Best Practices for Surveying and Mapping Roadways and Intersections for Connected Vehicle Applications

Task 3 Report: Map Representations

Executive Summary: Connected vehicles require accurate and up-to-date maps both to allow coordination between vehicles and with the infrastructure. Such maps may also have utility for application aspects such as vehicle position estimation or control. For successful collaboration with automakers, it is expected that some entities (government or commercial) will develop and maintain continent scale map databases, eventually global scale. Maintenance of this master map will result in differences between the master map and the maps stored on user vehicles. The master map is too large to be convenient for wireless communication to users in its entirety; therefore, mechanisms have been defined for communication of application relevant pieces of the map to connected vehicles. This report discusses these processes, general standards, and the SAE J2735 standard, which along with its modifications for demonstration purposes is the dominant standard for connected vehicle applications.

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I. Introduction

Detailed roadway feature maps will need to be developed, maintained, and communicated consistently to support Connected Vehicle (CV) applications. As a result, within the U.S. alone, hundreds of thousands of intersections and millions of miles of roadway will need to be surveyed, with application-relevant roadway features mapped to application-specific accuracies. Besides connected vehicle applications, accurate roadway digital databases are also important to other roadway applications such as: roadway planning, construction documentation, accident investigation, roadway inventory assessment, pavement characterization, and vertical clearances. While many of these applications have been of interest to Departments of Transportation (DOT's) for decades, connected and autonomous vehicles are now bringing these high accuracy maps within the interests of entities with commercial ambitions, such as auto manufacturers. Successful global commercialization of products incorporating high-accuracy digital maps has created a need for a standard digital map representation of the road way features and attributes. The digital map representation should possess the following important characteristics:

- **Spatial continuity:** Connected vehicle commercial success will require uniformity of database contents, accuracy, and behavior across geographic boundaries.
- **Automaker uniformity:** Connected vehicle market success will require uniform vehicle behavioral interactions with infrastructure and other vehicles across auto manufacturers.
- **Concise and transmittable**: Map information should be efficiently and reliably transmittable as certain roadway and intersection features must be shared in real-time with vehicles supporting CV applications.
- **Updatable:** The roadways, the continental plates on which they sit, the roadway environment, and the coordinate systems in which they are defined are all time varying. Hence, roadway maps should be readily updatable.

The automated sensor-based precision mapping process is discussed in the Task 1 report [1]. Map updating will be discussed in the Task 4 report.

II. Map Representation Approaches

This section reviews various map representations currently known to be available. For successful collaboration with automakers, it is expected that some entities (government or commercial) will develop and maintain a continent scale map database, eventually global scale, in some implementation of a GIS. That GIS maintenance will result in differences between the master GIS and the maps stored on user vehicles. The master GIS is too large to be convenient for wireless communication to users in its entirety; therefore, mechanisms have been defined for communication of application relevant pieces of the map to connected vehicles.

Geographic Information Systems (GIS)

Geographic information system (GIS) is a system designed to capture, store, manipulate, analyze, manage, and present all types of spatial or geographical data. ESRI is the dominant supplier of GIS database, display, management, and analysis tools (e.g., ArcGIS). Such GIS store related data in layers each of which contains one type of attribute data: street-level data (highways, major roads, minor roads, one-way arrow indicators, railways), water features, landmarks, building footprints, administrative boundaries and shaded relief imagery. Even within a single jurisdiction, there may be many different GIS databases or one combined

GIS data base. The GIS itself does not impose any standardized set of layers nor requirements for accuracy or data representation format for any given layer. Such standards are determined by outside professional organizations (e.g., SAE, ISO).

As an example, the National Map is a collaborative effort of the United States Geological Survey (USGS) and other federal, state, and local agencies to improve and deliver topographic information for the United States. The National Map is part of the USGS National Geospatial Program. The geographic information available includes orthoimagery (aerial photographs), elevation, geographic names, hydrography, boundaries, transportation, structures and land cover. The National Map is accessible via the Web, as products and services, and as downloadable data. Its applications range from recreation to scientific analysis to emergency response.

Related to transportation, various entities (e.g., federal, state, and regional DOT's; commercial entities) maintain their own internal GIS roadway and roadway feature databases. These may be in unique or proprietary formats, with unique data representations, and entity and geographically dependent accuracies.

The GIS master roadway map of any of these entities is typically very large, containing the roadway map for a large region, possibly with underlying raw sensor data, and many features and attributes necessary for other current and potential applications; therefore, this master GIS is not concise and transmittable as required for CV applications. Instead, certain portions of the master GIS are extracted and converted into other formats (e.g., SAE J2735, ISO 14825) that are designed to be concise and transmittable.

Proprietary Corporate Approaches

There are efforts to develop digital maps with global coverage. Certain corporations (e.g., Apple, Bing, Google) are developing maps intended to be used in consumer applications (routing, advertising, context based search, autonomous taxi service). Such maps do not require high-accuracy and do not contain roadway relative features.

Other corporations (e.g., HERE) are developing highly accurate maps with global coverage, intending to use a "data as a service" business model. HERE will have a fleet of over 300 Mobile Terrestrial Laser Scanner (MTLS) vehicles allowing them to guarantee a maximum time between surveys of three years for any road in the U.S., with higher frequency surveys in urban areas, or surveys on demand in areas that are thought to have changed. Changes may be detected using crowd sourced data or through authorized persons (e.g., DOT employees). HERE is developing at least two products of interest:

- HERE Reality Lens provides calibrated street-level panoramic views. The user can fly thorough the roadway environment and perform various types of measurements to support analysis. This product builds on the EarthMine technology. The database can be accessed via an internet user interface or downloaded (regionally) to the user computer. This is an advanced form of a photolog.
- HERE HD Live Map provides a lane-level map with lane edges and centerline. This product is intended for connected vehicle and autonomous vehicle type of applications. Point features can be stored along the lanes. Both real-time and historical traffic information is expected to be included on a per lane basis.

Both of these products are still under development. If they succeed, it would be the first global roadway map.

Corporate entities define proprietary GIS data structures convenient for their internal use and management. Selected portions of their internal GIS can be export in the pieces and formats (e.g., SAE J2735) defined by DOT's and automobile manufacturers for specific applications such as CV's.

Navigation Data Standard (NDS)

The effort and cost required to maintain proprietary internal GIS formats and convert them to various customer and application specific standards led a consortium of entities to form of the Navigation Data Standard (NDS) Association[1] in 2006. The [National Data Standard (NDS)] specifies the content (e.g., which items), structure (e.g., how stored), and precision of the physical format (e.g., SD card) of a map database suitable for automotive applications.

The NDS specification includes in its HD model various items useful for Advanced Driver Assistance Systems (ADAS), Connected Vehicles (CV), and Autonomous Vehicles (AV):

- High-definition lane models: Store the centerline, boundaries, number of lanes, and attributes (e.g., stop bar, speed limit).
  - May be stored as vectors or splines. Current accuracy is at the meter level. Decimeter level (5-10 cm) accuracy is desired, as it is expected to be required and sufficient for such advanced applications. Items are stored with centimeter precision.
  - Lane connectivity is included, even across intersections, merged lanes, turning pockets, and stopping lanes.
- 3d positioning objects: These are items with locations that may be useful for estimating the position (and state) of a vehicle.
- Grade is accounted for as suitable for Eco-driving and EV range conscious routing.

The standard was originally designed for map databases physically stored on the vehicle.

At present, the on-vehicle physical format map is the main approach on which the system will rely. When there is a communication link, two way communications are possible. Cars could sense the infrastructure and communicate to a server roadway features that are detected. The cars do not communicate to each other. The server (i.e. the cloud), after accumulating sufficient confidence, may alter the map database with such crowd sourced information. The server may communicate map updates to the vehicles. At present, the methods in this paragraph are not standardized, but under consideration.

The standard does discuss methods and means for incremental updates. The communication medium is outside the scope of the specification. Whether or not to include a specification for communication of mapping messages is currently under discussion.

Connected Vehicle Standard

Connected vehicle applications expect to communicate map representations for smaller sections of roadway, via wireless mechanisms, either between vehicles or from the infrastructure to vehicles. This need for transmit-ability, reliability, and accuracy yields a very different set of requirements from those for the large internal roadway GIS's used either statically (without real-time updates) on a vehicle or within government and commercial entities. These specialized needs for communicable roadway map pieces have

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[1] The members of the NDS consortium as of January 2016 includes at least: Auto Navi, BMW, Bosch, Daimler, Denso, Garmin, HERE, Hyundai, Mitsubishi Electric, Mxnavi, Nav Info, Panasonic, Tom Tom, Volkswagen, Volvo. BMW, Volkswagen and Daimler (Mercedes) are already offering their infotainment systems with NDS. TomTom and Nav Info also have NDS products.

Note that the NDS Association is a separate entity from either Society of Automotive Engineers (SAE) or the International Standards Organization (ISO).

resulted in the SAE J2735 standard that is reviewed next. At present, the SAE J2735 is the dominant standard intended to CV applications.

III. SAE J2735

The SAE J2735 standard [3, 4] was designed to enable the mapping needs of CV applications, within limited communication constraints. SAE J2735 specifies the format by which selected elements of a larger roadway feature database are communicated between end-users (connected vehicles and infrastructure).

SAE J2735 Message Set Overview

SAE J2735 supports communication of roadway feature and attribute information between vehicles and infrastructure. Typically, the Map GIS is stored on the infrastructure and communicated to the vehicles, where it is stored and used for some short period of time in support of a CV application. For example, in signal, phase, and timing applications, the intersection controller might broadcast a description of the intersection to all vehicles in the vicinity of the intersection. The vehicles would maintain that intersection map in their local memory at least until they leave the vicinity of the intersection.

SAE J2735 Standard specifies a message set, data frames and data elements and is specifically designed to support applications intended to utilize the 5.9 GHz Dedicated Short Range Communications for Wireless Access in Vehicular Environments (DSRC/WAVE, referred in this document simply as "DSRC"), communications systems. As an example, one of the message sets that is transmitted from roadway to vehicle includes: current operational status, signal phase and timing information, intersection geometry, surface conditions, warnings of potential violations or hazardous conditions, and approaching vehicle information.

The MapData message is used to convey many types of geographic information used in the message set. At present, its primary use is to convey one or more intersection lane geometry maps in a single message. The map message content can include such items as complex intersection descriptions, road segment descriptions, high speed curve outlines (used in curve safety alerts), and segments of roadway (used in platoon applications).

The MapData message can contain information for up to 32 intersections and 32 roadway segments. It contains information regarding intersection geometry such as, total number of lanes in the intersection, lane width, position of the nodes that make up the lanes, position of the stop bar, crown angle of the road etc. It also contains other attributes like direction of a lane, permitted maneuvers in a lane, connection to other lanes, lane sharing attributes etc.

The Signal Phase and Timing (SPAT) message communicates dynamic information related to the map. The SPAT message sends the current movement state of each active phase in the system as needed (values of what lights are active and values for the current status of the light is expected to continue). The state of un-active movements (typically all red) is not normally transmitted. Movements are mapped to specific lanes and approaches by use of lane identifiers present in the message. These lane identifiers correspond to the specific lanes described in the MAP message for that intersection. The current signal preemption and priority status values (when present or active) are also sent.

SAE J2735 Message Set Status

Distribution of such feature maps is still in its infancy. To date, it has not been implemented and tested over large regions (i.e., states, countries).

To date, various CV testbeds, on increasing size scales have been implemented. As these demonstrations have progressed recommended changes (e.g., larger sized messages to allow accurate descriptions of large intersections, additional features) to SAE J2735 have been one of the demonstration outcomes.

IV. Bibliography

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