14th IMEKO TC10 Workshop Technical Diagnostics
New Perspectives in Measurements, Tools and Techniques
for system's reliability, maintainability and safety
Milan, Italy, June 27-28, 2016

Reliability and Safety Considerations Affecting the Design of a Radar Based Railway Crossing Level Passage Monitoring System

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Abstract – **Railway crossing passage systems are designed to provide a barrier for unwanted intrusion on the railway tracks. Nevertheless an increase in incidents due to cars or trucks stuck in between the barriers are happening with higher frequency. Therefore the authors in this paper propose and discuss three potential configurations for undesired barrier intrusion detection system design, based on radar detectors and focussed their attention on the system reliability and safety aspects. In particular, the radar sensor is identified as the critical component and the configurations analysed accordingly.**

I. INTRODUCTION

Safety critical systems in railways applications should withstand the highest degree of integrity level according to all the applicable standards. Therefore proper intrusion detection method and techniques should be set up. The undesired intrusion can be spotted exploiting many common sensors among which the most widely exploited are laser, radars, ultrasound systems and inductive devices. The framework of the detection should anyhow be able to grant that the system could be on duty even if a single or multiple failure to both the hardware and the software tale place. Therefore such apparatus have to be designed according to some recognized well proven methods enabling to handle the required safety integrity level. In the present paper the authors compare three reliability configurations for the sensing part. Results are provided with the aim to show which is the landscape of configurations performance which could be used by designers and which are suitable to match basic reliability and safety requirements. Additionally on level passage crossing systems (LCPS) it should be mentioned that these are systems requiring high safety standards with implications on both systems 'performance, hardware requirements and software design and testing. Safety is a key aspect of this kind of applications which is often jeopardised by the different operating conditions which can be faced by the sensing system. Fog, rain, harsh environments affect both hardware and software components and modules respectively complicating enormously their choice. Moreover, ambient changes and anti-intrusion constrains may play a crucial role in technology selection. All these aspects should be faced in a linked approach because the choice of a solution with respect to another may have impact on the overall system. It is well known that higher safety implies lower system availability and a tradeoff usually should be reached. Nevertheless in railway applications safety constraints are mandatory during the preliminary design phases and therefore the design should be developed accordingly and the overall system availability evaluated in a second time only. The following paper is arranged to provide designers a roadmap on the needed steps for the design of a monitoring system for railway applications based on radar sensing technology which is able to meet the highest safety degree required by commonly used standards [1-4]. Several authors tried in the past to analyse the problem of safety related systems and reliability modelling in the railways or similar landscape and not limiting just to railways [5-9] without focussing on the radar technology. In particular the present paper will discuss the possible hardware solutions without taking into considerations side aspects as the probability of miss-detection which is strictly linked to the radar technology selection and which should be deeply analysed before drawing any conclusion on the overall system safety.

II. MEASUREMENT PRINCIPLE AND POSSIBLE SCENARIO

The problem of undesired object detection within a crossing level system rises when the barrier close and the train is approaching the crossing point. At that time there is no more time for any further action than stopping the train. The detection system drives the signalling one and no mistake due to failure or data misinterpretation or communication issue is allowed. To provide the information on the obstacle presence within the barrier several technologies have been used or proposed in the

past.
In general such detecting system can use different sensor technologies as lasers, radars, inductive sensors etc., but for the proposed application, the authors selected the radar one due to the numerous advantages provided for this specific application field whenever undergoing different ambient operating conditions. The detection system is asked to be able to manage periodic sample data set with tight constraints (usually max 400ms) according to the following relation:

$$T_s = T_c + T_{el} + T_{tr} \qquad (1)$$

and declare a safe situation within a time gap ranging from 3 up to 7 seconds upon barriers closure.
In (1) symbols refer to the time interval among consecutive scans (T_s), the contribution of the sampling time (T_c,), the processing time to create the data set (T_{el}), and the transmission time (T_{tr}).
The basic elaboration architecture is the one shown in Figure 1 where a sample threshold detection algorithm can be assumed. Nevertheless from a software standpoint more complicated algorithms can be chosen and embedded into the detection algorithm section.

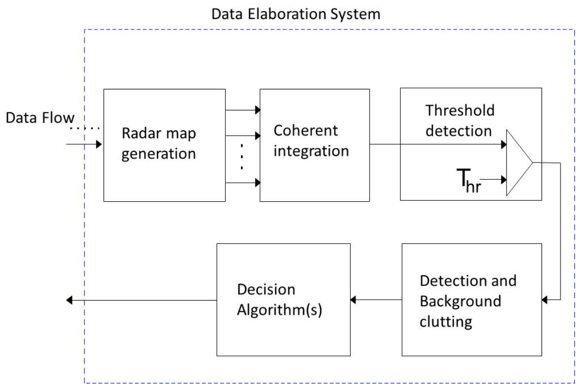

Fig. 1. General elaboration Schematics

More in details a sample architecture can be described as in Figure 2. Therefore the system measurement principle relies on a frequency modulated continuous wave (FMCW) radar information provided to an elaboration unit which is interfaced to the signalling apparatus as shown in Figure 2.

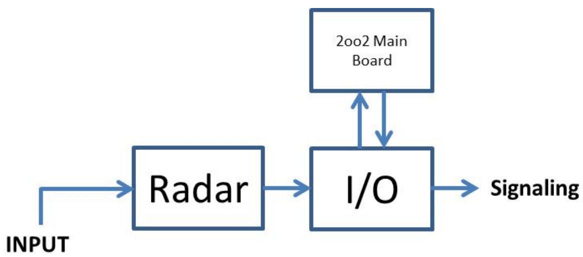

Fig. 2. Radar and downstream elaboration unit

architecture.

The selected radar simplified schematic is represented in Figure 3 where it is possible to notice the presence of a single transmission channel and two receiving ones providing the capability to determine both the target distance and angle on a pre-established detection area.

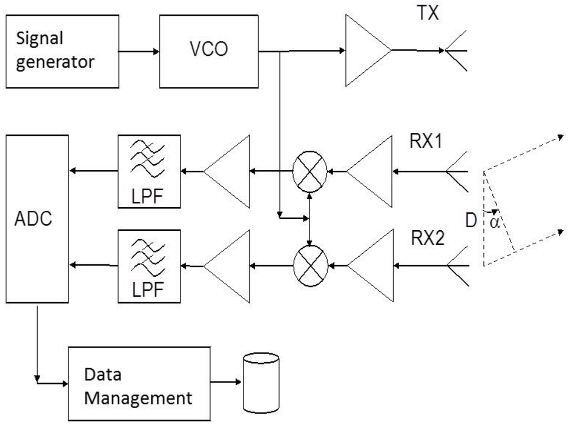

Fig. 3. Inner schematic of sample FMCW radar. technology

Received antennas signals are processed (demodulated by I/Q system), filtered and sampled. A FFT processor generates the proper datasets for post processing elaboration. The electromagnetic wave transmitted from the radar is a frequency linearly swept from a low frequency (*fmin*) up to a maximum one (*fmax*) within a predefined time interval (*Tc*). The two receiving antennas get the returning signal from the target and the distance R between sensor and the detected object is obtained by measuring the beat frequency which is proportional to the time delay of the signal traveling to and from the object. The periodic saw-wave function (*up*) and the beat frequency (*down*) vs. time is shown in Figure 4. *R* can be determined using equation (2).

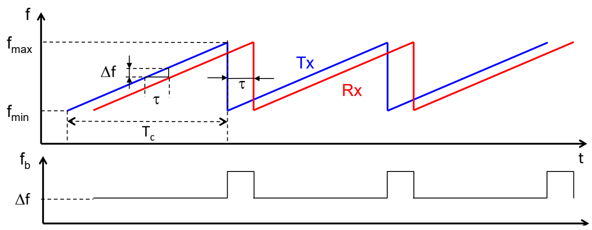

Fig. 4. Time scanning representation of FMCW radars

$$R = \frac{c_0 \tau}{2} = \frac{c_0 T_c}{2 B_s} \Delta f \qquad (2)$$

where Bs=(fmax-fmin) is the sweep bandwidth and Δf is measured beat frequency and c0 is the waveform travelling speed. The two receiving channels allow to estimate the angle position of a single object according to the phase monopulse principle. Furthermore the relative motion of the object with respect to the radar sensor causes a frequency shift in the beat frequency. At this point, range, angle position and, if needed, relative velocity may be estimated exploiting complex processing algorithms on the demodulated and sampled radar signals [1]. Several architecture can be used and exploited whenever the safety constraints imposed by the railway context have to be taken into account. Usually the maximum safety degree according to the applicable standards [2-4] in the field is selected. Therefore in the next session the authors propose three different system architecture and evaluate such proposal comparing the reliability and safety results achievable for each of them.

III. RELIABILITY AND SAFETY MODELING

Three reliability/safety configuration are examined in this manuscript as possible alternatives to the problem of obstacle detection in between two (four or full) gates level crossing passages. The proposed configurations take into consideration different numbers of radar sensors only for two reasons. The main one is that in this application the sensor is the weakest node of the measurement chain and additionally the main problems rely on the possibility to miss-detect an object more than expiring a transmission failure. Anyhow the authors analysed even the communication and architecture problems in another paperwork. The proposed reliability configurations (represented as Reliability Block Diagrams) are the one shown in figure 5.

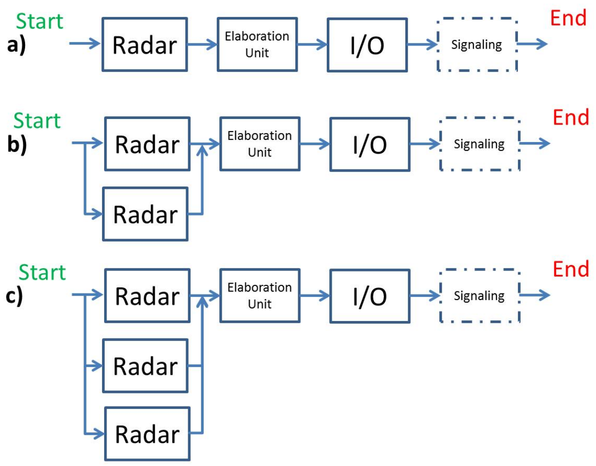

Fig. 5. Proposed functional architectures: a) simplex structure b)two radars structure c) triple redundant structure.

Configuration a) represent the simple model, while configuration b) and c) show the presence of multiple sensors as target detection entry points. Configuration b) in particular from a safety standpoint can generate two additional models which can be treated as the traditional 2oo2 or 1oo2D systems as per [2-4].

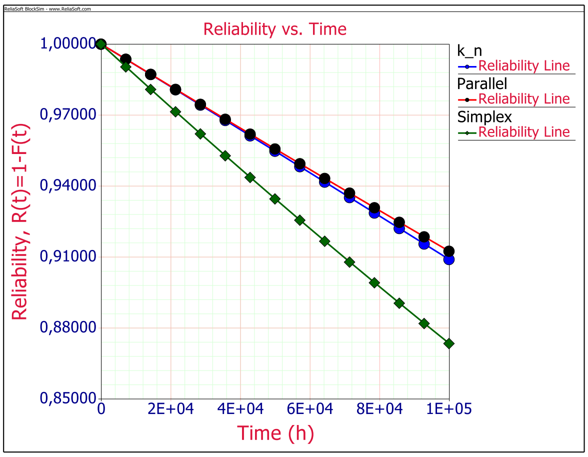

Fig. 6. Reliability over time behaviour of the proposed possible implementation solutions.

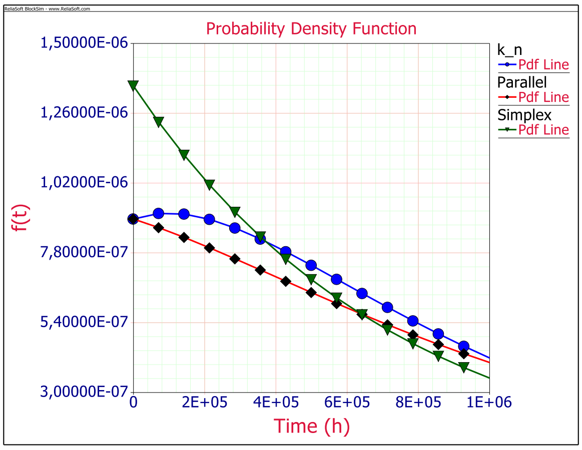

Fig. 7. Corresponding probability density functions of the proposed possible architectures of Figure 5.

In terms of reliability performance, as shown both in Figures 6 and 7 respectively, the study shows that the configuration to be chosen is the parallel one providing higher expectations in terms of system reliability over time. In terms of safety this choice is confirmed if and only if the parallel is considered as a 1oo2D safety configuration according to [2-4].

Table I

	λ_{DD}[f/h]	λ_{DU}[f/h]
Radar	2.2853e-007	2.3084e-009
Elaboration Unit	2.7423e-007	2.7700e-009
I/O	1.7395e-007	1.7570e-009

Table I. Dangerous Detectable and Undetectable failure rates of the subsystem components

This is because the other cannot meet the highest standard integrity level and cannot therefore be used in field. Simulations have been achieved exploiting sample rough data that are reported in Table I and which are strictly dependent on the radar and downstream logic technology.

Safety consideration can be deducted applying the IEC61508 standards or the corresponding CENELEC 50126, 50128 and 50129 standards for railways application. Nevertheless, it is evident again that due to the signalling requirements (usually SIL3 or SIL4) the configuration a) of Figure 5 cannot be taken into consideration because it is not fault tolerant for double fault events while configuration b and c both can meet (for example with the data of Table I) the needed safety goals.

IV. CONCLUSIONS

As closing remarks the authors proposed different sensing configurations for railway level crossing passage system based on radar technology and showed that among the proposed possible redundant solutions the parallel with the 1oo2D selection for safety analysis should be implemented to meet the required safety integrity level in signalling applications.

REFERENCES

[1] Kim, Y.-J., Baek, J.-H., Choi, K.-H. Algorithm development of level crossing obstacle detection using laser radar sensor 2013 Transactions of the Korean Institute of Electrical Engineers 62 (12), pp. 1813-1819

[2] EN 50126 Railway Applications - The Specification and Demonstration of Reliability, Availability, maintainability and Safety (RAMS).

[3] EN 50129 Railway Applications - Communications, signalling and processing systems – Safety related electronic systems for signalling.

[4] EN 50128 Railway Applications -Communications, signalling and processing systems.

[5] A. Fort, F. Bertocci, M. Mugnaini, V. Vignoli V. Gaggii, A. Galasso, M. Pieralli “Availability Modeling of A Safe Communication System for Rolling Stock Applications” IEEE I2MTC2013 Conference Proceedings

[6] A. Fort, M. Mugnaini, V. Vignoli, “Hidden Markov Models approach used for life parameters estimations” 2015 Reliability Engineering and System Safety 136, pp. 85-91

[7] M. Catelani, M. Mugnaini, R. Singuaroli. “Effects of test sequences on the degradation analysis in high speed connectors” Microelectronics Reliability, vol. 40, p. 1461-1465, ISSN:0026-2714.

[8] Mugnainis, M., Catelani, M., Ceschini, G., Masf, A., Nocentini, F. Pseudo time-variant parameters in centrifugal compressor availability studies by means of Markov models 2002 Microelectronics Reliability 42 (9-11), pp. 1373-1376

[9] Ceschini, G., Mugnain, M., Masi, A A reliability study for a submarine compression application 2002 Microelectronics Reliability 42 (9-11), pp. 1377-1380