Stereo Vision Inside Tire

P.S. Els
C.M. Becker

University of Pretoria

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14. ABSTRACT

This document forms the final report on the development of a stereo vision system that can be mounted inside a rolling tire, known as T2-CAM for **T**ire-**T**errain **CAM**era. The T2-CAM system measures the three dimensional deformation of the inside of a tire as it rolls over the terrain. The system is designed to work in conjunction with the previously developed Vehicle Dynamics Group (VDG) wheel force transducer that can measure the forces and moments between a tire and terrain under off-road conditions. The combination of these two systems provide the three dimensional geometry, describing the tire-terrain interface from inside the tire, in combination with all forces and moments acting on the tire. The report describes the experimental results obtained with the T2-CAM System. Results indicate that the system is feasible and can provide valuable data to researchers working in the areas of terramechanics as well as tire modeling and testing. The system meets the initial specifications and is expected to provide much needed new insight in understanding of tire-terrain interaction.

15. SUBJECT TERMS

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Scientific Work done during reporting period

1. Abstract

This document forms the final report on the development of a stereo vision system that can be mounted inside a rolling tire, known as T2-CAM for Tire-Terrain CAMera. The T2-CAM system measures the three dimensional deformation of the inside of a tire as it rolls over the terrain. The system is designed to work in conjunction with the previously developed Vehicle Dynamics Group (VDG) wheel force transducer that can measure the forces and moments between a tire and terrain under off-road conditions. The combination of these two systems provide the three dimensional geometry, describing the tire-terrain interface from inside the tire, in combination with all forces and moments acting on the tire. The report describes the experimental results obtained with the T2-CAM System. Results indicate that the system is feasible and can provide valuable data to researchers working in the areas of terramechanics as well as tire modeling and testing. The system meets the initial specifications and is expected to provide much needed new insight in understanding of tire-terrain interaction.

2. Problem statement

Obtaining tire characteristics on off-road terrain for use in tire models, as well as suitable tire models represent a significant research challenge. A first, but extremely important step in this research is to develop suitable tire test equipment. Due to the difficulty of simulating off-road terrain under laboratory conditions, field test equipment is required that can determine tire characteristics on vehicles whilst driving over these terrains. The primary research problem, addressed by this proposal, is the development of field test equipment that can measure dynamic tire deformation from inside a tire rolling over rough and/or soft terrain. The tire deformation can then be compared to the measured forces and moments with the use of the Vehicle Dynamics Group (VDG) wheel force transducer as described in the Wheel Force Transducer Research and Development final report [1].

3. Objectives

In order to obtain tire characteristics over rough off-road terrain, cost-effective field test equipment is required. The proposal therefore has three main objectives [2,3]:

a) Develop a stereo vision system for mounting inside a tire to measure tire deformation on a vehicle whilst driving
b) Develop software to post process the measured data
c) Manufacture, validate and calibrate the stereo vision system inside the tire.

The first objective, namely to develop a stereo vision system for mounting inside a tire to measure tire deformation on a vehicle whilst driving, was achieved and described in [4].

The second interim report [5] described the development of the software used to post process the measured data under point b) above as well the manufacturing of the hardware (point c above). The validation and calibration of the complete stereo vision system inside the tire under point c) is covered in this final report.

4. Stereo vision

Stereo vision works on the same principles as human vision. In very basic terms, two cameras, representing the human eyes, are used to observe the same object from a slightly different viewpoint. The distance between the object and the camera determines where the object is projected onto the image. Objects which are further away from the cameras show less horizontal displacement difference between images, termed the disparity of the object. By finding corresponding pixels between the images a map disparity map can be generated. Re-projection is then used to determine the three dimensional (3-D) position of an object from the two images. Figure 1 shows the different images seen by each camera and how depth affects the re-projected objects and their disparity.

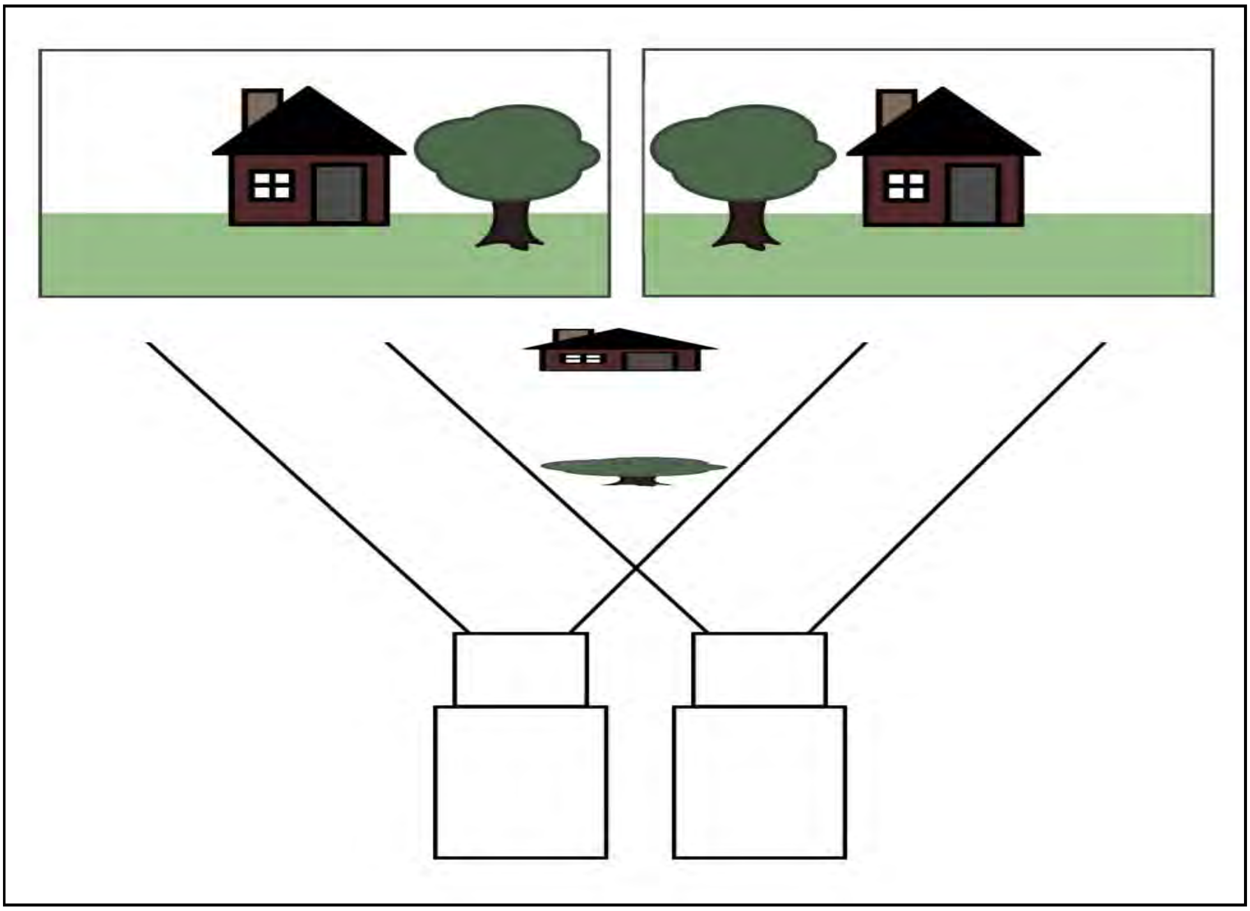


Figure 1 *- How stereo vision works*

5. Post processing software development

The calibration process (shown in Figure 2) was implemented in a piece of software developed as part of this project and aimed to make the calibration, visualization and stereo camera setup easier. The software was built for the Windows operating system using the Open Computer Vision (OpenCV) libraries [6] for computer vision and the Qt library [7] for the user interface.

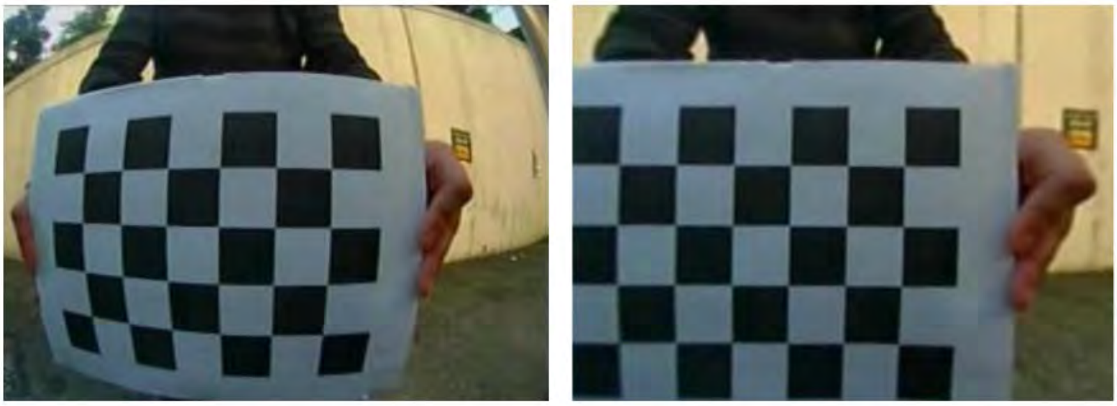
The software has the following features:

- Generates calibration data for stereo cameras using any asymmetric dot calibration surface and saves the data to an ".xml" file.
- Rectifies and show images by applying calibration data (from file or newly generated) to input data.
- Allows input from video files or cameras connected to the computer via USB.
- Provides full control of video playback with options for pause, fast forward, rewind, step forward by a frame or step back by a frame.
- Displays disparity between the rectified images using one of two matching algorithms (Block matching or Semi Global Block matching).
- Tunes stereo matching parameters to improve disparity quality.
- Applies a color-map onto the disparity to allow clear visualization of depth.

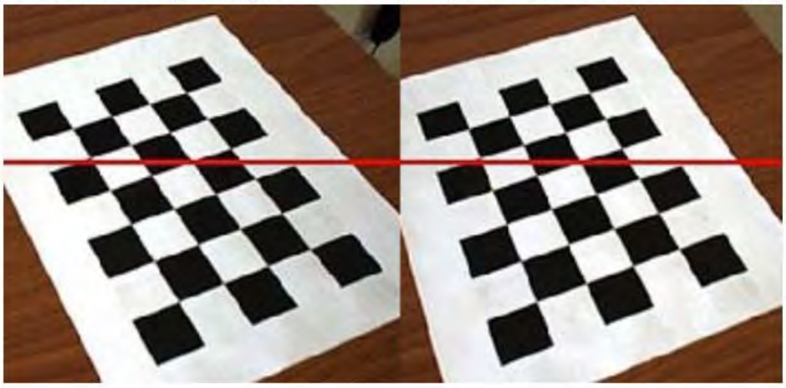
The software application calibrates the cameras using the plane based calibration model from the OpenCV calib3D module and allows the cameras to be calibrated before being mounted in the tire. The calibration process consists of the following steps:

1. Multiple snapshots are taken of a calibration surface with both cameras.

2. An optimization is performed to calculate the distortion coefficients which will allow the lens distortion to be removed from each image individually.
3. The rotational and translational matrices between the two cameras are calculated from the calibration plane data and the two camera views are re-projected to form horizontal epipolar lines.



(a) Capture left and a right images **(b)** Remove lens distortion through calibration



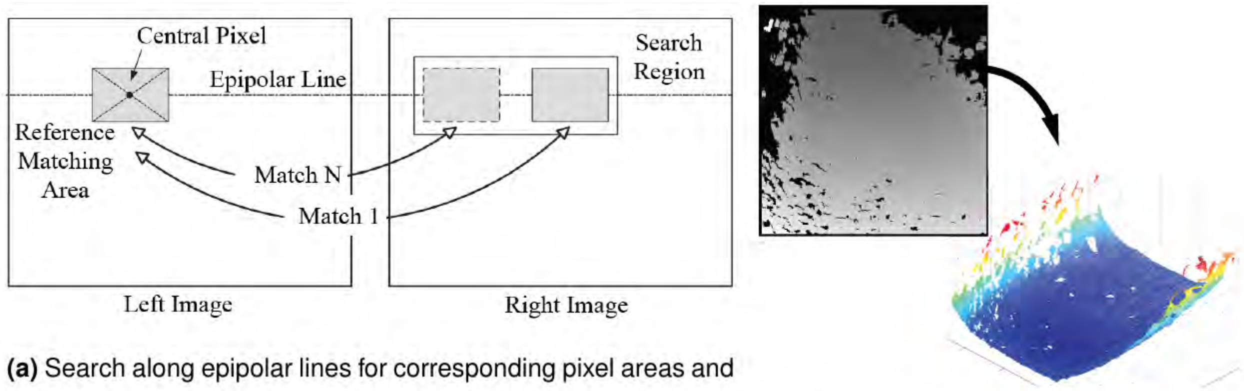
(c) Remove vertical disparity to create epipolar lines

Figure 2 *- Calibrating the cameras and removing disparities in images*

The epipole is the re-projection of the cameras center of projection onto the other cameras image plane. Thus the epipole is the image, in one camera, of the optical center of the other camera. An epipolar line is the projection of a ray, which passes through the center of projection, from the other camera. All epipolar lines intersect at the epipole. The process of aligning the images along epipolar lines is called rectification. The process re-projects the two camera views such that an object projected onto both cameras lie on the same horizontal line. Corresponding pixels between the two views can be obtained by simple line searches. This process is vital for fast and accurate calculation of the horizontal disparity.

Once the epipolar lines are determined the software is able to search along these lines for corresponding pixel areas (shown in Figure 3) and compute the horizontal disparity using either a Block Matching or Semi-Global Block Matching algorithm. The disparity is then used to calculate a 3-D point cloud which creates a visual of what is happening inside the tire as shown in Figure 3.

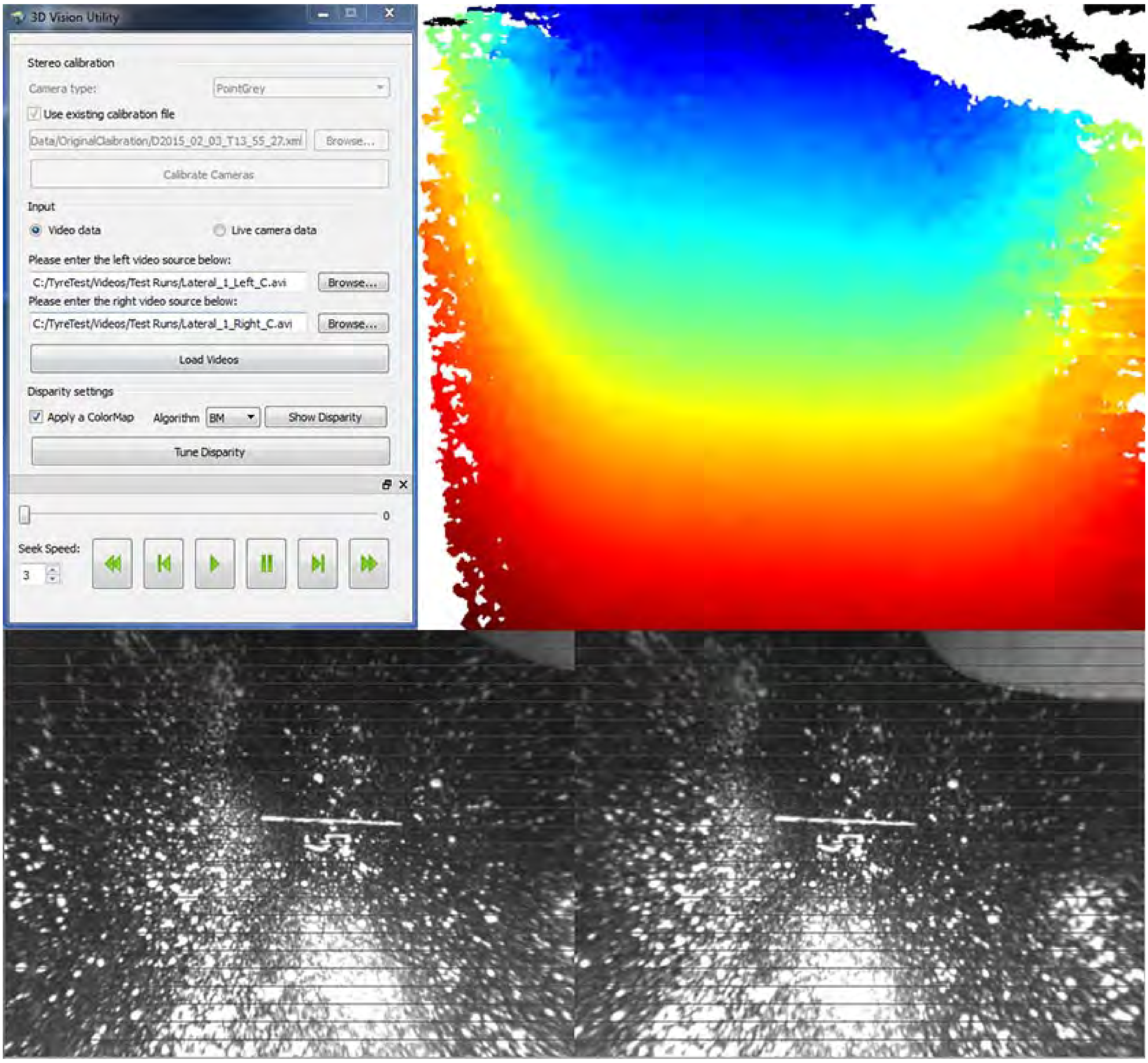
A screenshot of the stereovision software is shown in Figure 4. The figure shows the user interface with rectified images from both the left and right videos captured from inside the tire. A colored depth map is also shown. The map is colored according to the distance from the camera, with red signifying points is closer to the camera and blue further away. The curve of the tire and sidewall is observable even in this simple colored map. The white areas around the edges of the image indicate features are not visible in both camera images.



(a) Search along epipolar lines for corresponding pixel areas and compute disparity

(b) Calculate 3D point cloud from disparity

Figure 3 *- Creating a 3-D point cloud from disparity*



Camera type: PointGrey

☑ Use existing calibration file

Data/OriginalCalibration/D2015_02_03_T13_55_27.xml

● Video data ○ Live camera data

Please enter the left video source below:

C:/TyreTest/Videos/Test Runs/Lateral_1_Left_C.avi

Please enter the right video source below:

C:/TyreTest/Videos/Test Runs/Lateral_1_Right_C.avi

☑ Apply a ColorMap Algorithm BM

Seek Speed: 3

Figure 4 *- Screenshot of the stereovision software interface with an example of a rectified stereo image pair and the corresponding disparity map (colored with red being the closest points to the camera and blue being the furthest.*

6. Hardware

Figure 5 indicates the original design of the hardware to be fitted inside the tire (left), compared to the actual hardware manufactured (right). The rim was painted white to reflect the light from the LED's evenly towards the tire.

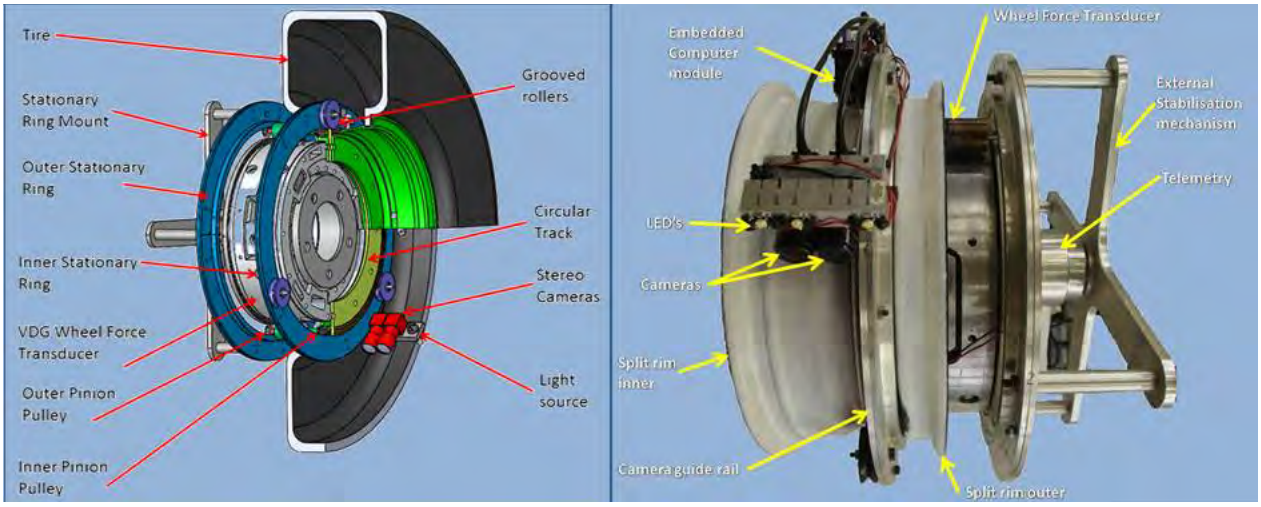


Figure 5 *– Description of complete T2-CAM system with VDG wheel force transducer*

The prototype T2-CAM system was assembled inside the tire. The complete T2-CAM system, in conjunction with the VDG wheel force transducer, is mounted on a test vehicle as indicated in Figure 6. Several static tests were performed including vertical loading on flat surface as well as cleats at different angles. Dynamic tests were performed with the vehicle driving lateral and longitudinal cleats as well as obstacles of different sizes.

Figure 6 *– Complete T2-CAM system with VDG wheel force transducer fitted to test vehicle*

7. Results

The most exciting and intuitive test results were obtained by driving over cleats. Figure ***9***7 shows the 3-D point cloud obtained from the stereo vision system (colored points) superimposed on the camera image (dark grey with white speckle pattern). The flat contact area when the tire is moving on the level road can be seen. The color is scaled according to the vertical displacement of the tire e.g. blue is low and red is high. The image disappears beyond the red part of the spectrum because these parts of the side wall of the tire are not visible in both camera images and correspondences can therefore not be found.

Figure 8 (left) shows the corresponding results when the vehicle is driven over a longitudinal cleat (round bar) as indicated in Figure 8 (right). The three-dimensional deformation of the tire can be clearly seen.

Making lateral cuts through the three-dimensional image result in lines representing the vertical deformation of the tire at specified longitudinal positions as indicated in Figure 9. It should be noted that these displacements are referenced relative to the camera and not to the ground.

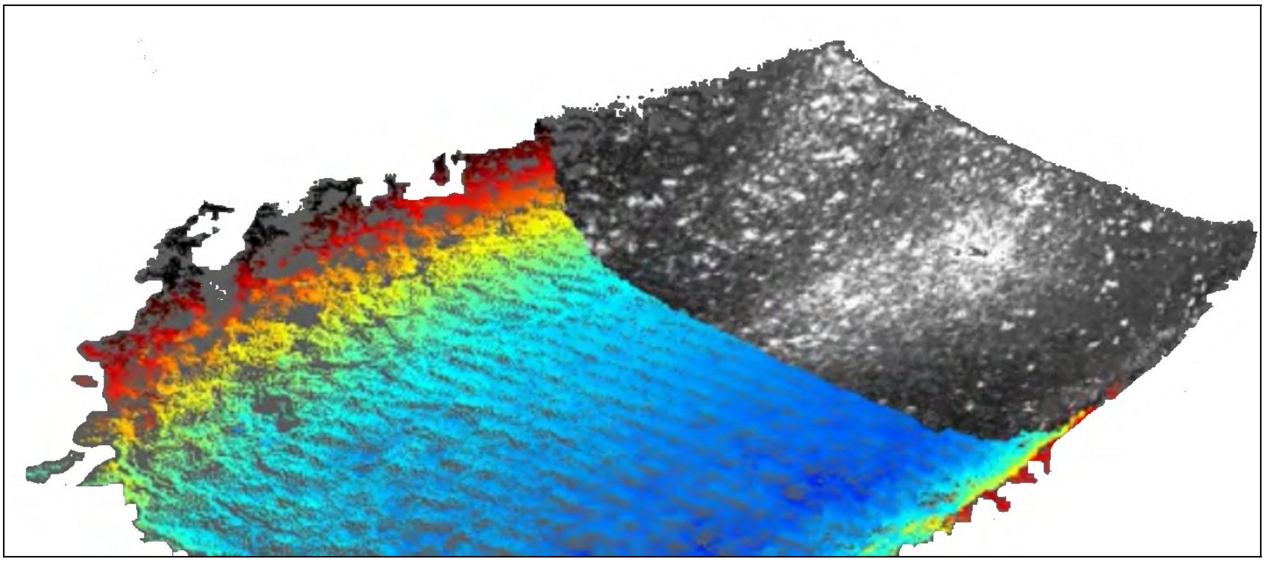


Figure 7 *– Three-dimensional deformation with tire on level surface*

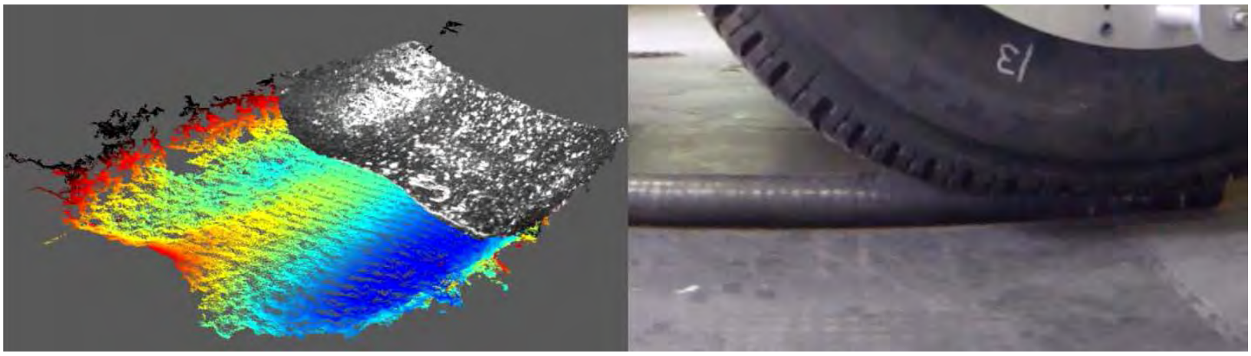


Figure 8 *– Three-dimensional surface for tire driving over longitudinal cleat (left) as well as test setup on vehicle (right)*

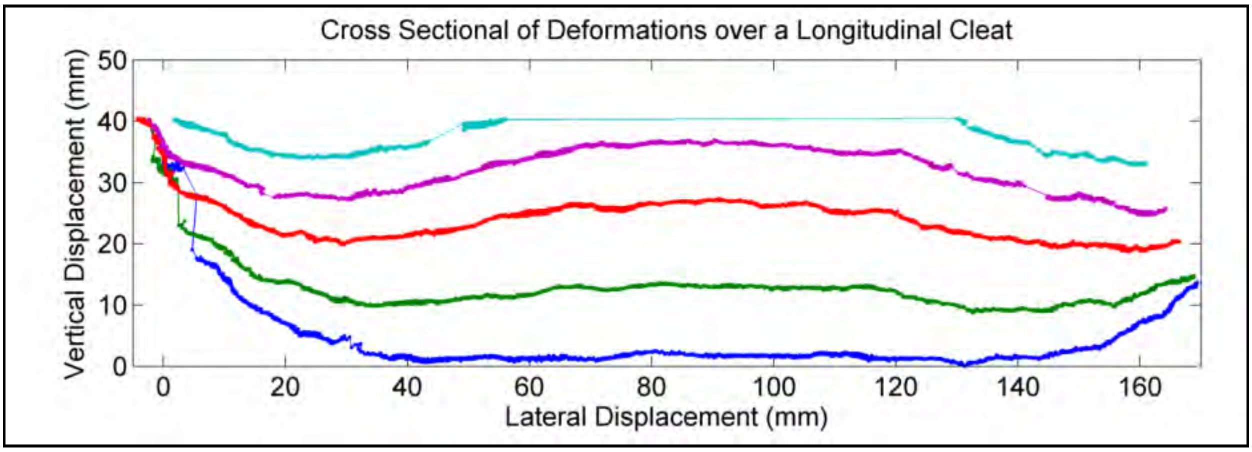


Figure 9 *– Lateral cuts from 3-D image at different longitudinal positions when driving over a longitudinal cleat*

9. References

[1] Wheel Force Transducer Research and Development, W911NF-10-1-0463, Final report, February 2012

[2] Proposal: Stereo Vision inside tire, May 2014.

[3] Contract W911NF-14-1-0590, awarded on 21 Aug 2014.

[4] Stereo Vision Inside Tire, W911NF-14-1-0590, 1st Interim Report, 24 November 2014

[5] Stereo Vision Inside Tire, W911NF-14-1-0590, 2nd Interim Report, 22 February 2015

[6] OpenCV. 2015. OpenCV Open Source Computer Vision. [Online]. Available at: opencv.org [Accessed]: 09/01/2015.

[7] Qt. 2015. Qt Project home page. [Online]. Available at: qt-project.org [Accessed]: 15/02/2015.

10. Administrative actions

None

11. Other important information

The project has been successfully completed. The project team also gave formal feedback to representatives from ERDC-GSL, ERDC-CRREL and ERDC-IRO on 3 August 2015 at ERDC-CRREL in Hanover, NH.