OpenCRG

A unified approach to represent 3D road data in tyre simulation

AK 6.1.3

Tire Models for Vehicle Dynamics, Ride Comfort and Uneven Roads

Dr. Jochen Rauh, Daimler AG, Sindelfingen
Heinz Schindler, BMW AG, München
Lothar Witte, Dr.Ing.h.c.F.Porsche AG, Weissach
Dr. Thomas Kersten, Volkswagen AG, Wolfsburg
Wilhelm Zipperer, Audi AG, Ingolstadt

Motivation

Simulation applications of

- Vehicle Handling,
- Ride Comfort, and
- Durability Load Profiles

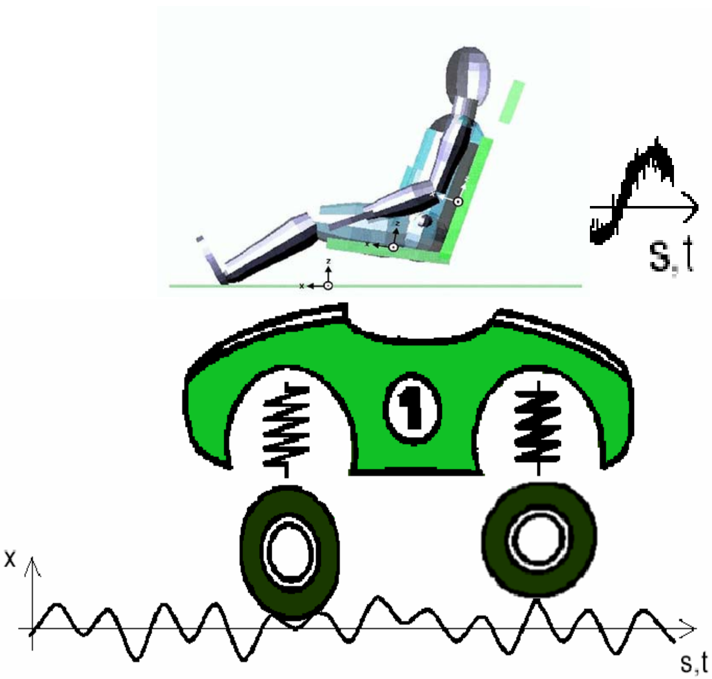
ask for a reliable and efficient road representations.

Seat Model

Chassis Model

Tire Model

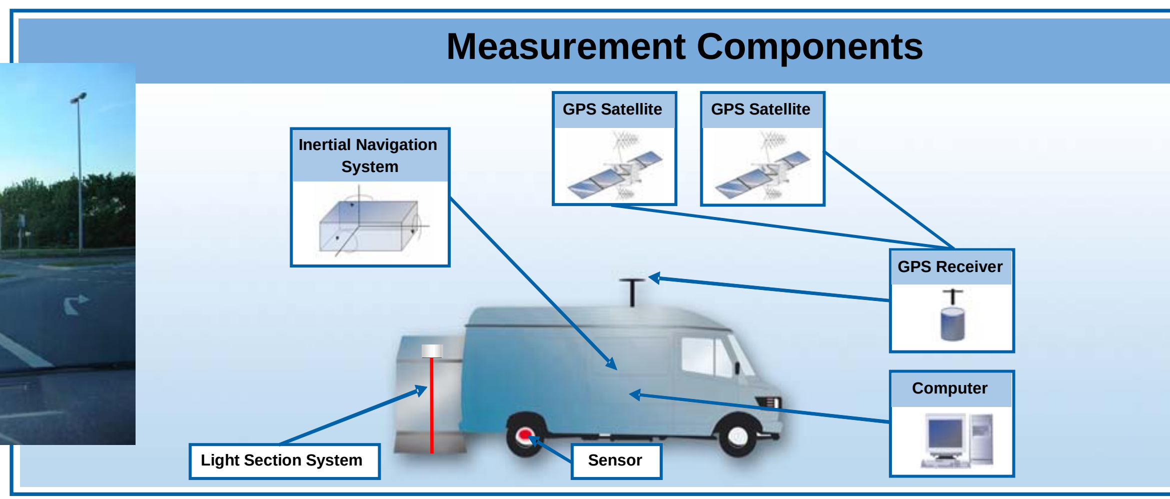
Road Excitation



Step 1: Precision 3D Road Surface Measurements

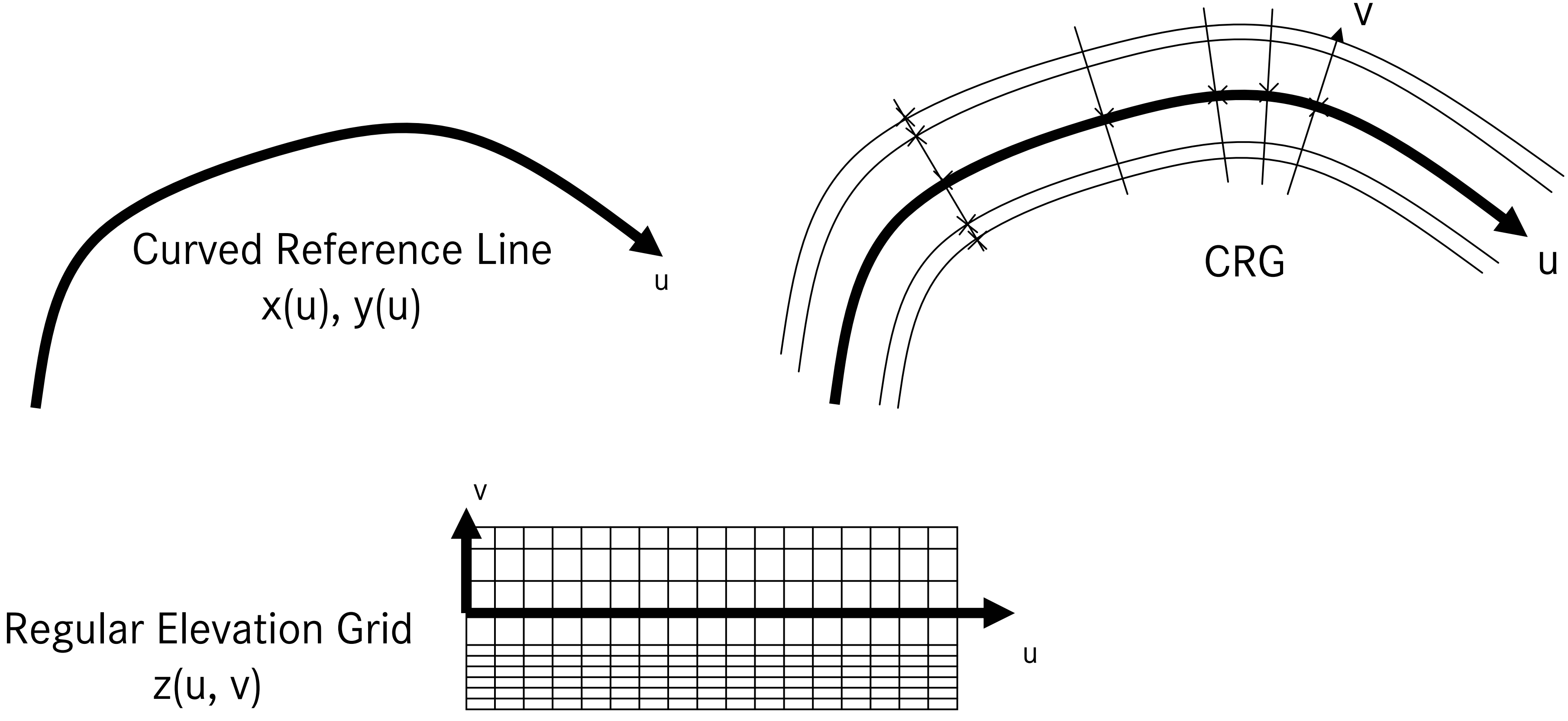
From time-consuming photogrammetric measurements …

… to fast measurements on public roads



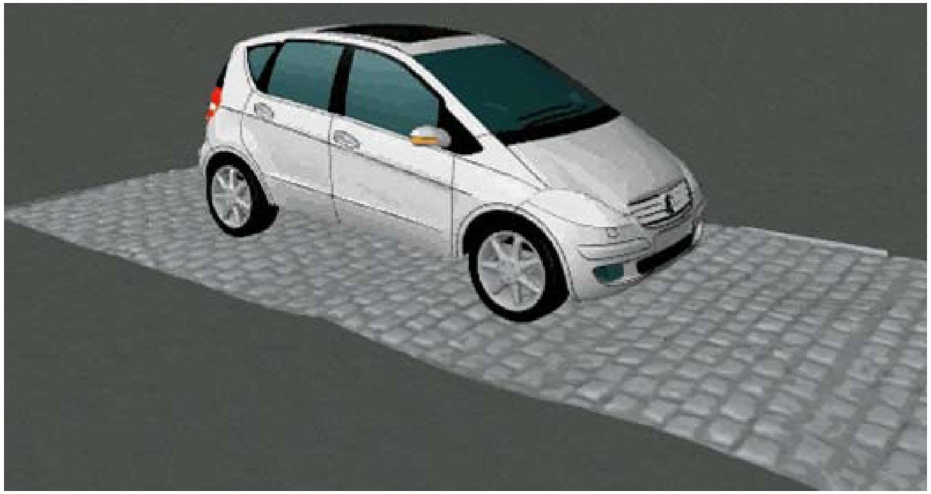
Step 2: Efficient 3D Road Data Representation
The CRG (curved regular grid) Idea

Task: Represent road elevation data close to an arbitrary road center line



Step 3: Implementation and Application Experiences

Original Daimler API implementation (non-public – as application example)



Basic Methods:

- CARCRR(file): open/read CRG file
- CARCRZ(x,y, z): evaluate z(x,y)

Extensions:

- CARCRV(x,y, u,v): evaluate u(x,y), v(x,y)
- CARCRU(u,v, z): evaluate z(u, v)
- CARCRX(u,v, x,y): evaluate x(u, v), y(u,v)

Typical Performance on rough road tracks (for comparison to other implementations):

2.5e-07 sec for one complete CARCRZ call on a 3GHz INTEL CPU

⇒ More than one order of magnitude faster than previous approach

Storage efficiency: only one single road data file of 80MB for 1km of test track to reproduce a longitudinal and lateral resolution of 1cm x 1cm

⇒ Only 1 data file of 80MB instead of > 100 files with > 1 GB total size in previous approach

Step 4: AK 6.1.3 makes OpenCRG available

The AK 6.1.3 working group

Tire Models for Vehicle Dynamics, Ride Comfort and Uneven Roads

of the German OEMs

Audi, BMW, Daimler, Porsche, VW

supports a common Open Source project

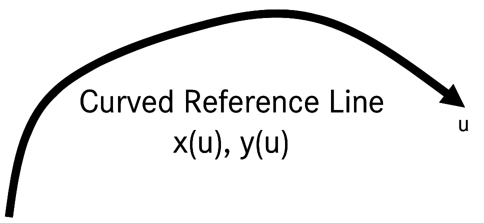
OpenCRG®

to make CRG available to everybody. The provided free material includes an efficient C-API implementation to evaluate the recorded 3D surface information and some Matlab® functions to handle the CRG road data files.

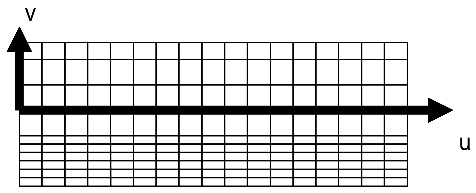
Based on the free Open Software reference implementation OpenCRG, we invite the community to share experiences and would be pleased to have further contributions to complement and extend our initial work.

CRG Basic Idea

Curved Reference Line (Chord Line, Track)



- Defined in base plane by
  - Direction (heading, yaw angle)
- Optionally complemented by
  - Hilliness (slope, inclination, grade, pitch angle)
  - Cross Slope (superelevation, banking, cant, camber, roll angle)



Regular Elevation Grid (locally orthogonal)

- Is a special form of a Regular Grid (a Curvilinear or Structured Grid)
- Defines the elevation in proximity of the *Reference Line*
- Columns are *Longitudinal Cuts* that are parallel to the *Reference Line*
- Rows are *Lateral Cuts* are orthogonal to the *Reference Line*

Reference Line Data Representation

Goals:

- Compact storage is important.
- Sufficient accuracy, even for longer tracks must be guaranteed.

Discussion of numerical aspects:

- *Reference line* positions are “big” numbers, requiring high precision data representations.
- Insufficient data precision leads to locally bad curvature representations achieved by simple 3-point-evaluations.

Solution:

- Data is stored as high precision start location and low precision heading angles describing the *reference line* path.
- Potential drift due to path integration is prevented by redundant high precision end location of the *reference line*.

Coordinate Systems

Optional: world geodetic system (WGS84, as used by GPS and Google Maps)

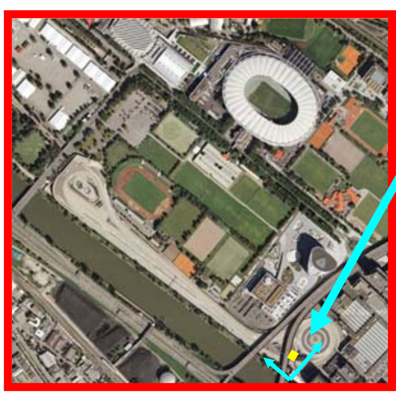
- Header keyword for longitude: reference_line_start_lon
- Header keyword for latitude: reference_line_start_lat

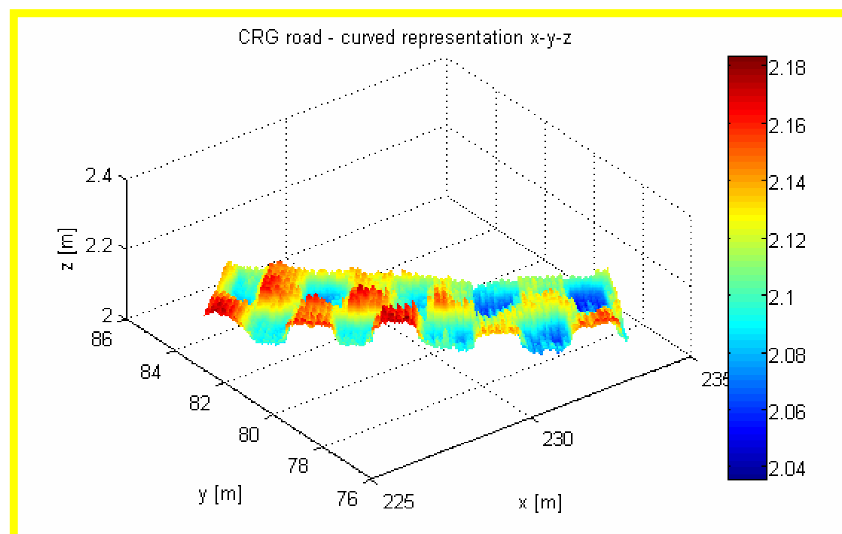
Required: local rectangular system, one of:

- UTM (global grid)
- Local x->east/y->north oriented
- Local rotated

Header keywords:

- reference_line_start_x
- reference_line_start_y





Elevation Grid Data Representation

Goals:

- Compact storage is extremely important.
- Sufficient accuracy, even for roads with big altitude differences.
- Marking of unmeasured road parts, e.g. at the waysides.

Discussion of numerical aspects:

- Low precision data representation is sufficient for most cases (eps~ 1E-6).
- Road with big altitude differences can be represented by a reference line complemented with inclination information without loss in accuracy.

Solution:

- Data is stored as low precision array where columns are lateral road cuts, rows are longitudinal road cuts.
- Unmeasured road parts are represented by NaN (not-a-number), which is replaced by user selectable extrapolation scheme only during evaluation.

Data File Format

Discussing some candidates:

- Matlab® is changing from release to release, and quite hard to read by external applications.
- Other typical measurement data formats: mostly proprietary implementations, no release stability.
- XML: well suited for small data volumes due to clear text representation, but slow to process for large data amounts.
- XML Binary: Standardization not yet completed.
- HDF: very common for large data volumes, but OpenCRG® would be dependent from a quite complex (free) implementation of the HDF library.

Decision: Use Daimler's measurement and simulation data format consisting of

- clear text header part, which allows to just read the beginning of the data file to know what it contains,
- optional clear text or binary data part, which allows to store data either very efficient for computers or readable for humans.
- The structure is most simple and stable (unchanged since it's IBM MVS host implementation in 1990).
- It's already well proven in previous CRG work done by Daimler, TÜV-Süd, and others.
- The data is stored in platform-independent representations (clear text in ISO-8859-1, binary in IEEE-big-endian)
- OpenCRG® will make available a reader as simple platform-independent ANSI-C representation, and a reader/writer-pair as Matlab® m-files.

Data File Format – Clear Text Example

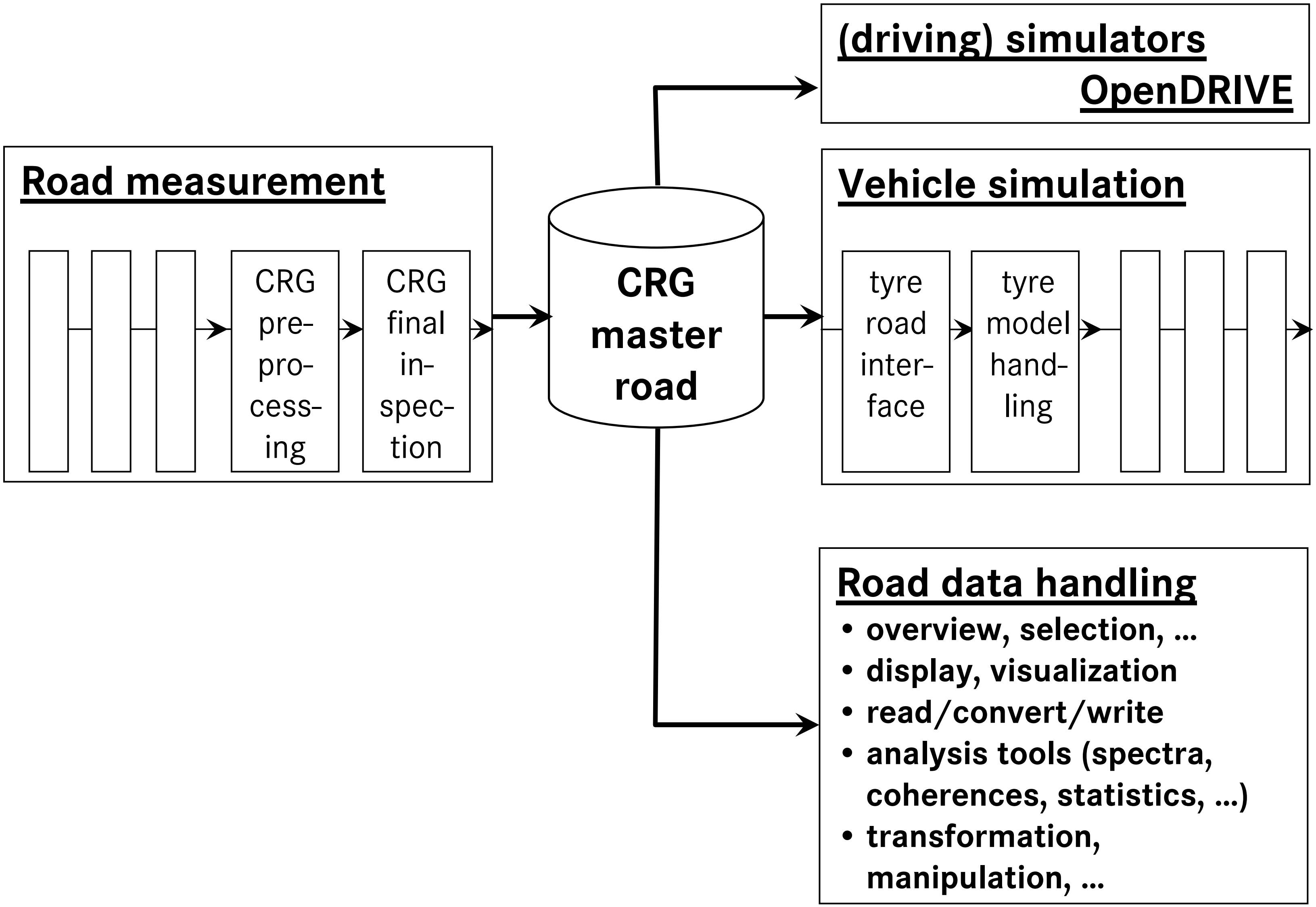
Header part: always clear text

```
$CT                                                   ! comment text block
crg file example for road surface description (width: 3m, length: 22m)
with curved referenceline and grid of (0.25m...1.0m) x 1.0m
$!**********************************************************************
$ROAD_CRG                                            ! crg road parameters
REFERENCE_LINE_START_U   = 0.0
REFERENCE_LINE_START_X   = 0.0
REFERENCE_LINE_START_Y   = 0.0
REFERENCE_LINE_START_PHI = 0.0
REFERENCE_LINE_END_U     = 22.0
REFERENCE_LINE_END_X     = 21.953
REFERENCE_LINE_END_Y     = 1.209
REFERENCE_LINE_END_PHI   = 0.0
REFERENCE_LINE_INCREMENT = 1.0
LONG_SECTION_V_RIGHT     =-1.50          ! with explicit definition below
LONG_SECTION_V_LEFT      = 1.50          ! with explicit definition below
LONG_SECTION_V_INCREMENT = 0.25          ! with explicit definition below
$!**********************************************************************
```

Data part: may be clear text or binary

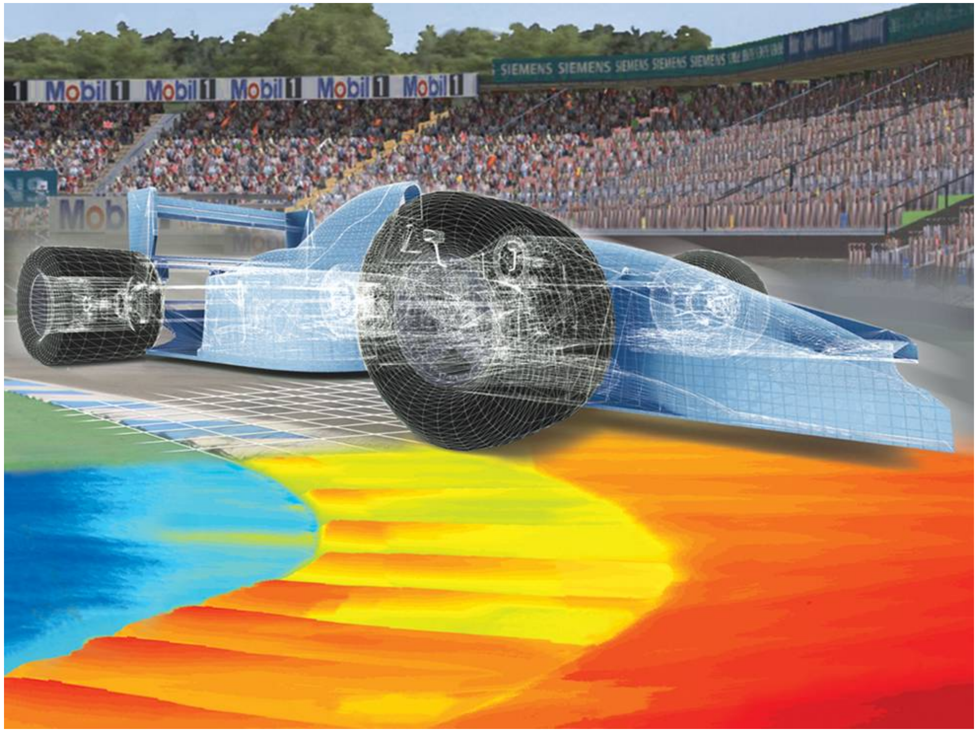
```
0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000
0.0000000 0.0000000 0.0000000 0.0000000 0.0111111 0.0000000 0.0000000 0.0000000
0.0110000 0.0000000 0.0000000 0.0111111 0.0111111 0.0111111 0.0000000 0.0000000
0.0220000 0.0000000 0.0111111 0.0111111 0.0111111 0.0111111 0.0111111 0.0000000
…
```

OpenCRG: the consistent road implementation



OpenCRG® and TÜV 3D-Track

- Mobile, high-resolution topology and roughness measuring of road surfaces to create 3D track models.
- Industrialized process originally based on Daimler's measurement vehicle.
- Ready to provide OpenCRG compatible measurements of private and public road surfaces.



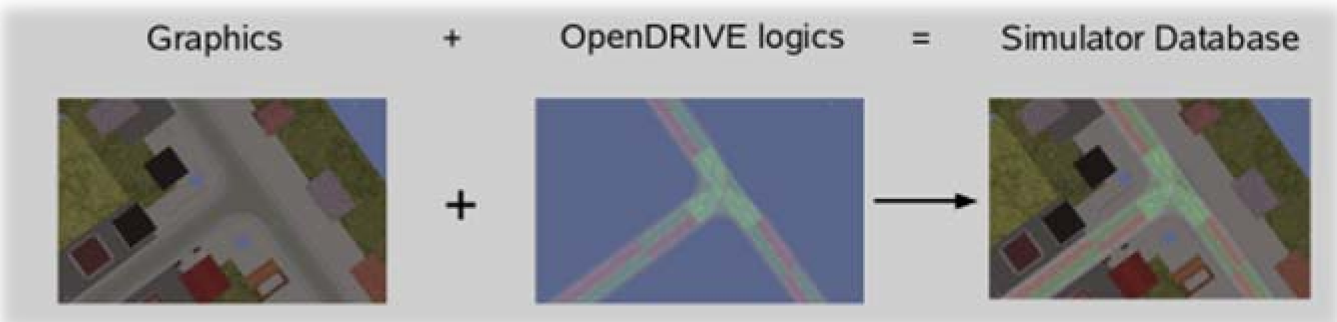
Further information:

http://www.tuev-sued.de/3D-Track

OpenCRG® and OpenDRIVE®

OpenDRIVE® is a file format describing physical properties of individual roads and road networks for driving simulation applications. The file format is made publicly available and may be used free of charge, see http://www.opendrive.org .

The file format is designed to become a common base for the interaction of driving simulators with road information. As already feasible for visual databases, all driving simulators based on OpenDRIVE® shall be capable of exchanging logical databases without the need for major adaptations.



The interaction between suppliers and users of driving simulator databases shall be facilitated by enabling both to refer to a common standard for the logical description of graphical database content.

Although already being used in actual driving simulators, the OpenDRIVE file format is designed to remain open for additional contents, so that features required by various users can still be incorporated into the format.

OpenCRG can be used as an extension to OpenDRIVE to represent precison 3D road surfaces in a complex road network and is already included in the OpenDRIVE V1.2 format description.

OpenCRG® and Matlab®

The Matlab demo routines are suited to read, write and show valid CRG files:

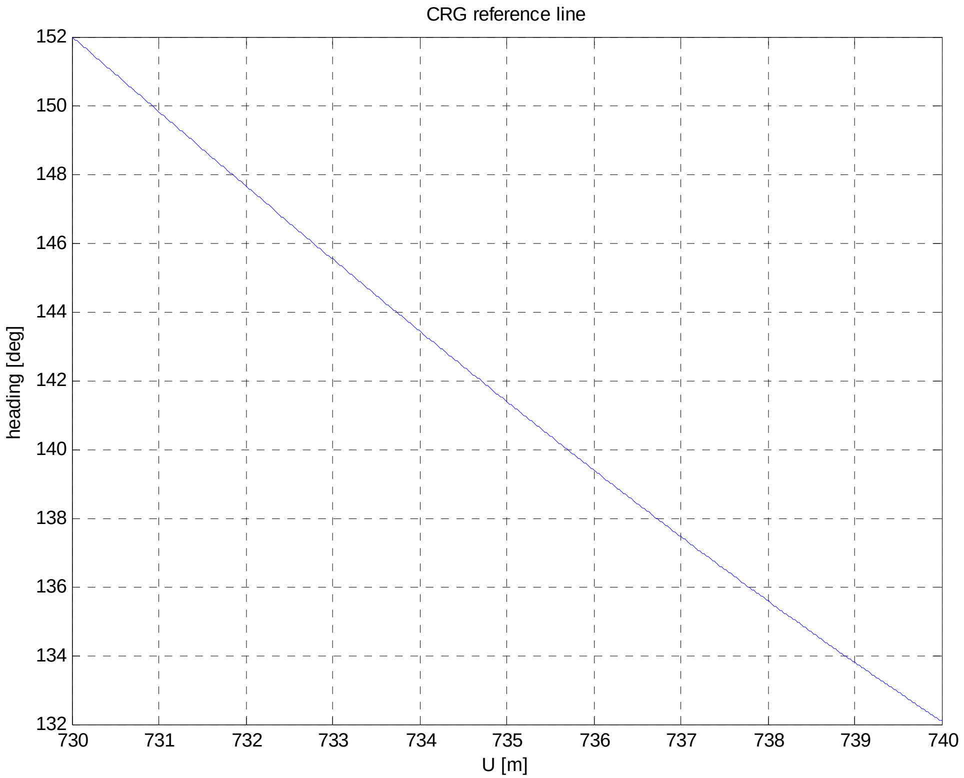
- crg_read: read CRG file contents to CRG Matlab structure
- crg_write: write CRG Matlab structure contents to CRG file.
- crg_show: show all relevant contents of a CRG Matlab structure.
- crg_demo: generates, reads and shows some CRG files. This is a good starting point to learn how to use the demo routines.

Matlab-Demo 1

Figure 1/9 of: `crg_show(crg_read('sample_belgianblock_road.crg'))`

The reference line coordinate u runs from 730m to 740m

we can see the heading angle decreasing by 20 deg.

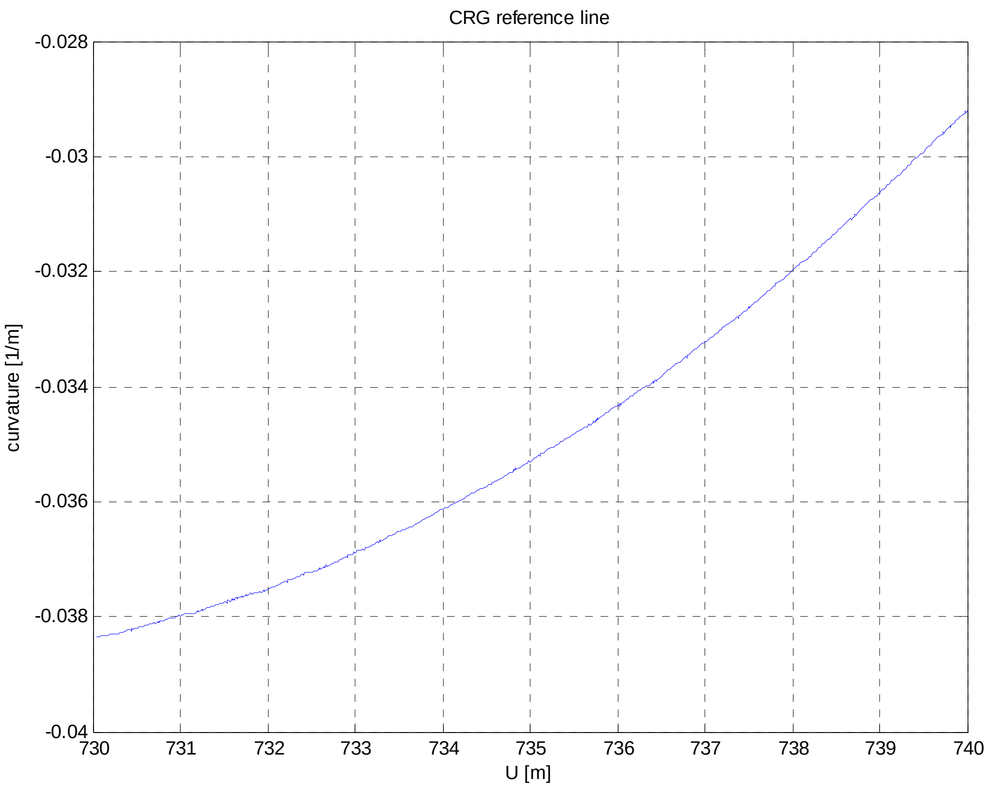


Matlab-Demo 1

Figure 2/9 of: `crg_show(crg_read('sample_belgianblock_road.crg'))`

The curvature of the reference line is starting with 0.04 m^{-1}, equivalent to a 25m radius.

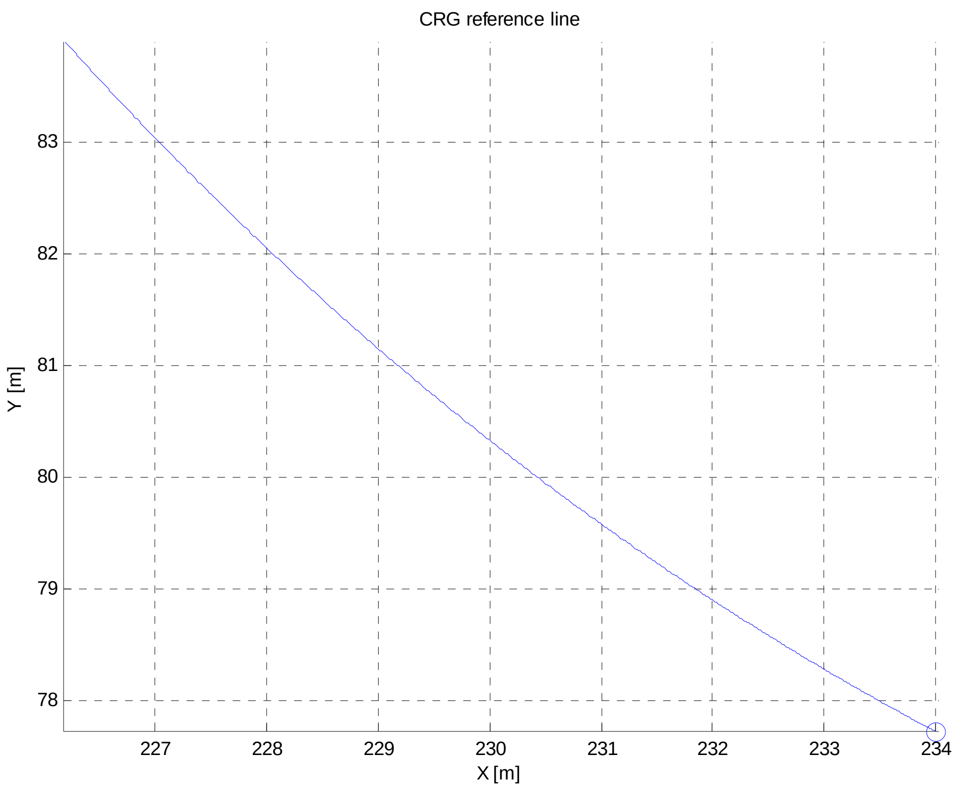
The curvature is smooth: this is very important for further use of the reference line e.g. for steering control.



Matlab-Demo 1

Figure 3/9 of: `crg_show(crg_read('sample_belgianblock_road.crg'))`

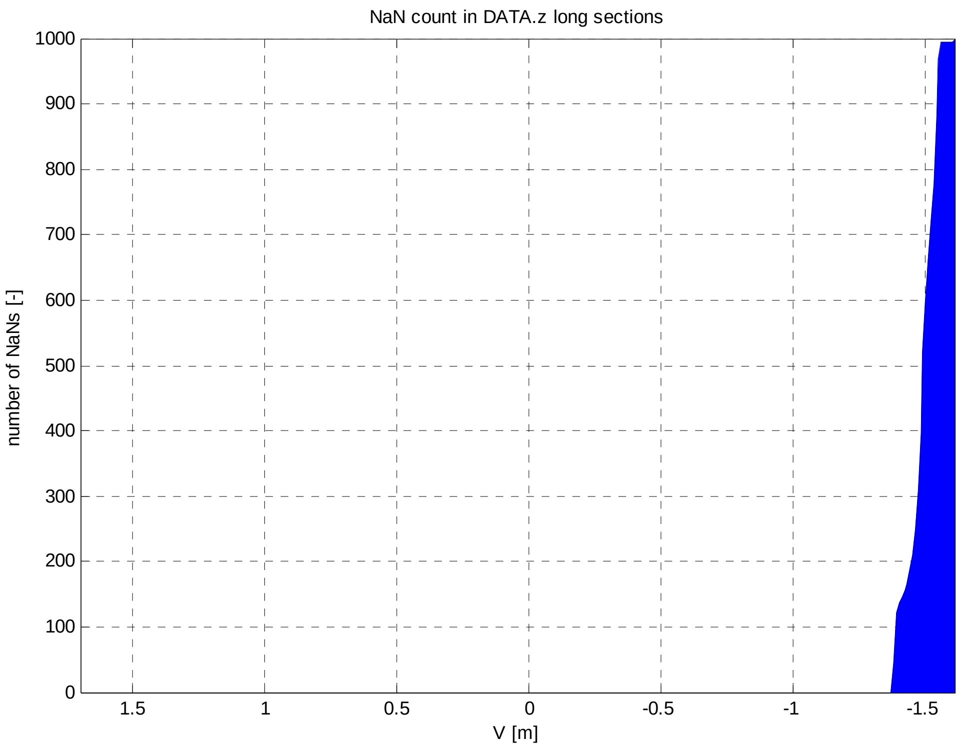
This is the “map” view of the reference line (starting at the lower right edge)



Matlab-Demo 1

Figure 4/9 of: `crg_show(crg_read('sample_belgianblock_road.crg'))`

Missing measurements are stored as NaNs. This shows where NaNs occur.

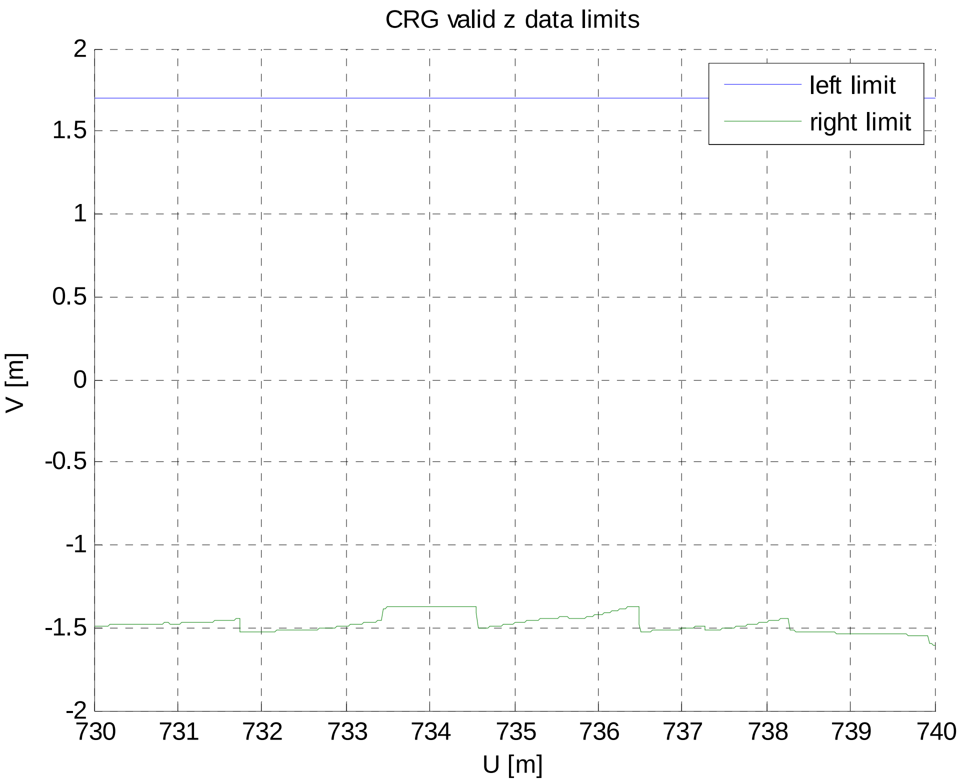


Matlab-Demo 1

Figure 5/9 of: `crg_show(crg_read('sample_belgianblock_road.crg'))`

Limits of valid data along the road.

Missing measurements are stored as NaNs.



Matlab-Demo 1

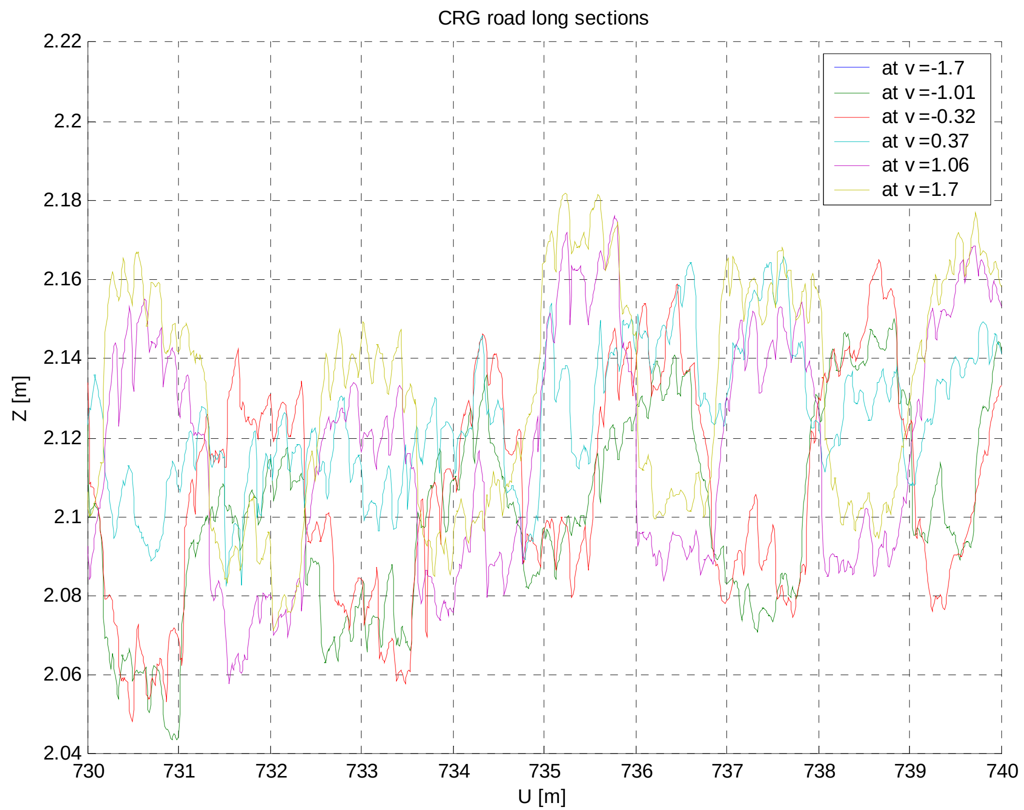
Figure 6/9 of: `crg_show(crg_read('sample_belgianblock_road.crg'))`

Some cross sections.
(yes – it's a rough road!)

Matlab-Demo 1

Figure 7/9 of: `crg_show(crg_read('sample_belgianblock_road.crg'))`

Some long sections.

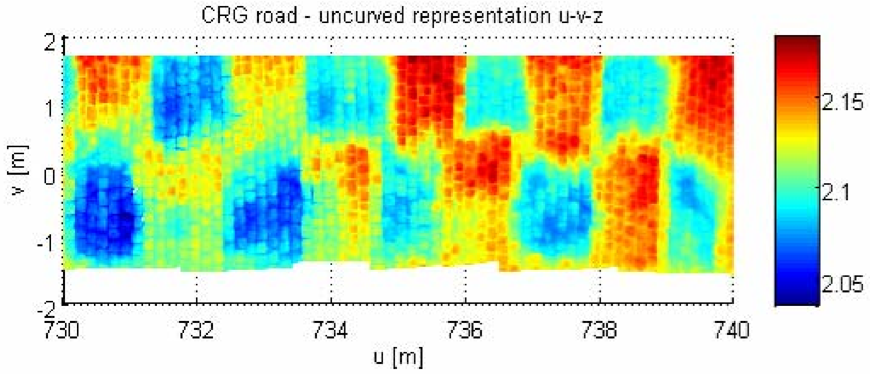


Matlab-Demo 1

Figure 8/9 of: `crg_show(crg_read('sample_belgianblock_road.crg'))`

This is the “straightened” curved road – this is the regular grid.

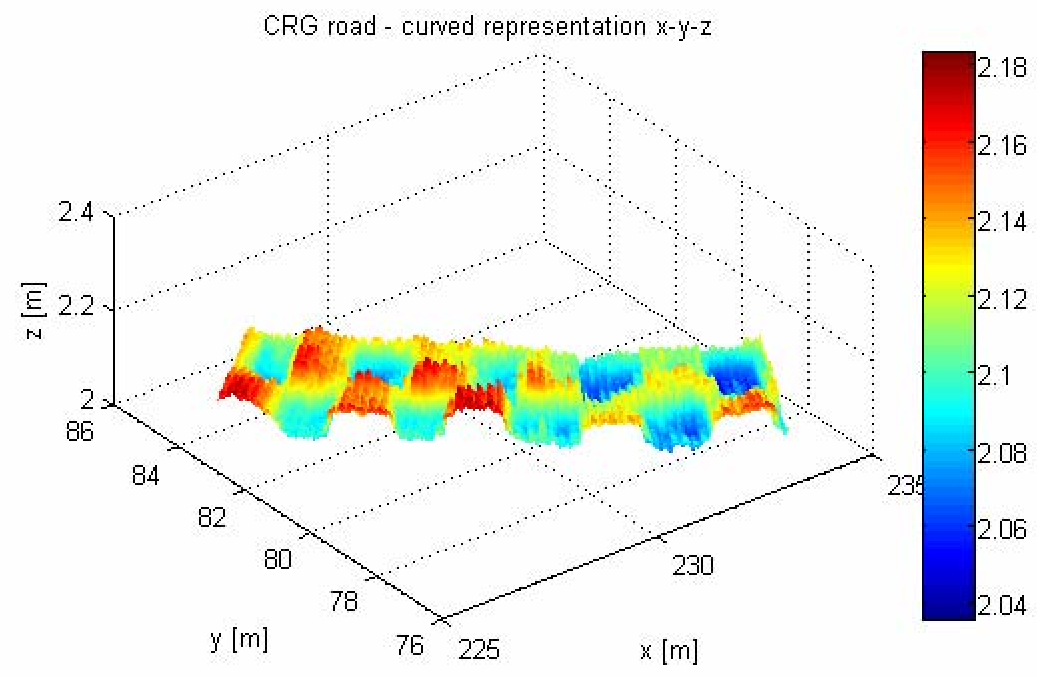
Missing measurements are stored as NaNs



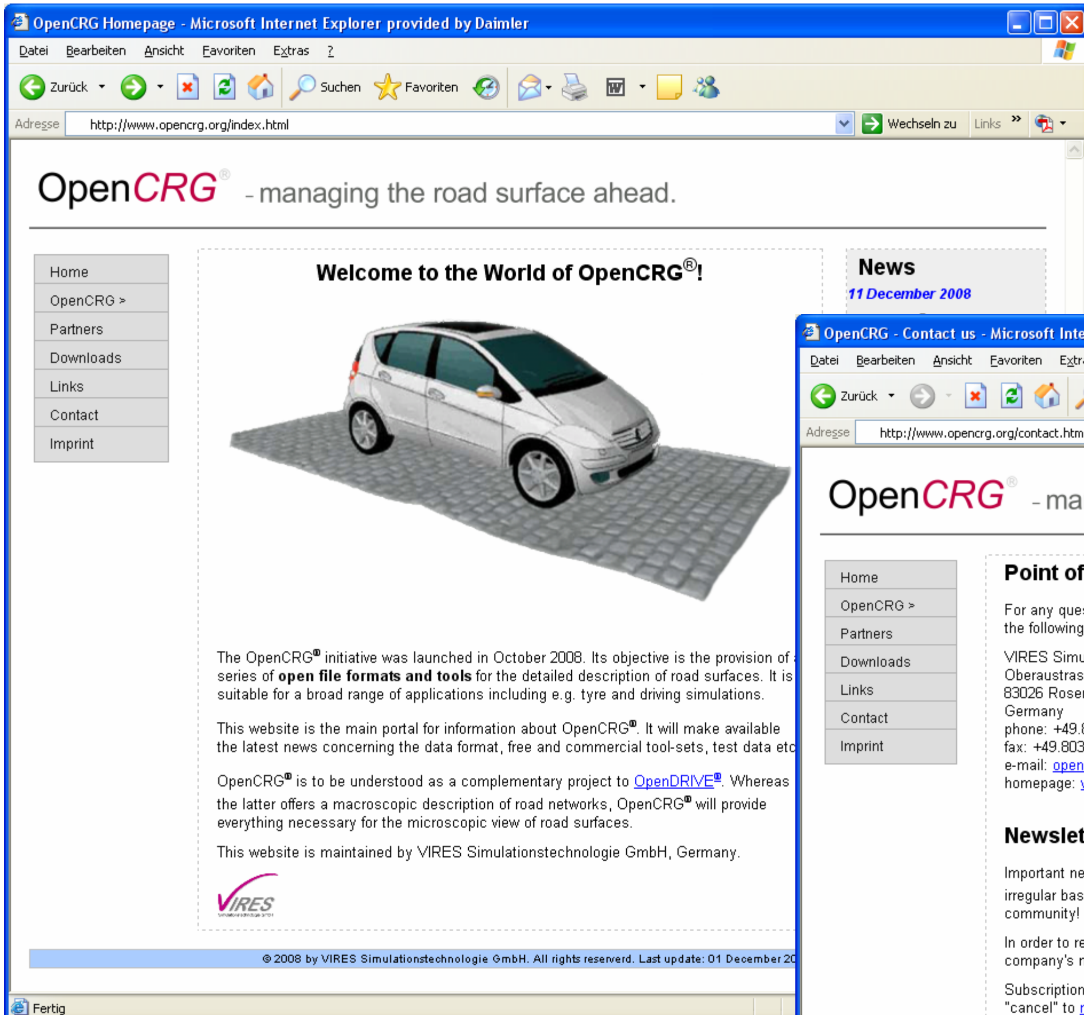
Matlab-Demo 1

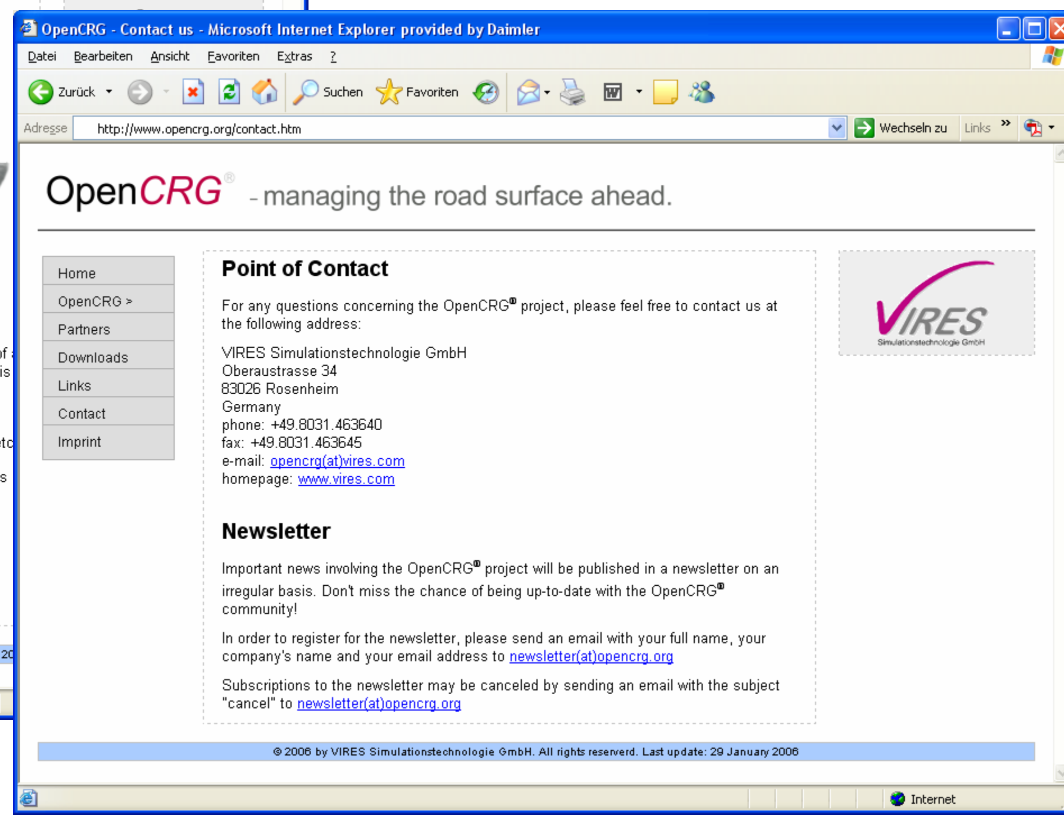
Figure 9/9 of: `crg_show(crg_read('sample_belgianblock_road.crg'))`

This is the "perfect" 3D reconstruction of the measured road – the **C**urved **R**egular **G**rid



OpenCRG is on http://www.opencrg.org





Further applications to come soon...

References

1. Gimmler H., Ammon D. & Rauh J. (2005). Road Profiles: Mobile Measurement, Data Processing for Efficient Simulation and Assessment of Road Properties. VDI-Report No. 1912, 335-352 (in German).
2. N.N. (2007). Announcement of OpenDRIVE extension with CRG (Curved Regular Grid) Road Profile Data Format. http://www.opendrive.org
3. N.N. (2008). Announcement of OpenCRG http://www.opencrg.org
4. Rauh J. (2003). Virtual Development of Ride and Handling Characteristics for Advanced Passenger Cars. Vehicle System Dynamics 40(1):135-155.
5. Rauh J. (2005). CRG (Curved Regular Grid) Road Profile Data Format. http://www.tuev-sued.de/3D-Track.
6. Rauh J. & Mössner-Beigel M. (2008). Tyre simulation challenges. Vehicle System Dynamics, 46 (Supp 1), 49-62.
7. Schick B., Gimmler H., Rauh J. & Witschass S. (2006). 3D-TRACK – Give the simulation the chance for a better work! Mobile, high-resolution topology and roughness measuring of road surfaces to create 3D track models. F2006V095 FISITA automotive world congress, 22.-27.10.2006, Yokohama.