**684,000** people die from falls globally eve

the **second leading cause of unintentional injury**

A **1-Hour Delay** in medical assistance following f

**doubles** the mortality rate in the following six m

# Fall Pose Estimation Detectior

## Calculation Metrics

### Spatial & Pose Structure Metrics

Bounding Box Aspect Ratio (AR) determines if the box containing the person is "wide" (horizontal) or "tall" (vertical).

$$AR = \frac{x_{max} - x_{min}}{\max(1, y_{max} - y_{min})}$$

$$\text{mid}_{shoulder} = \frac{P_{L.sh} + P_{R.sh}}{2}, \quad \text{mid}_{hip} = \frac{P_{L.hip} + P_{R.h}}{2}$$

Torso Angle (θ). Calculated by finding the angle between the *mid-shoulder point and the mid-knee point* relative to the vertical axis.

$$\theta = \arctan 2(|\Delta x|, |\Delta y|) \times \frac{180}{\pi}$$

$$\Delta x = M_{knee}(x) - M_{shoulder}(x)$$

Anatomical Ruler (Length of Torso). The "ruler" is the distance between the *shoulders and hips*, used to normalize movement regardless of how close the person is to the camera.

$$L_{torso} = \text{median}(\{L_{inst,1}, L_{inst,2}, .$$

$$L_{inst} = \sqrt{(x_{sh} - x_{hip})^2 + (y_{sh} - y_h$$

# #1: The Torso Ruler (Velocity Nor

Standard computer vision measures speed in pixels. This is unreliable because a person *close* to the camera (**Fig. 2a**) appears to move "faster" than someone *far away* (**Fig. 2b**).

My algorithm calculates the *median torso length*, or the *distance between shoulders and hips* (**Fig. 1**). The system measures movement relative to the user's own body size, making it distance-invariant. During fast descent or when the person lies down, it freezes to maintain a normal value and updates when the person stands up.

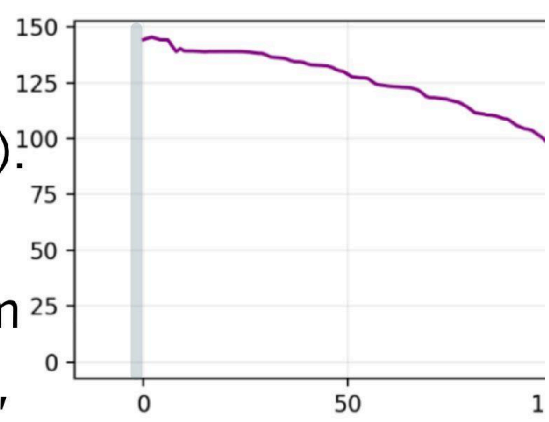


**Figure 1:** Graph of ruler from **Figure 2a** (frame 0, 146 pixels) to **Figure 2b** (frame 110, 83 pixels)

**Figu**
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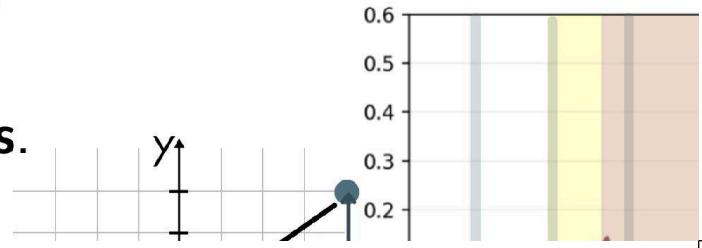
# #2: Laying Down Posture Analysis

Once a rapid descent (0.0625 torso lengths change in one frame) is detected, the program checks the **angle of the vector from the shoulders to the knees**. If this angle exceeds 35°, an initial fall is flagged.



*very year,*

**ıry deaths**

g falls

months

Seniors in households with annual incomes under **$20,000** have a **4%** higher prevalence of fall injuries, where expensive medical monitoring and fall-detection wearables are unavailable or too expensive

## on Algorithm

### s

**Motion Metrics**

Normalized Vertical Velocity: Determines the downward speed of the body center, scaled by the person's own torso size to be distance-invariant.

$$V_y = \frac{\bar{y}_t - \bar{y}_{t-1}}{L_{torso}}$$

$P_{R.hip}$

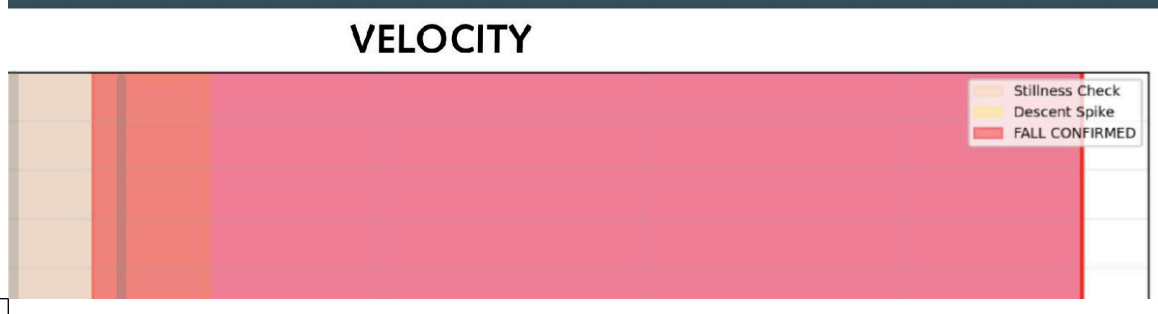
) $\Delta y = M_{knee}(y) - M_{shoulder}(y)$

$_{t,2}, \ldots, L_{inst,30}\})$

$- y_{hip})^2}$ $\bar{y}_t = \frac{y_{L.sh} + y_{R.sh} + y_{L.hip} + y_{R.hip}}{4}$

## ormalization)


**Figure 2:** Comparison of perspective distortion in movement. **(a)** Subject walking near the camera. **(b)** Subject walking far from the camera




**FallCam Device (Pi Zero 2W, Thinkpad, ESP32 CAM, etc...)**

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**Tailscale Encrypted Tunnel VPN → Mac Dashboard**

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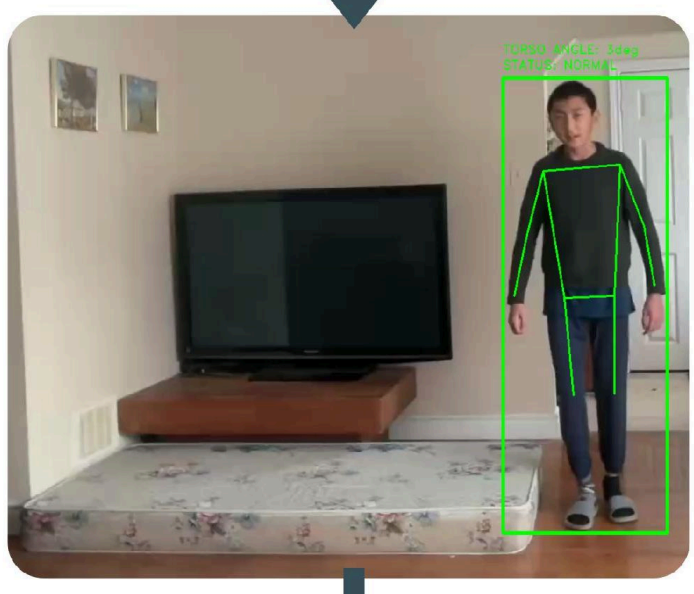

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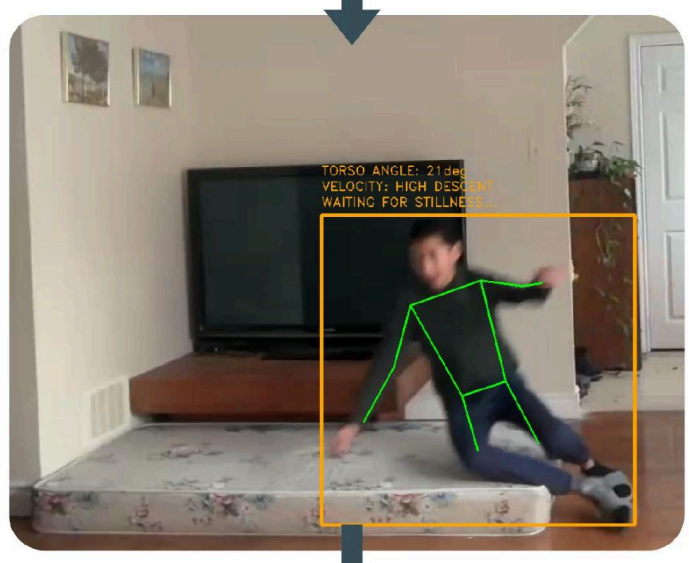


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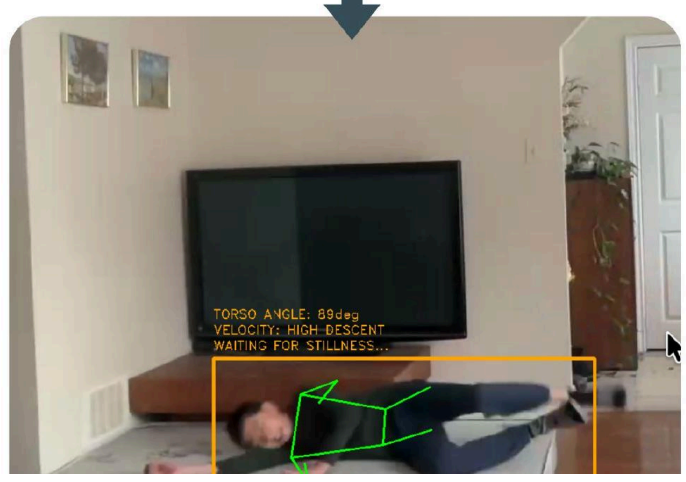
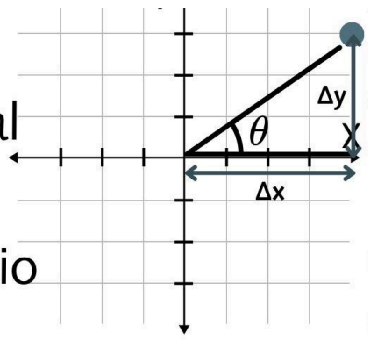


If this angle exceeds 35°, an initial fall is flagged. In addition, to catch forward falls where the skeletal angle might look vertical from the camera's perspective, I integrated a bounding box aspect ratio check as backup (width/height > 2).




## #3: The Confirmation Window

Most vision-based systems trigger an alert based on a single frame, which leads to false positives from many daily activities. To ensure a fall is a crisis and not a stumble, the system has a **lay-down stillness timer (Fig. 3).** The algorithm requires 30 consecutive frames (~1 second) of near-zero velocity while in a horizontal state. I also added a coordinate check where the subject must be in the lower 45% of the frame (Y > 0.55) to confirm they are on the floor. This confirmation window effectively filters out many common daily movements that might be considered a fall.

## Dealing with Data Occlusion and Gaps

Motion blur and falling behind furniture (chairs, beds) causes data gaps. To solve it, I Implemented a **memory buffer** that maintains an alert state during visual gaps, ensuring the system confirms the fall once the subject is partially re-visible.

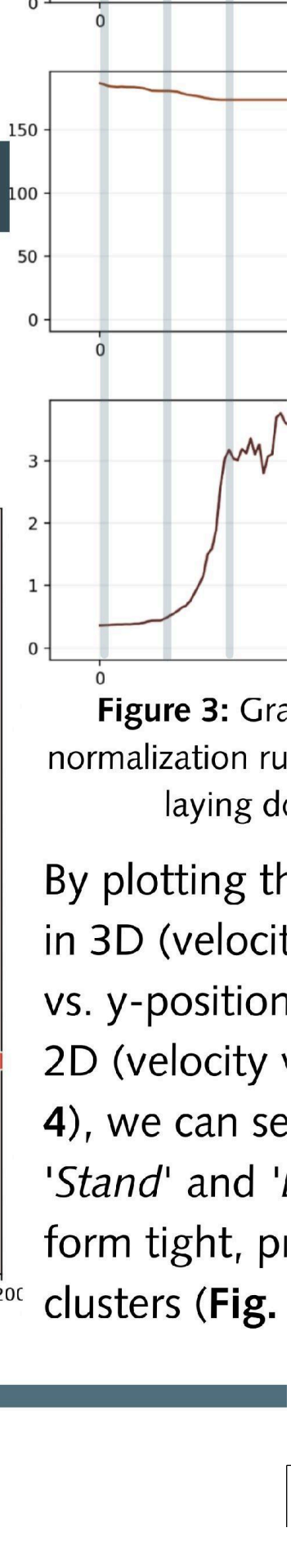



**Figure 3:** Gra
normalization ru
laying d

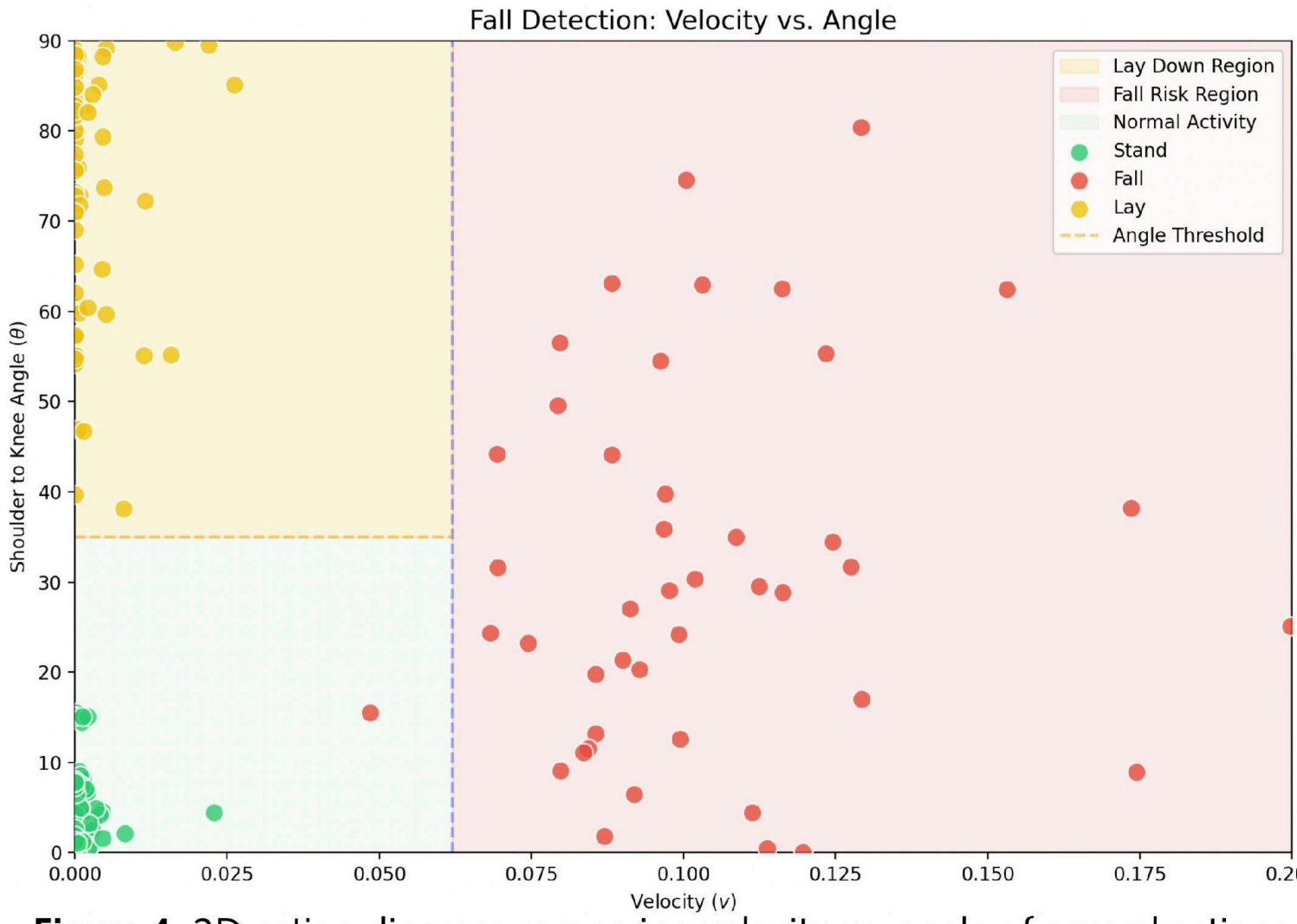
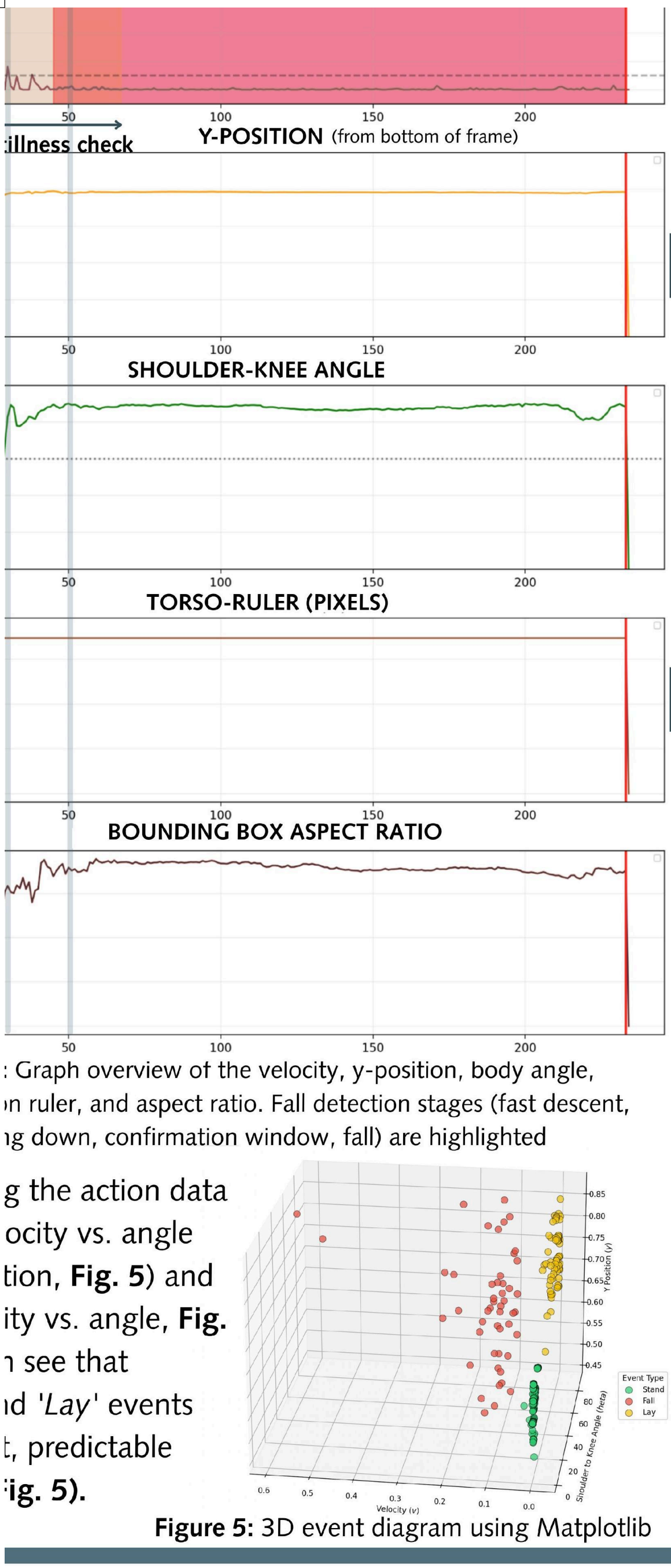



**Figure 4:** 2D action diagram comparing velocity vs. angle of several actions

By plotting th
in 3D (velocit
vs. y-position
2D (velocity
**4**), we can se
'*Stand*' and '
form tight, p
clusters (**Fig.**




: Graph overview of the velocity, y-position, body angle,
ın ruler, and aspect ratio. Fall detection stages (fast descent,
ıg down, confirmation window, fall) are highlighted

g the action data
ocity vs. angle
tion, **Fig. 5**) and
ity vs. angle, **Fig.**
ı see that
ıd '*Lay*' events
t, predictable
**ig. 5).**

**Figure 5:** 3D event diagram using Matplotlib