OpenDRIVE Standard for Road Description

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***Abstract*—The world of autonomous vehicles is developing fast. The best new ideas become new improvements, and later after the testing process, they can be used in the real world. These improvements need countless tests too. Simulation software provide a safer and cheaper alternative to execute them. Simulations are supported with real environment data, which makes the test more reliable and various. The OpenX family is an open format standard family, that provides road data in simulation software. OpenDRIVE was the first project, it gives the basic, the logical road description for simulation software in a standardized way.**

Keywords*—*OpenDRIVE, standard, autonomous driving, road

I. Introduction

The expression "autonomous vehicle" represents a vehicle, that is capable of transport without human help. SAE International, an automotive expert board has developed the J3016 standard, which defines individual levels for driving automation. According to this standard, there are six levels, numbered from zero to five. Level 0 is the level of no automation when the human driver controls the car completely, perhaps some warning functions can be built-in at this level, e.g.: lane departure warning. The automation starts at level 1 (driver assistance), using lateral or longitudinal support features, such as steering or acceleration. At level 2 (partial automation) lateral and longitudinal control can be used together at the same time in the same vehicle. From level of conditional automation (level 3) the vehicle starts to monitor its surround, and it can activate the right driving task if it is necessary, but the driver has to be ready to take back the control in some special cases. An example of level 3 is the traffic jam chauffeur. From level 4, the level of high automation, the vehicle is capable of transport on the roads, but it can't handle all situations. At level 5 the vehicle can drive itself without human help in all conditions. Figure 1 shows the main features of the automation levels according to SAE. [1]

Nowadays the vehicles on the road are maximum at the level of partial automation. The difference between the lower levels are the numbers and types of driver assistance functions. The new developments are coming continuously, and there is a big competition between the companies. The main factors of the developments are money and time. Both are supported by using simulators for testing the new results. These evaluations become more useful when real

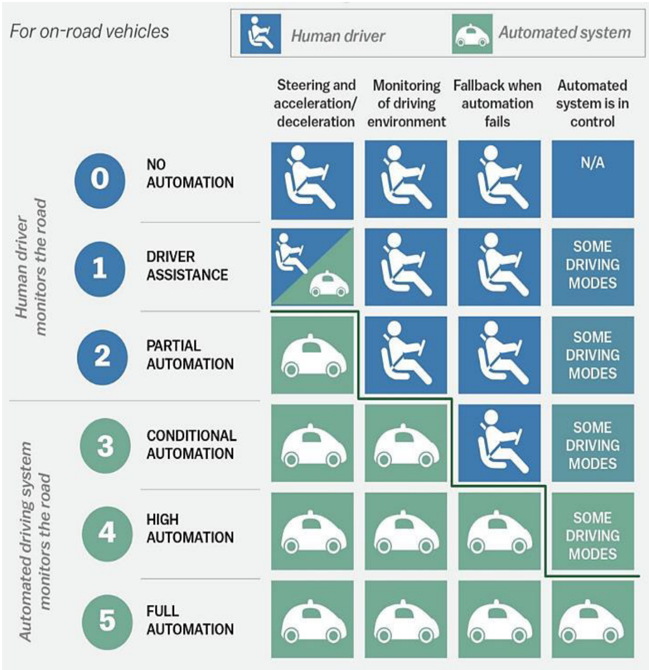


Fig. 1. Levels of automation according to SAE J 3016 [2]

environmental data are used instead of built-in opportunities. The OpenDRIVE, OpenCRG and OpenSCENARIO standards are used in simulation software for modeling the road. They are open projects, and the file structure is based on XML, therefore the creating and using of OpenX data in simulations is advantageous and preferred.

We will introduce the OpenX family and its basic, the OpenDRIVE standard in this paper and a road will be created using the OpenDRIVE standard.

II. The OpenX Standard Family

A. *The OpenDRIVE project*

OpenDRIVE is an open solution, project, and format, for describing road geometry and road connections. Its format can be handled by many simulation software, e.g.: Vires, PreScan, and SUMO.

The OpenDRIVE project was initiated by Vires Simulationstechnologie GmbH, when it started to build a visual database for driving simulators. OpenDRIVE meant a unified platform that is suitable for road description in various simulators. It has started in 2006 with the help of Daimler Driving Simulator company and later more important companies joined this development. From 2018 the ASAM (Association for Standardization of Automation and Measuring Systems) took over and continued the whole project including OpenCRG and OpenSCENARIO, too. [3] [4]

B. OpenCRG project

The OpenCRG project deals with the microscopic surface of the road, that is usable in various driving and tire simulations. It was introduced in 2008. In the name, the "CRG" means Curved Regular Grid, which refers to the elevation data in grid frame with curved reference line. There is an example of OpenCRG data from real laser-scanned point cloud in Figure 2. It shows the unevenness of a cobblestone paved road. The blue color shows the deeper and the yellow color shows the higher part of the road. It was made in centimeter resolution. [5]

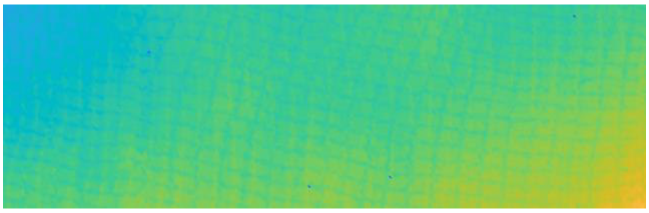


Fig. 2. Microscopic visulization of the road using OpenCRG

C. Static content of the road

Road network from OpenDRIVE and road surface description from OpenCRG gives the description of the static content of the road (Figure 3). Figure 4 shows the connection, the origin and the application of the static content. The data come from planning software, real road scans or another way. Later it can be modified or the whole road geometry can be edited manually. It has a surface feature too, that can use various OpenCRG data too, instead of the original basic road surface descriptions, that makes the simulation more efficient. The result, the static environment allows testing of various situations. Traffic simulation is a good way to test the effect of the road network for the traffic, because the parking ways, bus stops, etc. can influence it too. In autonomous simulations, the vehicle dynamics deals with the vehicle's reaction to the input action or data on a given surface. The different road surface data can be studied using the OpenCRG surface model. Various sensors (camera, Lidar, radar...) are tested in simulations too. The sensing and reaction functions of the vehicle are also investigated. These simulations mean a cheaper and safer way to test the new improvements, this is the biggest advantage of using them. [2]

Fig. 3. Static elements of the road [6]

D. OpenSCENARIO project

OpenSCENARIO is the newest member of the standard family. This project started in 2014. It completes the static content with dynamic content. The basics are OpenDRIVE and OpenCRG standards, and OpenSCENARIO helps to simulate moving objects on the road, and test their behavior in various situations. Traffic or pedestrians can be simulated and ADAS functions can be tested in this way. [6]

III. Road Modeling by OpenDRIVE Tools

The current stable version of OpenDRIVE is 1.4. H. It came out in November 4, 2015. This version was developed by Vires, which came out with a new 1.5 version in February 17, 2019, but most simulation software works better with the version of 1.4. The new owner, ASAM is working on version 1.6, but it improves a new 2.0 version parallel with 1.6.[4]

A. XML

The file name extension of OpenDRIVE is xodr, or xodrz for the zipped files. OpenCRG has crg and OpenSCENARIO uses xosc extension.

OpenDRIVE format is based on XML syntax, which means Extensible Markup Language. It is a describing language that arranges data in hierarchical structure. Tags are used to separate the data. The result can be interpreted by humans and computers too. Because of the good composition the creation, interpretation, and processing are well manageable using this format. There is an example for a road description in xodr format in Notepad++ software in Figure 5.

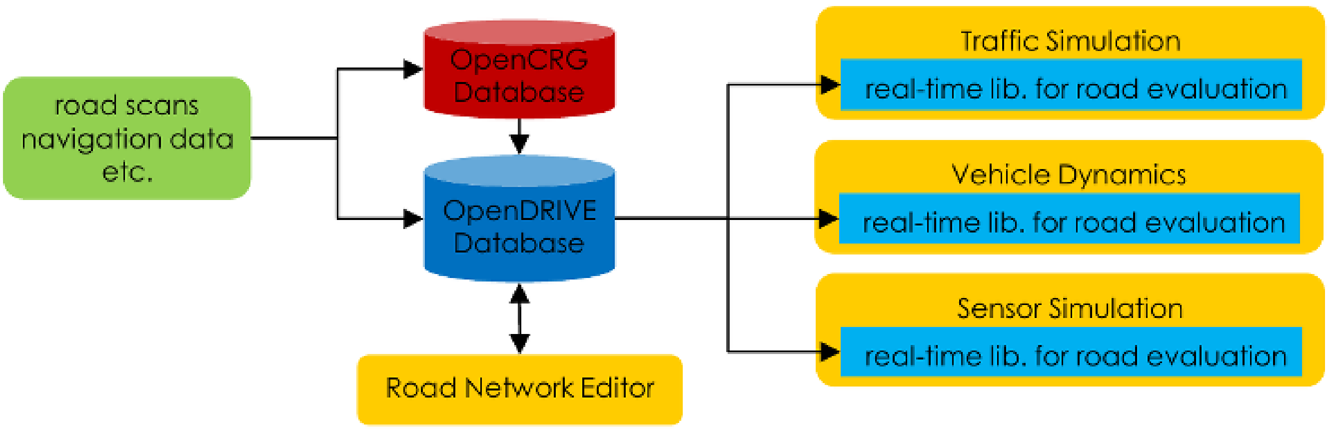


Fig. 4. The connection between OpenDRIVE and OpenCRG [3]

```xml
<?xml version="1.0" encoding="utf-8"?>
<OpenDRIVE>
    <header revMajor="1" revMinor="4" name="Rome, Italy" version
    </header>
    <road name="Via Biscotti" length="15.71" id="1" junction="-1
        <planView>
            <geometry s="0.00" x="0" y="0" hdg="1.57" length="15
                <arc curvature="-0.10"/>
            </geometry>
        </planView>
        <lanes>
            <laneSection s="0">
                <center>
                    <lane id="0" type="none" level= "0">
                        <width sOffset="0.00" a="0.1" b="0" c="0
                    </lane>
                </center>
                <right>
                    <lane id="-1" type="driving" level= "0">
                        <width sOffset="0.00" a="3.00" b="0.00"
                    </lane>
                </right>
            </laneSection>
        </lanes>
    </road>
    <road name="Piazza Mazzini" length="15.71" id="2" junction="
        <planView>
            <geometry s="0.00" x="0" y="0" hdg="1.57" length="15
                <arc curvature="0.10"/>
```

Fig. 5. Road description in OpenDRIVE in XML schema

It starts with a header, that contains some main information. Then the file is divided according to roads and describes the plan view geometry and lane information. [7]

B. *OpenDRIVE description*

Besides the upper example in Figure 5, other information can be defined also in OpenDRIVE format. The first lines contain main information about the OpenDRIVE and XML. The next segment is the header, which describes the data about the road network per road, e.g.: type, plan view, elevation. Signals and signs are defined also for each road. The junctions show the connection between the defined roads, and controllers define the connection between the junctions.

1) Units

The standard contains specifications about the units too. It usually uses SI units, e.g.: position and distance are in meter, angles in radian, time data in secundum; except some special cases, when a given unit has to be used.

2) Coordinate systems

Inertial and track coordinates are used in OpenDRIVE. They are right-handed. The inertial system uses x, y, z coordinates to define the position. The track system is used along the reference line measured the s coordinate from its starting point, the beginning of the road. The lateral position is signed with t, and h is for upward direction. The local system is used for local positioning using u, v, z coordinates, where u is forward, v is left and z is up direction. Curvatures are distinguished according to their direction. The left curve means the positive curvature when the direction of the motion is counter-clockwise. The opposite direction is the negative curvature with the right curve with clockwise motion.

3) Road layout

The road description is divided into three main parts; they are shown in Figure 6. The reference line gives the basis that determines the road geometry. Along the reference line, additional features can be described, e.g.: lanes, traffic signs. Their parameters can be given according to the standard description along the reference line grouped by the properties of the same type in ascending order.

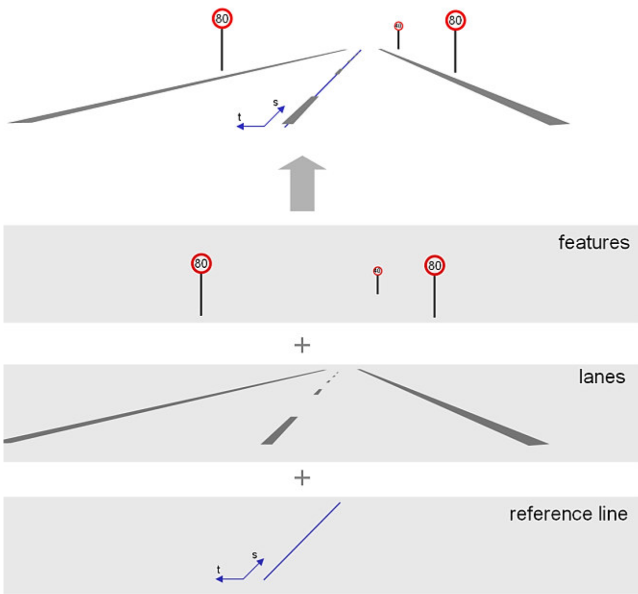


Fig. 6. Main parts of road layout [3]

4) Reference line

The reference line is demonstrated in Figure 7. It is a single line, usually a road centerline, that separates the two different moving directions. The s coordinate starts at the beginning of the road and it increases continuously. Geometric primitives are used to describe the geometry. The known types are a straight line, spiral, curve, cubic polynomial, and parametric cubic curves. Arcs and curves are used for modeling the curves of the road, and spirals ensure the continuous transition between the straight lines and arcs.

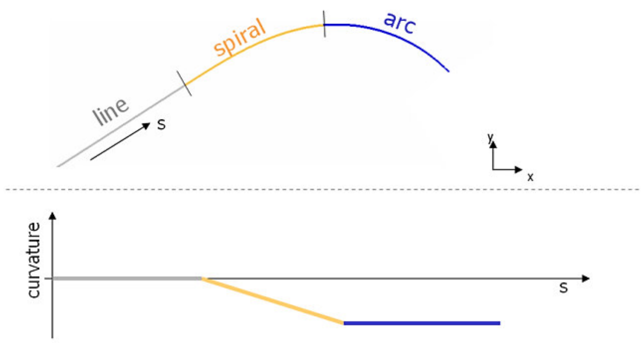


Fig. 7. Reference line [3]

5) Lanes

The road consists of lanes. The lanes have a main transport direction. The reference line is usually in the middle of the road, it has zero width and lane number. The other lanes are numbered relative to the reference line. The numbers increase to the positive t-direction, to the left side, and decrease to negative t-direction, to the right side. The numbers have to be unique in each lane section, and the numbering has to be continuous from the reference line, although the number of lanes can change, as it changes on the roads too. In some cases, the zeroth lane (reference line) has to be offset, e.g. because of a new left-turn lane from the opposite direction lane in the middle of the road. Then a cubic polynom can be applied to solve the lane offset. Figure 8 presents the lane numbers with the described rules.

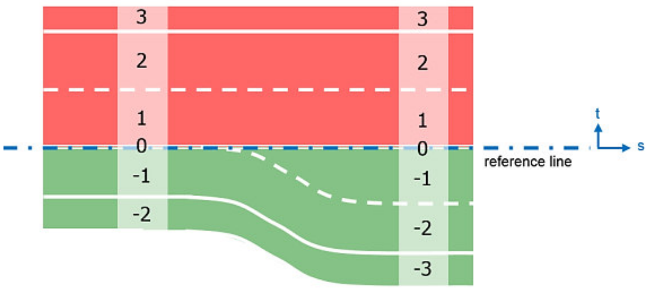


Fig. 8. Lanerepresentation in OpenDRIVE [3]

To handle the changes, the road is divided to lane sections along the reference line. Change in the lane starts a new lane section. It is signed with letters, Figure 9 shows an example of a motorway entry and exit lanes. It shows also, that the lane section is defined only for one side of the road. Lane properties can be assigned to each lane section. Superelevation and crossfall can be defined in OpenDRIVE too when the road is elevated to one side or to the center or other elevation data can be given using surface data or other analytical methods.

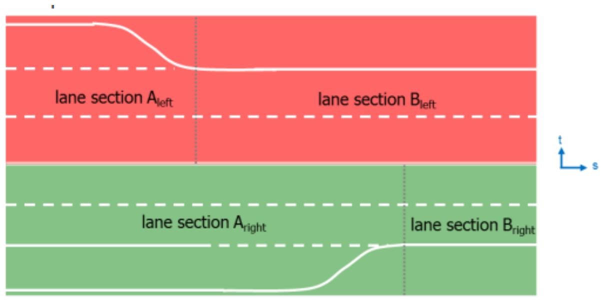
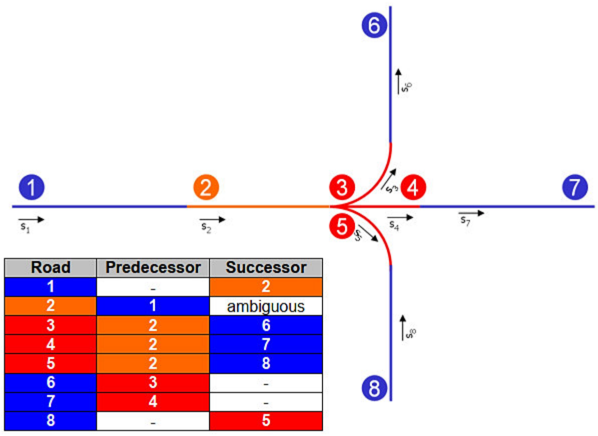


Fig. 9. Lane sections in OpenDRIVE [3]

6) Road Linkage

The individual roads are connected to each other and form a road network. The standard linkage is the continuous connection between two roads, it's type can be a successor or predecessor. Junctions are used in complicated connections. Figure 10 contains an image of a road network and a table with



Road	Predecessor	Successor
1	-	2
2	1	ambiguous
3	2	6
4	2	7
5	2	8
6	3	-
7	4	-
8	-	5

Fig. 10. Linkage types in OpenDRIVE [3]

its connections. Between road 1 and 2 are standard connections. According to the reference line (s coordinate) road 2 comes after road 1, so road 1 has predecessor and road 2 has the successor type. There are more options from road 2, so this connection has to be modeled as a junction. Junction builds the connection between ingoing and outgoing roads. In more complex situations, e.g.: roundabouts, junctions can be organized to junction groups.

7) Neighbors

Other types of road connections are neighbors. Roads can be defined with only one driving direction too. These roads usually have a neighbor parallel with their reference line. Figure 11 shows three roads: a blue, a green and a yellow one. The green road has the maximum, two neighbors, the blue and the yellow has only one. The figure shows the directions of reference line too. The road network editing can be more simplified using neighbors, but the creators of the standard don't suggest to use them.

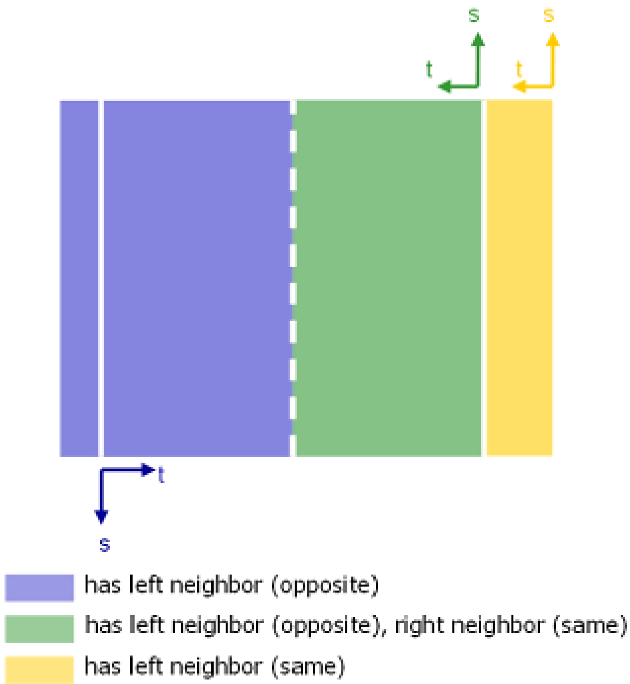


Fig. 11. Neighbors in OpenDRIVE [3]

8) Surface

The surface can be described in OpenDRIVE using standard or extended description. Standard description means a simple description of surface material code, roughness and friction data per lanes. The extended description uses OpenCRG data.

In some cases, roads can meet with railroads, therefore railroads can be described in OpenDRIVE too.

C. OpenDRIVE in practice

OpenDRIVE files can be viewed in OpenDRIVE Viewer simulation software, or e.g. Matlab too. The OpenDRIVE Viewer can be downloaded from the OpenDRIVE webpage under the Downloads tab. It runs under Linux operation system.

A simple road network was created and it is shown in OpenDRIVE Viewer in Figure 12. The OpenDRIVE Viewer was chosen as test software to eliminate the accidental simulation software problems. Figure 5 contains a description of one of these roads. It represents a curvature, so it follows the geometry of Figure 7. It begins with a line and it turns into an arc using a short spiral (clothoid), and then it turns to straight line applying another spiral. The grey color refers to the straight segment, the darker blue color shows the spirals, and the light blue presents the arc.

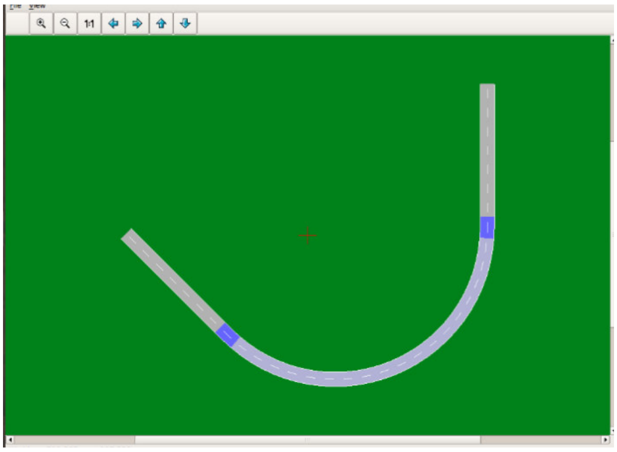


Fig. 12. Created OpenDRIVE road in Viewer

IV. Conclusions

OpenDRIVE is a good choice to describe the road geometry. Its big advantage is the open file format, and the widespread usability in simulation software. ASAM is working on OpenDRIVE 1.6 and 2.0 parallel. It indicates further improvements and features, that supports further success to this standard.

The test road was created successfully in OpenDRIVE file and shown in OpenDRIVE Viewer. The manually editing works well. The examples from the webpage can be used in the Viewer program. The future plan is to test the result in simulation software and create and test complex road geometry in OpenDRIVE.

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