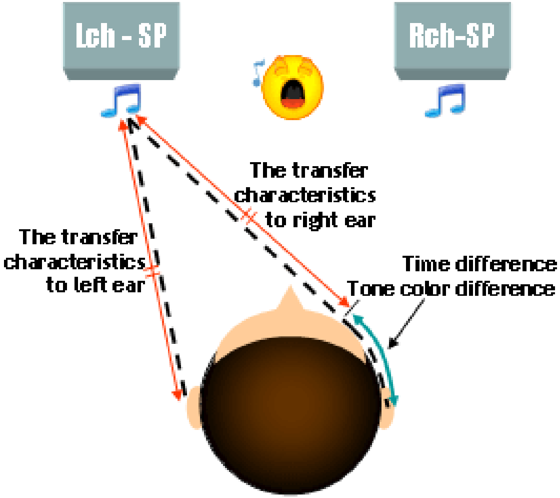
Sensor Fusion
Multi-Sensor Data Fusion

Felix Riegler

8. Mai 2014



The difference of transfer characteristics

Definition

Richardson and March - 1988

Fusion of Multisensor data.

Hall - 1992

Multisensor data fusion seeks to combine data from multiple sensors to perform inferences that may not be possible from a single sensor alone.

Starr and Desforges - 1998

Data fusion is a process that combines data and knowledge from different sources with the aim of maximising the useful information content, for improved reliability or discriminant capability, while minimising the quantity of data ultimately retained.

Breakdown

- Input: sensor data from multiple sensors

Breakdown

- Input: sensor data from multiple sensors
- Process: combining data

Breakdown

- Input: sensor data from multiple sensors
- Process: combining data
- Goal: to get better and/or more reliable data

Domains and properties

Domains

- Military

Domains

- Military
- Localization/Detection

Domains

- Military
- Localization/Detection
- Navigation/Pathfinding

Domains

- Military
- Localization/Detection
- Navigation/Pathfinding
- (Air-)Traffic control

Domains

- Military
- Localization/Detection
- Navigation/Pathfinding
- (Air-)Traffic control
- Environment prediction

Domains

- Military
- Localization/Detection
- Navigation/Pathfinding
- (Air-)Traffic control
- Environment prediction
- Robotics

Domains

- Military
- Localization/Detection
- Navigation/Pathfinding
- (Air-)Traffic control
- Environment prediction
- Robotics
- ....

3 Properties

- **Source:**

3 Properties

- **Source:**
- homogeneous

3 Properties

- **Source:**
- homogeneous
- heterogeneous

3 Properties

- **Source:**
- homogeneous
- heterogeneous
-

3 Properties

- **Source:**
- homogeneous
- heterogeneous
-
- **Goal:**

3 Properties

- **Source:**
- homogeneous
- heterogeneous
-
- **Goal:**
- reliability

3 Properties

- **Source:**
- homogeneous
- heterogeneous
-
- **Goal:**
- reliability
- new data

3 Properties

- **Source:**
- homogeneous
- heterogeneous
-
- **Goal:**
- reliability
- new data
-

3 Properties

- **Source:**
- homogeneous
- heterogeneous
-
- **Goal:**
- reliability
- new data
-
- **Representation in a system:**

3 Properties

- **Source:**
- homogeneous
- heterogeneous
-
- **Goal:**
- reliability
- new data
-
- **Representation in a system:**
- blackboard

3 Properties

- **Source:**
- homogeneous
- heterogeneous
-
- **Goal:**
- reliability
- new data
-
- **Representation in a system:**
- blackboard
- module

Examples

Radar

- emits electromagnetic waves and detects reflections

Radar

- emits electromagnetic waves and detects reflections
- surveillance radar

Radar

- emits electromagnetic waves and detects reflections
- surveillance radar
- secondary or active radar

Radar

- emits electromagnetic waves and detects reflections
- surveillance radar
- secondary or active radar
- + fire control radar

Radar

- emits electromagnetic waves and detects reflections
- surveillance radar
- secondary or active radar
- $+$ fire control radar
- heterogeneous; reliability and new data; blackboard

sound locatisation

- two microphones

sound locatisation

- two microphones
- homogeneous

sound locatisation

- two microphones
- homogeneous
- new data

sound locatisation

- two microphones
- homogeneous
- new data
- module

camera + infrared projector

- e.g. Kinect

camera + infrared projector

- e.g. Kinect
- heterogeneous

camera + infrared projector

- e.g. Kinect
- heterogeneous
- new data

camera + infrared projector

- e.g. Kinect
- heterogeneous
- new data
- ?

stereo vision

- two cameras

stereo vision

- two cameras
- homogeneous

stereo vision

- two cameras
- homogeneous
- new data

stereo vision

- two cameras
- homogeneous
- new data
- module

General data fusion methods

General data fusion methods

- Bayesian network

General data fusion methods

- Bayesian network
- Kalman filter

General data fusion methods

- Bayesian network
- Kalman filter
- Fuzzy logic

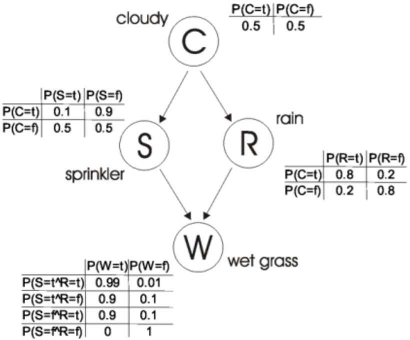
General data fusion methods

- Bayesian network
- Kalman filter
- Fuzzy logic
- Monte Carlo methods

General data fusion methods

- Bayesian network
- Kalman filter
- Fuzzy logic
- Monte Carlo methods
- Dempster–Shafer theory

Bayesian network



Design on abstract or raw data?

Kalman Filter

- tracking, localisation, navigation

Kalman Filter

- tracking, localisation, navigation
- suited for many different (sensor-)inputs

Kalman Filter

- tracking, localisation, navigation
- suited for many different (sensor-)inputs
- recursive state estimation, thus

Kalman Filter

- tracking, localisation, navigation
- suited for many different (sensor-)inputs
- recursive state estimation, thus
- simple and efficient in many cases

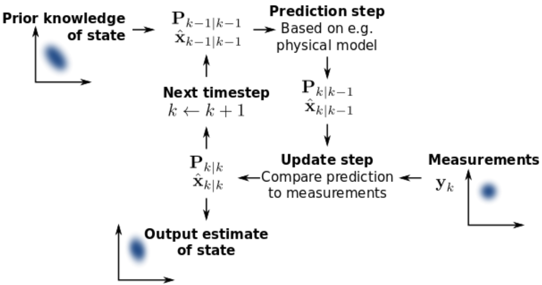
Kalman Filter

- tracking, localisation, navigation
- suited for many different (sensor-)inputs
- recursive state estimation, thus
- simple and efficient in many cases
- $x(t|t-1)$ - state at time t with data t-1

Kalman Filter

- tracking, localisation, navigation
- suited for many different (sensor-)inputs
- recursive state estimation, thus
- simple and efficient in many cases
- $x(t|t-1)$ - state at time t with data t-1
- $P(t|t)$ - covariant - error estimate

Kalman Filter in a nutshell



Fuzzy logic

- many-value logic

Fuzzy logic

- many-value logic
- $f \to [0, 1]$

Fuzzy logic

- many-value logic
- $f \rightarrow [0, 1]$
- degree of certainty

Fuzzy logic

- many-value logic
- $f \to [0, 1]$
- degree of certainty
- especially use in threshold controlled systems

Stereo Vision

Stereo Vision

- stereopsis

Stereo Vision

- stereopsis
- PR2 has 2 stereo vision systems

Stereo Vision

- stereopsis
- PR2 has 2 stereo vision systems
- another way for depth recognition

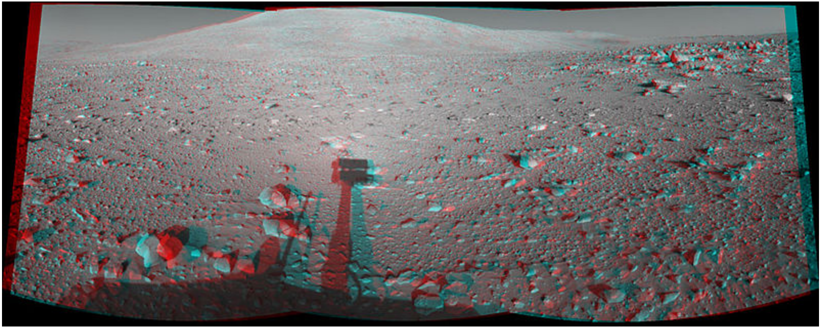
Stereo Vision

- stereopsis
- PR2 has 2 stereo vision systems
- another way for depth recognition
- obviously 2 cameras capturing (more or less) the same picture

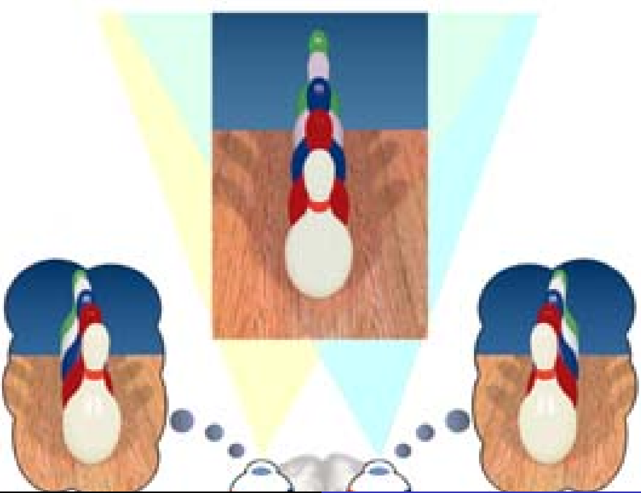
Stereo Vision

- stereopsis
- PR2 has 2 stereo vision systems
- another way for depth recognition
- obviously 2 cameras capturing (more or less) the same picture
- calibration is problematic

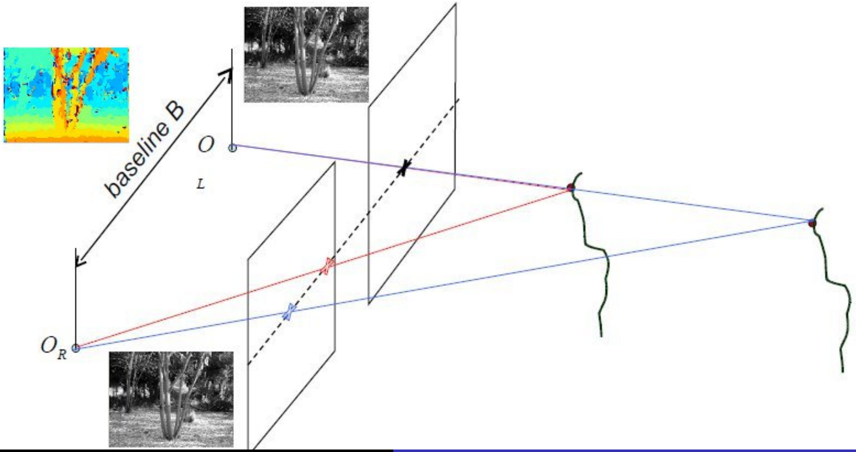
Anaglyph 3D



2 pictures



3D Reconstruction



Standard Geometry

$$z = \frac{b * focallength}{x_{camL} - x_{camR}}$$

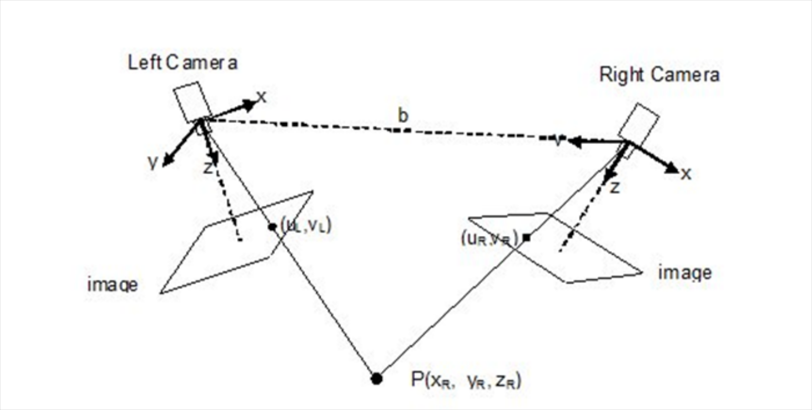
$$x = \frac{x_{camL} * z}{focallength}$$

$$y = \frac{y_{camL} * z}{focalwidth}$$

Triangulation

- general case
- cameras need to be thoroughly calibrated
- both intrinsic and extrinsic matrix have to be known
- (lens properties + position in relation to the global coordinate system)

Triangulation

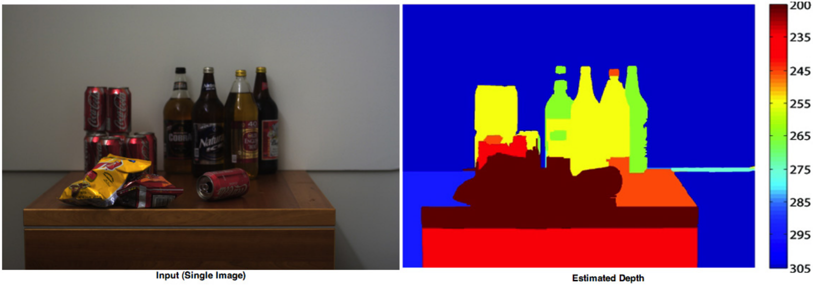


Traingulation Calculation

$$z_1 * point_1 = camMatrix_1 * point_{real}$$

$$z_2 * point_2 = camMatrix_2 * point_{real}$$

1 image + depth information



Conclusion

Sensor fusion

- combining (multiple) sensor data to get better and/or more reliable data

Sensor fusion

- combining (multiple) sensor data to get better and/or more reliable data
- core ability for humans

Sensor fusion

- combining (multiple) sensor data to get better and/or more reliable data
- core ability for humans
- used in many domains

Sensor fusion

- combining (multiple) sensor data to get better and/or more reliable data
- core ability for humans
- used in many domains
- (humanoid)robotics

Algorithms for sensor fusion

- Bayesian networks

Algorithms for sensor fusion

- Bayesian networks
- Kalman filter

Algorithms for sensor fusion

- Bayesian networks
- Kalman filter
- Fuzzy logic

Algorithms for sensor fusion

- Bayesian networks
- Kalman filter
- Fuzzy logic
- stereo vision - depth recognition

Thank you,
Questions?