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# Report

## Analysing automatically captured traffic sign data from the Vionice system

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**ABSTRACT**

The Finnish startup company Vionice has developed a system for automatically capturing data about road signs. The system uses mobile phones with camera and GPS placed in the windscreen of NPRA vehicles, and computer vision and machine learning algorithms to recognize and position signs. This system has been used to capture data about all speed limit and road works signs that the vehicles are passing, and the results have been analysed.

The analysis shows that the system looks very promising, but since the actual sign locations from NVDB, which are used to validate the system, are shown to be inaccurate, the system still lacks a solid validation.

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# Document history

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| 0.9 | 2017-05-30 | Initial version. Adapting contents from the memo from 2016, and adding an analysis of data from Molde as appendix.<br>Sent to client for comments. |

# Table of contents

## Summary

Vionice is a Finnish startup company founded as a result of a research project conducted by the Finnish Transport Agency and Lappeenranta University of Technology in 2014. They have developed a smart phone app that records video using the phone camera, adds information from various sensors in the phone, and uploads this to Vionice's servers, where computer vision and machine learning algorithms are used to detect and recognize signs.

The Norwegian Public Roads Administration (NPRA) needs to have an always up-to-date inventory of every object that is placed on or around the roads they are responsible for. The regular way of doing this is to have employees driving around with complicated tools, measuring exact positions and assessing the conditions of the objects.

The Vionice system attempts to automate parts of this process by using mobile phones with camera and GPS placed in the windscreen of NPRA vehicles. Data captured using this system is analysed in this report. The analysis shows that the system looks very promising, but since the actual sign locations from NVDB, which are used to validate the system, are shown to be inaccurate, the system still lacks a solid validation.

# 1 Background

The Norwegian Public Roads Administration (NPRA) needs to have an always up-to-date inventory of every object that is placed on or around the roads they are responsible for. The regular way of doing this is to have employees driving around with complicated tools, measuring exact positions and assessing the conditions of the objects.

The system analysed in this project will attempt to automate parts of this process, by using mobile phones with camera and GPS placed in the windscreen of vehicles, and computer vision and machine learning algorithms to recognize and position all speed limit and road works signs that the vehicles are passing. Such a system, if successful, will be able to greatly increase the efficiency of the data capture, since it can be done automatically from all vehicles that are driving around on a daily basis.

# 2 Method

To collect data, the Viominer app was installed on five smart phones which were placed in the windscreen of NPRA vehicles. These phones will then record everything the vehicle passes, and send the recording to Vionice's servers.

The exact method behind the sign extraction and recognizing on Vionice's servers are unknown, and will be considered a blackbox.

After Vionice has processed the recordings, the NPRA and SINTEF can see the detected signs in a web interface, and extract data as CSV files. The NVDB is a similar web interface that presents (among other road details) all road signs. Data about the detected signs were extracted from the Vionice web interface, while data about actual signs were extracted from the NVDB.

These two datasets were then merged by comparing the GPS locations of all sign detections to the GPS locations of the actual signs, and the results were grouped by closeness in location and whether the Vionice system had recognized the sign correctly. In cases where Vionice and NVDB disagrees, the original recordings were manually checked to find out if it was a detection error or an error in NVDB.

Finally, in cases where the signs were correctly recognized, the location accuracy of the Vionice system was assessed by calculating the distances between the detection and the actual sign.

# 3 Vionice

Vionice is a Finnish startup company founded as a result of a research project conducted by the Finnish Transport Agency and Lappeenranta University of Technology in 2014. They have developed a smart phone app that records video using the phone camera, adds information from various sensors in the phone, and uploads this to Vionice's servers. On the servers, they utilize computer vision and machine learning techniques to detect and recognize road side objects. The system can detect multiple kinds of objects, for example traffic signs, road paintings or potholes.

# 4 Vionice's system

The system utilized in this project consists of the smart phone app (Viominer), the computer vision and machine learning algorithms on the servers, and the web page. This section will explain the app and the web page.

## 4.1 The app

The smart phone app is easily installed on any phone, but to ensure consistent results with the system, Vionice recommended that we used one specific phone: the Huawei Honor 6. This was because they had experience with this phone, and knew the necessary details about the camera on the phone.

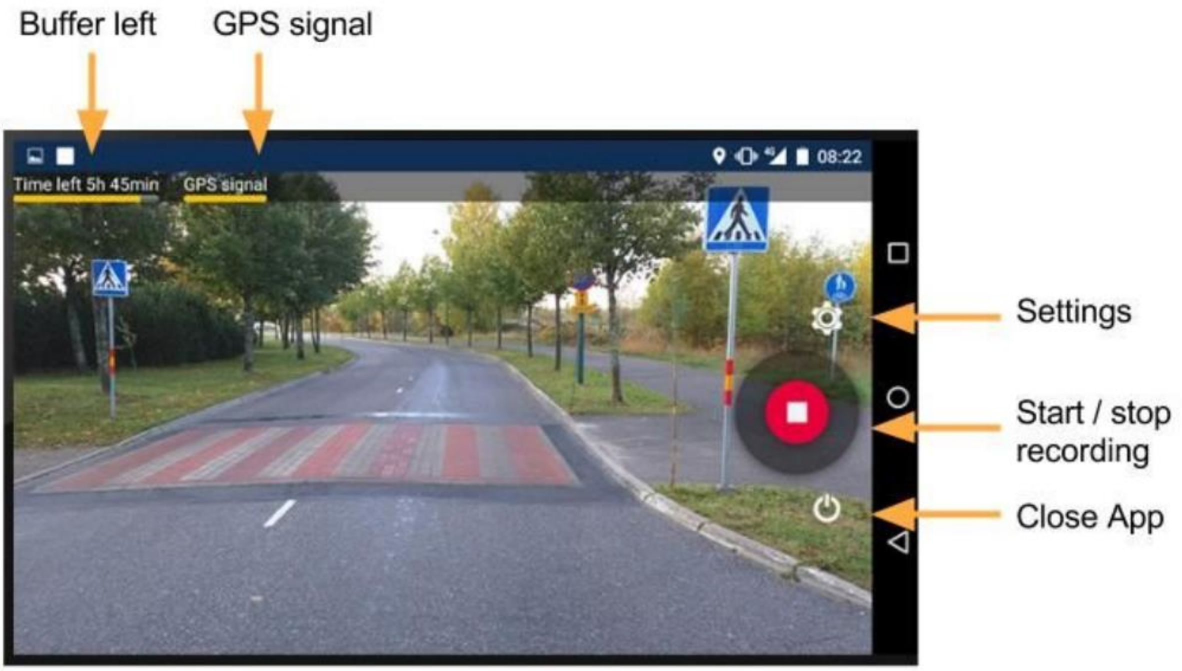


**Figure 1 When installed and opened, the Viominer app fills the screen with the current camera view.**

In most cases the data collection can be started by simply opening the app, and starting the recording by clicking the button on the right hand side (Figure 1). If it is the first time, the app needs to be configured by choosing Settings and entering username and password (otherwise data will not be uploaded).

The app will continue to collect and upload data until it is stopped, or runs out of hard drive space or battery power.

## 4.2 The web page

The web page shows all the collected data. There are three main views: the list view (shown to the left on Figure 2), the map view (shown to the right on Figure 2), and the video view (shown in Figure 3).

By clicking a sign on the map, we can see a detailed overview on the sign detection, showing information about the sign, and how it was detected (Figure 3).

By clicking the blue lines on the map (representing the trips), we can open the video(s) that have been recorded on this route, and see exactly what the detection is based on (Figure 3).

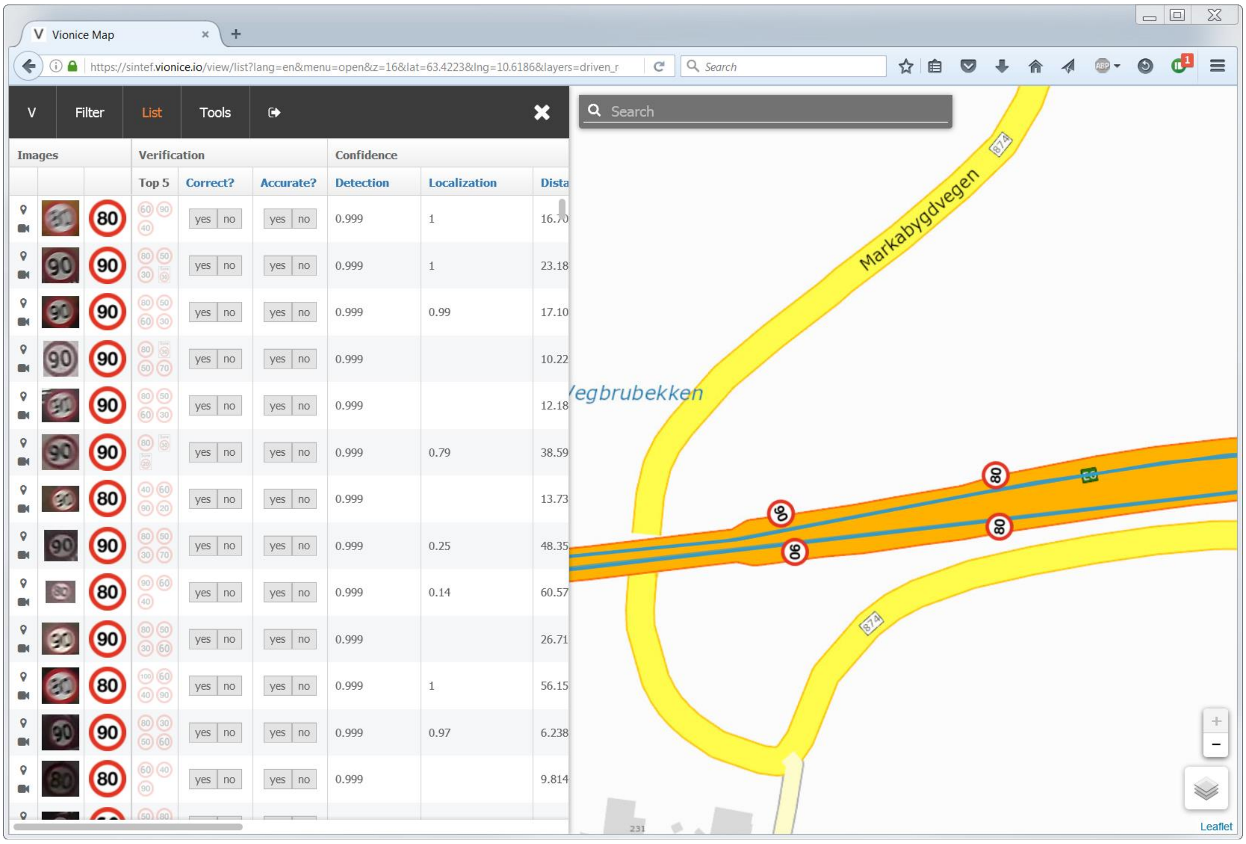


Figure 2 The web page, showing four of the traffic signs that were detected on the E6 on the map, and all the detections in the list.

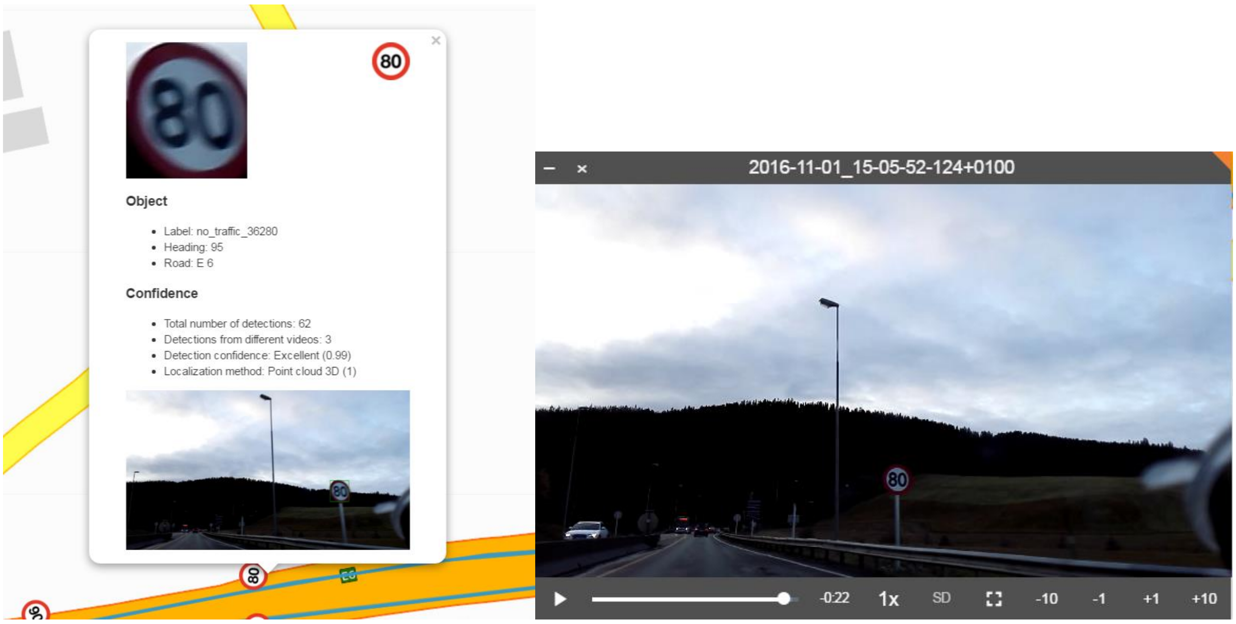


Figure 3 Detailed overview of the sign detection (left), and the corresponding source video (right).

## 5 The test setup

To test Vionice's system, the NPRA drove a car with multiple Viominer phones on one of their test stretches, a road where they have taken extra care to position the signs in NVDB (Norwegian Road Database) as precise as possible. This particular test stretch is the FV705, going from Stjørdal to Brekken (Figure 4).

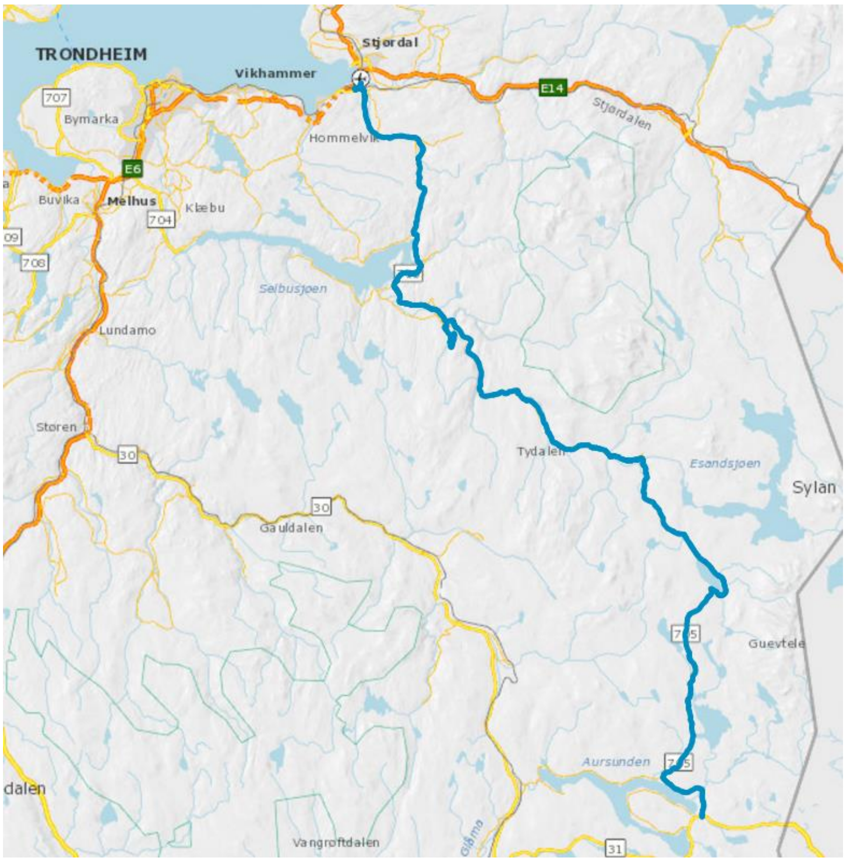


**Figure 4 The route used for testing the Vionice system.**

The route was driven on November 2nd 2016, starting in Trondheim around 09:00, reaching Brekken around 12:00, and returning to Trondheim around 15:30.

All the signs collected on FV705 from this trip were compared against all signs on FV705 from NVDB, the NPRA's publicly available database.

# 6 The results

## 6.1 Map plots

When plotting the Vionice signs and the NVDB signs on a map, we can see that, at least when zoomed out, it looks very similar. In fact, the only significant difference is the additional 50km/h sign that Vionice found straight north of the "T" in Tydalen (Figure 5). This sign is a temporary sign because of road works, which explains why it is not in NVDB.

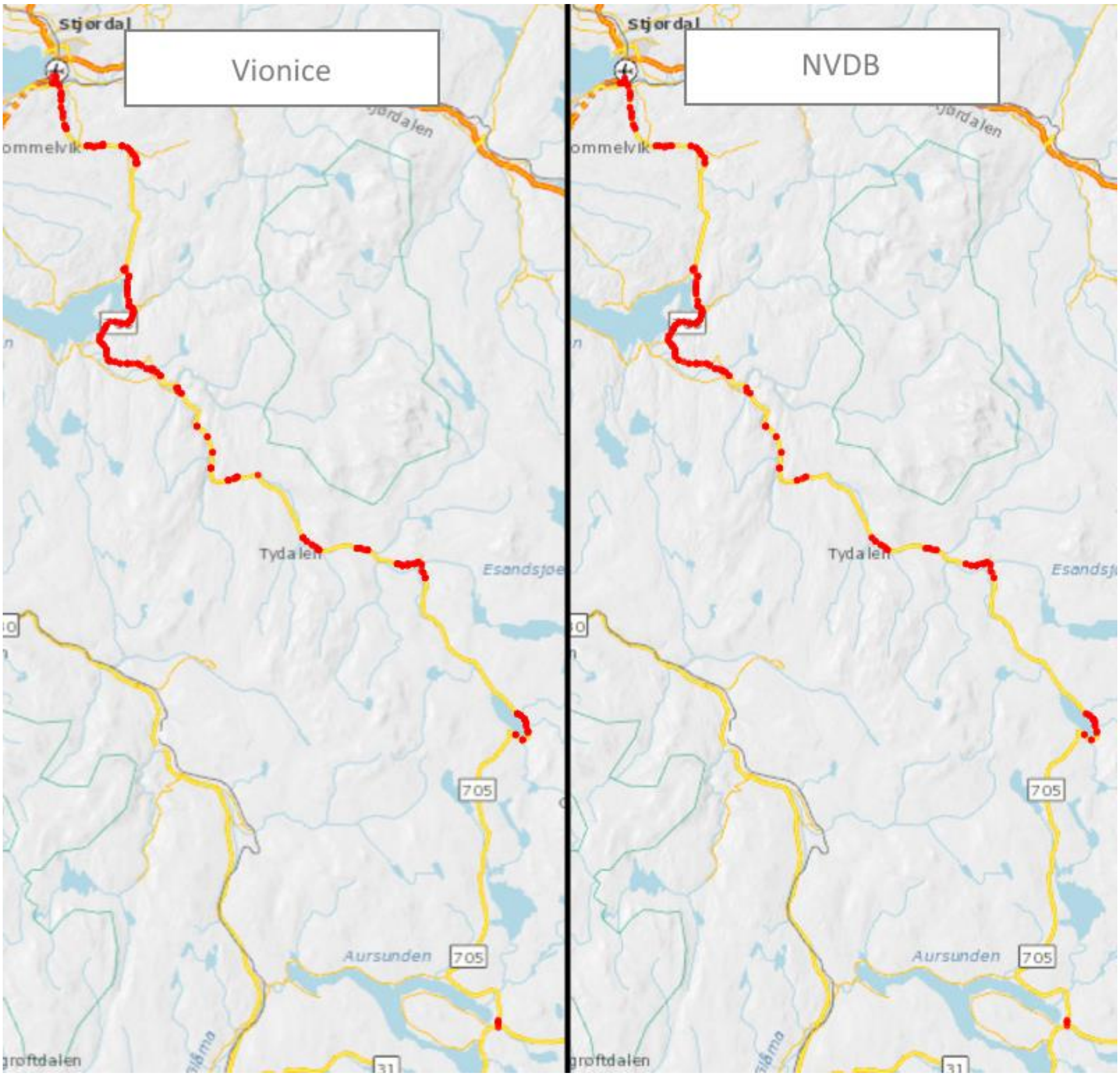


**Figure 5 The signs captured with the Vionice system compared to the signs in NVDB**

To compare the two data sets in more detail, the Vionice detections were divided into two classes:

- Incorrect (red): no NVDB signs are within a 100 meters from this Vionice detection, OR all signs within a 100 meters are of another type than Vionice detected.

- Correct (green): the nearest NVDB sign is within a 100 meters from the detection, and the correct sign type was detected by Vionice.

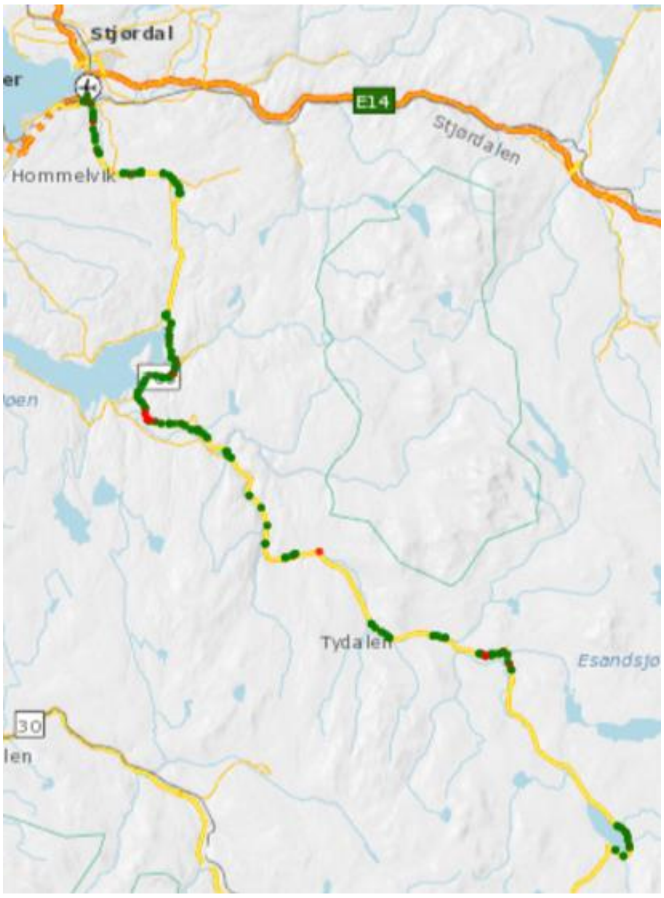


**Figure 6 The Vionice detections plotted with color codes corresponding to their numeric classification. Red means that the detections matches no NVDB signs, and green means that there is a nearby NVDB sign of the detected sign type.**

When plotting the Vionice detections with colors corresponding the their classifications, the map shows that the detections are mostly classified as correct, which means that there is at least one sign of the correct type within a 100 meters from the detection (Figure 6).

Note that these automatically generated classifications will be replaced by more detailed and reliable manual classifications in the next section.

## 6.2 Detailed analysis of detection rates

A detailed analysis was performed by manually re-tracing the driving route on the map, comparing NVDB signs to signs detected by Vionice. When Vionice and NVDB disagreed, the source videos collected by Vionice were checked. As seen in Table 1, Vionice successfully detected the location and sign type of 92% of the signs that existed.

**Table 1 A summary of the detection performance of the Vionice system.**

| | | |
|---|---|---|
| Correct | 260 | |
| Correct (missing in NVDB) | 12 | |
| **Correct (error in NVDB)** | **5** | |
| Sum correct detections | 277 | **92** % |
| Incorrect detections | 1 | |
| **Not detected** | **7** | |
| Sum critical errors | 8 | **3** % |
| Duplicate hit (incorrect) | 2 | |
| **Duplicate hit (inaccurate)** | **2** | |
| Sum duplicates | 4 | **1** % |
| Hit (side road) | 10 | |
| **Possible hit** | **2** | |
| Sum ignored | 12 | 4 % |
| Sum | 301 | 100 % |

NVDB were missing some signs (case B), most of which were road work signs or temporary speed limit signs because of road work.

The two "Possible hits" (case H) were hits that were difficult to analyse, because they were captured while the vehicle was moving around in a parking lot, looking for a place to park. Since it was hard to locate them properly, and therefore hard to find a match in NVDB, it is uncertain if these signs are correctly detected and placed.

As shown in Figure 7, most of the cases where Vionice failed to detect signs (case D) were when the signs were very far to the left of the screen, often only completely visible for a few frames, if visible at all.

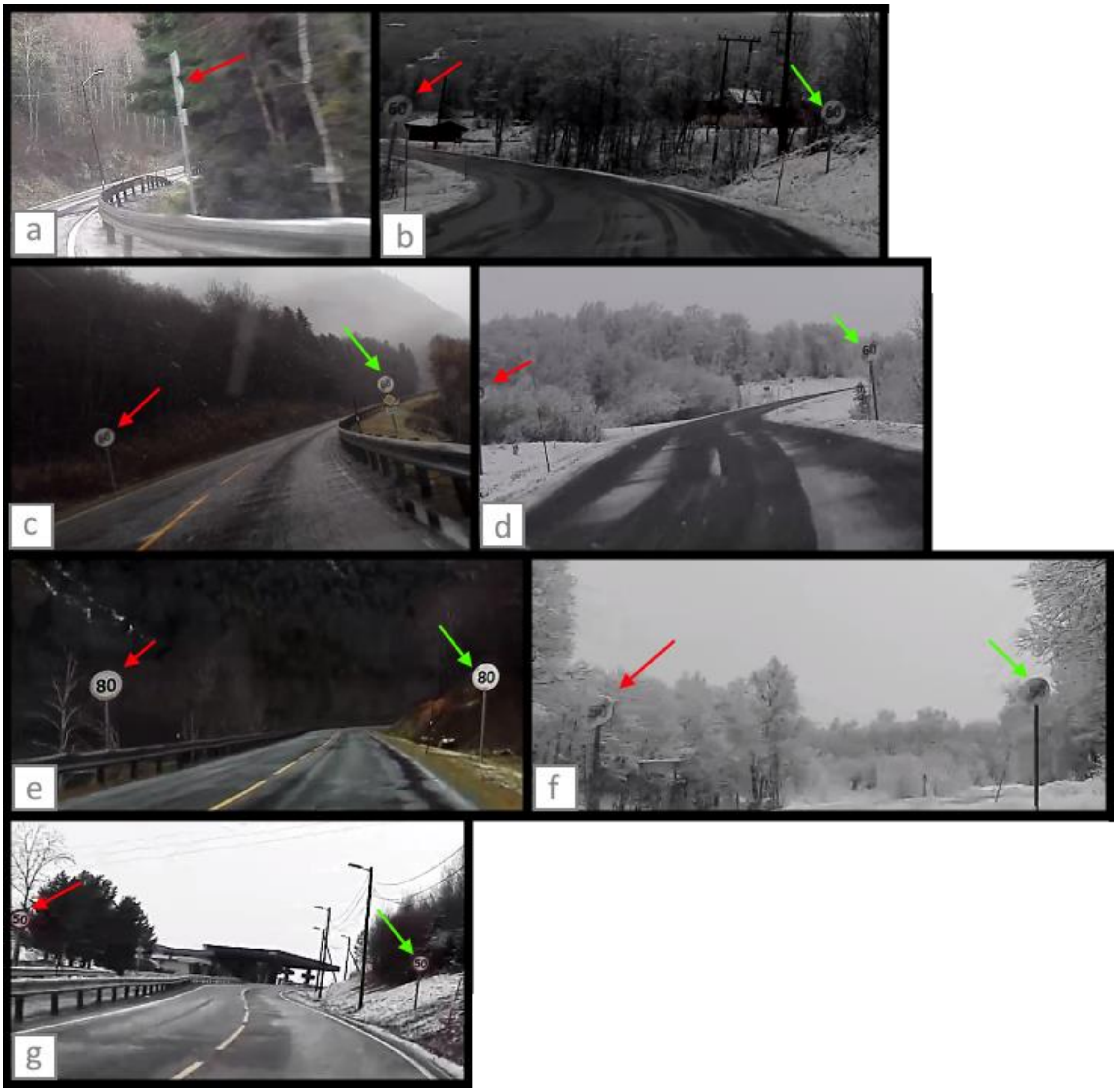


**Figure 7 The signs Vionice did not detect. The sign in image a) seems to be turned away from the road, making it impossible to see. In the other cases, the missed signs (red arrows) were far to the left of the video, in some cases partially outside of the video. The green arrows show signs that were correctly detected.**

**Table 2 A summary of the sign types that were correctly or incorrectly detected, or not detected at all. This table excludes the two misses that were completely impossible to detect, as shown in figure 7a) and d).**

| Sign type | Correct detections | Incorrect detections | Not detected |
|---|---|---|---|
| 40 km/h | 4 | | |
| 50 km/h | 52 | | 1 |
| 60 km/h | 119 | | 2 |
| 70 km/h | 48 | | |
| 80 km/h | 3 | 2 | 1 |

| | | | |
|---|---|---|---|
| **90 km/h** | 8 | | |
| **End of 50 km/h** | 5 | 1 | 1 |
| **End of 60 km/h** | 27 | | |
| **End of 70 km/h** | 8 | | |
| **Road work** | 3 | | |
| **Sum** | 277 | 3 | 5 * |

With so few incorrect or missed detections, it is hard to say anything about which signs are more difficult to detect, if any, but it could be harder to detect "End of X km/h" signs (91% hit rate) than the regular "X km/h" signs (98% hit rate).

## 6.3 Positioning the signs

In addition to recognizing the signs, Vionice also attempts to correctly locate them using the known GPS position of the camera, and the 3D movement of the signs as the vehicle drives past them.

Unfortunately, the GPS positions of signs in NVDB seems to be placed in the center of the road. Therefore, comparing the positions detected by Vionice and the positions from NVDB does not tell us much about the positioning precision of Vionice.

**Table 3 Min, max, median, average and standard deviation of the distances from the location detected by Vionice and the location stored in the NVDB. Only signs with correct detections.**

| | |
|---|---|
| **Signs** | **259** |
| **Min** | **0,7** |
| **Max** | **98** |
| **Median** | **7,1** |
| **Average** | **12** |
| **Standard deviation** | **16** |

As Table 3 shows, the GPS positions Vionice calculates are close to the GPS positions stored in NVDB. However, since NVDB often stores sign locations in the center of the road, these numbers are not very useful – even if the Vionice locations should be correct, comparing them to the possibly wrong NVDB positions would give an error.

Figure 8 shows some examples of the GPS positions Vionice have calculated, and the GPS positions stored in NVDB. The NVDB positions are clearly stored in the center of the road in these cases (note: this is not always the case). This could have been an effect of the zoom level on the NVDB map (which aggregates signs together when you zoom out), but when manually checking the GPS coordinates of the signs in these cases, we can confirm that they do indeed have coordinates from the center of the road. This can also be seen when counting the total number of signs and the total number of different positions in the NVDB dataset, as shown in Table 4.

**Table 4 The total number of signs NVDB has stored on the FV705 stretch, and the number of different GPS positions on the signs.**

| | |
|---|---|
| **Total number of signs** | 279 |
| **Total number of different GPS positions** | 148 |

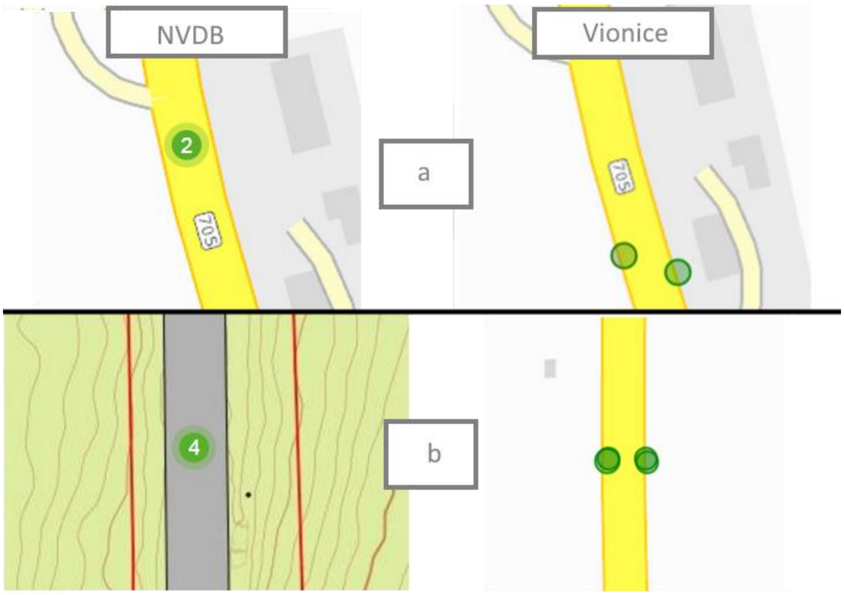


**Figure 8 Examples of how NVDB positions the signs in the center of the road (the two images in the left column), while Vionice attempts to position them on the sides of the road (the two images in the right column).**

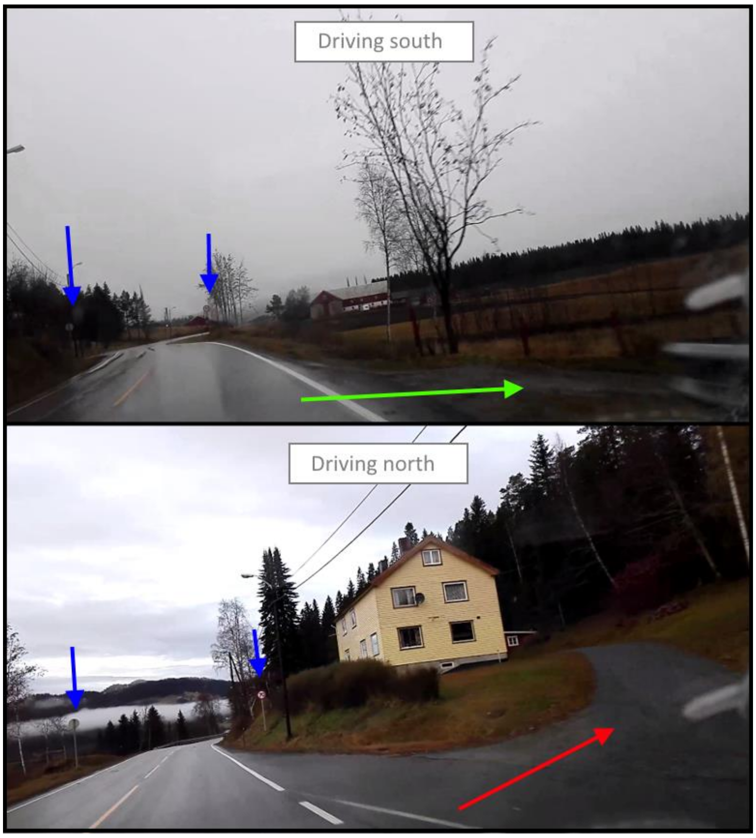


**Figure 9 Screenshots of the analysis videos (one southbound and one northbound) corresponding to the sign detections in Figure 8a shows that the signs are indeed placed on the sides of the road, and closer to the southern side road (red arrow) than the northern side road (green arrow).**

Figure 9 shows screenshots from two of the source videos that Vionice have used to detect and position the signs. It is not easy to illustrate in images, but when manually inspecting the videos, it looks like the signs are placed closer to the south side road shown in the lower right corner on the map in Figure 8a (and marked with a red arrow in Figure 9), than the northern side road. This could indicate that the NVDB positions also are placed too far to the north.

A similar situation can be seen at Setnan (Figure 10), where there is a side road that runs off to the left, then returns back on the FV705 a bit further ahead. Vionice has detected a sign on the short stretch of FV705 between these two points, while NVDB does not have any signs here (it does, however, have a sign of the same type a bit further east).

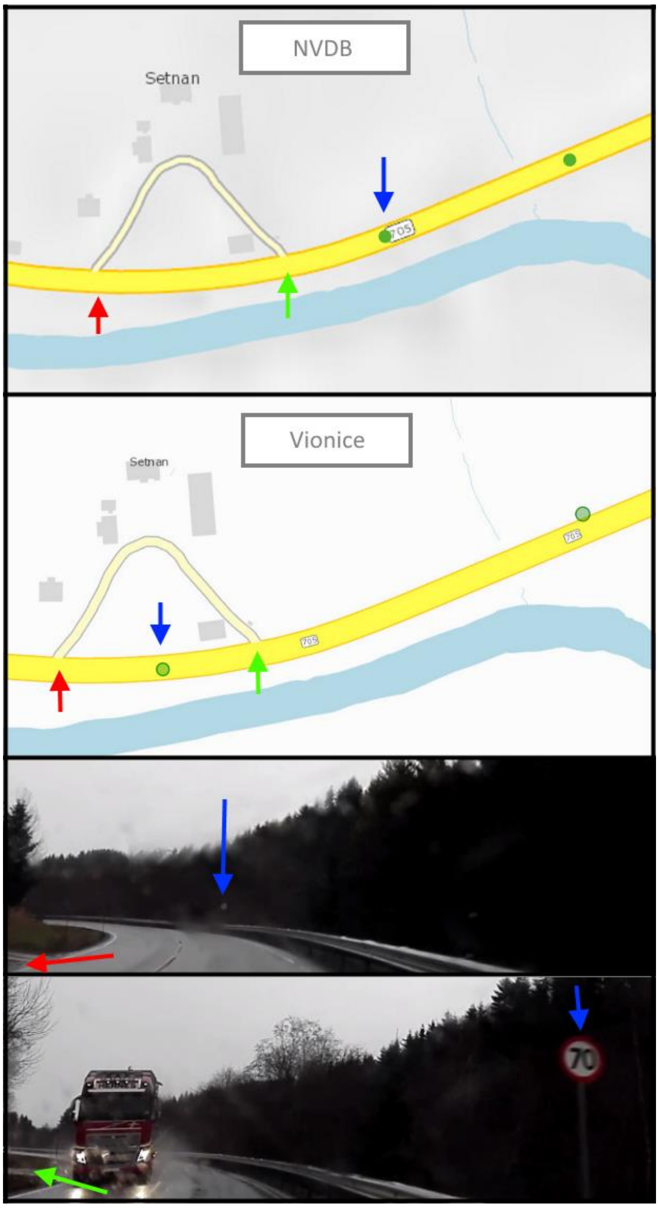


**Figure 10 The side road at Setnan. NVDB has the 70 sign positioned east of the side road, while Vionice positions it between the side road running off (red arrow) and coming back (green arrow). When checking the source videos, the sign (blue arrow) seems to be between the side roads.**

## 7 Conclusion and future work

This test was performed on a day with cloudy weather and a lot of precipitation. While the precipitation could hinder the detections, the Vionice system can compensate for this by analysing multiple frames from the video, giving it a lot of pictures of the signs to work with. The clouds themselves hides the sun, which can give images with very bright sky, and very dark details, and reflections that can disturb the algorithms.

There were three phones in the vehicle during this test, which gave the system thrice as many images to work with. It is not known if the good performance on this test is due to the number of phones collecting data, but it could be interesting to try the same test with just a single phone, and compare the results. All three phones were angled a bit to the right, making detections on the left side of the road a challenge (as shown in Figure 7

– all the missed signs where on the left side of the road). The detection rate could probably be improved by angling one or more of the phones more to the left.

In information retrieval scenarios, precision and recall is often used to rate a system. In this case, the precision is the number of correct detections divided by the total number of detections, while the recall is the number of correct detections divided by the actual number of signs. This gives the sign detection and recognition algorithm a precision of 98% and a recall of 98%, both very impressive.

The precision of the recognition algorithm could possibly be improved by utilizing logic from the traffic domain. For example, if the system knows that there are two "end of 70 km/h" signs at a given position, it can be fairly certain that there will be two "start of 70 km/h" signs in the opposite direction. Positions may be improved with similar logic, although that can prove to be challenging. In addition to this, there is also a limited set of signs that can appear at a given time – for example, there should never be a 50 sign directly after an 80 sign.

Due to a lack of quality data to compare against, the actual precision of the GPS coordinates the Vionice system has calculated can not be determined.

A An analysis of the location accuracy of signs detected in Molde

The NPRA ran a demonstrator in Molde in early 2017, collecting a total of 163 signs using the Viominer app. The NPRA manually extracted and labelled the detections from the Vionice system, and extracted a dataset of matching signs from NVDB and their GPS positions.

The distances between the NVDB sign locations and the Vionice sign detections were calculated using the Haversine formula[1], which according to the documentation of the relevant implementation should have an error of less than 0.1% [2].

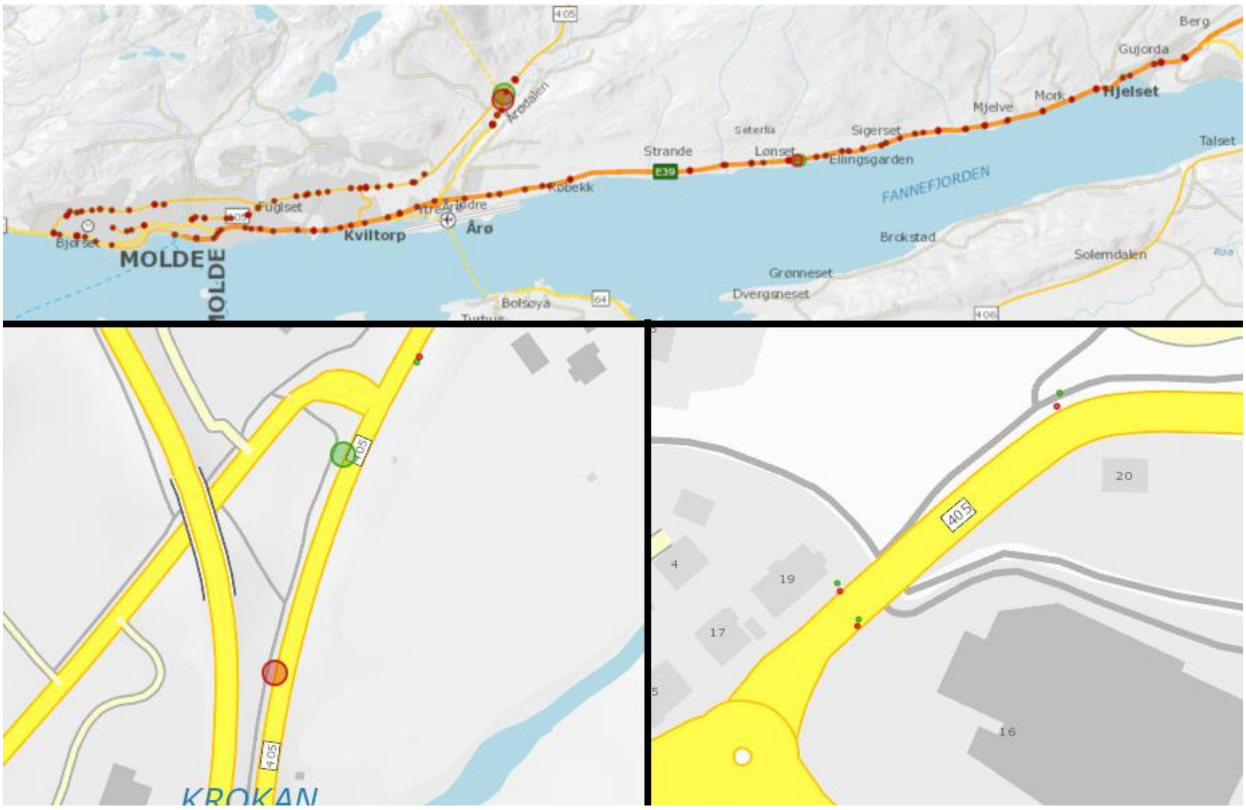


**Figure 11 Signs detected in the Molde demonstrator. Point colors represent their source (red points are signs from NVDB, while green points are signs detected using the Vionice system). Point size represents the distance from the Vionice detection to the matching sign from NVDB.**
**Top: All signs and their matching detections. Most detections are very close – only two obvious misplacements can be seen in this image (center top, and the fifth sign to the right of Strande).**
**Bottom left: Zoomed in on the biggest mismatch (detection 112 meters from actual sign).**
**Bottom right: Zoomed in on a random stretch of road to show some of the average detections.**

Figure 11 shows all the detected signs in the Molde demonstrator, and their NVDB counterparts. As the figure shows, the majority of the detected signs were placed very close to their NVDB locations (so close that most of the green points are hidden behind the red points), while a few detections missed with up to 112

[1] The Vincenty formula was also tested. The results were within 99.7% of the Haversine formula, which was chosen because of its implementation simplicity.

[2] The Haversine implementation documentation: https://msdn.microsoft.com/en-us/library/system.device.location.geocoordinate.getdistanceto(v=vs.110).aspx

meters. The bottom part of the figure zooms in on two areas of the map to show the biggest misplacement, and a random road stretch with some detections.

On average, the Vionice system placed the signs in Molde 3.4 meters from their matching NVDB signs, with a median of 2.0 meters and a standard deviation of 9.5 meters. Figure 12 shows the error distribution of the detected signs, and illustrates how most signs would be placed on a map.

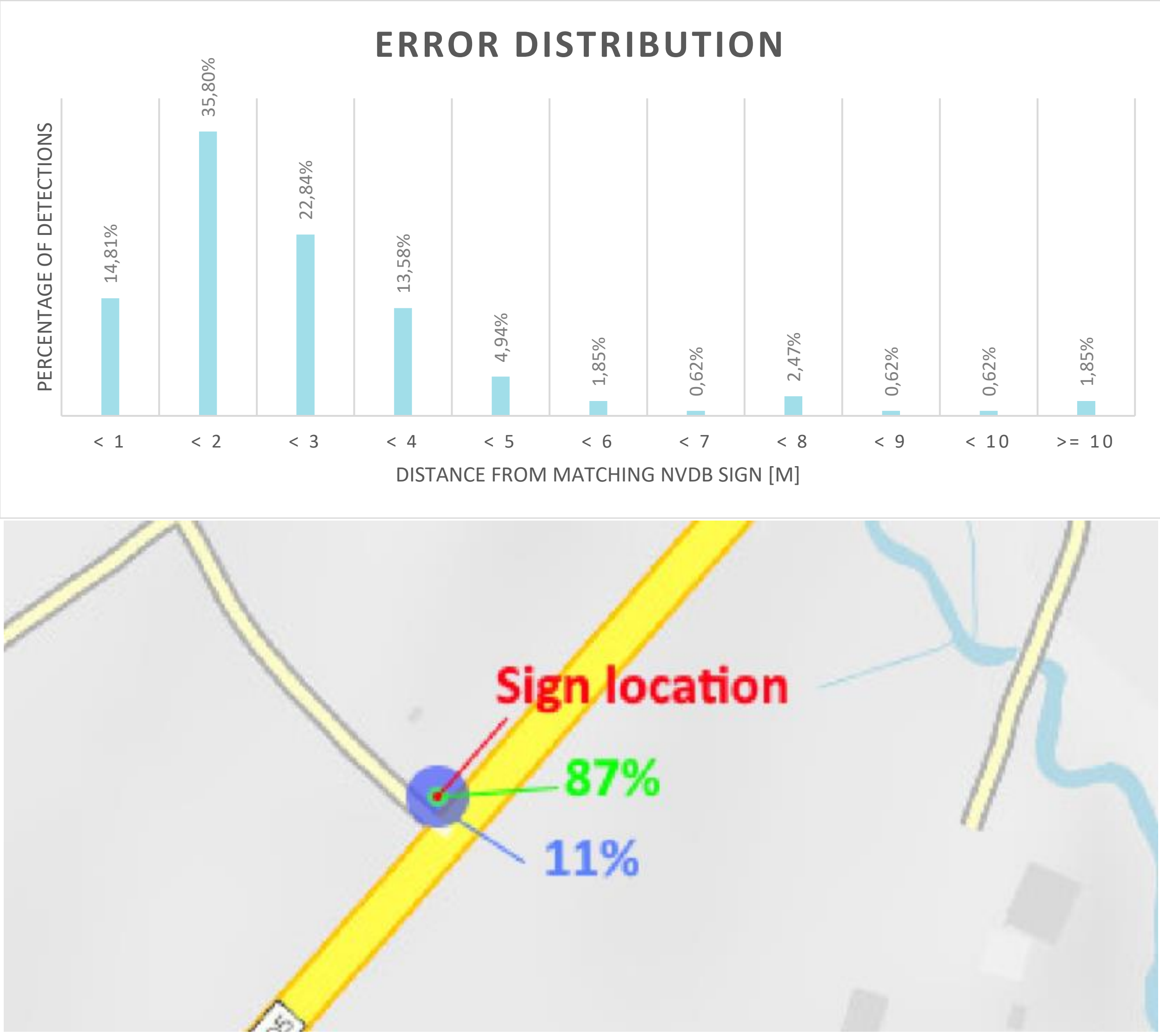


**Figure 12 The error distribution of the Vionice detections shown as a percentage plot (top), and visualized on a map (bottom). The map: if a sign is located on the red dot, 87% of the Vionice detections in this dataset would be placed inside the green circle. 11% would be placed inside the blue circle, and the remaining 2% would be outside of the circles.**

Note, however, that as the main body of this report shows, the NVDB signs show a tendency of being located in the middle of the road. In this analysis, the actual sign locations are unknown, but in most cases we can assume that the signs are not, in fact, in the middle of the road, but rather on the side of the road.

To actually validate the Vionice detections, a high-accuracy GPS unit should be used to accurately measure the exact positions of the signs.

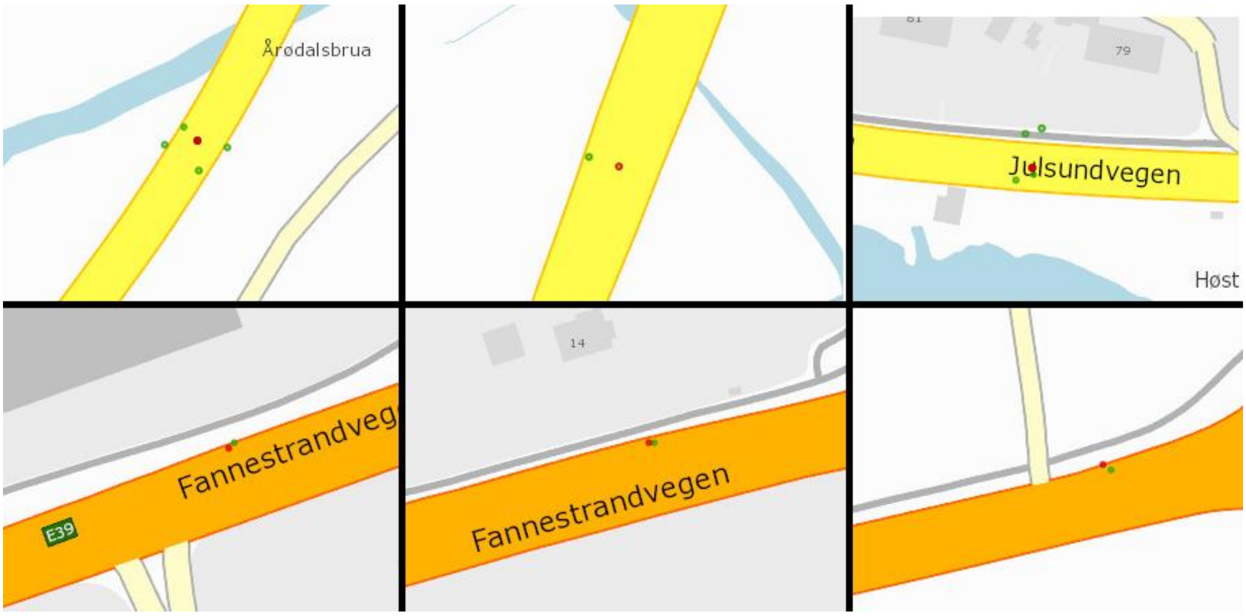


**Figure 13 Some examples of sign locations. The upper row demonstrates some cases where the NVDB signs (red) are placed in the middle of the road, while the lower row demonstrates some cases where they are placed on the side of the road.**

After manually inspecting every NVDB sign in the dataset, 11 signs were found to be placed in the middle of the road. For these signs, we subtracted half of an average road width (i.e. 4 meters were subtracted) from the distance between the Vionice detection and the NVDB location. After this adjustment, the Vionice system had an average location distance of 3.14 meters, a median of 1.95 meters, and a standard deviation of 9.41 meters. Table 1 shows these metrics before and after performing this manual adjustment.

**Table 1 Sign location distance before and after removing the signs that NVDB had placed in the middle of the road.**

| | Before filtering | After adjustment |
|---|---|---|
| Average | 3.38 meters | 3.14 meters |
| Median | 1.97 meters | 1.95 meters |
| Standard deviation | 9.53 meters | 9.41 meters |

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