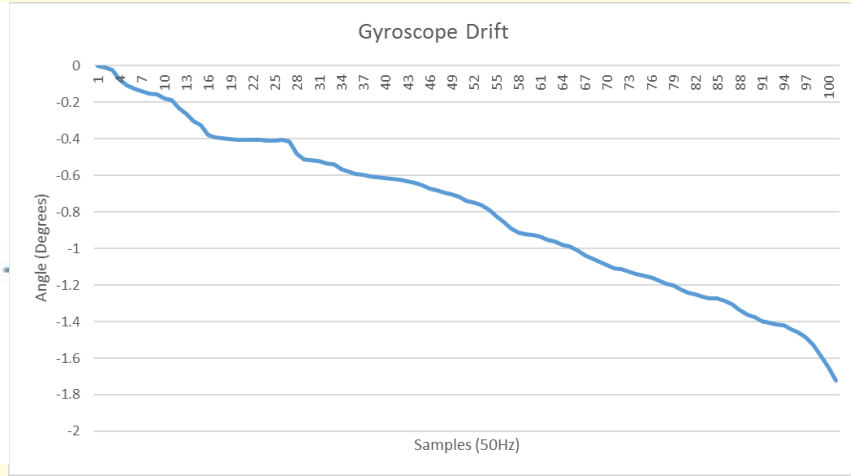
- Measuring g-forces
- Trigonometry to find inclinations
- External acceleration ☹
- No drifts ☺



Gyroscope

- Not affected by external acceleration ☺
- Integration drift ☹





Kalman Filtering

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Sensor Fusion Algorithm

- Mixing data from accelerometer and gyroscope
- Observe measurements (noise/inaccuracies)

Time Update

1. Project state ahead

$$\theta_{est}^{-}{}_{k} = A\,\theta_{est}^{-}{}_{k-1} + Bu_k + w_{k-1}$$

2. Project Error covariance (P)

$$P^{-}_{k} = AP_{k-1}\,A^{T} + Q$$

Measurement Update

1. Calculate Kalman Gain (K)

$$K_k = P^{-}_{k}\,H^{T}\,(HP^{-}_{k}\,H^{T} + R)^{-1}$$

2. Update estimate

$$\theta_{est\,k} = \theta_{est}^{-}{}_{k} + K_k\,(\theta_{gyro} - H\,\theta_{acc}^{-}{}_{k})$$

3. Update error covariance

$$P_k = (1-K_k\,H)\,P^{-}_{k}$$

A = State transition matrix
B = Optional control matrix
u_k = known system inputs
w_{k-1} = process noise vector
Q = covariance matrix

H = system observation matrix
^{T} = Transpose

Velocity Estimation

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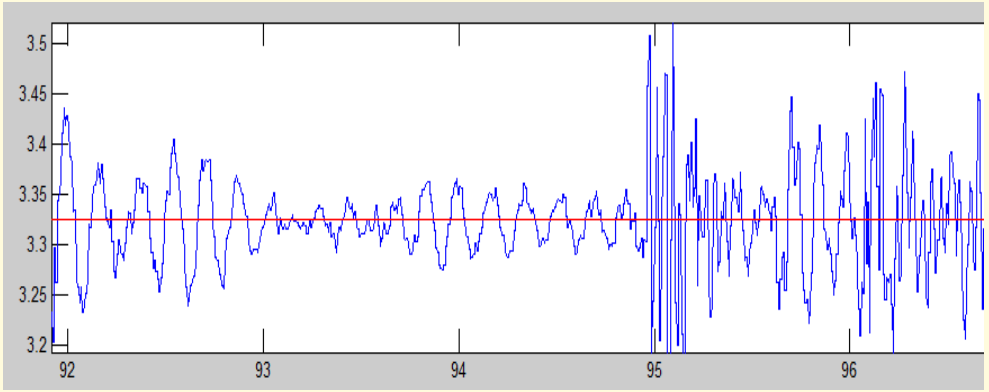
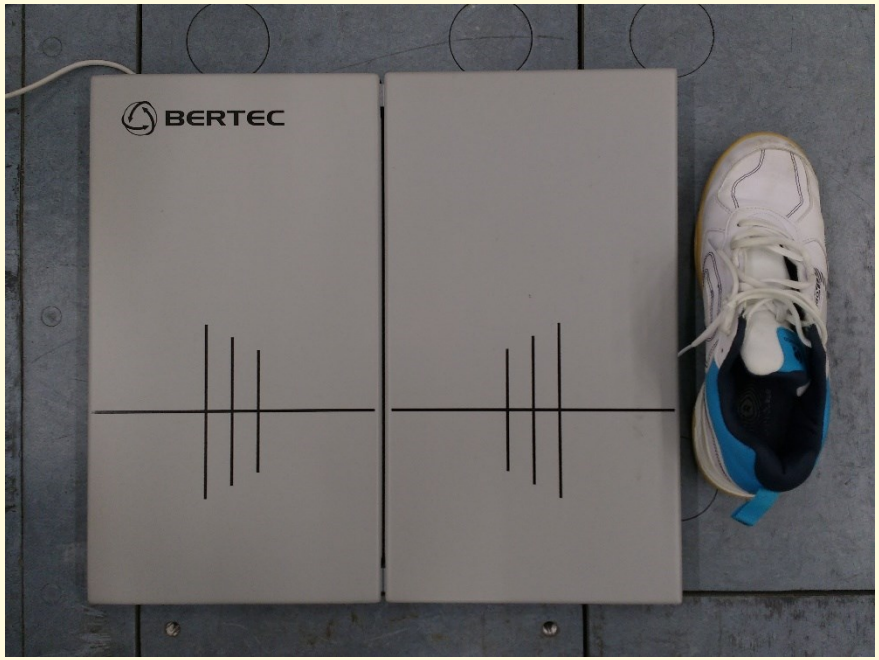
Accelerometer

- Integration drift ☹
  - Accumulation of errors
- Need to remove gravity
  - Gravity offset – Inclination
  - Sensitivity

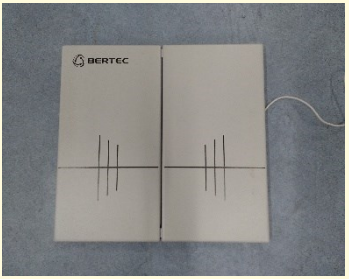


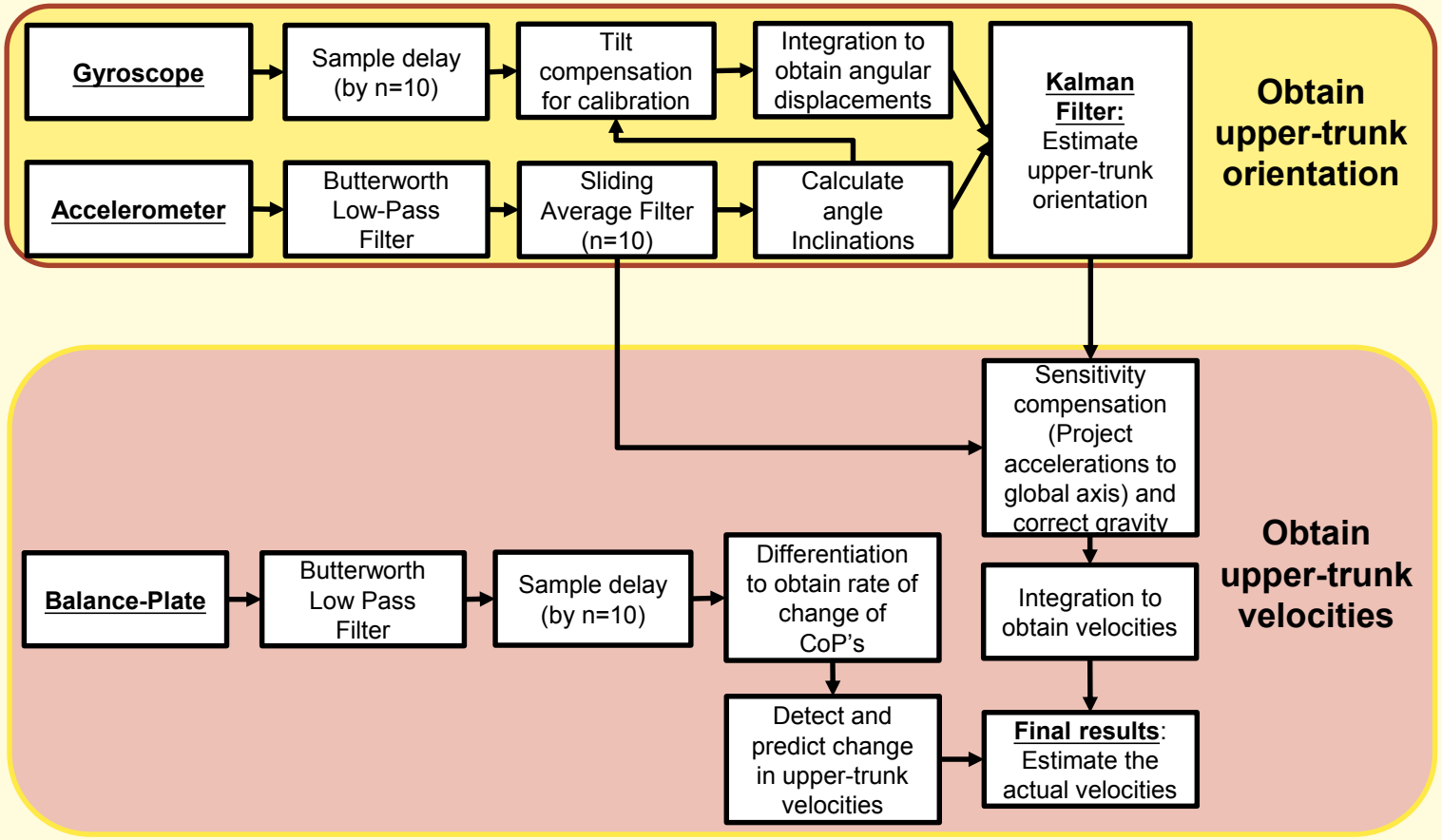
Balance-plate

- Centre of pressures
- Predict velocity
  - Need acceleration estimation



Sensor Fusion Algorithm





Implementation and Testing

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Capture STS performance via Vicon and Sensors

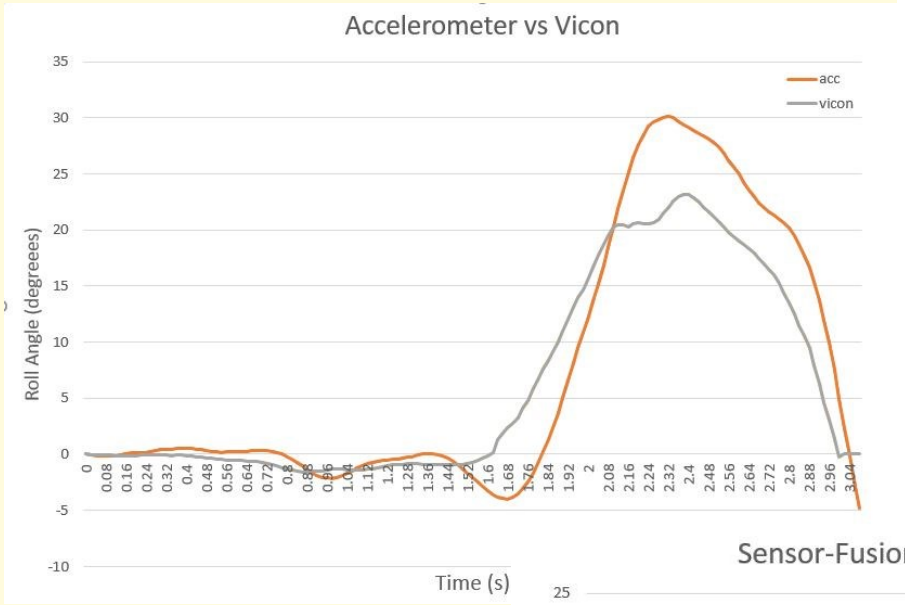
- Processed on Vicon Nexus and MatLab

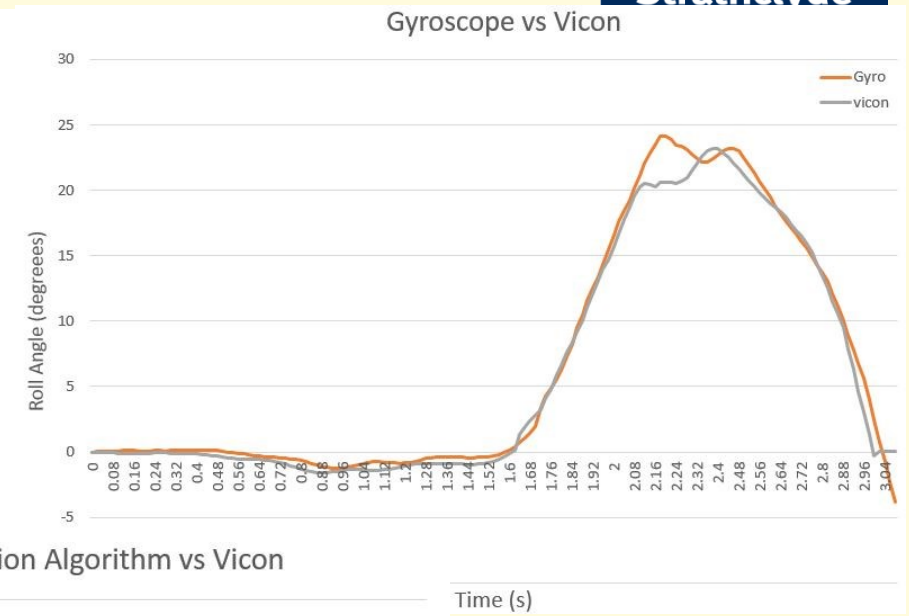
- Design algorithms and filters + simulations

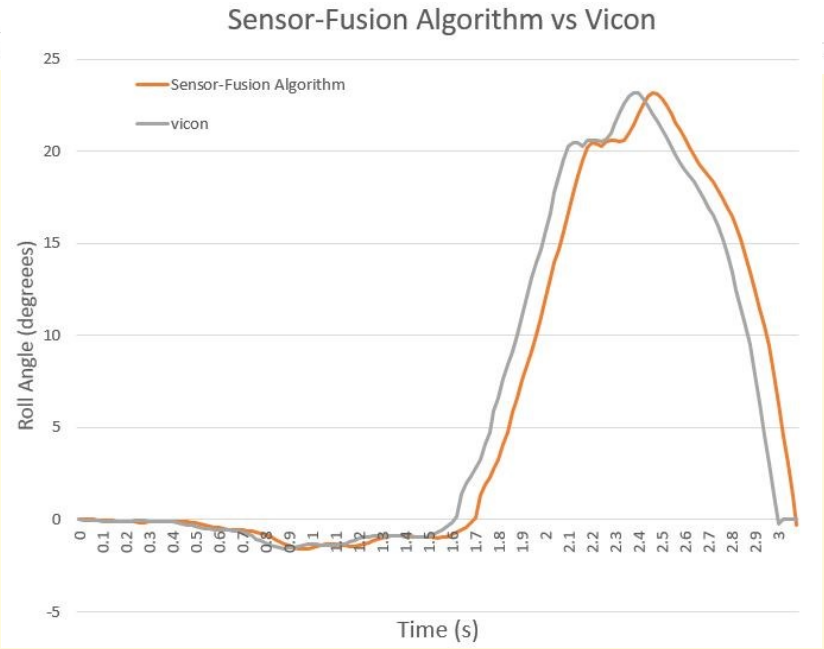
Performance Algorithms V.S. Vicon

- LabView (C, Mathscript code)

Results – Angle Estimation







Accelerometer

- Under and overestimated
- Linear acceleration
- Gravity

Gyroscope

- Overestimated
- Inaccuracy in raw signal
- Integration drifting

Sensor-Fusion

- Close estimate
- Delay (filtering)

Results – Velocity Estimation

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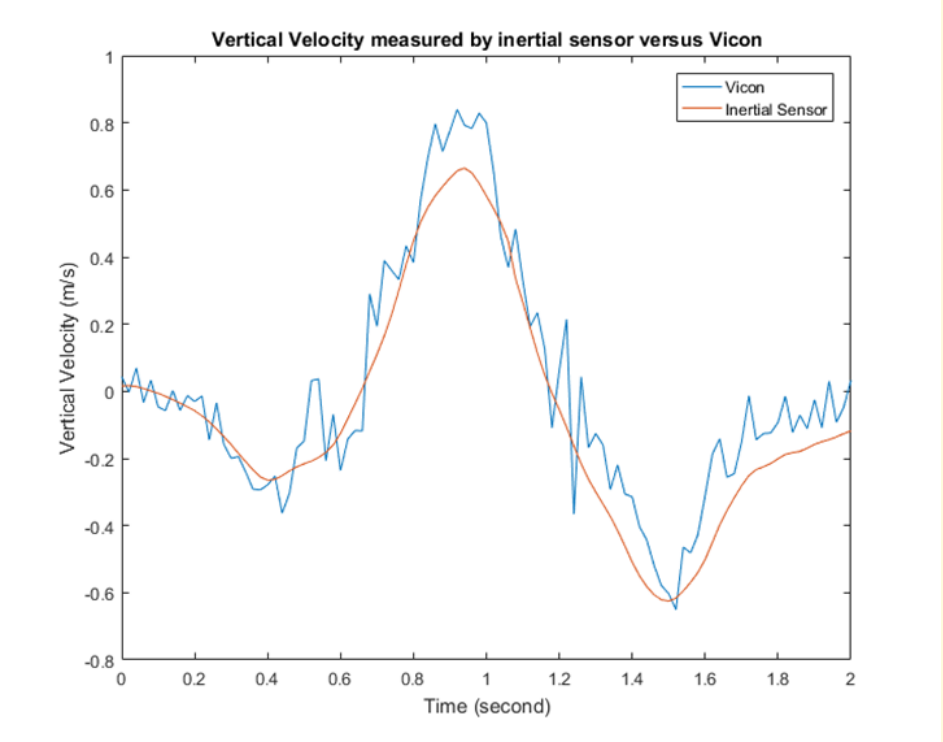
Slow motion

- Closely matched
- Smoothed by filters

Quick motion

- Small systematic bias
- Lower mean and peak vertical velocity
- Illegible with slower STS



Discussion

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Further Improvement

- Inconsistent sampling rate
- Better IMU
- More stroke survivors involve (e.g. those who can't stand-up)
- Diagnostic platform
  - Feedback on performance

Conclusion

- New approach in tracking STS movement
  - Sensor-Fusion
  - Finite State Machine
- Validated, Vicon and stroke survivors
- Estimate, Track and Analyse

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Thank you so much for your attention!

Any Questions?