Measurement of Human Movement

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Outline

- Need for measuring human movement
- Non-contact measurement
- Camera based measurement

The forward problem

- Given:
  - the geometry of the skeletal system
  - Force from the muscles
- Calculate the movement of limb segements
- Calculate external forces on the body

The *inverse* problem: movement analysis

Determining the physiological properties from the observed movement:

- What are the control signals from the nervous system?
- What are the characteristics of the musculoskeletal system?

Analysis of gait

- Observe
  - Limb movement
  - Ground reaction forces
  - Muscle activity
- Determine:
  - joint kinematics
  - Net moments
  - Power
  - Energy expenditure

Three parts of gait analysis

- Kinematics
- Kinetics
- EMG

Limb movement in space

Positions determined every 0.01 second:

- Foot
- Shank
- Thigh
- Pelvis

Kinematics

Get joint positions at successive time intervals

Calculate position changes of limb segments:

- Translation
- Rotation

Calculate translational velocities, V_x, V_y, V_z

Calculate rotational velocities, ρ_x, ρ_y, ρ_z

Similarly, calculate accelerations

$$\text{Velocity} = \frac{\text{Current position - previous position}}{\text{time interval between measurement}}$$

$$\text{Acceleration} = \frac{\text{Current velocity - previous velocity}}{\text{time interval}}$$

Segment movement forces

- Estimate mass & moment of inertia for each segment (foot, shank, thigh) from anthropometric data
- Using the acceleration calculated from the motion data, calculate the forces effected on these body segments

External forces on the body

Normal walking – only ground reaction forces

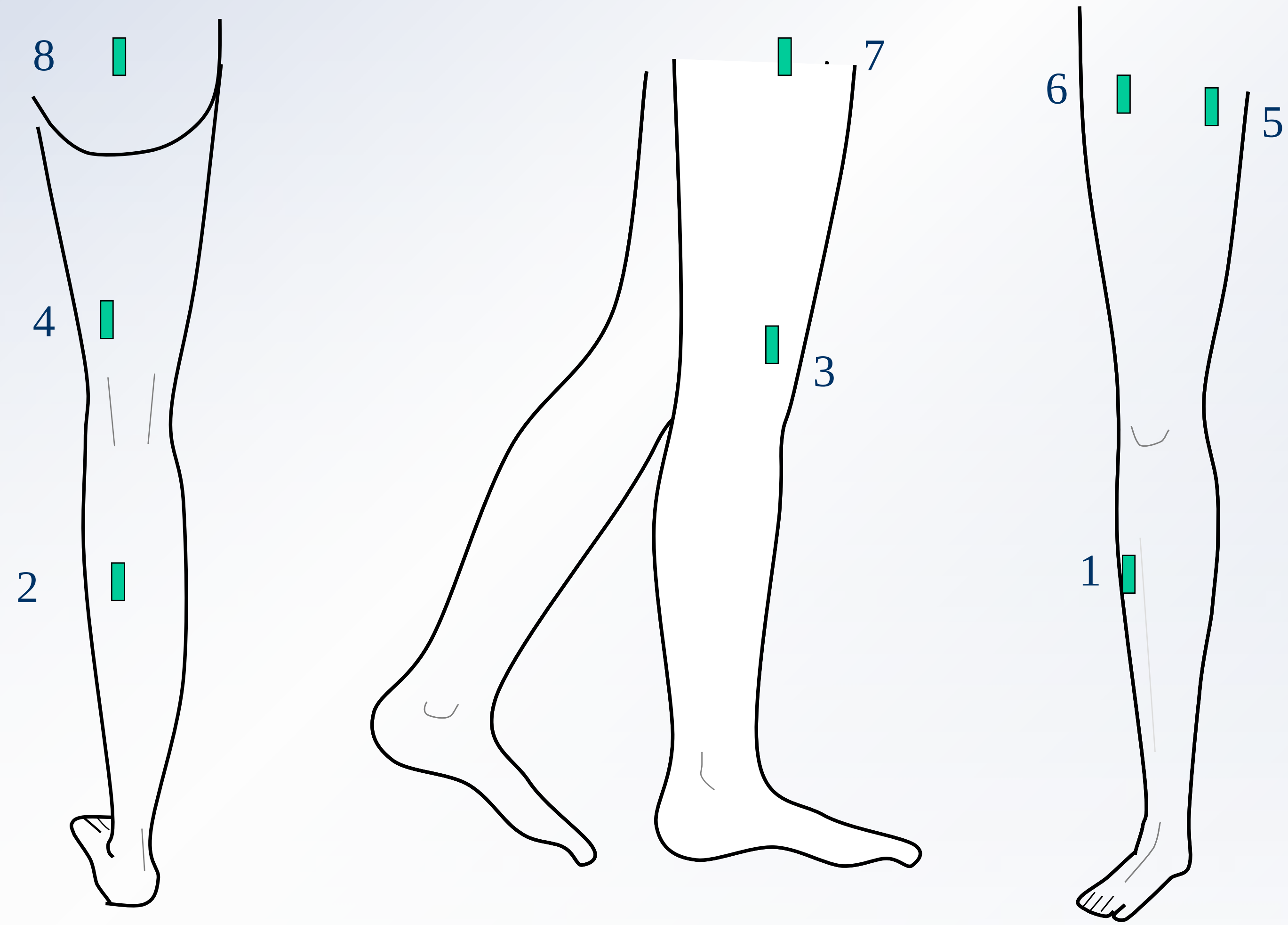
Sports – forces due to ball on limb/bat

Assisted walking – crutch, walker, etc.

Muscles involved in normal walking

- Ankle flexion/extension
  - Tibialis Anterior
  - Gastrocnemius
- Knee flexion/extension
  - Medial Hamstrings
  - Vastus Lateralis
- Hip flexion/extension
  - Rectus Femoris
  - Gluteus maximus
- Hip adduction/abduction
  - Adductor Longus
  - Tensor Fascia Lata

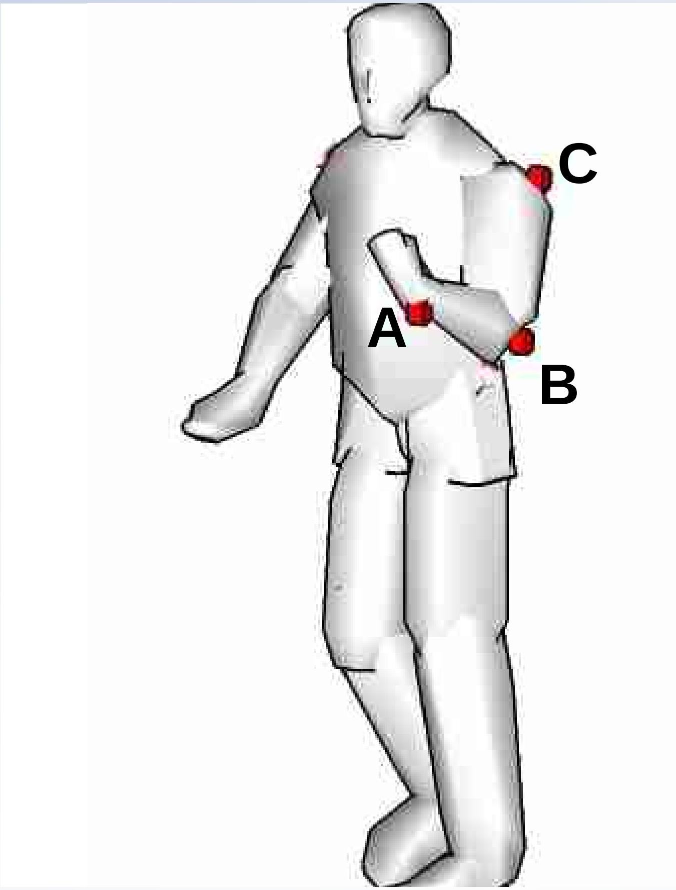
EMG measurement locations

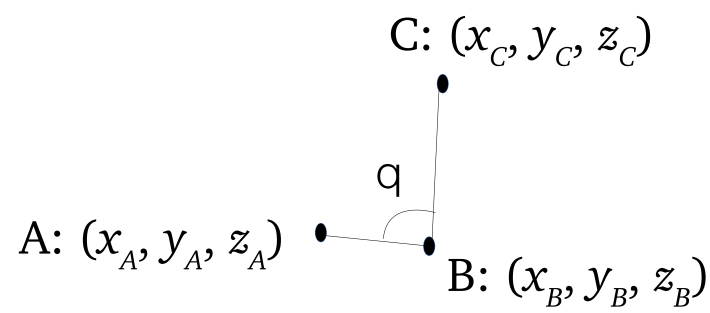


Lateral View   Anteromedial View

Tibialis Anterior
Gastrocnemius
Vastus lateralis
Medial Hamstrings
Adductor Longus
Tensor Fascia Lata
Rectus Femoris
Gluteus Maximus

Three points on a limb and angle of joint





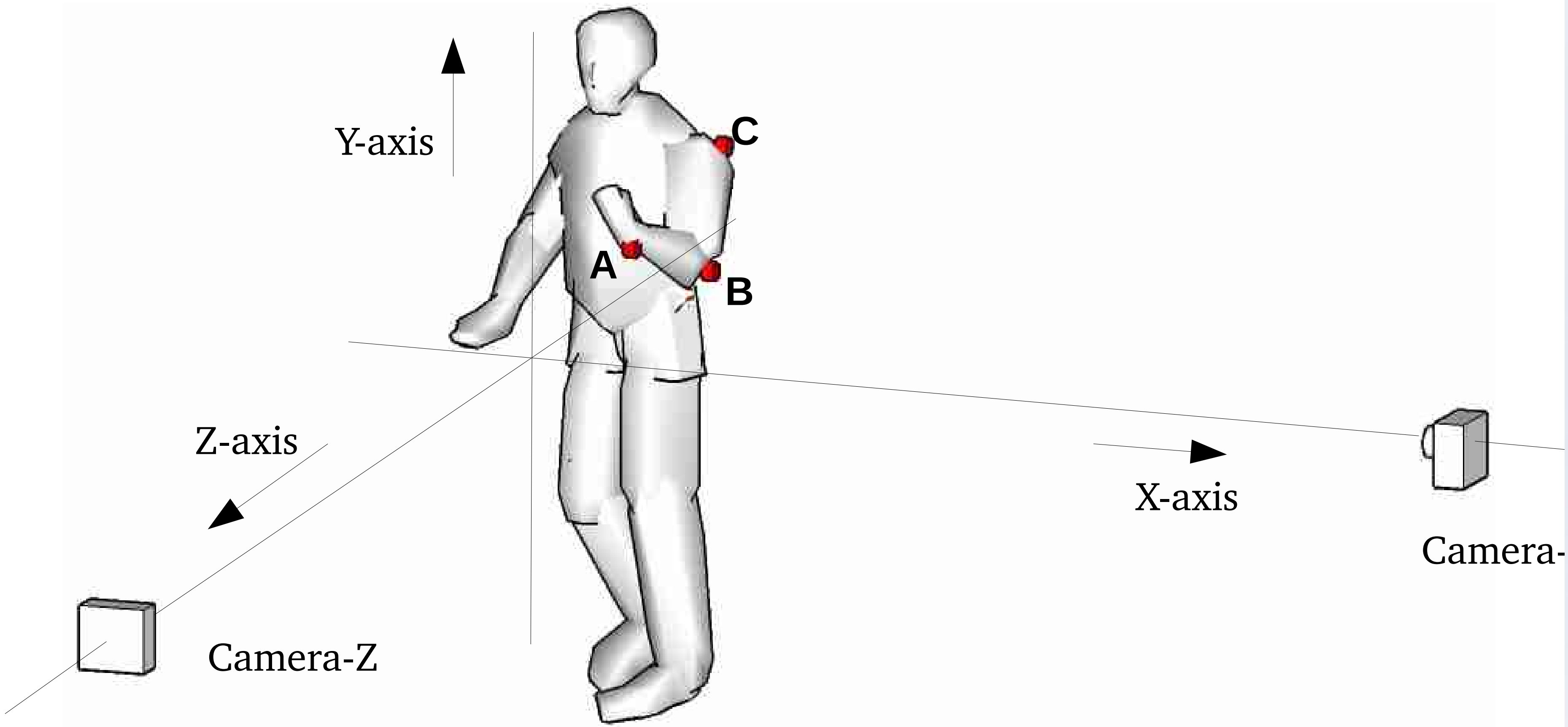
$$a = BC = \sqrt{(x_B - x_C)^2 + (y_B - y_C)^2 + (z_B - z_C)^2}$$

$$b = AC = \sqrt{(x_A - x_C)^2 + (y_A - y_C)^2 + (z_A - z_C)^2}$$

$$c = AB = \sqrt{(x_A - x_B)^2 + (y_A - y_B)^2 + (z_A - z_B)^2}$$

$$\cos(B) = \frac{a^2 + c^2 - b^2}{2ac}$$

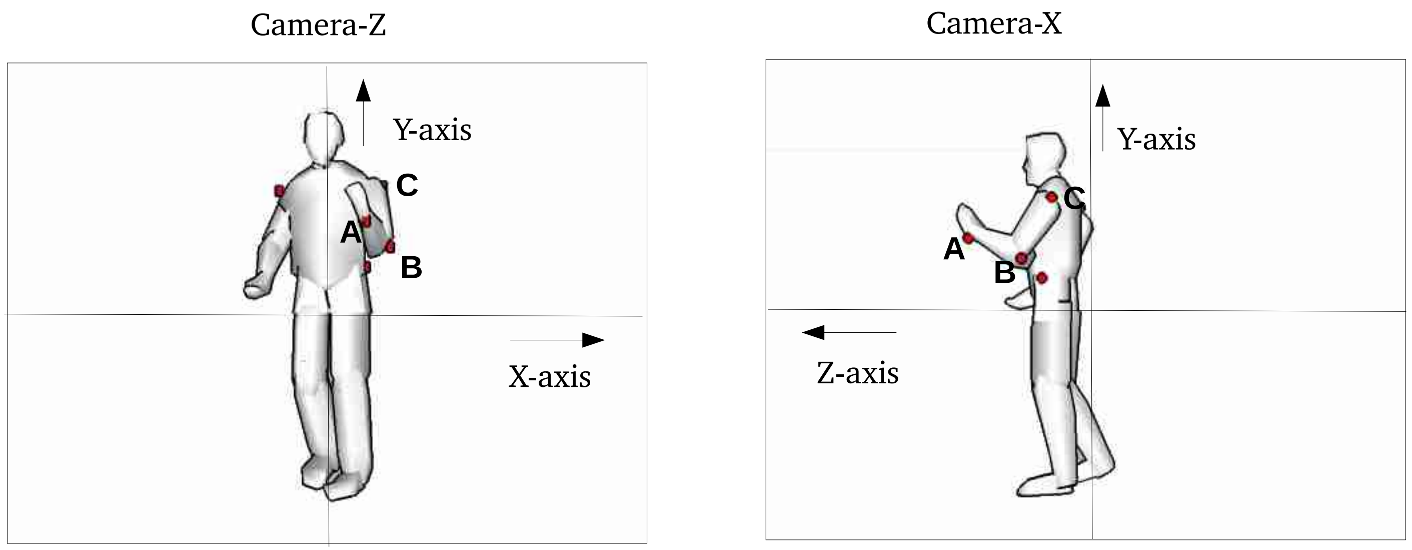
Camera placement



Room co-ordinates to camera image co-ordinates

$$camera \quad X \Rightarrow A = k_p(-z_A, y_A), B = k_p(-z_B, y_B), C = k_p(-z_C, y_C)$$
$$camera \quad Z \Rightarrow A = k_q(\ \ x_A, y_A), B = k_q(\ \ x_B, y_B), C = k_q(\ \ x_C, y_C)$$

Camera images

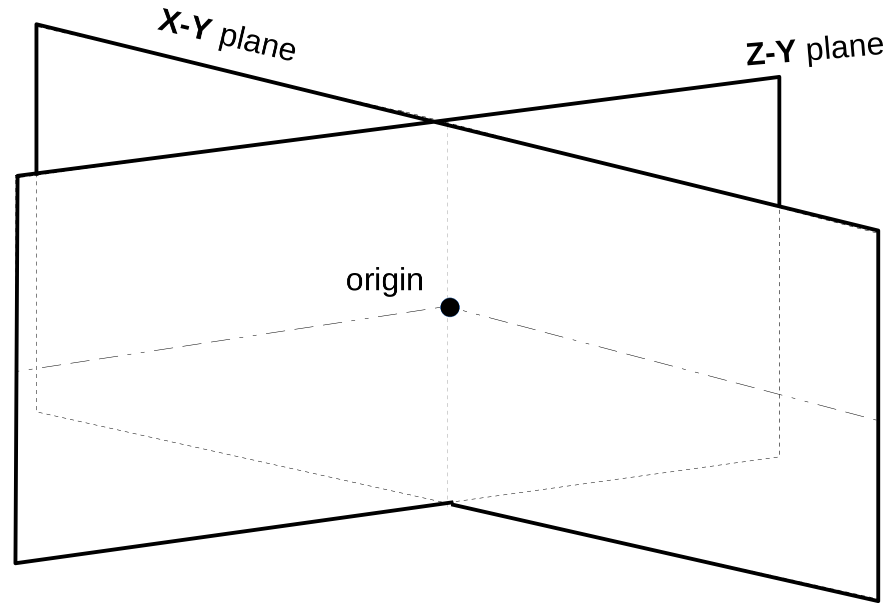


Camera image co-ordinates

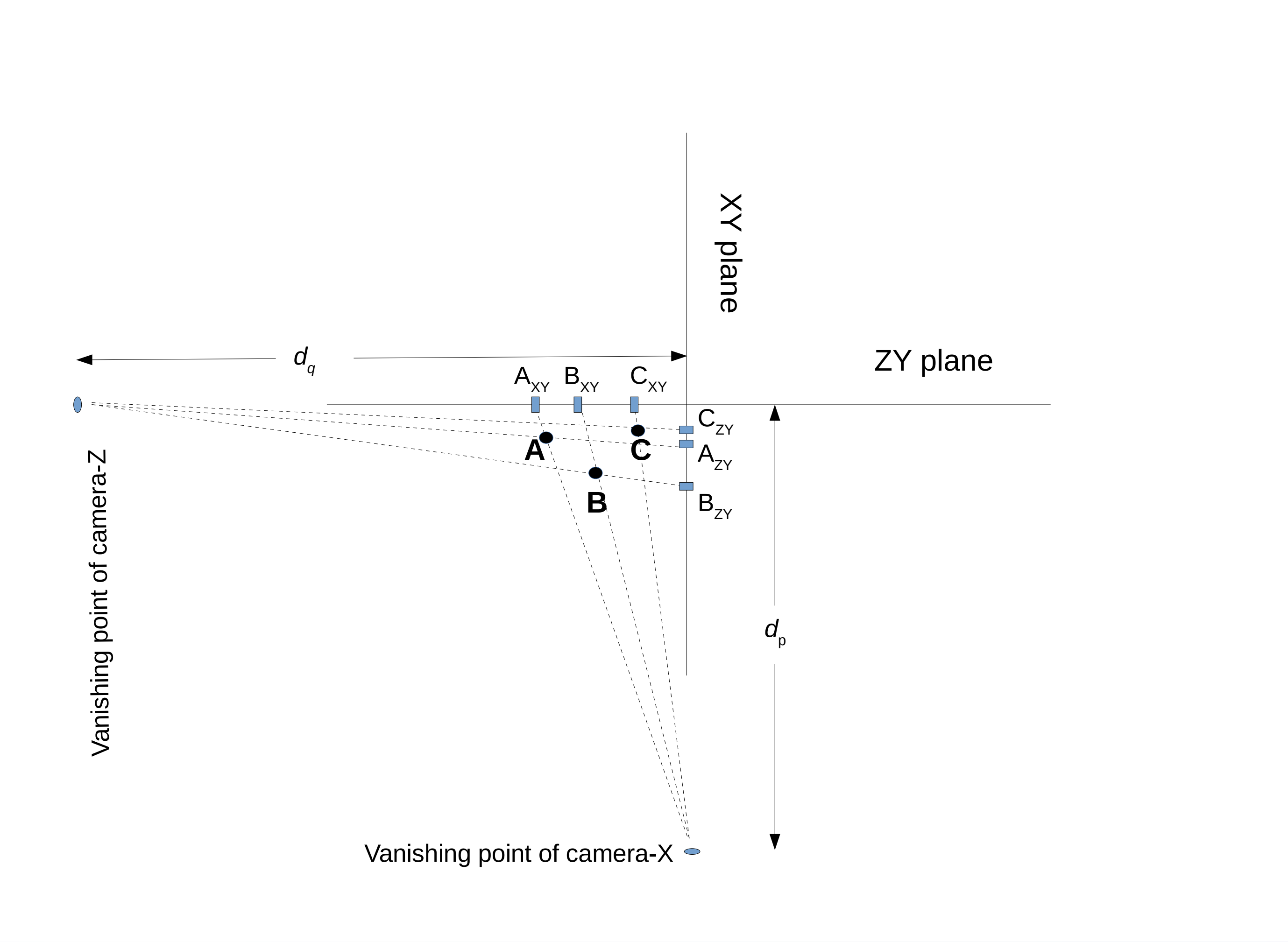
$$camera\quad Z \Rightarrow \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} k_q x_A \\ k_q y_A \\ k_q z_A \\ 1 \end{bmatrix} = \begin{bmatrix} k_q x_A \\ k_q y_A \\ 0 \\ 1 \end{bmatrix} = \begin{bmatrix} Image_{Horiz} \\ Image_{Vert} \\ - \\ - \end{bmatrix}$$

$$camera\quad X \Rightarrow \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} k_p x_A \\ k_p y_A \\ k_p z_A \\ 1 \end{bmatrix} = \begin{bmatrix} 0 \\ k_p y_A \\ -k_p z_A \\ 1 \end{bmatrix} = \begin{bmatrix} - \\ Image_{Vert} \\ Image_{Horiz} \\ - \end{bmatrix}$$

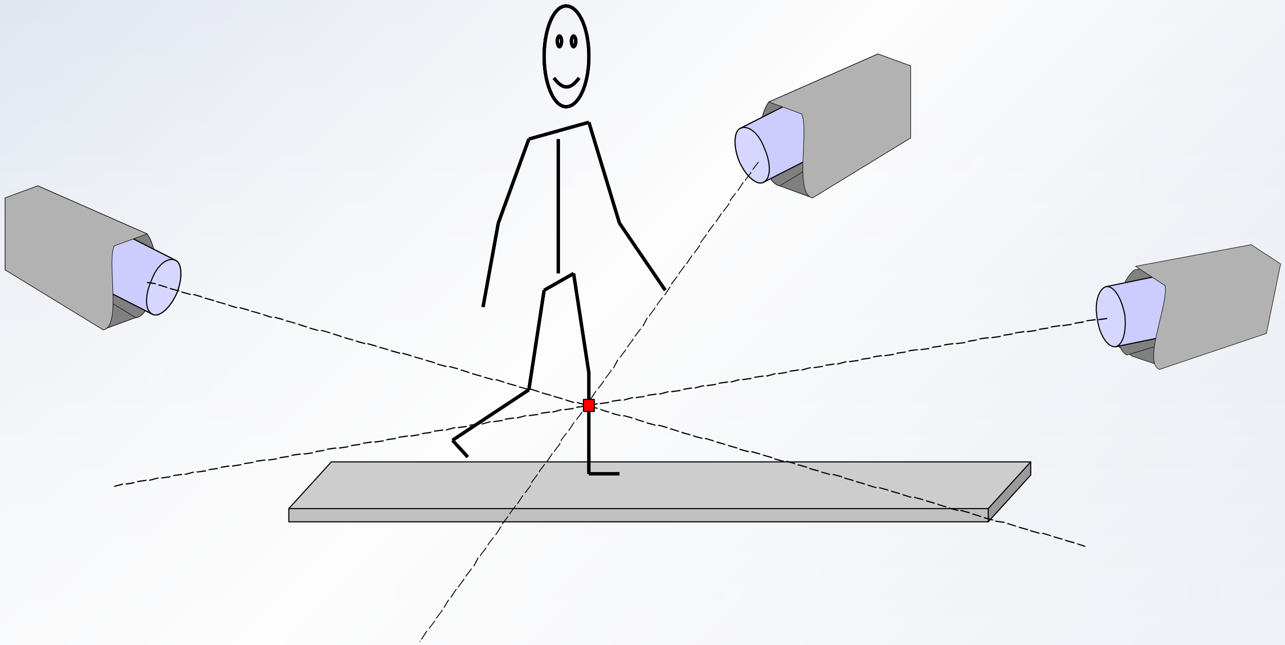
Room co-ordinate system



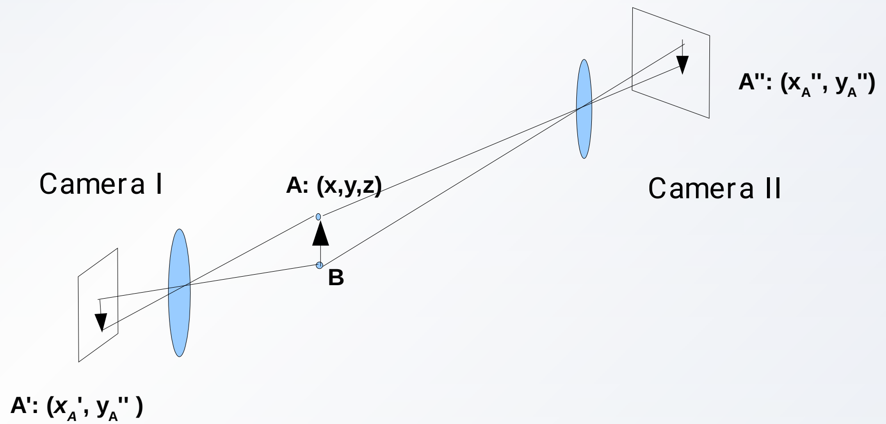
Magnification and depth dependent scale factor



Multiple camera systems



3D reconstruction



3D reconstruction from cameras

- Image of Marker A in camera I co-ords: x'_A, y'_A
- Image of Marker A in camera II co-ords: x''_A, y''_A
- Knowing positions of cameras I & II in room co-ordinates, we can calculate, x, y, z in room co-ordinates

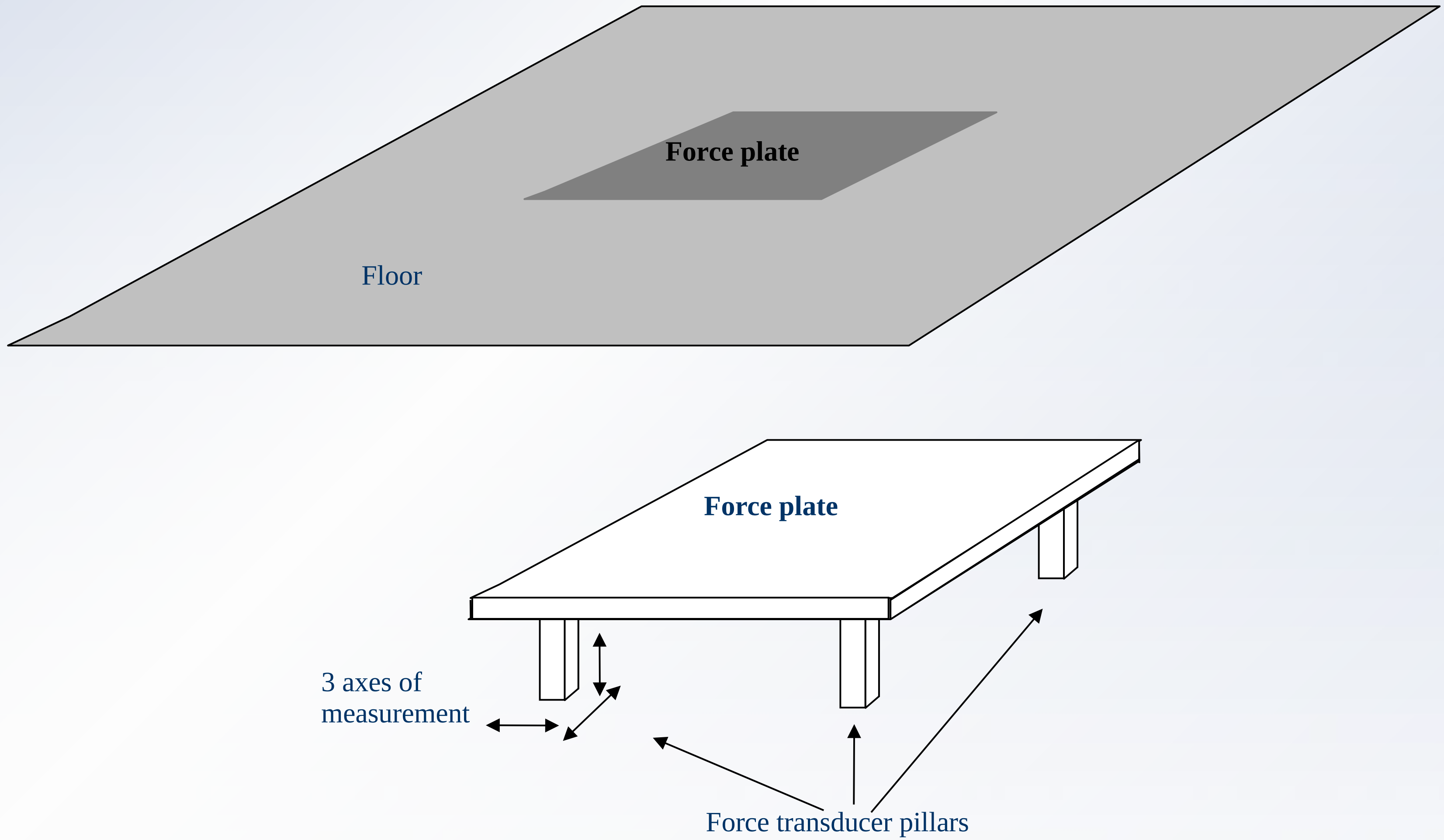
How many cameras ?

- Theoretical minimum number of cameras is 2
- The theoretical minimum assumes infinite spatial resolution for the imaging system, no distortion, visibility of all markers always, by each camera, etc.
- In practice these assumptions are not true
- The 3D reconstruction is done by SVD (i.e., not by direct solution) and the accuracy improves with more cameras

Measurement of ground forces

- Force vector: direction and magnitude of force by foot on the ground
- Centre of pressure determines the position of the force vector (i.e., whether at the heel, toe, or in-between)

Force plate recording



Force plate measurement

- Horizontal forces in forward-backward direction and lateral (left-right) direction are measured by all four pillars
- Centre of pressure is calculated from the relative vertical force on each pillar