

# Camera calibration procedure to improve safety in railway tunnel

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**Abstract** – The aim of this work is to propose a camera calibration procedure for transportation applications in traffic engineering. In particular, a set of camera parameters that describes the mapping between 3-D world referenced coordinates and 2-D image coordinates was identified. This paper describes the camera calibration procedure steps to obtain acquisition of a entire 3-D train profile in critical points of the network.

**Keywords:** linear camera calibration, concentric semicircles, augmented reality, railway engineering

## I. INTRODUCTION

In recent years the issue of tunnels safety has become a matter of great attention because of the needing to integrate traffic engineering with safety engineering. In the last ten years a number of accidents took place in European railway tunnels, which caused serious loss of life and significant damage to structures. These events also stimulated for a critical re-examination of the actual policies.

The growth of railways traffic volume for both passenger cars and cargo trains is an important rate of socio-economic development of a country and often highlights the inadequacy of transportations infrastructures made some years ago. Adjustment, maintenance and installation of appropriate technological systems in existing tunnels and design of innovative criteria for the new ones are topics of great interest in terms of safety.

European standards for safety in railway tunnels essentially refer to the risks associated with fire, collision and derailment. The fire in passenger trains, because of its potential catastrophic consequences, is regarded as the greatest risk, and therefore all the operations proposed by various regulations are focused primarily on this type of risk. The European standard framework is basically made by:

- UIC 779-9 Safety in Railway Tunnels [1] regarding actions to improve safety in tunnels. It provides guidelines for ensuring an adequate level of safety in

railway tunnels, through the adoption of actions of prevention and protection in order to reduce critical events that may endanger human life, and mitigate the impact of accidents. The document applies to all railway tunnels longer than one kilometer, whether they are in operation, under construction or at the design, located on the railway infrastructures.

- The ERA Technical Specification for Interoperability (TSI) [2] drafted by the European Railway Agency and adopted in a Decision by the European Commission, to ensure the interoperability of the trans-European rail system. The interoperability issues apply to the lines within the Trans-European Rail network. TSIs are related to infrastructure, energy, rolling stock, control-command and signaling, maintenance and operation and are in force since 1 December 2002.

Everyday thousands of railways and rapid transits carry billions of passengers and goods all over the world. They are very different transportation systems with a fundamental need in common: to assure a good service to customers through reliable, safe and efficient rail operations. For this reason, the railway companies need a more multidisciplinary and innovative approach to maintenance and traffic management.

They are looking for cutting-edge technology able to give their own people the ability to work at their full potential and fix problems before they arise. According to recent data from the International Union of Railways [3], the Italian railway network is one of the safest in Europe. This confirms that technical innovation has always been a priority for Rete Ferroviaria Italiana, and the safety of its infrastructure is guaranteed by the consistent development of both lineside and onboard safety systems, as well as enhanced operating standards.

## II. SIL4 TRAIN INSPECTION PORTAL

New technologies enable to control maintenance costs, using RAMS (Reliability, Availability, Maintainability and Safety) [4] parameters to feed into the equipment design and the supplier selection, [5]. Monitoring systems and mobile detectors keep track of the infrastructure state,

allowing railway companies to adopt condition-based maintenance and optimize life-cycle costs when setting investment priorities. In recent years, a wide range of innovative technologies has become available on the market: the functional modularity, the interchangeability, and the diagnostics features are the main characteristics to implement in order to realize easy maintenance.

Technology has introduced a variety of tools over the past two decades to improve the condition and capability of the national rail network, but these need to be integrated and managed effectively in order to maximize the benefits they offer.

In this context, MERMEC Group [6][1], global leader and technology innovator specialized in the design and development of end-to-end measurement, signaling and asset management solutions for railways and rapid transits worldwide, has recently developed the *SIL4 Train Inspection Portal* (shown in Fig. 1); a multifunction portal developed to guarantee a complete monitoring of trains passing at speeds up to 300 km/h in critical points of the network (i.e. tunnels, bridges, country borders and junctions between different networks).



Fig. 1. *SIL4 Train Inspection Portal*

The portal consists of two subsystems. The first one analyses the shape of the train and any load using 3-D geometry scans (shown in Fig. 2) to ensure that loading gauge specifications are met on the template. The second subsystem provides a complete thermal map of the rolling stock to detect hot axle-boxes and brakes by means of infrared sensors [7].

The system is designed to be fully compliant with SIL4 according to the international standard IEC/EN 61508 [8] and integrated with signaling systems enable to automatically stop trains whenever defects are detected, without the intervention of the operator. Safety Integrity Level (SIL) is determined for components and systems with safety functions to reduce the risk associated with a device to a justifiable level or “tolerable risk”. More precisely, the safety integrity of a system can be defined as “the probability of a safety-related system performing the required safety function under all stated conditions

within a stated period of time” [8][8].

Thus the specification of the safety function includes both the actions to be taken in response to the existence of particular conditions and also the time for that response to take place. The SIL is a measure of the reliability of the safety function performing to specification.

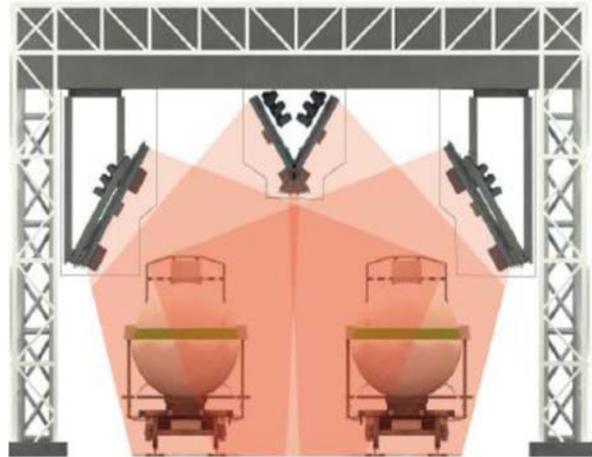


Fig. 2. *3-D Profile Subsystem*

To categorize the safety integrity of a safety function, the probability of failure is considered – in effect the inverse of the SIL definition, looking at failure to perform rather than success. It is easier to identify and quantify possible the conditions and the causes leading to failure of a safety function than to guarantee the desired action of a safety function when called upon. Two classes of SIL are identified, depending on the service provided by the safety function.

- For safety functions that are activated when required (on demand mode) the probability of failure to perform correctly is given
- For safety functions that are in place continuously the probability of a dangerous failure is expressed in terms of a given period of time (per hour)(continuous mode).

Tab. 1. *Probability of failure*

| Safety Integrity Level (SIL) | Probability of failure  |   |
|------------------------------|---|---|
|                              | Mode of operation – on demand (average probability of failure to perform its design function upon demand) | Model Of operation – continuous (probability of dangerous failure per hour) |
| 4                            | $\geq 10^{-5}$ to $< 10^{-4}$   | $\geq 10^{-9}$ to $< 10^{-8}$   |
| 3                            | $\geq 10^{-4}$ to $< 10^{-3}$   | $\geq 10^{-8}$ to $< 10^{-7}$   |
| 2                            | $\geq 10^{-3}$ to $< 10^{-2}$   | $\geq 10^{-7}$ to $< 10^{-6}$   |
| 1                            | $\geq 10^{-2}$ to $< 10^{-1}$   | $\geq 10^{-6}$ to $< 10^{-5}$   |

In summary, IEC/EN 61508 requires that safety integrity is specified in terms of a safety integrity level. The probabilities of failure are related to one of four safety integrity levels, as shown in Tab. 1.

SIL4 Train Inspection Portal allows accurate inspections of every part of the train promptly detects any safety issues (i.e. fire on board or irregular train shape) reducing risks of major accidents and increasing network availability.

The acquisition process of the 3D profile of the train, carried out by means of laser triangulation with high-resolution cameras, can take up to 3.000 profiles per second. A dedicated algorithm process the collected data and compares the acquired profile with thresholds determined according to UIC 505 [9], identifying irregular train shapes exceeding the allowed clearance wall recreated.

### III. CAMERA CALIBRATION

The 3-D Profile Subsystem consists of laser-camera triangulation units, fixed to the multifunction portal and oriented toward the top of rails. It includes four units, two for each line, for the acquisition of the entire profile even in the presence of simultaneous passage of trains. In particular, this specific design for double track installation enables simultaneous inspection of two running trains. In addition, there are several acquisition, elaboration and post-processing units to generate the final 3-D profile.

Camera calibration consists of a model estimation for an un-calibrated camera. The objective is to correctly identify the external parameters (position and orientation relatively to a world coordinate system), and the internal parameters of the camera (principal point or image center, focal length and distortion coefficients).

There are three requirements have to be strictly achieved to perform a calibration procedure for railway application:

1. calibration procedure has to be performed *in situ* as soon as possible;
2. calibration procedure has to be performed without stopping traffic;
3. calibration procedure has to be performed without power interruption.

In [10] Tsai proposes one of the actually most used camera calibration technique. It uses a two-stage technique to compute: first, the position and orientation and, second, the internal parameters of the camera. The implementation needs corresponding 3-D point coordinates and 2-D pixels in the image.

In order to obtain the entire profile of the train, from the

top of the rail to the overhead line, it is necessary to use a Calibration Tool about 5.5 meters high. For this reason, an insulated light stairway with fourteen steps is used (as shown in Fig. 3). This tool is fixed on the top of the rail and has a movement range of 90° in both directions. During the rotation of 180° each step of the tool ‘draws’ a semi-circumference in the 3-D world reference coordinates and the camera acquires the position of each step, illuminated by laser plane, with a frequency of 100 frame/s.

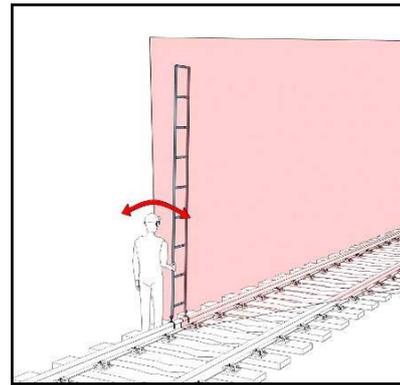


Fig. 3. Calibration Tool

An entire excursion of the tool produces a set of ellipses on camera sensor due to tangential and radial distortion of lenses.

Acquisition software stores all information in a binary file. Data referred to a frame, contain values of COGs associated to pixels illuminated on each row of the camera sensor. From user interface of the acquisition software it is possible to select the value of downsampling factor (in a range from 1 to 10) to use, for saving profile data in the file.

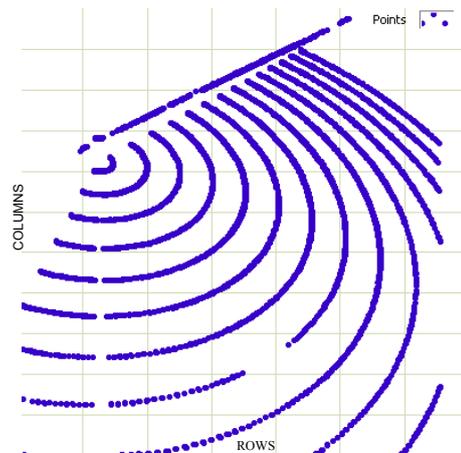


Fig. 4. Example of profile data

Calibration software plots two sets of concentric semi-circumferences, one set for each rail of the lines basing

on the values of the distance between rails, the distances between tool steps, the number of tool steps; then, it determines all coordinates of intersection (Fig. 4).

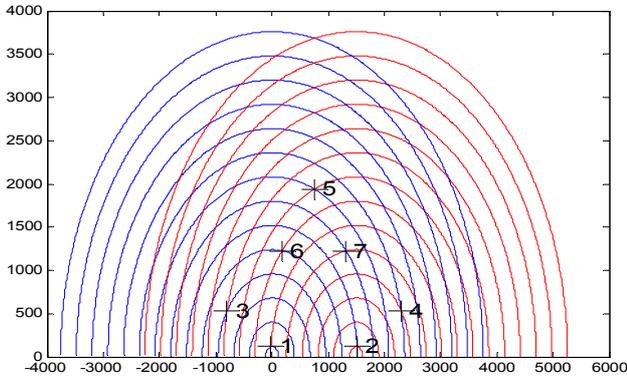


Fig. 5. Find the correspondent coordinates in 2-D domain referred to 3-D coordinates indicated here

The software utilizes Tsai model of camera to calculate extrinsic and intrinsic parameters. At the end of this step the software visualizes a report containing all information needed to analyze the calibration result. If it is correct, the software uses the estimated model to calculate equations of the ellipses that represent the transformation of the semi-circumferences in 2-D image plane.

Using profile data and Tsai estimation model calculated in previous step the calibration software is able to determine for each rails of the line the equation of the ellipses that best fit the profile data acquired in least-square sense as showed in Fig. 6. Joining the two set of best-fit concentric ellipses it is possible calculate the intersections on image plane and, if necessary, move these intersections on correct positions.

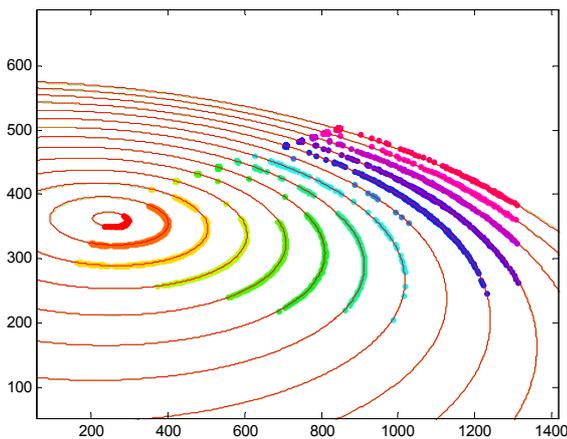


Fig. 6. Profile data fitting

Finally user can start the final parameter estimation and visualize the result achieved.

#### IV. EXPERIMENTS AND RESULTS

Calibration software has been tested with several profile images. Experimental tests have showed that ellipses approximation by means least-square minimization is strongly related to a good data acquisition process. Fig. 7 shows an example of image profile acquired by farthest camera respect to the rail. Ellipse referred to the first step of stairway has not been approximated by algorithm, while data approximation referred to second step is not correct. This situation suggests to not consider steps n.1 and n.2 for calibration procedure.

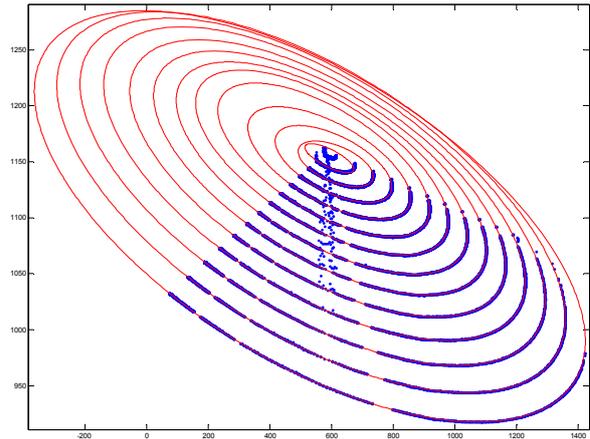


Fig. 7. Wrong data fitting

Furthermore, some intersections that are present in 3-D world referenced coordinates, in 2-D image plane are missing (Fig. 8) due to wrong approximation. For this reason it is better to consider only intersections present in both planes at the same time to estimate camera parameters according to Tsai algorithm.

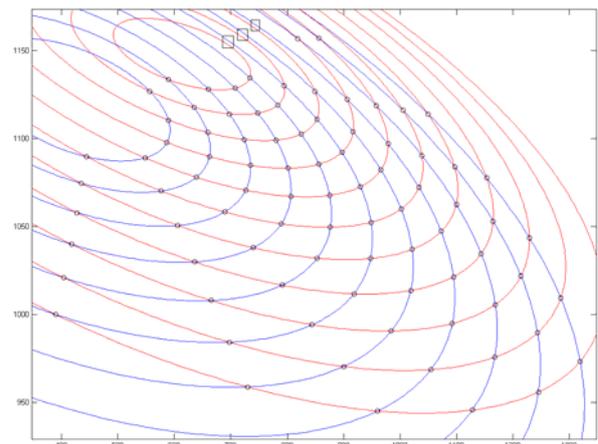


Fig. 8. Missing intersections

#### V. CONCLUSION

This paper presented a calibration procedure for a system, actually placed near an actual railway tunnel, to analyze the shape of the train and any load using 3-D geometry

scans and to detect hot axle-boxes and brakes by means of infrared sensors, according to UIC 505 and IEC 61508 Standards.

The procedure consists of: an optical unit that acquires raw measurements of the Calibration Tool movement profile; a pre-processing stage that executes necessary coordinate transformations, and a final processing stage that executes camera calibration techniques proposed by Tsai.

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