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Assignment Report
Gait analysis

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BM3500 - Biomechanics

Contents

1 Introduction

Walking, or human gait, is a fundamental daily activity requiring highly coordinated interactions between the musculoskeletal and nervous systems. A complete gait cycle begins when one foot contacts the ground (heel strike) and ends when that same foot contacts the ground again. This cycle includes two distinct phases: the stance phase, where the foot is in contact with the ground, and the swing phase, when the foot moves forward through the air. Generally, the stance phase accounts for approximately 60% of the gait cycle, and the swing phase makes up about 40%.

Gait analysis has wide applications in orthopedics, rehabilitation, sports science, and prosthetics. It provides objective measurements of joint movement, timing of gait events, and segmental motions, which are critical for diagnosing abnormalities, assessing treatment efficacy, and designing assistive technology. Unlike purely visual gait observation, which is subjective and unreliable, quantitative gait analysis yields precise and reproducible data.

This study used reflective marker data captured via motion tracking, analyzed through MATLAB, to extract key gait parameters such as stride length, cadence, progression velocity, limb segment lengths, and knee joint kinematics. This exercise provided practical experience with clinical gait analysis techniques and reinforced theoretical knowledge of human walking biomechanics.

2 Methods

The gait data analyzed in this study were obtained from a healthy adult male subject walking at a natural, self-selected pace. Reflective markers were strategically placed on specific anatomical landmarks that are widely recognized in gait analysis for accurately representing skeletal joint centers. Marker locations included the anterior superior iliac spine (ASIS) and posterior superior iliac spine (PSIS) of the pelvis, the greater trochanter of the hip, the lateral femoral condyle at the knee, the lateral malleolus of the ankle, and the second metatarsal head on the foot.

Data collection was performed using an optical motion capture system sampling at a frequency of 100 Hz. This high sampling rate provides the temporal resolution needed to precisely identify gait events such as heel strike and toe-off.

Data processing was conducted in MATLAB, leveraging its robust numerical computing and visualization capabilities. The raw marker coordinates were plotted in both the sagittal (XZ) plane and 3D space to visually inspect motion trajectories and verify data quality.

Gait events were identified by analyzing vertical displacement time series of the ankle and toe markers. Heel strikes corresponded to local minima in the ankle vertical displacement, while toe-off events were detected as minima in the toe marker vertical trajectory.

Spatio-temporal gait parameters, including gait cycle duration, stance and swing phase durations, stride length, cadence, and average velocity, were calculated. Segment lengths and knee joint angles were quantified in 2D and 3D using vector-based geometric methods. MATLAB's plotting functions were used for visualization throughout.

3 Results

3.1 Gait Event Timings and Spatio-Temporal Parameters

Table 1: Gait Event Timings and Spatio-Temporal Parameters

Parameter	**Value**
Heel strikes (two consecutive, data points)	(204, 89.1), (313, 87.71)
Toe-off (data point)	(275, 43.71)
Time for one gait cycle (s)	1.09
Time for stance phase (s)	0.71
Time for swing phase (s)	0.38
Stance phase (% of gait cycle)	65.13%
Swing phase (% of gait cycle)	34.86%
Comment on results	Slight deviation from healthy 60:40 stance–swing ratio

3.2 Spatio-Temporal and Velocity Parameters

Table 2: Spatio-Temporal and Velocity Parameters

Parameter	**Value**
Stride length (m)	1.4621
Cadence (steps/min)	$\frac{2 \times 60}{1.09} = 110.09$
Average velocity (m/s)	$\frac{1155 - (-308.6)}{313 - 204} = 1.343$

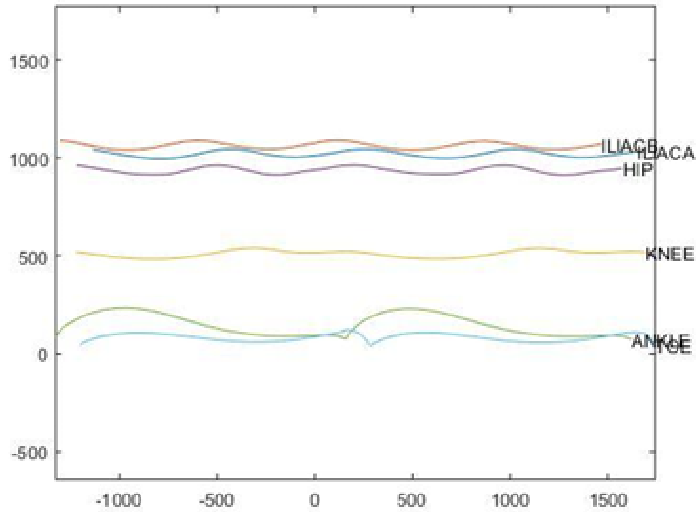

Figure 1: 2D-Iliac / Hip / Knee / Ankle / Toe Trajectories

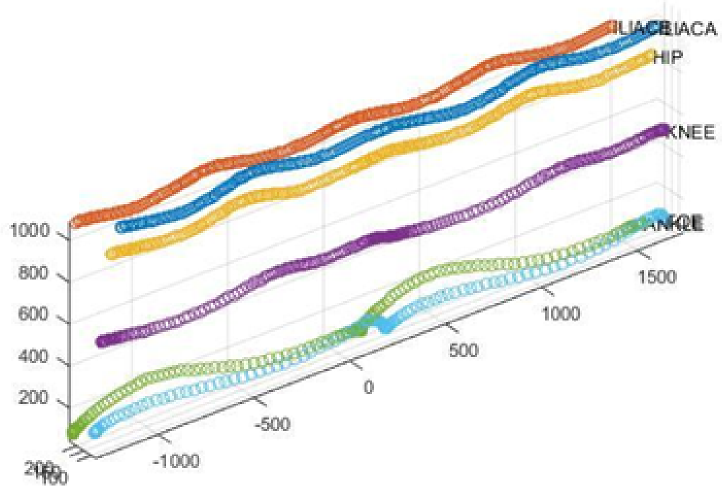

Figure 2: 3D-Iliac / Hip / Knee / Ankle / Toe Trajectories

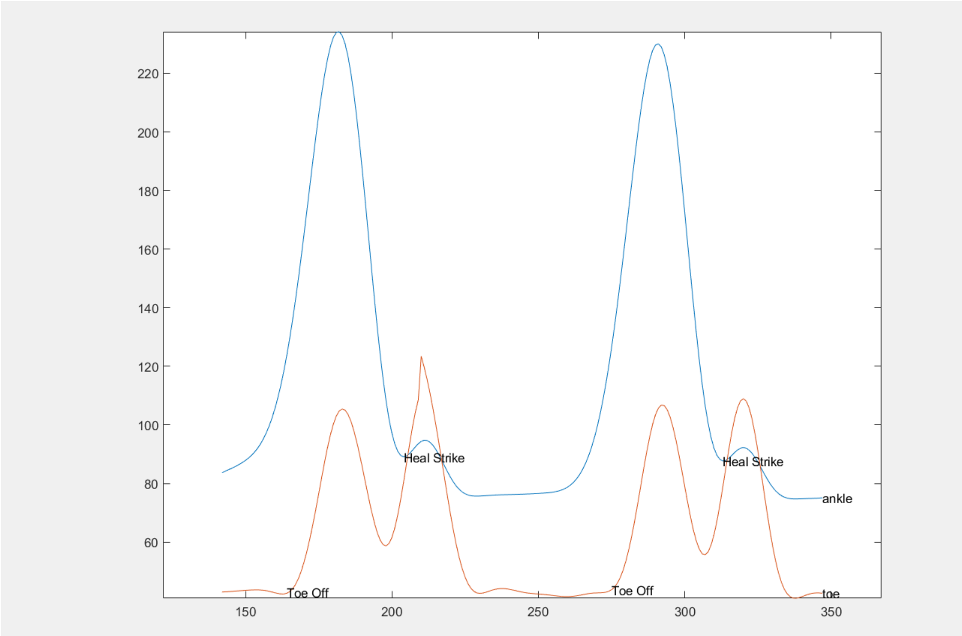

Figure 3: Iliac / Hip / Knee / Ankle / Toe Trajectories

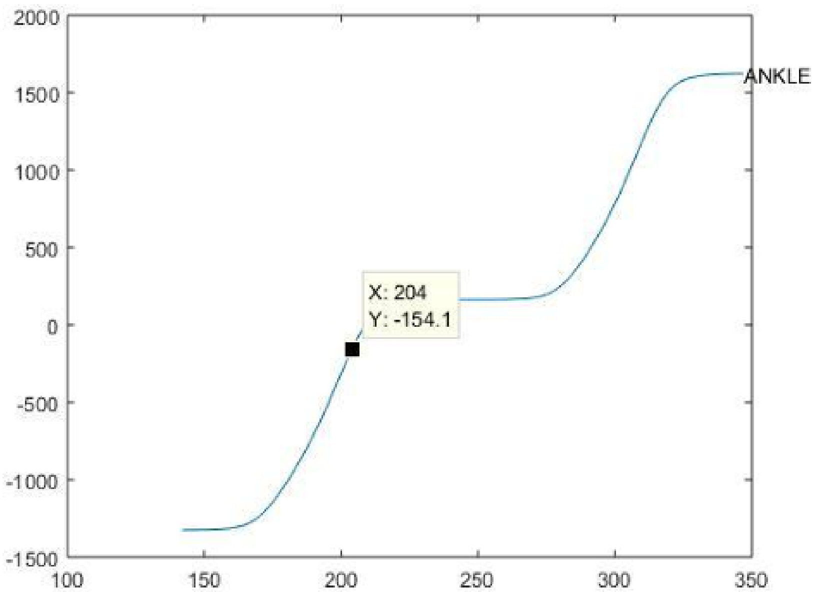

Figure 4: Ankle Trajectories

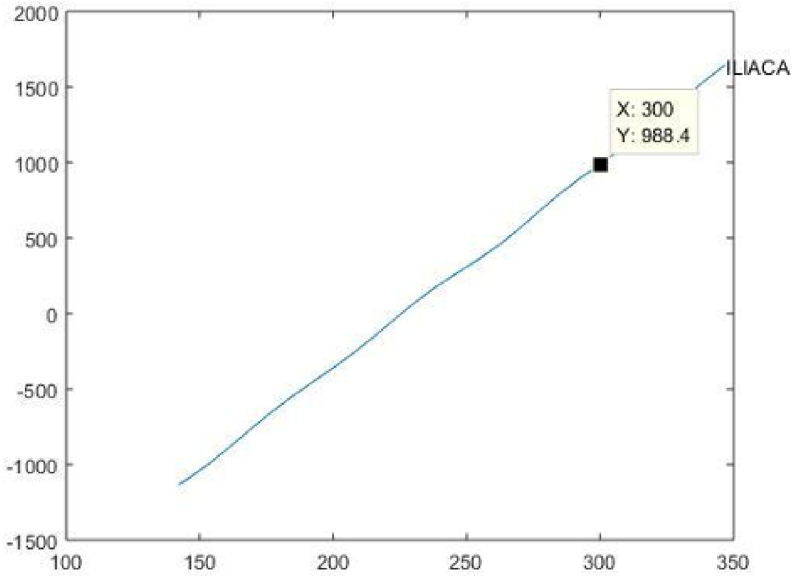

Figure 5: Iliac Trajectory

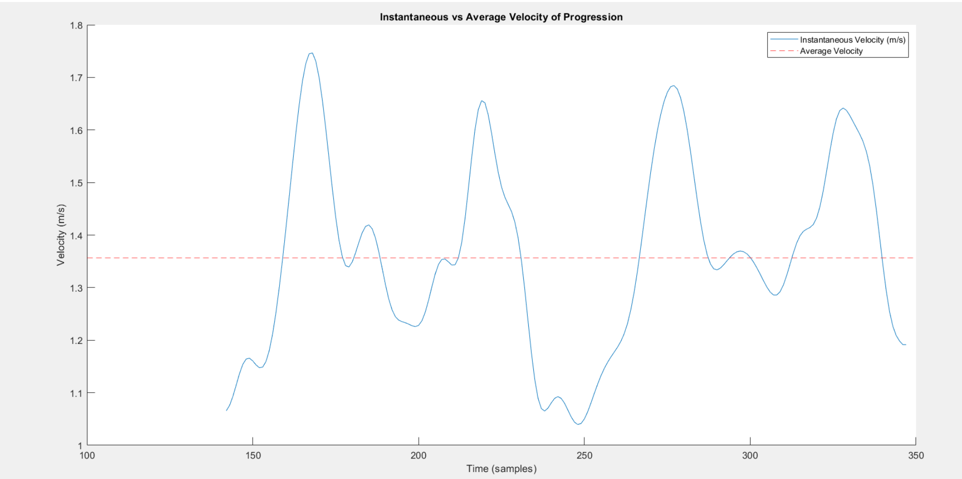

Figure 6: instantaneous vs average velocity of progression

The average velocity of gait progression was measured to be 1.34 m/s. The instantaneous velocity was not constant, oscillating between approximately 1.0 m/s and 1.7 m/s. This pattern exhibited characteristic periodic accelerations during the toe-off phase and decelerations near heel strike, which is typical of normal human gait.

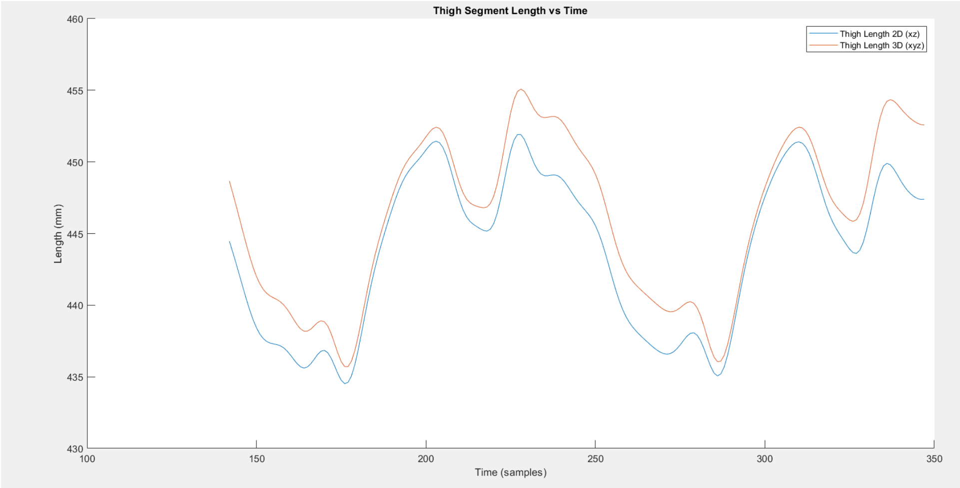

Figure 7: Thigh segment length vs time

The mean thigh segment length was calculated to be 0.444 in the 2D analysis and 0.446 in the 3D analysis. The observed fluctuations of approximately 5-6 are not reflective of actual anatomical change but arise from soft tissue artefacts and motion capture error, given the true bone length remains constant.

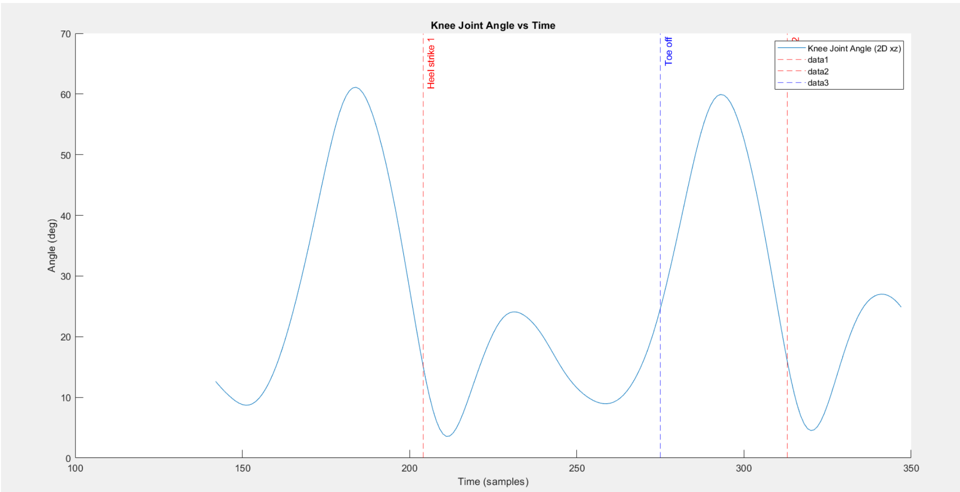

Figure 8: knee joint angle vs time

The knee joint angle was approximately 15 at heel strike, increased to 35 at toe-off, and measured 24 at the subsequent heel strike. Maximum flexion during the swing phase reached 65, a value which agrees well with normal gait kinematics.

4 Answer

4.1 Instantaneous Velocity of Progression

The instantaneous velocity of progression was computed and plotted against the data point number (time). While the average velocity of progression was found to be 1.34 m/s, the instantaneous values varied between approximately 1.0 and 1.7 m/s. These fluctuations are a result of the non-uniform nature of human walking: velocity decreases during heel strike due to the braking effect, and increases during toe-off as a result of propulsion. Consequently, the instantaneous velocity curve oscillates around the mean value, a characteristic feature of normal gait.

4.2 Thigh Segment Length in 2D and 3D

The length of the thigh segment was determined in both the xz plane (2D) and in full space (3D), and the values were plotted against the data point number. The mean thigh length was 0.444 m in 2D and 0.446 m in 3D, with only minor variations over time. Since the true bone length remains constant, these observed fluctuations can be attributed to soft tissue artefacts, skin movement relative to the bone, and small errors in marker placement.

4.3 Knee Joint Angle in 2D

The knee joint angle was calculated in 2D and plotted as a function of data point number, with heel strike and toe-off clearly indicated. The knee angle measured about 15° at heel strike, approximately 35° at toe-off, and around 24° at the following heel strike. During the swing phase, the maximum flexion reached nearly 65°. These results are consistent with normal gait patterns reported in the literature (typically 10° at heel strike, 30–40° at toe-off, and 60–70° during swing), indicating a physiologically normal gait cycle.

5 Discussion

- **Stance-to-swing ratio:** The subject's stance-to-swing ratio was 65 : 35, slightly different from the standard 60 : 40. Possible reasons include walking speed, individual gait characteristics, or minor measurement errors. This highlights that gait interpretation should be subject-specific rather than strictly based on textbook values.
- **Mean velocity and cadence:** With a cadence of 110 steps/min and a step length of 1.46 m, the average walking velocity was 1.34 m/s, which falls within the normal adult range (1.2–1.5 m/s).
- **Instantaneous velocity fluctuations:** The velocity plot revealed periodic oscillations between gait cycles. Speed decreased during heel strike (braking) and increased during toe-off (propulsion), demonstrating the dynamic nature of walking.

- **Segment length analysis:** The mean thigh length was stable (0.444–0.446 m), but small fluctuations of $\pm$5–6 mm were observed. These arose from soft tissue motion, slight marker placement errors, and limitations of the optical capture method. This confirms that measured data reflect skin markers, not exact bone geometry.
- **Knee joint angle:** Knee motion followed a typical gait pattern:
  - $\sim 15°$ at heel strike
  - Slight extension in stance
  - $\sim 35°$ at toe-off
  - Maximum flexion of $\sim 65°$ in swing

  These values align with normal gait kinematics, and no abnormal deviations were identified, confirming a healthy gait cycle.

6 Conclusion

This laboratory exercise demonstrated the use of optical motion capture and MATLAB-based processing to extract clinically relevant gait parameters from a basic marker dataset. Key findings and outcomes include:

- **Gait cycle:** Duration of 1.09 s, with a stance-to-swing ratio of 65% : 35%.
- **Spatio-temporal parameters:** Stride length of 1.46 m, cadence of 110 steps/min, and mean velocity of 1.34 m/s, all within the expected range for healthy adults.
- **Segment lengths:** Thigh length measured at ~ 0.445 m in both 2D and 3D, with minor fluctuations attributed to soft tissue artefacts and marker-related errors.
- **Knee joint kinematics:** Knee angles observed at $\sim 15°$ during heel strike, $\sim 35°$ at toe-off, and a peak flexion of $\sim 65°$ in swing, consistent with normal gait values.
- **Practical outcomes:** Gained understanding of how raw gait data can be transformed into clinically meaningful measurements, and how to critically interpret these results considering both normative values and potential artefacts.

These skills are directly relevant to applications in prosthetic design, rehabilitation engineering, and clinical biomechanics, where accurate and reliable gait analysis is essential.

Annex: MATLAB Code for Gait Data Analysis

```
%% gait.m -- Starter File for Gait Data Analysis
clear all

% Load the data into arrays A (marker data)
A = csvread('markers.csv');

% Find the number of rows and columns in A
[rA,cA] = size(A);

% initialize arrays of datapt number & assign to an array
datapt = zeros(rA,1);
datapt(:,1) = A(:,1);

% initialize arrays for marker data
iliaca = zeros(rA,3);     %anterior superior iliac spine (ASIS)
iliacp = zeros(rA,3);     %posterior superior iliac spine (PSIS)
hip = zeros(rA,3);        %greater trochanter (TRO)
knee = zeros(rA,3);       %lateral femoral condyle (LFC)
ankle = zeros(rA,3);      %later malleolus (LMA)
toe = zeros(rA,3);        %metatarsal 2nd head (TOE)

% Assign xyz coordinates of markers to right side iliac, hip, knee,
% ankle, toe arrays
iliaca(:,1) = A(:,5);   % ASIS x
iliaca(:,2) = A(:,6);   % ASIS y
iliaca(:,3) = A(:,7);   % ASIS z
iliacp(:,1) = A(:,11);  % PSIS x
iliacp(:,2) = A(:,12);  % PSIS y
iliacp(:,3) = A(:,13);  % PSIS z
hip(:,1) = A(:,17);     % TRO x
hip(:,2) = A(:,18);     % TRO y
hip(:,3) = A(:,19);     % TRO z
knee(:,1) = A(:,23);    % LFC x
knee(:,2) = A(:,24);    % LFC y
knee(:,3) = A(:,25);    % LFC z
ankle(:,1) = A(:,29);   % LMA x
ankle(:,2) = A(:,30);   % LMA y
ankle(:,3) = A(:,31);   % LMA z
toe(:,1) = A(:,35);     % TOE x
toe(:,2) = A(:,36);     % TOE y
toe(:,3) = A(:,37);     % TOE z

%%%%%%%%%%%%% YOU NEED TO CONTINUE THE CODE FROM HERE
figure(1)
% Plot xz trajectories
% iliaca
```

```
plot(iliaca(:,1),iliaca(:,3))
hold on
text(iliaca(rA,1),iliaca(rA,3),'ILIACA')

plot(iliacp(:,1),iliacp(:,3))
hold on
text(iliacp(rA,1),iliacp(rA,3),'ILIACP')

plot(hip(:,1),hip(:,3))
hold on
text(hip(rA,1),hip(rA,3),'hip')

plot(knee(:,1),knee(:,3))
hold on
text(knee(rA,1),knee(rA,3),'knee')

plot(ankle(:,1),ankle(:,3))
hold on
text(ankle(rA,1),ankle(rA,3),'ankle')

plot(toe(:,1),toe(:,3))
hold on
text(toe(rA,1),toe(rA,3),'toe')

axis('equal')

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
figure(2)

scatter3(iliaca(:,1),iliaca(:,2),iliaca(:,3))
hold on
text(iliaca(rA,1),iliaca(rA,2),iliaca(rA,3),'ILIACA')

scatter3(iliacp(:,1),iliacp(:,2),iliacp(:,3))
hold on
text(iliacp(rA,1),iliacp(rA,2),iliacp(rA,3),'iliacp')

scatter3(hip(:,1),hip(:,2),hip(:,3))
hold on
text(hip(rA,1),hip(rA,2),hip(rA,3),'hip')

scatter3(knee(:,1),knee(:,2),knee(:,3))
hold on
text(knee(rA,1),knee(rA,2),knee(rA,3),'knee')

scatter3(ankle(:,1),ankle(:,2),ankle(:,3))
hold on
text(ankle(rA,1),ankle(rA,2),ankle(rA,3),'ankle')

```

```
scatter3(toe(:,1),toe(:,2),toe(:,3))
hold on
text(toe(rA,1),toe(rA,2),toe(rA,3),'toe')

axis('equal')

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

figure(3)

plot(datapt(:,1),ankle(:,3))
hold on
text(datapt(rA,1),ankle(rA,3),'ankle')

plot(datapt(:,1),toe(:,3))
hold on
text(datapt(rA,1),toe(rA,3),'toe')

text(204,89.1,'Heal Strike')
text(313,87.71,'Heal Strike')
text(164,42.8,'Toe Off')
text(275,43.71,'Toe Off')


axis('equal')

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

figure(4)

plot(datapt(:,1),ankle(:,1))
hold on
text(datapt(rA,1),ankle(rA,1),'ankle')

figure(5)

plot(datapt(:,1),iliaca(:,1))
hold on
text(datapt(rA,1),iliaca(rA,1),'iliaca')


title('Ankle X vs Time');
%% 6. Instantaneous velocity of progression
% Use hip marker x-coordinate as proxy for COM progression
dt = 1/100; % Sampling period (100 Hz)
vx = diff(hip(:,1)) / dt; % velocity in mm/s
vx = [vx; vx(end)]; % pad to keep same length as datapt

avg_velocity = (hip(end,1) - hip(1,1)) / (length(datapt)*dt); % mm/s
```

```matlab
avg_velocity_mps = avg_velocity / 1000; % convert to m/s

figure(6); hold on;
plot(datapt, vx/1000, 'DisplayName','Instantaneous Velocity (m/s)');
yline(avg_velocity_mps, 'r--', 'DisplayName','Average Velocity');
legend show;
xlabel('Time (samples)'); ylabel('Velocity (m/s)');
title('Instantaneous vs Average Velocity of Progression');

%% 7. Thigh segment length ( h i p knee )
% 2D (xz)
thigh_len_2D = sqrt((hip(:,1)-knee(:,1)).^2 + (hip(:,3)-knee(:,3)).^2);

% 3D (xyz)
thigh_len_3D = sqrt(sum((hip - knee).^2,2));

figure(7); hold on;
plot(datapt, thigh_len_2D, 'DisplayName','Thigh Length 2D (xz)');
plot(datapt, thigh_len_3D, 'DisplayName','Thigh Length 3D (xyz)');
legend show;
xlabel('Time (samples)'); ylabel('Length (mm)');
title('Thigh Segment Length vs Time');

%% 8. Knee joint angle in 2D (xz plane)
% Define thigh vector (hip -> knee) and shank vector (knee -> ankle) in xz

thigh_vec = [knee(:,1)-hip(:,1), knee(:,3)-hip(:,3)];
shank_vec = [ankle(:,1)-knee(:,1), ankle(:,3)-knee(:,3)];

% Compute angle using dot product
dotprod = sum(thigh_vec .* shank_vec,2);
mag_thigh = sqrt(sum(thigh_vec.^2,2));
mag_shank = sqrt(sum(shank_vec.^2,2));
knee_angle = acosd(dotprod ./ (mag_thigh .* mag_shank));

figure(8); hold on;
plot(datapt, knee_angle, 'DisplayName','Knee Joint Angle (2D xz)');
xline(204,'r--','Heel strike 1');
xline(313,'r--','Heel strike 2');
xline(275,'b--','Toe off');
legend show;
xlabel('Time (samples)'); ylabel('Angle (deg)');
title('Knee Joint Angle vs Time');
```

Listing 1: Gait Data Analysis MATLAB Code