IMU-Based Vertical Motion Detection Algorithm

Purpose:

Detect vertical motion events (e.g., takeoff or bounce) using 6-axis IMU data (ICM-20948). Focus on Z-axis acceleration forming a smooth sinusoidal-like cycle, while filtering out noise, tilt, or sudden disturbances.

Algorithm Steps

1. Idle (Reset) State Detection

- **Condition:**
- All axes (AccX, AccY, AccZ, GyroX, GyroY, GyroZ) are approximately zero ± small noise margin.
- **Action:**
- Confirm system is in rest/reset state.

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2. Motor Activation Detection

- **Condition:**
- All axes show low-level ripple noise.
- If any axis exceeds a large threshold → **Reset** to Idle.
- **Action:**
- Confirm motors are spinning, but system is not lifting yet.

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3. Sine Wave Pattern (First Half Cycle) – Z Gradual Rise → Fall

3.1 Gradual Z Rise Detection

- **Condition:**
- AccZ increases **gradually** over a fixed time window (e.g., 10–15 samples).
- No spikes on AccX/Y or any gyros.
- **Method to Detect:**
- Use a **sliding window** and check if AccZ values are mostly increasing:

```
count = 0
for i in range(1, len(window)):
    if window[i] > window[i-1] - margin:
        count += 1
if count >= threshold:
    gradual_rise = True
```

- Typical: `margin = 0.05g`, `threshold = 7/10`.

3.2 Gradual Z Fall Detection

- **Condition:**
- AccZ now **gradually decreases** from peak value (after previous rise).
- Again, no spikes on other axes.
- **Method:**
- Same as above, but check for decreasing trend.
- **If both rise + fall detected in sequence → Sine Wave Half-Cycle detected.**

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4. Sine Wave Pattern (Second Half Cycle) – Z Gradual Fall → Rise

4.1 Gradual Z Fall Detection

- **Condition:**
- Start from steady Z, detect a **smooth drop** in AccZ over time.
- Other axes remain stable.
- **Action:**
- Track sliding window for mostly decreasing values.

4.2 Gradual Z Rise Detection

- **Condition:**
- After minimum, AccZ **gradually increases** again toward zero.
- Maintain ripple-only status on other axes.
- **Action:**
- If both fall + rise patterns completed → Second half-cycle complete.

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5. Steady State Detection

- **Condition:**
- AccZ returns to low-ripple region (± small noise).
- All axes within ripple limits.
- **Action:**
- Confirm motion is over and return to stable state.

Gradual Trend Detection – Sliding Window Logic

Use a buffer of recent Z samples:

```
def is_gradual_trend(window, direction, margin=0.05, threshold=7):
    count = 0
    for i in range(1, len(window)):
        if direction == 'rising':
            if window[i] > window[i-1] - margin:
```

```
                count += 1
        elif direction == 'falling':
            if window[i] < window[i-1] + margin:
                count += 1
    return count >= threshold
```

Summary of Conditions:

Step	AccZ Trend	Other Axes	Result
Step 1	Near zero	Near zero	Idle
Step 2	Ripples	Ripples	Motor active
Step 3	Gradual rise → fall	Ripple only	Sine wave 1st half-cycle
Step 4	Gradual fall → rise	Ripple only	Sine wave 2nd half-cycle
Step 5	Ripple zone	Ripple zone	Stable / return to reset

State Diagram:

```
[Idle State]
   ↓
[Motor ON – ripples only]
   ↓
[Gradual Z Rise]
   ↓
[Gradual Z Fall]
   ↓
[Gradual Z Fall]
   ↓
[Gradual Z Rise]
   ↓
[Steady State]
   ↑ (Any spike → Reset to Idle)
```