

# Autonomous Navigation for Flying Robots

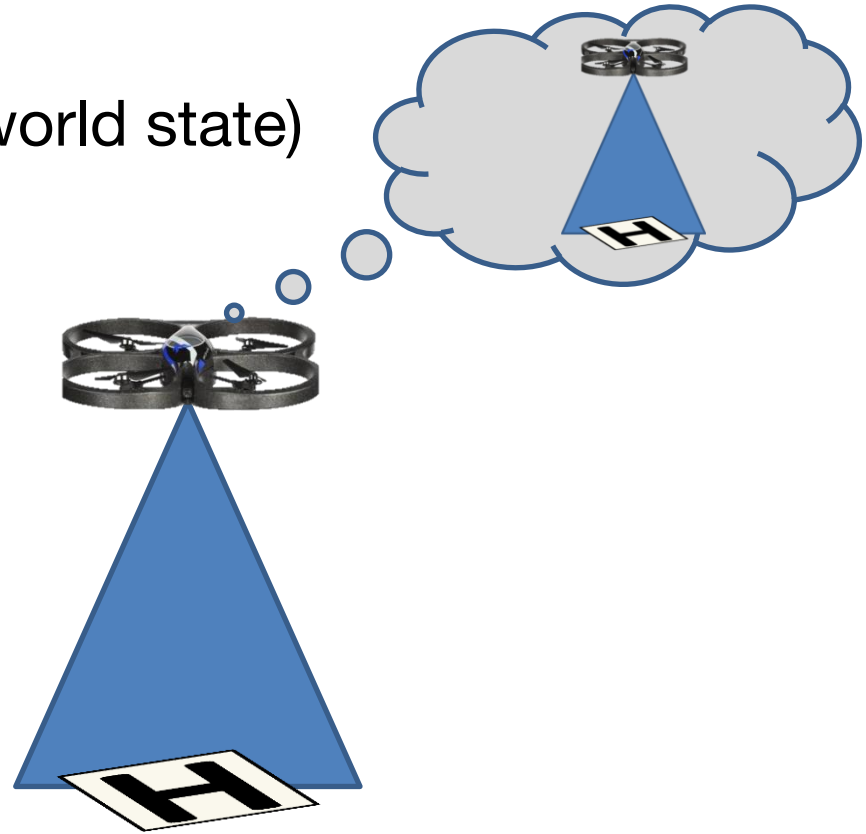
## Lecture 5.1: State Estimation

Jürgen Sturm
Technische Universität München

# World State (or System State)

- Belief State
  (our belief/estimate of the world state)

- World State
  (real state of the real world)



# State Estimation

What parts of the world state are (most) relevant for a flying robot?

- Position
- Velocity
- Obstacles
- Map
- Positions and intentions of other robots/humans
- …

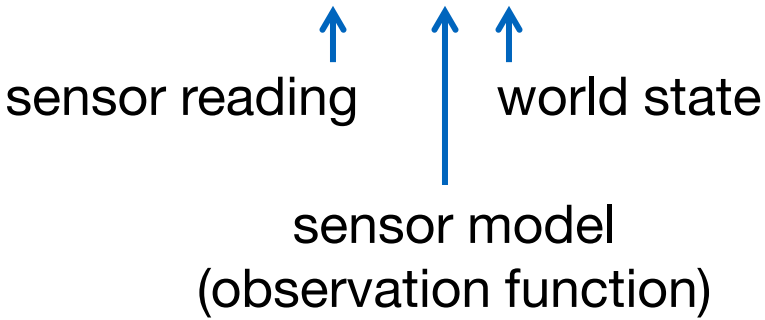
# State Estimation

- Cannot observe world state directly
- Need to estimate the world state, but how?
- Infer world state from sensor observations
- Infer world state from executed motions/actions

# Sensor Model

- Robot perceives the environment through its sensors

$$\mathbf{z} = h(\mathbf{x})$$



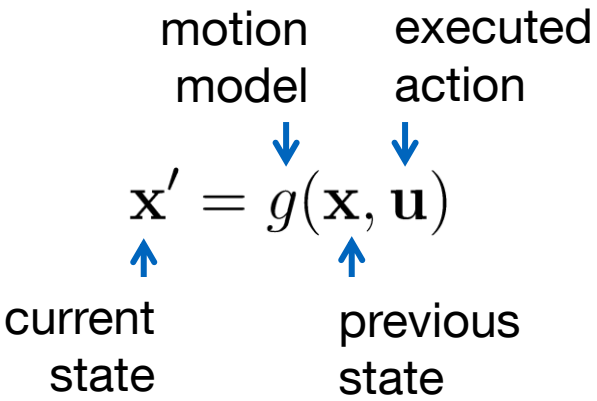

- Goal: Infer the state of the world from sensor readings

$$\mathbf{x} = h^{-1}(\mathbf{z})$$

# Motion Model

- Robot executes an action (or control) $\mathbf{u}$ (e.g., move forward at 1m/s)

- Update belief state according to motion model



# Probabilistic Robotics

- Sensor observations are noisy, partial, potentially missing
- All models are partially wrong and incomplete
- Usually we have prior knowledge

# Probabilistic Robotics

- Probabilistic sensor models $p(\mathbf{z} \mid \mathbf{x})$
- Probabilistic motion models $p(\mathbf{x}' \mid \mathbf{x}, \mathbf{u})$
- Fuse data between multiple sensors (multi-modal)

$$p(\mathbf{x} \mid \mathbf{z}_{\text{vision}}, \mathbf{z}_{\text{ultrasound}}, \mathbf{z}_{\text{IMU}})$$

- Fuse data over time (filtering)

$$p(\mathbf{x} \mid \mathbf{z}_1, \mathbf{z}_2, \ldots, \mathbf{z}_t)$$

$$p(\mathbf{x} \mid \mathbf{z}_1, \mathbf{u}_1, \mathbf{z}_2, \mathbf{u}_1, \ldots, \mathbf{z}_t, \mathbf{u}_t)$$

# Lessons Learned

- World state vs. (internal) belief state
- Sensor and motion models
- Model uncertainty using probability theory

- Next:
  Recap on Probability Theory