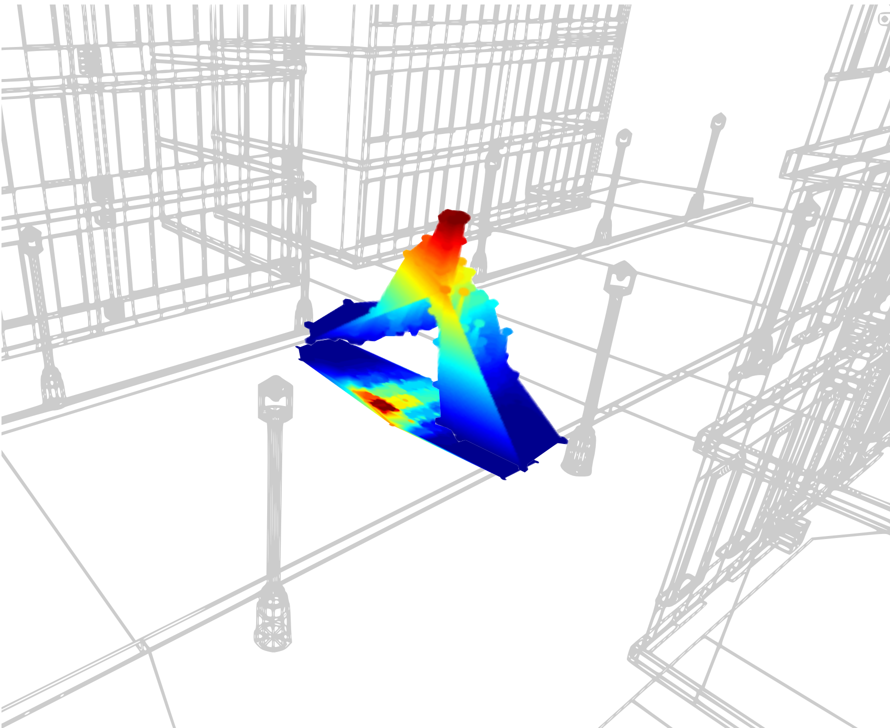
University of Stuttgart
Institute for Photogrammetry

Qualification and accuracy analysis of modern vehicle localization processes with the help of the entropy



Master thesis in the course of studies

Geodesy and Geoinformatics

at the University of Stuttgart

Peter Hurt

Stuttgart, December 2017

Prüfer: Prof. Dr.-Ing. Norbert Haala
Universität Stuttgart

Betreuer: Frank Schuster
Daimler AG

Introduction:

Autonomous driving, and the accompanying automation of vehicles, in traffic situations is currently a hot topic, which is becoming more and more broadly discussed in the media. The upcoming approaches of the big automotive manufacturers are designed to increase safety and comfort. Daimler AG is a global player in this business because they push the boundaries of innovation by using the knowledge gained from the past experiences and by understanding the need for safety moving forward. However, considering safety and comfort alone is not enough; the accuracy and safety of the process are also critical topics in autonomous driving.

In most studies, special attention is given to the accuracy of the sensors and how precisely they can measure the near and far range environments of the vehicle to protect outside traffic participants, pedestrians and property from harm. Nevertheless, one of the biggest components of autonomous driving is the localization of the vehicle. At first it is most important to know where the vehicle is, then it can automatically decide what maneuver it will do next. This work takes a conscious look at the accuracy of the vehicle localization and how such a process can be qualified.

To do this, the author chose a comparison method based on a ground truth position; using the residuals to the true position, a significance test on the standard deviation of the pose extraction, and the integrity containing the protection and alert limit as comparison criteria. Additionally a fourth and new argument in this topic is introduced and tested with which one is able to qualify the localization algorithm itself, this is known as the entropy.

Localization:

Calculation of the pose x_t of a vehicle related to a given map by measurements and movements of the vehicle. The coordinate systems and state definitions within this work are given in the DIN 7000 norm.

Test concept:

The basic idea of the qualification and error-propagation in this work is to compare two measurements with each other. In other words, the key concept is to get comparison values by using a reference measurement.

In summary, the algorithm's comparison parameters to qualify the automotive localization will be

1. **Residuals** to the reference localization. Acceptance thresholds $\varepsilon_{\Delta x_V}$ and $\varepsilon_{\Delta y_V}$ must be defined. The residuals can either be calculated in the vehicle or the global coordinate frame. For the use case of this work, it makes more sense to calculate the residuals in the lateral and longitudinal direction which are defined in the vehicle coordinate frame.

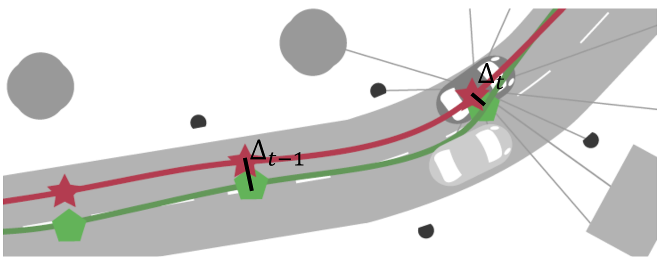


Figure 1: Residuals.

2. **Statistical two-sided significance test** on σ_{x_V} and σ_{y_V} of the pose extraction which tests to see if the automotive pose extraction is significantly less accurate. The V refers to the vehicle

coordinate system DIN 7000. The significance test must be made on the variances in the vehicle frame. Only then will it carry the information as to whether or not the vehicle is significantly wrong in the lateral and / or longitudinal direction.

Hypothesis: $H_0 : \sigma_2^2 = \sigma_1^2$, $H_1 : \sigma_2^2 > \sigma_1^2$
Test value: $F = \frac{\sigma_2^2}{\sigma_1^2}$, mit $F > 1$
Quantil: $F_{f_1, f_2, 1-\frac{\alpha}{2}}$
Testdecision: $F < F_{f_1, f_2, 1-\frac{\alpha}{2}} \rightarrow H_0$ accepted

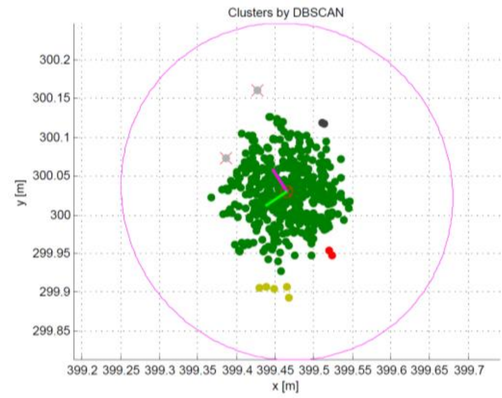


Figure 2: Discrete pseudo density function at state t. Green dots represent the particles on which the pose is extracted.

3. **Entropy** comparison. It will be compared stepwise. If the automotive entropy overgrows the reference entropy in the particular time step, it gets rejected.
The entropy is defined after Shannon (1948) as the gainable information of a pseudo density function, and is written as $H(\bar{\chi}_t) = -\sum_{i=1}^{N} p_t(x_i) \cdot \log(p_t(x_i))$, with N particles.

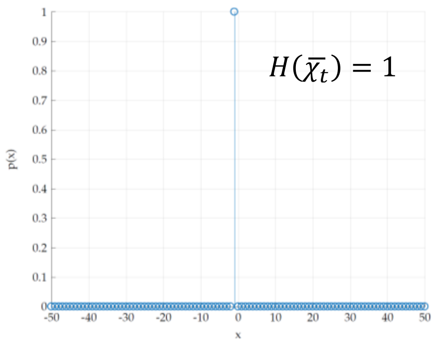


Figure 3: Dirac. Maximum information.

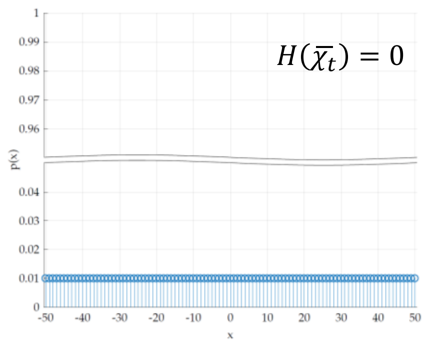


Figure 4: Uniform distribution. No information.

The PDF can be subdivided in lateral and longitudinal direction which makes it possible to investigate the information gain separately as shown in figure 5.

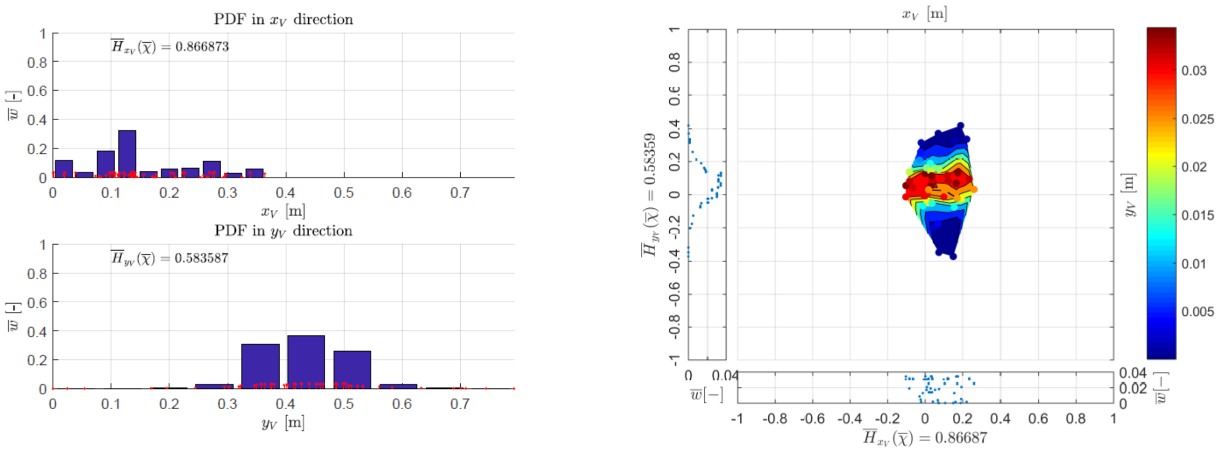


Figure 5: Split entropy in x_V and y_V.

4. Comparing the **integrity** of both localizations. The integrity is also calculated in the vehicle frame. The integrity examines the reliability of a localization by a defined protection limit. This protection limit is calculated by the variance of the pseudo density function of the current vehicle pose, or the range of the particles which discretize this function. The alert limit tells what errors are excepted for a current use case. And the residuals are the real errors, which are usually not known without having a reference.
The integrity is subdivided in *System Available (SA), System Unavailable (SU), Misleading information (MI)* and *Hazardously Misleading Information (HMI).*

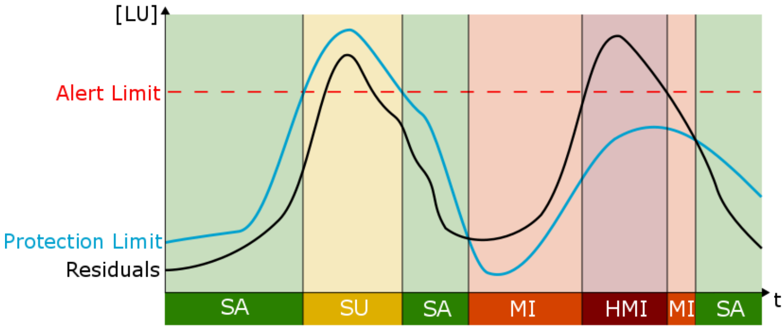


Figure 6: Integrity.

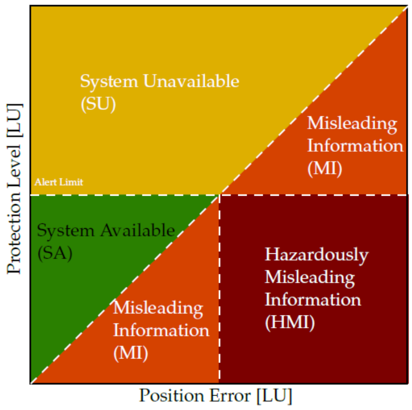
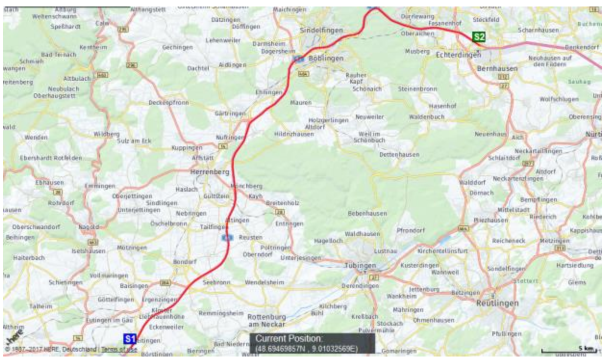


Figure 7: Stanford-ESA integrity diagram (Wörner 2016).

The HMI are the crucial situations, where the protection limit does not secure the residuals and the alert limit is violated by these residuals. In these situations the localization is not reliable. All four situations can be seen in figure 6. Another representation for measurements can be done in the Stanford-ESA integrity diagram in figure 7, where the region are the subdivided situations.

Evaluation and conclusion:

These criteria are evaluated on a dataset gathered during several test drives on the German autobahn A81 and A8 between *Horb am Neckar* and *Stuttgart airport* (figure 8). It is thirty minutes long and includes 28 288 estimated poses.



The reference measurement was manipulated in so far, that the inertial measurement unit contained wrong covariance matrices. Still it is possible to qualify a localization with the mentioned parameters.

The introduced way to qualify and to examine a localization proved itself to be able to present the weaknesses and strengths of a localization process and to outline the reasons for that. A closed loop study within this work shows, in a controlled environment, how a Monte Carlo localization behaves under certain circumstances and how a direction change influences the estimated particles at each time step.

The real dataset, yet with a manipulated reference measurement device, was qualified as well. With the knowledge of incorrect reference data, the focus was split into the initial idea of comparison and in finding a way to qualify a localization without reference information, but with the help of the newly introduced localization qualification argument, the entropy. It turned out that the entropy is able to be a stand alone argument which does not have to be compared and that it can be used to improve the chosen protection limit in certain situations by giving more information about the PDF of the pose extraction on which the protection limit is based.

Future Prospect:

For test issues, the introduced qualification with the four parameters: the residuals, the significance, the entropy and the integrity, work and qualify very well. A perfect application could be the qualification of two different sensor sets compared to a reference like an IMU. The algorithm would give two lucid overviews of both qualifications, on which one could easily decide which sensor set was better. Another strength of this algorithm could be to identify incorrectly calibrated measurement devices, for example, automotive sensor equipped cars on a test track. Here, every vehicle should at least achieve more or less the same localization result. In the past, the values were compared by hand, without giving any further information about where exactly the localization failed and why. This work, and the accompanying qualification methods, give a solution to show these spots directly on the map with the percentages of failures in vehicle, as well as in global coordinates. It includes a full error calculation of the estimated positions. The entropy helps to understand the particle filter and interpret along the prediction of the particles.

The author sees the entropy as a potential argument in future qualifications of vehicle localizations. Especially because it is laid out for any probabilistic localization algorithm and can therefore be applied to future computationally low cost algorithms. The entropy complements the present qualification possibilities. Henceforward, it is not only possible to qualify the reliability (integrity), the correctness (residuals Δ) and the safety of the pose extraction (significance of the standard deviation σ), but to also qualify the algorithm by the entropy $\overline{H}$ with which all process parameters are covered.

Bibliography:

- Abmessungen der neuen E-Klasse (2017), **URL:** https://m.mercedes-benz.ch.
- DIN 7000 (2013), *Straßenfahrzeuge - Fahrzeugdynamik und Fahrverhalten - Begriffe (ISO 8855:2011 DIN 7000).*
- Here WeGo (2017), **URL:** https://wego.here.com/.
- Matlab (2017).
- Niemeier, W. (2008), *Ausgleichungsrechnung*, Vol. 2, Walter de Gruyter.
- Schubert, E., Sander, J., Ester, M. und Xu, X. (2017), *DBSCAN revisited: Why and how you should (still) use dbscan.*
- Shannon, C. (1948), *A mathematical theory of communication.*
- Stübler, M. (2017), *Abschlussbericht AB-LOC: Hochgenaue Lokalisierung und statische Umgebungspräsentation für die Autobahn AB-LOC.*
- Technische Dokumentation ADMA 3.0 (2015), **URL**: www.genesys-adma.de.
- Thrun, S., Burgard, W. and Fox, D. (2006), *Probabilistic Robotics*, The MIT Press.
- Winner, H. (2016), *Handbook of Driver Assitance Systems: Basic Information, Components and Systems for Active Safety and Comfort*, Springer International Publishing.

- Wörner, M., Schuster, F., Dölitzscher, F., Keller, C., G., Haueis, M. and Dietmayer, K. (2016) *Integrity for autonomous driving: A survey.*