Mobile sensors
CS 407
Various types of sensors

- Accelerometer
- Gyroscope
- Magnetic field
- Light
- Proximity
- Temperature
- Pressure
- Humidity
Accelerometer

• Impact of force applied to the device
  – \( F = m \times a \)

• Units: m/s^2

• When device is stationary, we get +1g in one axis

• Can give you device orientation
How about displacement?

• $u = a \times t$

• $s = u_0 \times t + \frac{1}{2} a \times t^2$

• Dead reckoning

• Does this work?
  – Sometimes, but can be inaccurate since $a$ is not always as accurate
Gyroscope
Gyroscope

- Unit: rad/s
Magnetometer

• Hall effect measure of current to evaluate magnetic field

• Unit: Tesla (T) or uT
Light sensor

- Usually located near the front-facing camera

- Unit: Lux
Proximity sensor

• Could measure distance from device in cm

• Could be a binary output
  – Something is close by or not

• Sometimes uses the light sensor to infer this
Sensor framework

- Implemented as a callback

- `SensorEventListener()`

- Can also indicate how frequent updates are needed
Smoothing of data
Smoothing of data

• Simple moving average

\[ s_t = \frac{1}{k} \sum_{n=0}^{k-1} x_{t-n} = \frac{x_t + x_{t-1} + x_{t-2} + \cdots + x_{t-k+1}}{k} = s_{t-1} + \frac{x_t - x_{t-k}}{k}, \]
Smoothing of data

• Weighted moving average

\[ s_t = \sum_{n=1}^{k} w_n x_{t+1-n} = w_1 x_t + w_2 x_{t-1} + \cdots + w_k x_{t-k+1}. \]
Smoothing data

- Exponentially Weighted Moving Average (EWMA)

\[
\begin{align*}
    s_0 &= x_0 \\
    s_t &= \alpha x_t + (1 - \alpha)s_{t-1}, \quad t > 0
\end{align*}
\]
Smoothing data

- Exponentially Weighted Moving Average (EWMA)

\[ s_0 = x_0 \]
\[ s_t = \alpha x_t + (1 - \alpha) s_{t-1}, \quad t > 0 \]

\[
\begin{align*}
  s_t &= \alpha x_t + (1 - \alpha) s_{t-1} \\
  &= \alpha x_t + \alpha (1 - \alpha) x_{t-1} + (1 - \alpha)^2 s_{t-2} \\
  &= \alpha \left[ x_t + (1 - \alpha) x_{t-1} + (1 - \alpha)^2 x_{t-2} + (1 - \alpha)^3 x_{t-3} + \cdots + (1 - \alpha)^{t-1} x_0 \right] + (1 - \alpha)^t s_0.
\end{align*}
\]
Dead reckoning

How to estimate position indoors using sensors?
Orient the phone
Put it Flat: Project Device Coordinates

- World Coordinates \((x_w \ y_w \ z_w)\)
- Tablet Coordinates \((x_t \ y_t \ z_t)\)

Rotation Matrix \(R = \begin{bmatrix} x_{11} & x_{12} & x_{13} \\ x_{21} & x_{22} & x_{23} \\ x_{31} & x_{32} & x_{33} \end{bmatrix}\)

\[
\begin{bmatrix} x_w \\ y_w \\ z_w \end{bmatrix} = \begin{bmatrix} x_{11} & x_{12} & x_{13} \\ x_{21} & x_{22} & x_{23} \\ x_{31} & x_{32} & x_{33} \end{bmatrix} \begin{bmatrix} x_t \\ y_t \\ z_t \end{bmatrix}
\]
Speed and Distance Estimation

- Speed estimation: \( v_{i+1} = v_i + a_i t_i \)
- Distance estimation: \( s_i = v_i t_i + \frac{1}{2} a_i t_i^2 \)
Smoothing data

- Exponentially Weighted Moving Average (EWMA)

\[
\begin{align*}
  s_0 &= x_0 \\
  s_t &= \alpha x_t + (1 - \alpha) s_{t-1}, \quad t > 0 \\
  s_t &= \alpha x_t + (1 - \alpha) s_{t-1} \\
  &= \alpha x_t + \alpha (1 - \alpha) x_{t-1} + (1 - \alpha)^2 s_{t-2} \\
  &= \alpha [x_t + (1 - \alpha) x_{t-1} + (1 - \alpha)^2 x_{t-2} + (1 - \alpha)^3 x_{t-3} + \cdots + (1 - \alpha)^{t-1} x_0] + (1 - \alpha)^t s_0.
\end{align*}
\]
Here is a walk pattern

- Android tablet in a cart
- Fixed by tape
- Tablet is flat
Accelerometer

Series 1
Series 2
Series 3
Alpha = 0.8
Alpha = 0.5
Alpha = 0.2
Alpha = 0.1
Alpha = 0.1
Step counting