Semester Project

-

Robust object tracking in 3D by fusing ultra-wideband and vision

-

ETH zürich
Advanced Interactive Technologies
BIWI Computer Vision

Contents

Motivation

- Object tracking is an important building block

Motivation

- Object tracking is an important building block
- Most state-of-the-art robust approaches work with predefined objects $\rightarrow$ not engough flexible

Motivation

- Object tracking is an important building block
- Most state-of-the-art robust approaches work with predefined objects → not engough flexible
- Online visual tracking → limited labeled data

Motivation

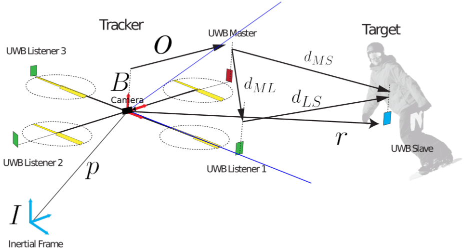
- Object tracking is an important building block
- Most state-of-the-art robust approaches work with predefined objects $\rightarrow$ not engough flexible
- Online visual tracking $\rightarrow$ limited labeled data
- New approach: Fusion of Ultra-wideband (UWB) and a visual tracker with an Extended Kalman Filter (EKF)

Semester Project

Andreas Ziegler

Motivation
Related work
UWB
KCF
Setup
Mounting
Matching
Transform
Fusing
Re-detection
Results
Conclusion
Conclusion
Outlook
Questions
References

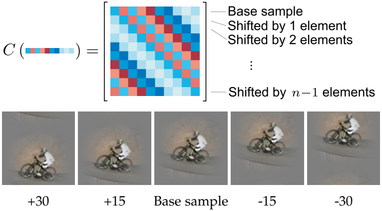
Related work - Ultra-wideband (UWB)



- Provides 3D position and velocity information
- Accuracy of $\approx 10cm$

[Tobias Naegeli, 2016]

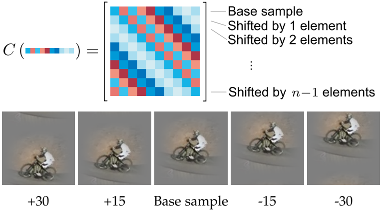
Related work - Kernelized correlation filters (KCF)



- Translated and scaled patches are riddled with redundancies → Can be represented as a circulant matrix in a compact way

[Henriques et al., 2015]
Figures from Henriques et al. 2015. High-speed tracking with kernelized correlation filters

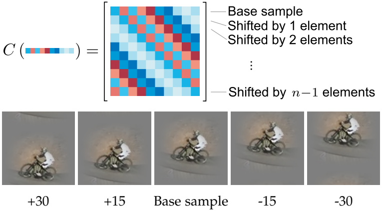
Related work - Kernelized correlation filters (KCF)



- Translated and scaled patches are riddled with redundancies → Can be represented as a circulant matrix in a compact way
- Circulant matrices can be diagonalized with the Discrete Fourier Transform → Reduces storage as well as computation

[Henriques et al., 2015]
Figures from Henriques et al. 2015. High-speed tracking with kernelized correlation filters

Related work - Kernelized correlation filters (KCF)



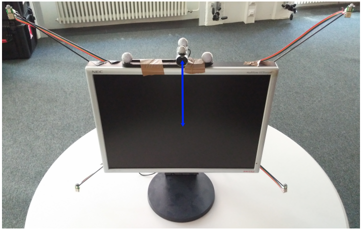
- Translated and scaled patches are riddled with redundancies → Can be represented as a circulant matrix in a compact way
- Circulant matrices can be diagonalized with the Discrete Fourier Transform → Reduces storage as well as computation
- The KCF tracker can be implemented with only a few lines of code.

[Henriques et al., 2015]

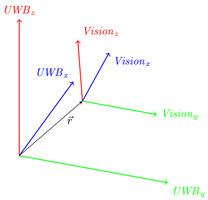
Figures from Henriques et al. 2015. High-speed tracking with kernelized correlation filters

Setup - Mounting

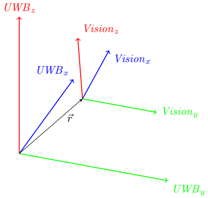
- Camera calibration
- UWB and camera mounting



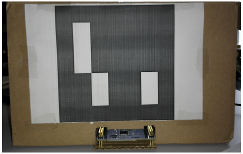
Setup - Matching the two coordinate systems



Setup - Matching the two coordinate systems

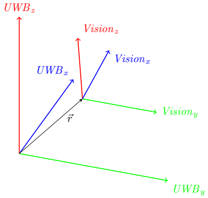


- ArUco [Garrido-Jurado et al., 2014]: Provides 3D position from detected markers:

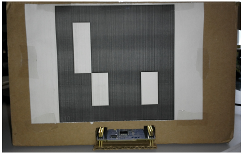


Setup - Matching the two coordinate systems

Semester Project
Andreas Ziegler
Motivation
Related work
UWB
KCF
Setup
Mounting
Matching
Transform
Fusing
Re-detection
Results
Conclusion
Conclusion
Outlook
Questions
References



- ArUco [Garrido-Jurado et al., 2014]: Provides 3D position from detected markers:



- Kabsch: Get rotation matrix **U** and translation vector $\vec{r}$ which results in the *lrms*

Setup - Transform between the coordinate systems

Transform a point (position or velocity):

$$\begin{bmatrix} x_{\mathsf{Vision}} \\ y_{\mathsf{Vision}} \\ z_{\mathsf{Vision}} \end{bmatrix} = \frac{1}{scale} \cdot \mathbf{U} \left(\begin{bmatrix} x_{\mathsf{UWB}} \\ y_{\mathsf{UWB}} \\ z_{\mathsf{UWB}} \end{bmatrix} - \vec{r} \right) \tag{1}$$

Transform the covariance matrix of the position and the velocity:

$$\mathbf{C}' = \frac{1}{scale^2} \mathbf{U}' \mathbf{C} \mathbf{U}'^T \tag{2}$$

where

$$\mathbf{U}' = \begin{bmatrix} \mathbf{U} & \mathbf{0} \\ \mathbf{0} & \mathbf{U} \end{bmatrix} \tag{3}$$

Fusing with an Extended Kalman Filter (EKF)

The states: $\vec{x} = [\vec{r}, \dot{\vec{r}}]^T$ with positon $\vec{r} \in \mathbb{R}^3$, velocity $\dot{\vec{r}} \in \mathbb{R}^3$
System model:

$$\vec{x}(k) = \begin{bmatrix} \mathbf{I}_3 & \Delta \mathbf{T} \\ \mathbf{0} & \mathbf{I}_3 \end{bmatrix} \vec{x}(k-1) + \vec{v}(k-1))$$

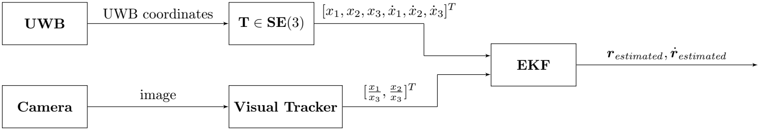
$$\vec{v}(k-1) \sim \mathcal{N}(\vec{0}, \mathbf{Q})$$

Fusing with an Extended Kalman Filter (EKF)

The states: $\vec{x} = [\vec{r}, \dot{\vec{r}}]^T$ with positon $\vec{r} \in \mathbb{R}^3$, velocity $\dot{\vec{r}} \in \mathbb{R}^3$
System model:

$$\vec{x}(k) = \begin{bmatrix} \mathbf{I}_3 & \Delta\mathbf{T} \\ \mathbf{0} & \mathbf{I}_3 \end{bmatrix} \vec{x}(k-1) + \vec{v}(k-1))$$

$$\vec{v}(k-1) \sim \mathcal{N}(\vec{0}, \mathbf{Q})$$



Fusing with an Extended Kalman Filter (EKF)

- Step 1:
  Make a prediction for the mean of the states $\hat{\vec{x}}_p(k)$ and the co-variance matrix $\mathbf{P}_p(k)$:
- Step 2:
  The information gained from the measurements is used to perform an a posteriori update, resulting in a updated mean of the states $\hat{\vec{x}}_m(k)$ and an updated co-variance matrix $\mathbf{P}_m(k)$.

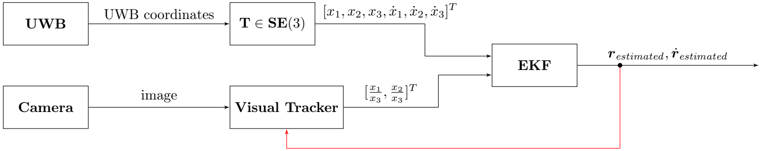
Fusing with an Extended Kalman Filter (EKF)

- Step 1:
  Make a prediction for the mean of the states $\hat{\vec{x}}_p(k)$ and the co-variance matrix $\mathbf{P}_p(k)$:
- Step 2:
  The information gained from the measurements is used to perform an a posteriori update, resulting in a updated mean of the states $\hat{\vec{x}}_m(k)$ and an updated co-variance matrix $\mathbf{P}_m(k)$.

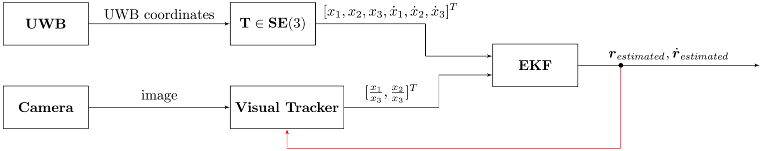
Fusing with an Extended Kalman Filter (EKF)

- Step 1:
  Make a prediction for the mean of the states $\hat{\vec{x}}_p(k)$ and the co-variance matrix $\mathbf{P}_p(k)$:
- Step 2:
  The information gained from the measurements is used to perform an a posteriori update, resulting in a updated mean of the states $\hat{\vec{x}}_m(k)$ and an updated co-variance matrix $\mathbf{P}_m(k)$.

Re-detection



Re-detection




```
while true do
    if target not detected then
        Adapt PSR and response threshold
        Set re-detection = true
    else
        if Object was detected in 5 consecutive frames then
            Reset PSR and response threshold
            Set re-detection flag = false
        end if
    end if
    if re-detection flag = true then
        Take 2D position from EKF
    end if
end while
```

Results

- The measurements of a motion detection system (VICON) serve as ground truth

Results

- The measurements of a motion detection system (VICON) serve as ground truth
- For comparison the *rmse* and the $rmse_{xy}$ of the EKF and of the UWB system were calculated and compared

Results

- The measurements of a motion detection system (VICON) serve as ground truth
- For comparison the *rmse* and the $rmse_{xy}$ of the EKF and of the UWB system were calculated and compared
- The accuracy of the EKF is at least doubled compared to the UWB system

Results

- The measurements of a motion detection system (VICON) serve as ground truth
- For comparison the *rmse* and the $rmse_{xy}$ of the EKF and of the UWB system were calculated and compared
- The accuracy of the EKF is at least doubled compared to the UWB system
- For the cases, where the visual tracker found the object

Results

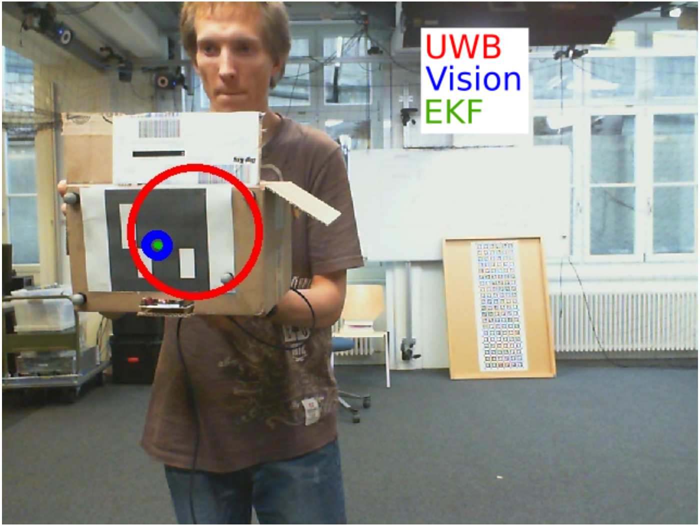
- The measurements of a motion detection system (VICON) serve as ground truth
- For comparison the *rmse* and the $rmse_{xy}$ of the EKF and of the UWB system were calculated and compared
- The accuracy of the EKF is at least doubled compared to the UWB system
- For the cases, where the visual tracker found the object
- Inaccuracies in the system are possible

Results

- The measurements of a motion detection system (VICON) serve as ground truth
- For comparison the *rmse* and the $rmse_{xy}$ of the EKF and of the UWB system were calculated and compared
- The accuracy of the EKF is at least doubled compared to the UWB system
- For the cases, where the visual tracker found the object
- Inaccuracies in the system are possible

See demo video!

Results - Demo



Conclusion/Limitation

Conclusion:

- The proposed method of fusing UWB and visual tracker impoved the accuracy
- The implemented re-detection mechanism performs well

Limitation:

- The EKF does not consists of an outlier-detection
- Parameter tuning required for the re-detection mechanism

Conclusion/Limitation

Conclusion:

- The proposed method of fusing UWB and visual tracker impoved the accuracy
- The implemented re-detection mechanism performs well

Limitation:

- The EKF does not consists of an outlier-detection
- Parameter tuning required for the re-detection mechanism

Conclusion/Limitation

Conclusion:

- The proposed method of fusing UWB and visual tracker impoved the accuracy
- The implemented re-detection mechanism performs well

Limitation:

- The EKF does not consists of an outlier-detection
- Parameter tuning required for the re-detection mechanism

ETH zürich

Conclusion/Limitation

Conclusion:

- The proposed method of fusing UWB and visual tracker impoved the accuracy
- The implemented re-detection mechanism performs well

Limitation:

- The EKF does not consists of an outlier-detection
- Parameter tuning required for the re-detection mechanism

Conclusion/Limitation

Conclusion:

- The proposed method of fusing UWB and visual tracker impoved the accuracy
- The implemented re-detection mechanism performs well

Limitation:

- The EKF does not consists of an outlier-detection
- Parameter tuning required for the re-detection mechanism

Conclusion/Limitation

Conclusion:

- The proposed method of fusing UWB and visual tracker impoved the accuracy
- The implemented re-detection mechanism performs well

Limitation:

- The EKF does not consists of an outlier-detection
- Parameter tuning required for the re-detection mechanism

Outlook

Outlook:

- Profiling/C++ implementation for usage with higher frequency
- More sophisticated re-detection
- Calibration of the UWB system with the help of ArUco
- Automatic target detection/learning
- Multi target tracking

Outlook

Outlook:

- Profiling/C++ implementation for usage with higher frequency
- More sophisticated re-detection
- Calibration of the UWB system with the help of ArUco
- Automatic target detection/learning
- Multi target tracking

Outlook

Outlook:

- Profiling/C++ implementation for usage with higher frequency
- More sophisticated re-detection
- Calibration of the UWB system with the help of ArUco
- Automatic target detection/learning
- Multi target tracking

Outlook

Outlook:

- Profiling/C++ implementation for usage with higher frequency
- More sophisticated re-detection
- Calibration of the UWB system with the help of ArUco
- Automatic target detection/learning
- Multi target tracking

Outlook

Outlook:

- Profiling/C++ implementation for usage with higher frequency
- More sophisticated re-detection
- Calibration of the UWB system with the help of ArUco
- Automatic target detection/learning
- Multi target tracking

Outlook

Outlook:

- Profiling/C++ implementation for usage with higher frequency
- More sophisticated re-detection
- Calibration of the UWB system with the help of ArUco
- Automatic target detection/learning
- Multi target tracking

Questions

References

Garrido-Jurado, S., noz Salinas, R. M., Madrid-Cuevas, F., and Marín-Jiménez, M. (2014).
Automatic generation and detection of highly reliable fiducial markers under occlusion.
Pattern Recognition, 47(6):2280 – 2292.

Henriques, J. F., Caseiro, R., Martins, P., and Batista, J. (2015).
High-speed tracking with kernelized correlation filters.
Pattern Analysis and Machine Intelligence, IEEE Transactions on.

Tobias Naegeli, Benjamin Hepp, O. H. (2016).
Omni-directional person tracking on a flying robot using occlusion-robust ultra-wideband signals.
IROS 2016.