Self-Generated Road Status Maps based on Vehicular Ad Hoc Communication

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Abstract— **The instantaneous knowledge of road course, condition and traffic situation ahead of the vehicle is of major value for all kinds of driver assistance systems. In this paper, a method for self-generating an up-to-date road status map of the local area onboard a driving vehicle is presented. A commercial digital road map is not required, since vehicles generate the map based upon satellite based positioning (e.g. GPS) and vehicular ad hoc communication.**

The vehicles record Geo-Reference Points (GRP) for the driven track, which – besides their geographic location – also include dynamic information recorded by the vehicle, such as road condition, temperature and traffic status. A number of GRPs is combined to form a Geo-Reference List (GRL) which is broadcasted using vehicular ad hoc communication. By integrating received GRLs in the local data basis, a dynamic road status map of the local area can be created. The required market penetration is low (<5%) since only occasional communication with a vehicle on the opposite lane is required. In addition to the proposed scheme for self-generated maps, the paper presents first simulative and experimental results.

I. Introduction

The application of wireless ad hoc communication in the automotive sector is an attractive candidate for future driver assistance systems. By allowing direct communication from vehicle to vehicle and the forwarding of received information by intermediate vehicles, a Vehicular Ad Hoc Network (VANET) can be formed which does not require any fixed infrastructure [2]. Based on VANET communication, many applications can be realized – ranging from safety applications such as hazard and emergency warning systems [1], [5] to comfort applications like the Self-Organizing Traffic Information System (SOTIS) [4]. In general, safety applications require a larger market penetration than comfort applications, which are feasible even if only <5% of all vehicles are equipped with the ad hoc communication system [4].

Conventional digital road maps are usually preinstalled in the navigation system onboard the vehicle and updated in relatively large time intervals, e.g. by distributing a CD-ROM with updated map data. Storing large digital road maps on board the vehicle imposes costs for licensing map data and computing resources. Furthermore, static maps cannot include dynamic information such as the road status.

In this paper, an approach is presented which allows vehicles to generate a road status map for the local area based on measurements received from other vehicles. The generated digital map can complement an existing digital map but does not depend on it. In addition to geographic information, it includes dynamic information measured by vehicles which characterizes the state of the road.

Potential applications for self-generated maps are manifold: Driver assistance and safety systems such as the Electronic Stability Program (ESP) can profit from the additional geographic and dynamic information on the course and status of the road ahead. For example, information on low temperature/ice on a GRP ahead can be used to warn the driver of potentially hazardous situations. Information currently not included in commercial maps but measurable by other vehicles can be obtained, such as height, mean velocity, curvature, etc. The generated digital map can also significantly improve the data dissemination in the VANET, e.g. for position based routing [3] or road segment oriented broadcast [4].

For the proposed scheme, only the following two components are required:

1) ad hoc capable air interface
2) satellite positioning system (e.g. GPS or Galileo)

The system is completely independent of conventional digital road maps and fixed infrastructure such as base stations or sensors deployed at the roadside. An additional advantage is that the required VANET penetration for typical highway situations is low, it is expected (based on the observations in [4]) that less than 5% of the vehicles need to be equipped.

The paper is organized as follows: Section II introduces the proposed scheme for generating maps based on vehicular communication, including the creation of map data to be transmitted (Section II-A and Section II-B) and the integration of received information (Section II-C). In Section III, first simulative and experimental results are presented. The approach is targeted at a highway/main road scenario – the performance in city situations has not been investigated. Section IV concludes the paper with a short summary.

II. SELF-GENERATED MAPS

The basic idea of the presented scheme for self-generated road maps is to exchange information between vehicles which describes the driven track. By combining the information obtained from all vehicles in transmission range, a digital map of the local area is created. Since a vehicle continuously transmits parts of its own locally generated map, track information is exchanged over multiple hops and the generated road map covers a distance much larger than the transmission range of an individual vehicle. This form of data dissemination is similar to SOTIS [4] and thus the scheme requires a similar low market penetration.

Information on the driven track is recorded in form of Geo-Reference Points (GRP) which describe the condition at a specific location. Multiple GRPs for a road are combined to form a Geo-Reference List (GRL). Since a GRL describes a connected track segment, it can be efficiently encoded and broadcasted to vehicles nearby.

In particular, the following steps are performed by each vehicle periodically: 1) generate GRPs and insert in local map, 2) create, encode and broadcast GRLs, 3) integrate received GRLs in own local map.

A. Generating the Geo-Reference List (GRL)

For generating GRPs in the Geo-Reference List (GRL), a global geodetic reference grid is used. It serves three purposes:

- unambiguous representation of a road by GRPs (within positioning inaccuracy D_{acc}),
- avoiding positioning error propagation when integrating received GRPs (Sec. II-C),
- restricting number of created GRPs for a road.

The reference grid is determined by the grid distance[1] D_{grid} and the point of origin. Such a grid is easily obtained by applying a transverse mercator projection, e.g. the Universal Transverse Mercator (UTM) or Gauss-Krüger coordinate system, to the geographic coordinates obtained via satellite navigation system.[2] The parameter D_{grid} determines the tradeoff between accuracy and required data rate: A smaller D_{grid} leads to a higher accuracy but also a higher data rate. Furthermore, D_{grid} should be larger than the expected position inaccuracy D_{acc} of the positioning system.

As depicted in Fig. 1, the road is now "sampled" with the resolution of the reference grid, by applying the following procedure: The vehicle continuously monitors its position. Whenever its track intersects with a line of the geo-reference grid, a GRP is generated with the following exception: In order to avoid continuous generation of GRPs separated by only small distances, a GRP is *not* generated if the direction of movement differs from the direction of the respective line of the geo-reference grid by less than $\frac{\alpha}{2}$. For example, only horizontal GRPs (GRPs on horizontal lines of the grid) are generated if the vehicle moves in a direction of $180° \pm \frac{\alpha}{2}$. Fig. 2 illustrates the type of GRP generated depending on the direction of movement.

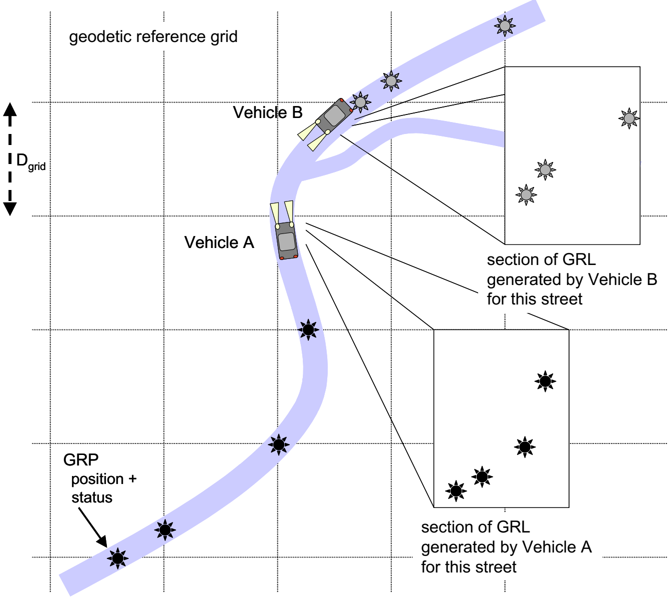

Fig. 1. Example for generated Geo-Reference Points (GRP) and Geo-Reference List (GRL).

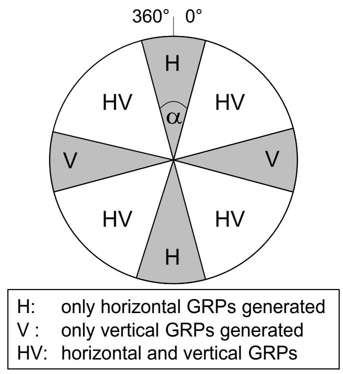

Fig. 2. Types of GRPs depending on angle of movement.

For each new GRP, the vehicle checks if it can be matched on an existing GRP on its local map. In case of a match within the assumed accuracy of the positioning, the existing GRP is updated with the currently sensed information – otherwise, the GRP is added. When inserting a new GRP, the vehicle first tries to append it to an existing road on its local map. This is only possible, if the distance to one of the existing GRPs is less than $\sqrt{2}D_{grid}$. Otherwise, it creates a new road with the GRP as starting point.

Multiple consecutive GRPs for a road form a GRL, which is the unit in which GRPs are broadcasted to vehicles. Periodically, the vehicle selects a part of its

[1] distance between two lines of the grid

[2] In the following, we assume GPS coordinates obtained in the World Geodetic System 1984 (WGS84) and use Gauss-Krüger coordinates for the geo-reference grid. However, the same approach can be applied using UTM and other coordinate systems.

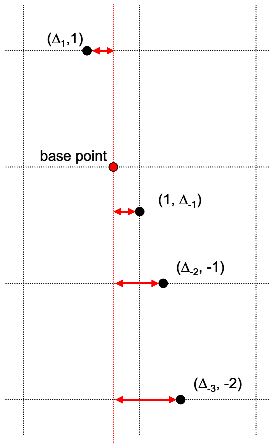

Fig. 3. Efficient encoding of geo-reference lists.

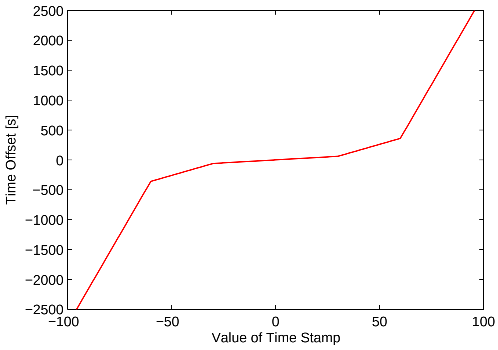

Fig. 4. Encoding of time offset in time stamp byte.

local digital map for transmission.[3] It creates a GRL, and broadcasts it to all vehicles currently in transmission range. This GRL can consist of GRPs generated by the vehicle itself as well as GRPs that were generated by other vehicles. In this way, a dissemination of GRPs over multiple hops is achieved.

B. *Efficient Encoding of a GRL*

The main advantage of GRLs is that they allow an efficient encoding of the geographic information since the GRPs in a GRL are colocated. This aspect is of particular importance since the available data rates in a VANET are relatively low and expected to be shared by many applications.

A GRL consisting of N GRPs is composed of two parts (Fig. 3):

1) a base point, which is an arbitrary GRP (e.g. at the center) of the GRL,
2) and N GRP offset specifications which describe the respective offset of a GRP compared to the base point. Since the base point as well as all GRPs are located on at least one line of the reference grid, a GRP location can be specified by a coordinate offset for one coordinate and an integer grid offset for the other. For the lowest GRP in Fig. 3, the non-grid offset would be the distance D_{-3} indicated by the arrow and a grid offset of -2.

Example: Required Overhead

As an example for the required overhead, the values from our experimental implementation are considered: For the GRL base point, the absolute coordinates need to be encoded, as well as a base time stamp value (22 bytes in total). Afterwards, each GRP of the GRL is encoded by the following offset values:

- 1-bit flag indicating a vertical or horizontal GRP
- 15-bit integer specifying the non-grid coordinate
- 1 byte grid offset for grid coordinate
- 1 byte data offset per direction of the road
- 1 byte time stamp offset per direction of the road

In order to store a time stamp offset covering a large range in a single byte, a simple companding method is used as shown in Fig. 4. It reflects the fact that for a GRL the time stamps usually differ by only a few seconds, the accuracy should be higher for small time offsets. In this example, an encoded GRL requires $22+7N$ bytes, which means that in a single 1400 byte data packet, 196 GRPs can be broadcasted.

C. *Integrating a Received GRL*

Whenever a vehicle receives a broadcasted GRL, the relative positions of the GRPs are first converted back to absolute positions. Afterwards, each GRP is matched on the existing map. [4] If a matching position at a distance less than or equal to the assumed positioning inaccuracy D_{acc} and with similar direction is found, the GRP is already known. The data values of the received GRP are used to update the existing map for each direction where the time stamp is newer than the time stamp in the existing map.[5]

Otherwise, the received GRP needs to be added to the vehicle's local map. If an existing GRP is within a distance less than or equal to $\sqrt{2}D_{\text{grid}}$ and is also the start/end point of an existing road in a similar direction, the respective road is extended with the new GRP. If this is not the case, the GRP is added as the starting point of a new road. Pseudo-code for this integration process is shown in Alg. 1. It also illustrates an important property of the global geo-reference grid: a propagation of positioning errors is avoided since data values for GRPs within D_{acc} are matched to the same local GRP.

The matching procedure here does not consider the side of the road on which a GRP is located. This in turn limits the achievable accuracy D_{acc}, since for the

[3] The scheduling algorithm for determining which GRPs to broadcast is out of the scope of this paper. Usually, it will be based on the distance to the local position and the time at which a GRP was last transmitted/received.

[4] The direction needs to be taken into account to avoid matching to an incorrect road, e.g. in intersection situations. Therefore, matching only occurs on roads in the same direction as the GRL at the GRP.

[5] similar to the procedure for updating road segment values in [4]

Algorithm 1: Pseudo-code for integration of GRL.

```
Data: Received GRL
Result: Updated local map
Convert GRPs of GRL to absolute coordinates;
foreach GRP in GRL do
    γ ← Direction(previousGRP, GRP, nextGRP);
    matched ← MapMatchedPosition(GRP,γ);
    if Distance(matched, GRP) ⩽ D_acc then
        update data values for matched with GRP;
    else
        if road start/end GRP within distance √2·D_grid then
            extend existing road with GRP;
        else
            create new road with GRP;
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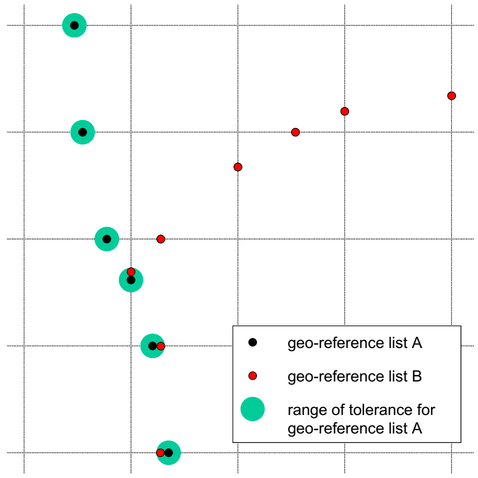


Fig. 5. Comparing two different geo-reference lists.

two directions, GRPs with an offset of about half of the road width will be observed. Although heuristics can be integrated which are aware of this fact, for simplicity they were not applied in the following.

D. Distinguishing Different Roads

Since transmitter and receiver of a GRL can have traveled on different sequences of roads, their local assignment of GRPs to roads is not necessarily identical. Therefore, the receiver must be able to distinguish different roads in a received GRL. A simple approach is illustrated in Fig. 5: Each GRP has a specific "range of tolerance" D_{acc}. As long as GRPs are within this range, they are considered to be part of the same road. In the example, the lower three GRPs of the two GRLs belong to the same road, the remaining ones differ.

E. Merging Roads

Depending on the order in which GRPs are received, a single road can be fragmented in the local map of the vehicle. E.g., if two disconnected parts of a road are received for an unknown road, the vehicle will create two separate road entries in its local map since at that time it is unknown if the parts are connected. Since for some applications the knowledge of roads is beneficial [4], fragmentation needs to be limited. This could either be done by actively searching for connected roads in the local map periodically or – as it is currently implemented – by merging two roads whenever a vehicle traverses the connection of two roads (directly moving from the end/start GRP of one road to the end/start GRP of another road).

TABLE I
PARAMETERS IN SIMULATIVE AND EXPERIMENTAL EVALUATION

Parameter	Value
grid distance D_{grid}	100.0 m
assumed position accuracy D_{acc}	30.0 m
angle α for H/V GRP	30.0 °
transmitted GRLs	0.5/s
data rate	approx. 500 byte/s
RMSE for GPS error model (sim.)	0.0-20.0 m

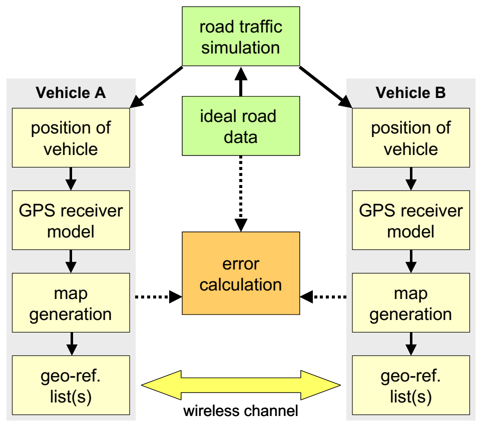


Fig. 6. Structure of simulative performance evaluation.

III. Performance Evaluation

In the following, first simulative and experimental results for the scheme introduced in Section II are briefly presented. The parameters were chosen to be identical, as listed in Table I.

A. Simulation Results

The structure for the simulative evaluation is shown in Fig. 6: Based on digital street data read from a commercial vector map, a road pattern is created in the simulator. It is used to calculate the true simulated position of the vehicle based on a simple road traffic simulation. A random positioning error (see appendix) is added and the resulting position is reported to the self-generating map implementation.[6] The generated map is then compared to the ideal road data for each position of the vehicle. The simulation scenario considers an approx. 35 km highway segment of the A250 (Lüneburg ↔ Hamburg) in Germany.

[6]Linear interpolation between GRPs. More complex interpolation schemes are advantageous but out of the scope of this paper.

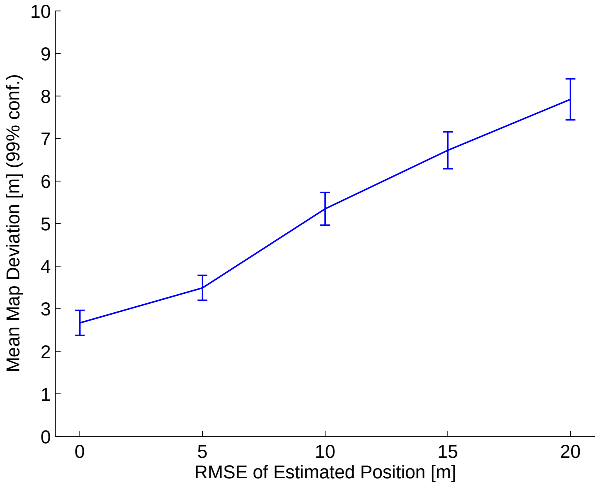


Fig. 7. Mean deviation of generated map compared to ideal map when the RMSE of the position estimate increases.

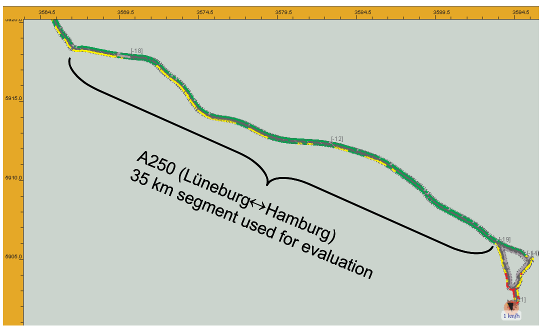


Fig. 8. Generated map in experiments.

Fig. 7 shows the mean deviation of the generated map compared to the ideal map, including the 99% confidence intervals. When the Root-Mean Squared Error (RMSE, corresponding to $\sqrt{2}\sigma_\mathrm{d}$ in the GPS error model in appendix) increases, a corresponding increase in deviation is observed. However, even if the positioning error is zero, a mean deviation of $\approx$2.7 m is observed. This is explained by the fact that the number of GRPs is limited by the grid distance D_grid and GRP accuracy is influenced by the encoding for transmitted GRLs (Section II-B).

B. Experimental Results

For the experimental evaluation, the map deviation cannot be easily calculated since the "true" positions are unknown. Therefore, as an indicator the histograms of the observed distances in the integration process (Section II-C) are shown in Fig. 9. The results were measured at the same highway segment of the A250 that was used in the previous section (Fig. 8). In the comparison of GRPs generated for the same side of the road (Fig. 9(a)), the matching distance exceeds 20 m with a probability of less than 0.1. If GRPs for the opposite direction are considered, a bias of about 15 m can be observed in the matching distance. This is approximately the distance from one side to the other (assumed width of lane $\approx$3.75 m, road median $\approx$4 m). It indicates that the integration of heuristics to estimate and subtract this constant bias, which occurs due to positions obtained for different sides of the road, could improve the accuracy.

In the experiments, two different consumer class GPS receivers were used (Rikaline X5 and Holux GM 200). Interestingly, the results using different GPS receivers (9(c)) show a smaller variation than those with two identical receivers (9(b)). This might be due to different measurement conditions since the results were obtained in separate test runs.

IV. Conclusions

Based on vehicular ad hoc communication and satellite positioning, a self-generated road status map can be obtained for the local area of a vehicle. The self-generated map allows a vehicle to predict the course and conditions ahead. It is valuable for driver assistance systems as well as for improving data dissemination in a VANET. First simulative and experimental results illustrate that the presented scheme can be successfully applied in vehicular ad hoc networks with limited data rates and low market penetration. Since no commercial digital map data is required, the approach can also be applied in low-cost systems.

Appendix: Simple Positioning Error Model for Simulations

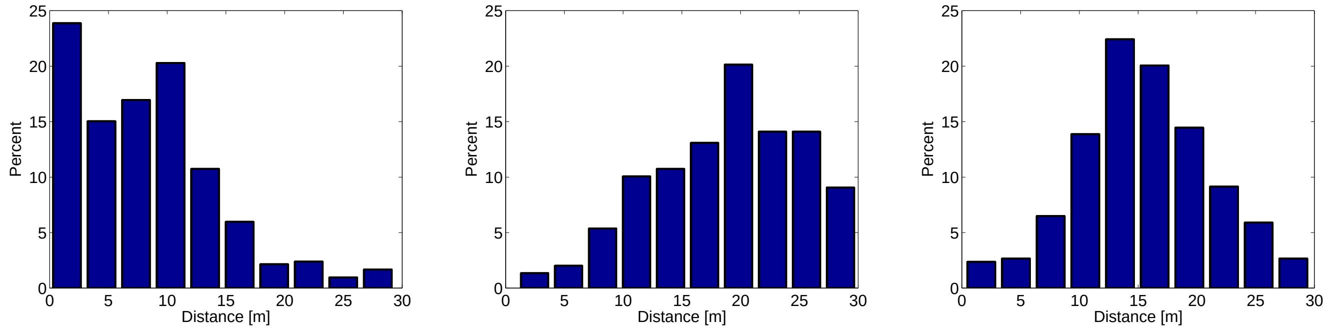
Positioning errors of GPS receivers are introduced by various factors such as ionospheric/tropospheric effects, inaccuracies in ephemeris data and of satellite clocks, receiver noise and multipath effects. Accurate modeling of GPS errors is therefore a challenging task, and various complex models exist. However, in this paper only a very simple GPS error model is used, since it is assumed that in a real system GPS data can be augmented by vehicle dynamics data (e.g. read from the in-vehicle CAN bus). Therefore, a more detailed GPS error model would still not represent the expected positioning error accurately.

Thus, for simplicity a 2D-normal distributed error is assumed which is unbiased and has the same variance σ_d^2 for both spatial directions. This leads to a Rayleigh distributed error with an expected value of $\sigma_d\sqrt{\frac{2}{\pi}}$. As illustrated in Fig. 10, this is only a rough approximation.

With this simple error model, the positions "jump" since the correlation in time is not taken into account. As in a GPS receiver, the obtained positions are therefore filtered. A simple Kalman filter is used, in which the current state of the vehicle is represented by the following state vector

$$X(n) = \begin{bmatrix} p_x(n) \\ v_x(n) \\ p_y(n) \\ v_y(n) \end{bmatrix} \tag{1}$$

where p_x and p_y are the position x- and y-coordinates and v_x and v_y are the corresponding velocities. The state



(a) same direction, different GPS receiver (b) opposite direction, same GPS receiver (c) opposite direction, different GPS receiver

Fig. 9. Histograms of measured distances when matching to the same geo-reference point.

transition matrix Φ is given by

$$\Phi = \begin{bmatrix} 1 & T & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & T \\ 0 & 0 & 0 & 1 \end{bmatrix}. \tag{2}$$

Here, the constant T is the time between two state transitions. The changes in direction and velocity of the vehicle movement are modeled by the random process noise $\mathbf{U}(n)$:

$$\mathbf{U}(n) = \begin{bmatrix} 0 \\ u_x(n) \\ 0 \\ u_y(n) \end{bmatrix} \tag{3}$$

For simplicity, it is assumed that changes in velocity occur only right before a time step and that their influence on the position is reflected beginning a the next time step. The only measurements used as input for the filter are the currently measured positions. Therefore, the observation matrix is

$$M = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}. \tag{4}$$

and the observed measurement $\mathbf{Y}(n)$ is the determined by the true system state and the observation error $\mathbf{N}(n)$.

$$\mathbf{Y}(n) = \mathbf{MX}(n) + \mathbf{N}(n) \tag{5}$$

Now the only additional parameters of the Kalman filter, which need to be defined, are the covariance matrix $\mathbf{R}(n)$ of the measurement vector and the covariance matrix $\mathbf{Q}(n)$ of the system dynamics model noise vector. Due to the simplifying assumption that the components of $\mathbf{Y}(n)$ are independent, they are defined based on the variance σ_R of the measurement of a component and the variance $\sigma_a$of the velocity changes.

$$R = \begin{bmatrix} \sigma_R^2 & 0 \\ 0 & \sigma_R^2 \end{bmatrix}. \tag{6}$$

$$Q = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & \sigma_a^2 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \sigma_a^2 \end{bmatrix}. \tag{7}$$

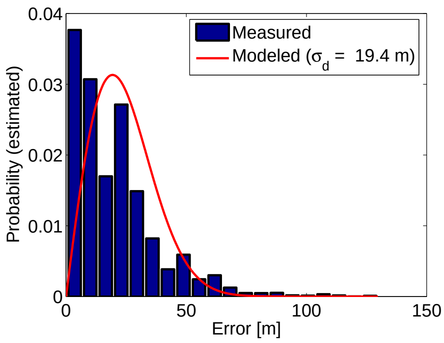


Fig. 10. Comparison of modeled and measured position error for a situation with relatively bad GPS reception.

With these definitions, the standard Kalman estimation procedure can be applied.

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