Public HD maps for automatic vehicles

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1. Introduction

Autonomous cars can sense their surroundings and navigate traffic and other obstacles on their own with minimal or no human intervention, which may be able to be safer, more secure, and more efficient than non-automatic vehicles. Self-driving cars have exploded in popularity in recent years as a result of technological advancements. Tesla, Waymo, Uber, and a slew of other companies, for example, have embraced driverless cars with remarkable outcomes. According to Autonomous (Driverless) Car Market - Growth, Trends, COVID-19 Impact, and Forecast (2022–2027), the autonomous (driverless) car market was valued at

USD 22.22 billion in 2021 and is expected to reach USD 75.95 billion by 2027; between 2022 and 2027, it is projected to register a CAGR of 22.75% [1].

With the gradual transition of driving from humans to machines, digital maps play an increasingly important role beyond just navigation. GPS solutions cannot keep up with driverless cars, as the data they provide is not dynamic and accurate enough for driverless vehicles. Therefore, High definition (HD) maps that provide detailed inventories of road features and roadside objects such as lane models, localization items, and lane-level speed limitations play an important role in autonomous driving. However, high-definition maps continue to encounter a number of obstacles. The first is that HD maps include a great quantity of data that must be processed instantly in order to generate immediate output, which imposes a burden on computing power. Moreover, each country has its own set of regulations controlling the collection, protection, and sharing of geographical data, resulting in geospatial data sharing still being hindered in many cases.

This paper introduces a simplified version of the autopilot help system for assisting self-driving cars by using information from the public Ottawa HD map regarding roads and traffic signs. This system includes a novel approach to showing locations on the HD map as well as extracting detailed information from it. Our approach is based on automatic acquisition technology, which is typically used for automatically testing. We use it here to automatically display the current location of the device on the Ottawa HD map. By acquiring information about the road, such as the number of lanes, the maximum speed, and the direction of the road (turn right/left), as well as the surrounding environment, our application could assist automatic vehicles in making driving decisions.

The rest of this paper is structured as follows. Section 2 is a discussion of autonomous driving technologies, companies, and HD maps. Section 3 provides a detailed overview of the application and discusses the improvements. Lastly, Section 4 serves as the conclusion.

2. Research

2.1 Techniques for autonomous vehicles

2.1.1 Sensor

Self-driving cars use three major sensors to mimic the function of the human brain and eyes, which are LIDAR, RADAR, and cameras. This gives the car a clear view of its environment, as well as helps the car to identify objects in its immediate surroundings based on their location, speed, and 3D shapes.

LIDAR is placed on the roofs of autonomous vehicles, as well as the sides and grilles, where they send out thousands of laser points to map the surrounding environment. A LIDAR sensor system is capable of identifying a wide variety of objects and .distinguish between various types of vehicles, bicycles, children, and animals.

Most importantly, LIDAR can track movements and their direction, which makes a computer easier to predict the roLIDARr's activities and make decisions while driving, which is why lidar is vital for autonomous cars.

One disadvantage of LIDAR is that LIDAR sensors are weather-dependent, hence, they are incapable of providing realistic views of their surroundings in fog, snow, or dust. Apart from that, a typical rotating LIDAR that fires lasers in several directions includes a large number of moving elements, which increases the cost of production and maintenance. However, the primary downside of lidar system technology is its high cost. According to the report from *Barrons* in 2021, the costs of LIDAR vary widely by its producer, but an automotive LIDAR sensor can easily top $1,000 per car [16].

RADAR stands for radio detection and ranging. The technology uses radio waves to measure the distance to objects as well as their velocity and angle. Similar to LIDAR, RADAR continuously transmits signals that are reflected by barriers, then interprets the surroundings by comparing the transmitted and received signals.

RADAR is excellent at avoiding crashes, assisting with parking, and powering cruise control systems. Unlike LIDAR, RADAR is not impacted by changes in the weather like fog, snow, and rain.

Additionally, a RADAR sensor that costs between $50 and $200 is compact, lightweight, and inexpensive. Additionally, a RADAR sensor contains no moving elements and consumes less energy than a LIDAR sensor. All of this makes the technology extremely appealing to automakers.

As a complement to RADAR and LIDAR, cameras are another essential tool for autonomous driving since they provide images that artificial intelligence software can analyze with a high level of accuracy. For example, the cameras on Tesla models are used by its Autopilot self-driving feature to provide a 360-degree view of its surrounding. It is all visual and does not rely on ranging and detection like LIDAR.

Autonomous cars rely on cameras mounted on all four sides: front, rear, left, and right, to provide a 360-degree vision of their surroundings. Certain models feature a broad field of view, up to 120 degrees, but a limited range. Others take a more restricted view to provide long-range visuals. To enable self-parking, some vehicles even use fish-eye cameras that provide a panoramic view to view what's behind the vehicle from any angle [17].

While cameras give precise pictures, they do have limits. They are capable of distinguishing features in their environment; nevertheless, the distances between such things must be computed to determine their precise location. Additionally, camera-based sensors have a harder time detecting things in low-visibility settings such as fog, rain, or dusk.

Until now, companies like Waymo, Cruise, Uber, and Velodyne have embraced LIDAR and cameras. Tesla, on the other hand, has preferred camera-based systems [18].

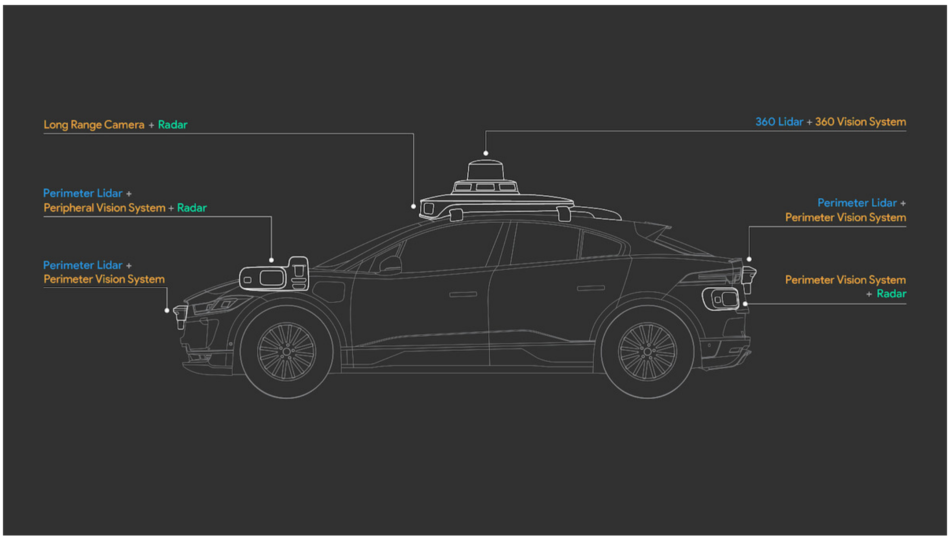

Figure 1. Verge Waymo's next-generation self-driving system

2.1.2 Machine Learning

Machine Learning plays an important role in the detection and classification of objects by being federated with data from sensors. By using machine learning on the output from each of the sensor modalities, it is possible to classify objects, detect distance and movement, and predict the actions of other road users. Thus, it is capable of deriving inferences from camera output. RADAR signals and point clouds are employed to improve clustering, which results in a more accurate three-dimensional image of things. Similarly, high-resolution LIDAR data may be used to categorize objects using machine learning [11].
However, a vehicle may confuse a stop sign for something more innocuous, such as a speed limit sign, with just a few pixels of difference in an image provided by a camera system. If the system mistakes a pedestrian for a lamp post, in the same way, it would not predict its movement. Through enhanced and more broad training of the machine learning models, the systems may increase perception and accurately identify things. By training the system on a wider variety of inputs for the critical parameters on which it bases its choices, the data's validity may be improved and the distribution being trained on is indicative of the genuine distribution in real life may be guaranteed. In this manner, there is no excessive reliance on a single parameter or a small group of details.

2.2 Autonomous vehicle companies

Over the past several decades, more firms and initiatives have been formed with the goal of creating autonomous, intelligent, and safe cars. As of now, Tesla and Waymo are two of the top automatic vehicle companies [21].

Waymo is created by tech giant Google itself as the front-runner for a spot among the top autonomous car firms, aiming to deliver autonomous vehicles. Since 2009, Google has been developing self-driving automobile technology. The project was formerly known as the Google autonomous automobile project. Waymo produces different types of self-driving automobiles such as commuters and self-driving vehicles in order to address the needs of different consumers depending on their transportation needs.

In 2020, Waymo allowed customers to hail self-driving taxis, a service called Waymo One. Waymo One services within the roughly 50-square-mile territory covering most of Tempe, Chandler, and Mesa, Arizona (expanding soon to downtown Phoenix) [22].

Tesla Motors introduced its semi-autonomous driving system, called Autopilot, in 2014. With its array of cameras, radar and ultrasonic sensors, it essentially integrates the car's suite of driver-assistance features in order to enable rudimentary self-driving on highways [23]. At almost every other company working on self-driving cars, Elon Musk insists that autonomy can only be achieved by cameras tracking their surroundings. Many Tesla engineers, however, questioned whether it was safe to rely solely on cameras without the assistance of other sensors - and whether Musk was overpromising the capabilities of Autopilot.

Ontario, as North America's second-biggest IT cluster, has spawned many autonomous driving companies. AutoGuardian, an automatic vehicles company founded in Ottawa, Canada, has created a new way for autonomous vehicles to operate. Its unique service combines turnkey autonomous shuttle operations with IoT-enabled intelligent infrastructure capabilities. This enables advanced data collecting as well as alerting vulnerable road users to the presence of impending shuttles via auditory and visual indications, as well as complete route surveillance. These sophisticated warning systems provide sufficient time for cars, C/AVs, bikers, and pedestrians to react and remain safe.

Figure 2. Autonomous Shuttle created by AutoGuardian

2.3 High-definition maps for autonomous vehicles

High definition (HD) maps are used to detect lane boundaries, road signals, crosswalks, traffic lights, and others to safely navigate autonomous cars. HD maps are crucial components of autonomous cars since they give them the ability to perceive their surroundings and the road ahead.

2.3.1 How to create and update HD maps

There are two typical mapping processes: data collection and data processing. To build detailed maps for navigation systems and custom solutions, accurate information on road attributes needs to be collected from around the globe.

The basic data can be collected through the official website of the government, such as the number of traffic lights and the rules of the road. More accurate data are collected by survey vehicles that are equipped with cameras, sensors and lidars. Data could be gathered from mobile cameras, sensors, and GPS devices of survey vehicles to locate traffic lights, signs, poles, stop lines, lane markings, roadside barriers, junctions etc.

Once the data have been collected, they must be validated. The first step will be to automatically identify objects and scene semantics from images. Following this, the 3D scene structure and camera motions will be recovered from the images. Lastly, map objects can be extracted by combining object recognition and motion information. Using these components, geotagged images could detect objects automatically and their location on a map could be determined.

Static HD maps are not adequate for autonomous driving. To be able to mimic human actions, autonomous vehicles must be able to obtain accurate and timely information. It is possible to obtain information about roads through feedback received from reliable and precise locators. Through the use of locators combined with cameras and radar, the distance and angle of the position from obstacles, such as traffic lights ahead, can be determined. A more efficient method would be to ingest vehicle data to the cloud. If a change in the roadway is detected, vehicles can identify and reroute themselves in real-time, and automatically transfer this information to the operations center and the rest of the fleet.

Since 2016 HERE, a German AV company, integrated live vehicle sensor data from Audi, BMW and Mercedes-Benz vehicles with traffic probe information to a global real-time traffic service, resulting in significantly higher accuracy and more precise information about traffic conditions. “In the era of autonomous driving, cars will share and receive real-time data about what's happening on the road, and this is where HD maps and advanced connectivity will play a crucial role,” said Ian Huh, SVP IoT/data Division Head at SK Telecom [5].

2.3.2 Companies that make HD Maps

Global firms like TomTom (the Netherlands), HERE Technologies (the Netherlands), NVIDIA (the United States), Waymo (the United States), and NavInfo (the United States) lead the high-definition map industry. A slew of new businesses, including Fixposition (Switzerland), Point One Navigation (US), Geo Digital (Canada), and CivilMaps (US), have also boosted competitiveness in this market segment [7].

Commenting on TomTom’s competitiveness, Research Analyst, Mohit Sharma, noted, “Within automotive and enterprise space it is becoming a two-horse race between HERE and TomTom, though TomTom still lags on a comprehensive location platform capability compared to HERE in terms of developer workspace, visualization tools, marketplace and so forth.”[6]

2.3.2.1 TOMTOM

Due to the volume of data that must be collected and stored, as well as the inherent accuracy requirements, TomTom relies on deep learning and machine learning algorithms to automate the expansion of the production pipeline. TomTom's data processing using machine learning techniques results in more scalable and accurate maps. For example, when identifying 30 different types of lane dividers, some of which (such as solid and dashed lines) are seen frequently while others exist only in specific countries, it takes substantial effort for even an experienced human map editor to accurately label each divider. Machine learning algorithms, on the other hand, can speed up this process, allowing for ten times more annotations to be made in the same amount of time.

2.3.2.2 HERE

HERE is among the world’s first companies to provide an HD map for commercial production vehicles with Level 3 automated driving capabilities. HERE leverage over 80,000 data sources, including a fleet of vehicles that collects data via panoramic cameras, position sensors, and laser technologies to create 3D footprints. The automobiles are equipped with a camera array that captures 360-degree street views, as well as lidar sensors that collect 1.3 billion data points every minute. Another bank of high-resolution cameras records street names and speed restrictions. Additionally, HERE depends on local source data and user input to continuously update maps with real-time traffic, turn-by-turn instructions, public transit routes, and information about nearby businesses and attractions.

By 2013, about four out of every five autos equipped with fully integrated in-dash navigation systems used HERE data. Among others, HERE supplies map data to Alpine, BMW, Mercedes-Benz, Garmin, Hyundai, Pioneer, Volkswagen, and Toyota.
Today, over 150 million automobiles and 50 original equipment manufacturers rely on HERE technology. By 2022, the HERE platform will have collected data from over 30 million connected vehicles via its numerous automotive, telematics, and fleet partners to power its ADAS, linked, and autonomous vehicle services [19].

2.3.3 Tracking autonomous vehicles with HD maps

The United States owns the Global Positioning System, a 24-satellite-based radio navigation system (GPS). Devices equipped with a GPS receiver can retrieve geolocation and time data. Self-driving cars may utilize GPS to geolocate their physical positions in space using numerical coordinates (e.g. latitude, longitude). Additionally, they are capable of navigation by combining GPS coordinates in real-time with other digital map data (e.g., via Google Maps). However, GPS data frequently fluctuates within a five-meter radius. To compensate for imperfect GPS data, self-driving cars can enhance position accuracy through the deployment of novel data processing techniques such as particle filtering.

Here is how particle filtering works. As shown in Figure 3, we have the GPS spot. However, the size of the spot can vary based on factors like the number of satellites visible to the receiver, reflections from buildings and other environmental effects.

Particle filtering begins by dividing or discretizing the GPS point into a tiny grid. Figure 4 illustrates a typical grid with points laid over grid positions where the automobile is physically present. Particles, seen in Figure 4 as orange dots, correspond to plausible vehicle positions, which reflect the car's most likely locations within the GPS point. Other items, such as those that are green or blue, might be called trees or structures.

Then, by comparing the distances between a particle and known landmarks to the observed distances between the same landmark objects and the vehicle, the probability that the particle accurately represents the vehicle's real location and orientation may be determined. For instance, assume that there are three landmarks near the particle's location on the map, with predicted distances of 50.7m, 30.3m, and 110.1m. If the real distance between the vehicle's LIDAR or RADAR and the same landmarks is 51.2m, 28.9m, or 107.7m, the particle is in close proximity to the vehicle's genuine position. Otherwise, if the observed distances differ significantly from the estimated distances, for example, 32.9m, 44.5m, and 78.8m, the particle is likely to be in a location or orientation that is significantly different from the genuine position or orientation of the automobile. Particle filtering will be applied throughout the autopilot's continual movement.

Figure 3. A GPS spot

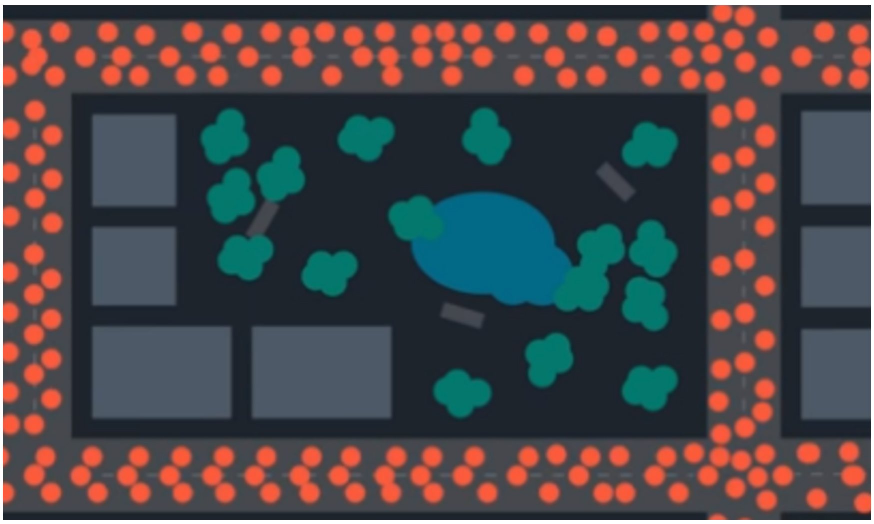

Figure 4. Particles, shown as orange dots here, correspond to feasible vehicle positions inside a GPS spot.

2.4 Free HD map platforms

2.4.1 OpenStreetMap

OpenStreetMap (OSM) was founded in 2004 and now has over two million registered users, making it one of the most popular free HD map platforms. OSM is a global digital map database created through crowdsourcing contributed geographic data. OSM data is freely available for viewing, querying, downloading, and modification. Also, almost all features are editable by any member of the user community like Wikipedia. Although just a small percentage of them are active map editors, the map has evolved to the point where its detail and precision approach those of "authoritative" information from governments and commercial organizations in certain regions, which is especially true in Western Europe and certain portions of the United States. Figure 5 is a picture of the Penn State campus, which illustrates the complexity of the features that may be added to OSM.

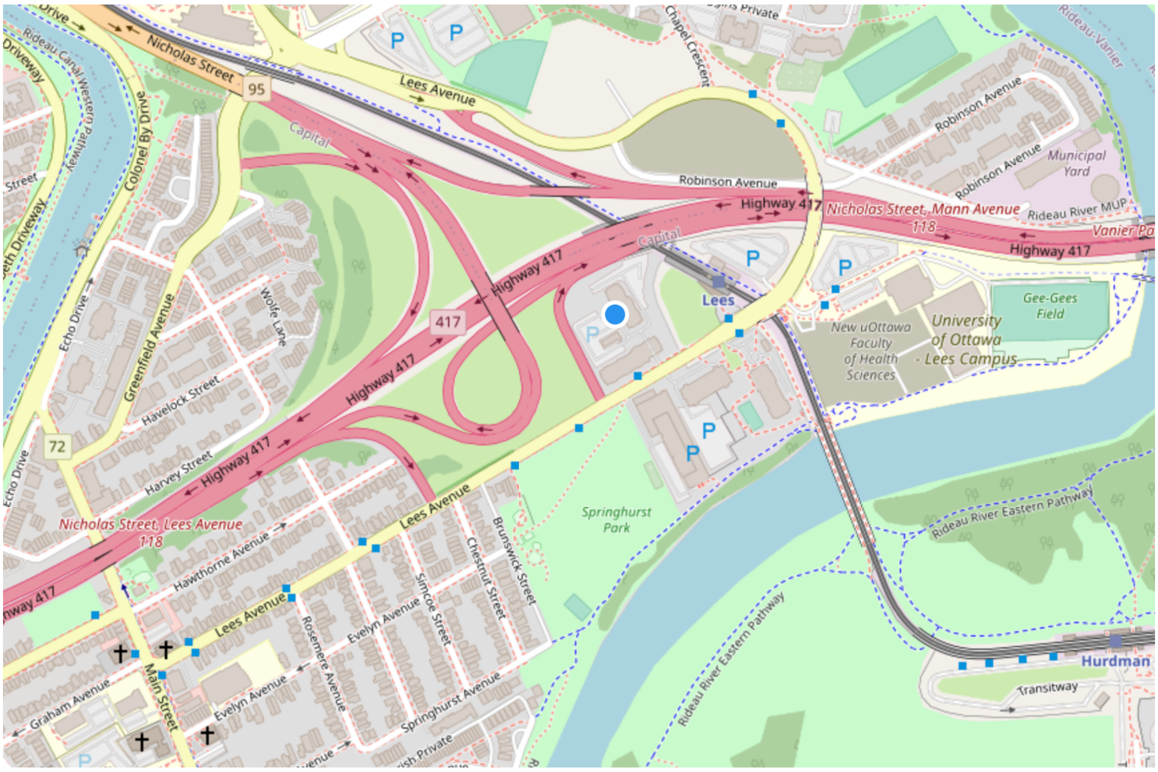

Figure 5. An example of a map in OSM

Elements are the basic components of OpenStreetMap's conceptual data model of the physical world. Elements are of three types:

- node

  A *node* represents a specific point on the earth's surface defined by its latitude and longitude. Also, *Nodes* can be used to define standalone point features. For example, a *node* could represent a park bench or water well. Additionally, *nodes* are also used to define the shape of a *way* [23].

- way

  A *way* is an ordered list *nodes* that represent linear features such as rivers and roads [23].

- relation

  A *relation* is a multi-purpose data structure that documents a relationship between two or more data elements (nodes, ways, and/or other relations). For example, a route relation, which lists the *ways* that form a major (numbered) highway, a cycle route, or a bus route [23].

When querying a feature, the information of the feature will be shown on the left side. Figure 6 demonstrates the information of Highway 417. The information includes the id of way, the tags information, the relations and nodes.

Each feature contains tag information that describes specific features of map elements (nodes, ways, or relations). A tag consists of two items, a *key* and a *value*. The key is used to describe a topic, category, or type of feature, and the value provides detail for the key-specified feature. For example, *highway=residential* a tag with a key of highway and a value of residential which should be used on a way to indicate a road along which people live. Figure 7 shows the tags that can be viewed as an explanation dictionary of Highway 417.

OSM provides a wiki document called Map Features that lists all the tags used, and all the possible values corresponding. For example, Figure 8 not only shows the category of the highway, such as *motorway*, *primary*, and *secondary* but also shows the description and example(image) of that category [14].

In addition, TagFinder, developed during a semester thesis in informatics at the Geometa Lab, University for Applied Sciences Rapperswil (Switzerland) [15], uses to search whether a tag is present (shown in Figure 9). TagFinder is a web page where one can simply type a term into the search box and get back a manageable list of related tags. It provides the most relevant information about tags, as well as links to additional details on the OpenStreetMap wiki and statistics at TagInfo.org.

As OSM allows anyone to contribute any type of feature, it may have a more diverse and important collection of features than commercial or government maps, for example, trees, accessible ramps, food banks, and spigots for drinking water, however, there is no systematic quality control being performed on the data. Hence, users take their own risks.

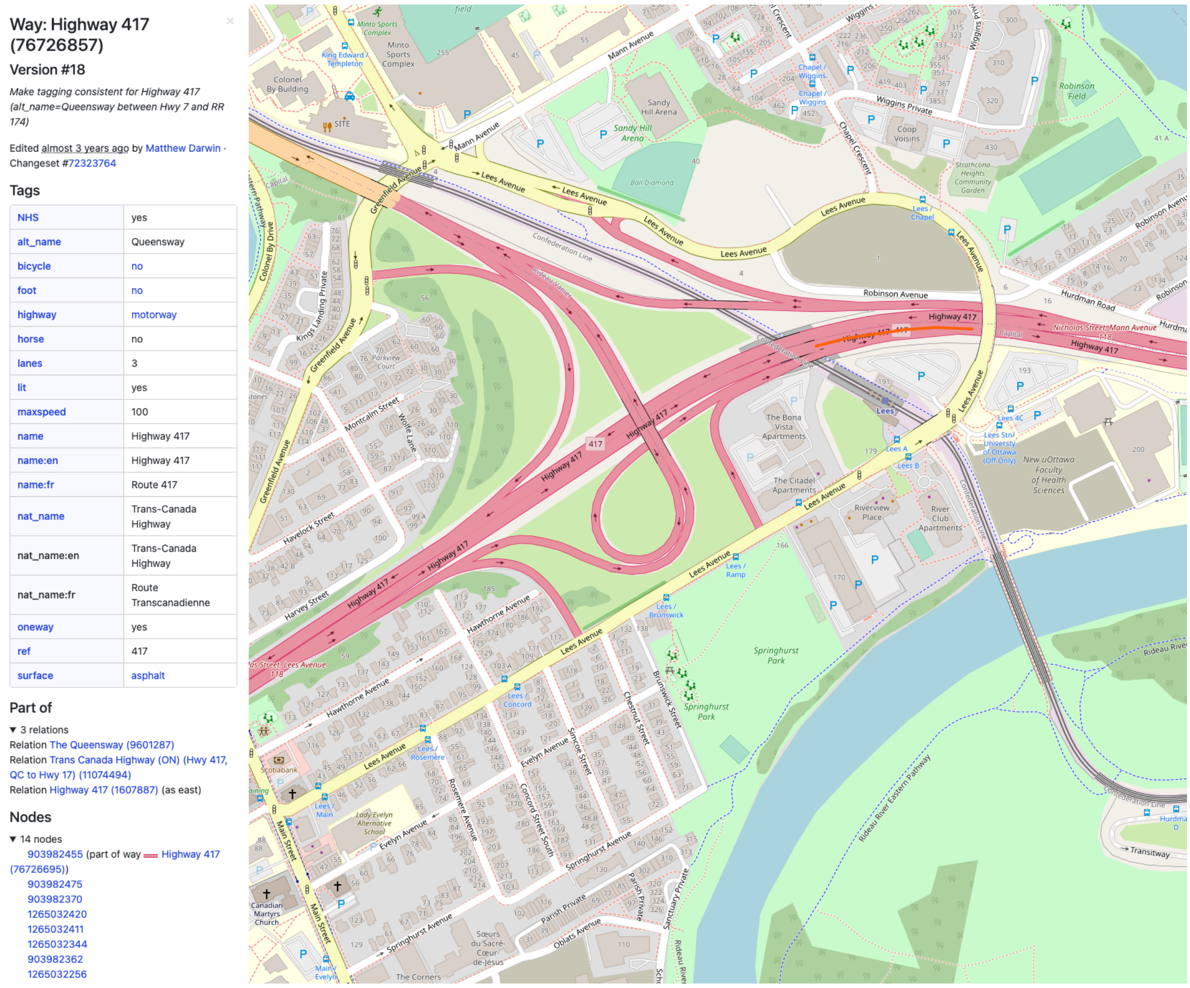

Figure 6. Information on Highway 417 in OSM

Tags

NHS	yes
alt_name	Queensway
bicycle	no
foot	no
highway	motorway
horse	no
lanes	3
lit	yes
maxheight	4.3
maxheight:physical	4.3
maxspeed	100
name	Highway 417
name:en	Highway 417
name:fr	Route 417
nat_name	Trans-Canada Highway
nat_name:en	Trans-Canada Highway
nat_name:fr	Route Transcanadienne
oneway	yes
ref	417
surface	asphalt

Figure 7. Tag information of highway 47

Key	Value	Element	Comment	Rendering carto	Examples
Roads					
These are the principal tags for the road network. They range from the most to least important.					
highway	motorway		A restricted access major divided highway, normally with 2 or more running lanes plus emergency hard shoulder. Equivalent to the Freeway, Autobahn, etc..		
highway	trunk		The most important roads in a country's system that aren't motorways. (Need not necessarily be a divided highway.)		
highway	primary		The next most important roads in a country's system. (Often link larger towns.)		
highway	secondary		The next most important roads in a country's system. (Often link towns.)		
highway	tertiary		The next most important roads in a country's system. (Often link smaller towns and villages)		

Figure 8. List of tags in Wiki document

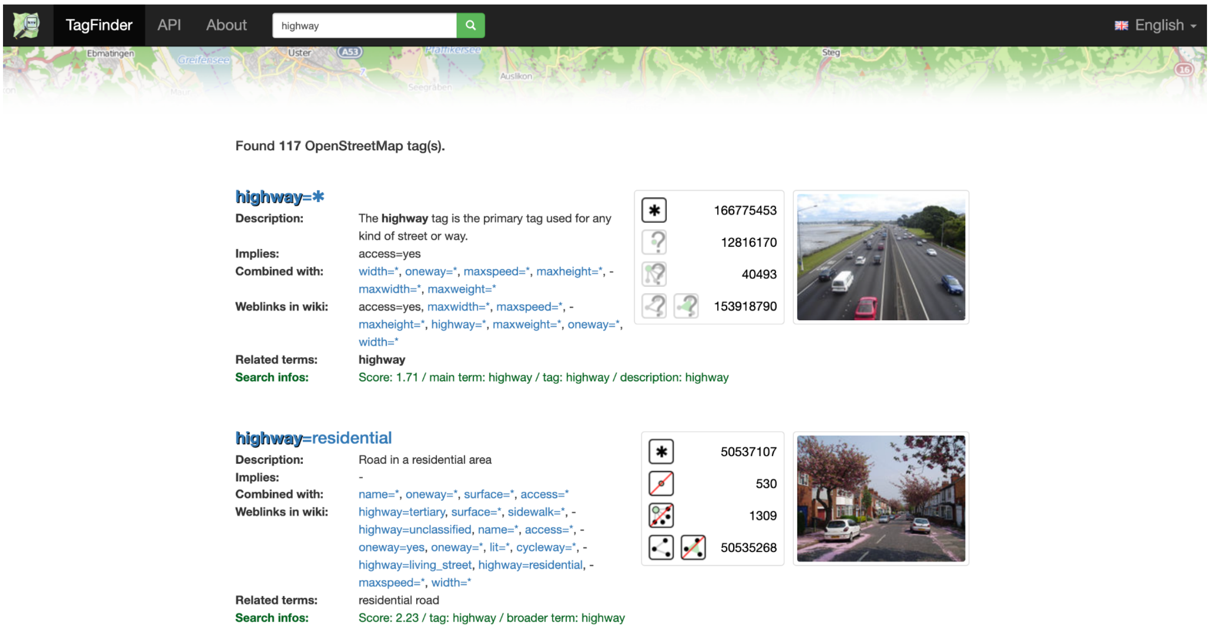

Figure 9. Search keyword "highway" in TagFinder

2.4.2 Open HD Maps

Open HD Map is a community built around an open-source high-definition mapping platform that hosts disparate data sets from participating organizations while leveraging the expertise of all members to accelerate the development of new and existing applications that use precise mapping data. Open HD Maps is a collaborative initiative, established and led by Communitech, the University of Waterloo and the Waterloo Economic Development Corporation.

Open HD Maps provides different types of maps including HD Vector Basemaps, LiDAR Data Maps, and Open Data Sources Maps for different cities such as Toronto, Waterloo, and Ottawa.

In the Map Browser, maps could be viewed and the Map Browser provides functions for searching locations, viewing coordinates, calculating distances between any two points, querying fields by SQL, etc. In the Layer Panel, each category is categorized by colour, as shown in Figure 10 which shows a portion of the categories transportation_line and Service_Point of the Ottawa map.

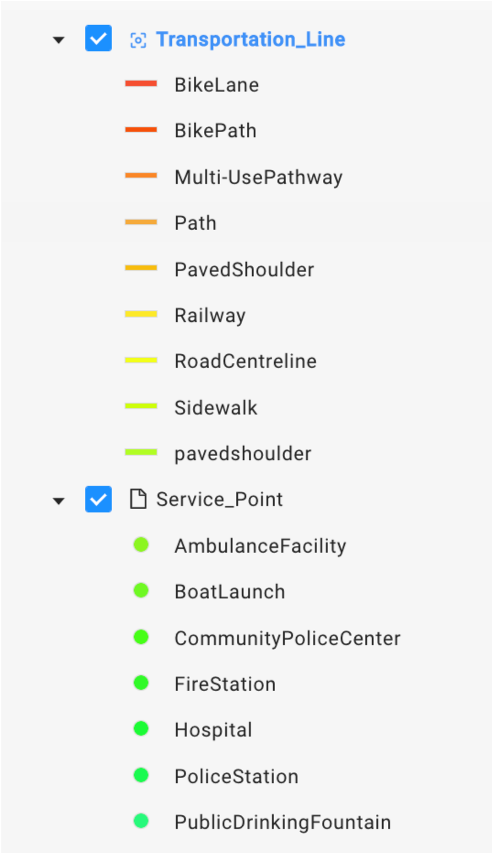

Figure 10. An example of colour classification in Open HD Maps

3. Application and discussion

3.1 Application

Using public maps, this application aids automatic vehicles in making decisions on the road as a simple version of an autopilot help system. First of all, positioning is an integral part of autonomous driving, and the method we are using is called WatchPosition from HTML, which retrieves periodic updates about the current geographical location of the device (such as a GPS in a car). In our case, we use the sharing location feature in Chrome to mimic a car GPS.

As the coordinates are received in real-time, the location will be displayed on the Ottawa HD map via the Open HD Maps platform. Specifically, we use Selenium, a tool for automating web applications for testing purposes, to compensate for the absence of geolocation APIs of Open HD Maps, in order to display the real-time location on the Ottawa HD map automatically.

Open HD Maps divides the area by colour. Figure 11 illustrates 11 categories of the Waterloo HD map, and each category is further subdivided. We use the *Get features API* from Open HD Maps to retrieve all features with their classification within 500m of the specified point.

OSM provides more detailed information on road and traffic signals that we would like to emphasize. Using Overpass API, we are able to send a request for current road information and traffic signs to OSM and they will send back the data set that corresponds to the request. As an example, road information could include the name, type, maximum speed, number of lanes, and direction of the road where the device is currently located. In this way, we are able to provide real-time information on roads and traffic signs to automatic vehicles.

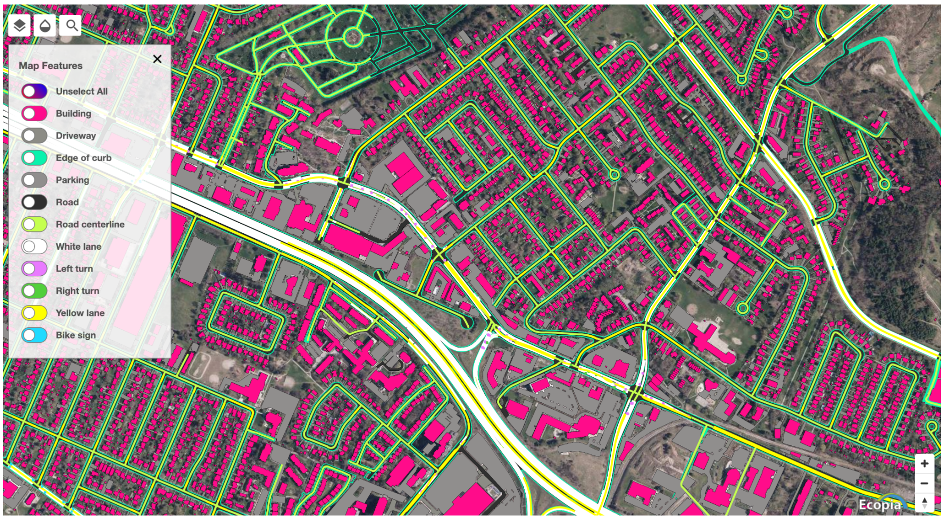

Figure 11. Waterloo HD Map from Open HD Maps

3.2 Discussion

Due to the fact that this application is built on a free HD map, we must get the current location of the car in a relatively difficult way as the map does not provide an API. An alternative method for obtaining a location is the Geocoding API offered by Google.

Google Maps shows vehicles' directions and uses real-time traffic information to find the best route to the destination. The traffic data of Google Maps comes from a variety of sources, including government departments of transportation and private data providers. Besides, the billion Google Maps users on the road act as sensors for the app, which make the service as precise as possible.

Google Maps' early versions relied on traffic sensors placed by governments and commercial enterprises. By utilizing radar technology and sensors, road traffic conditions are able determined. In 2013, Google Maps improved its accuracy following the acquisition of the famous Waze software. Waze software is used by drivers to report traffic issues such as disabled cars, accidents, slowdowns, and even speed traps. Thus, Google Maps is able to obtain precise real-time traffic information, which is useful for our application. The only drawback is that Google Map API requires payment.

4. Conclusion

In this paper, we describe the research on automatic vehicles, including the techniques they used, the companies that developed them, and the most important tool to accomplish them: HD maps. This report shows how HD maps are made, and the two giant companies that make HD maps. Also, the general positioning technology: GPS, and the more accurate positioning technology: Particle filtering are presented here. Creating HD maps is difficult, so open HD map platforms are especially important for the development of HD maps. Two major HD map platforms are presented here: Open Street Map and OpenHDMaps.

This application provides assistance for self-driving cars by utilizing OpenStreetMap and OpenHD Maps as a simplified version of the Autopilot help system. With the help of this application, the automated vehicles could receive real-time information about roads, street lamps, and traffic signals, as well as their location on a map. By combining this application with Google Maps, it could be enhanced with real-time traffic data. That way we will be able to get a more detailed and functional autopilot help system, and it will be the next step we will take.

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