RAMS Analysis of a Bio-Inspired Traffic Data Sensor (“Smart Eye”)

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Abstract—**The Austrian Research Centers have developed a compact low-power embedded vision system “Smart Eye TDS”, capable of detecting, counting and measuring the velocity of passing vehicles simultaneously on up to four lanes of a motorway.**

The system is based on an entirely new bio-inspired wide dynamic “silicon retina” optical sensor. Each of the 128x128 pixels operates autonomously and delivers asynchronous events representing relative changes in illumination with low latency, high temporal resolution and independence of scene illumination. The resulting data rate is significantly lower and reaction significantly faster than for conventional vision systems. In ADOSE, an FP7 project started 2008 (see acknowledgment at the end of the paper), the sensor will be tested on-board for pre-crash warning and pedestrian protection systems.

For safety-related control applications, it is evident that dependability issues are important. Therefore a RAMS analysis was performed with the goal of improving the quality of this new traffic data sensor technology, in particular with respect to reliability and availability. This paper describes the methods used and the results found by applying a RAMS analysis to this specific case of a vision system.

Keywords - ***RAMS, reliability analysis; FMEA; traffic data sensor; bio-inspired sensor; silicon retina; vision system; harsh environment***

I. INTRODUCTION

With regard to ever increasing traffic volume, the prevention of traffic congestion is not only important for the safety of drivers but also for environment protection. The problem with traffic monitoring has been tackled since long time, using various types of monitoring systems.

The main problem with conventional video systems is the high data volume delivered by the image sensor. Read-out and processing of the largely redundant data ultimately faces limitations due to computational effort and power consumption.

“Smart Eye TDS” – this new compact low-power embedded vision system developed by the Austrian Research Centers - is in its current implementation capable of detecting, counting and measuring the velocity of passing vehicles simultaneously on up to four lanes of a motorway and detecting the first indication of road congestion and analyzing traffic conditions to provide data for traffic management systems. Like the eye, the bio-inspired vision-sensor responds asynchronously to relative light intensity changes. It sends digital events encoding the addresses of pixels which "see" these changes.

Figure 1. Smart Eye Traffic Data Sensor with opened housing

The resulting data rate is significantly lower and reaction significantly faster than for conventional vision systems. This sensor combines sparse asynchronous data output with high temporal resolution and low latency, high dynamic range and low power consumption. In contrast to many other non-video based traffic data acquisition systems, the sensor has a high degree of freedom regarding its mounting position and is able to service several lanes simultaneously.

For safety-related traffic control applications, it is evident that dependability issues are important. Therefore a RAMS analysis was performed with the goal of improving the quality of this new traffic data sensor technology, in particular with respect to reliability and availability, which is prerequisite for critical applications. Safety issues have to be assessed in context of a specific application.

This paper is structured as follows: In section 2, the silicon retina embedded sensor system is briefly described. Section 3 presents definitions and methods used by applying a RAMS-Analysis. Section 4 describes the concrete FMEA analysis of the Smart Eye Traffic Data Sensor. The results found by applying the RAMS analysis are discussed in Chapter 5 and Section 6 contains conclusions.

II. DESCRIPTION OF THE SILICON-RETINA EMBEDDED SENSOR SYSTEM

In this section, the silicon retina sensor and the embedded traffic monitoring system are briefly described.

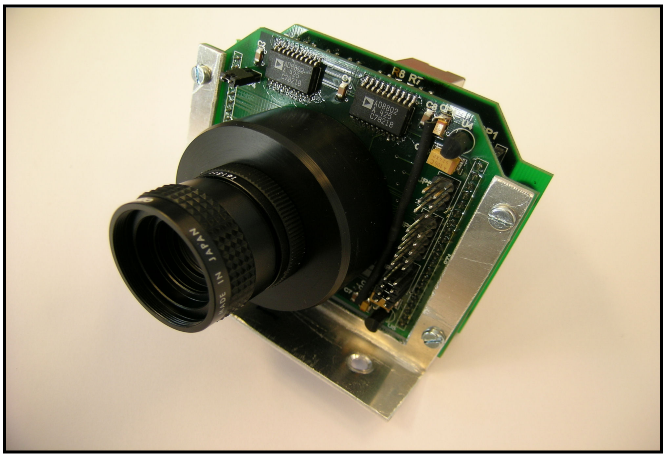

Figure 2. Silicon retina module including lens, optical sensor board and DSP board

The eye-inspired Silicon Retina is a mixed analogue-digital integrated circuit which generates events with location and timestamp when illumination of pixels changes. In contrast to traditional CCD or CMOS imagers which encode image irradiance and produce constant data volume at a fixed frame rate, irrespective of scene activity, the Smart Eye sensor contains an array of autonomous, self-signalling pixels which individually respond in real-time to relative changes in light intensity by placing their address on an asynchronous arbitrated bus. Pixels, that are not stimulated by change in illumination are not triggered, hence static scenes produce no output.

The sensor operates largely independent of scene illumination and greatly reduces redundancy while preserving precise timing information. The scene information is transmitted event-by-event to a DSP (Digital Signal Processor) via an asynchronous bus.

The analogue pre-processing of the visual motion information on the sensor focal plane allows for using a low-cost, low-power DSP for data post processing, limiting system size, cost and price. [1]

III. RAMS ANALYSIS OF THE "SMART EYE" TRAFFIC DATA SENSOR

A. Term Definitions

RAMS is an acronym for the following quality attributes of dependable systems:

- **Reliability.**
  The ability of a system or component to perform its required functions under stated conditions for a specified period of time [3].
- **Availability.**
  The degree to which a system or component is operational and accessible when required for use [3].
- **Maintainability.**
  The ability of an item, under stated conditions of use, to be retained in, or restored to, a state in which it can perform its required functions, when maintenance is performed under stated conditions and using prescribed procedures and resources [9].
- **Safety.**
  Freedom from those conditions that can cause death, injury, occupational illness, or damage or loss of equipment or property [4].

Some authors include "security" as additional quality attribute in "RAMSS":

- **Security.**
  Protection from unauthorized access or uncontrolled losses or effect [10].

B. Method for the RAMS Analysis

For evaluating the reliability of a system, its failure modes have to be investigated in detail and exhaustively. For this purpose, the well-introduced Failure Modes and Effects Analysis (FMEA) is a very appropriate method. FMEA is one of the well-known analysis methods having an established position in the traditional reliability analysis. The purpose of FMEA is to identify possible failure modes of the system components, evaluate their influence on system behavior and propose proper countermeasures to suppress or mitigate these effects. Anticipating these failure modes is the central step in the analysis, which needs to be carried out diligently in order to prepare a complete list of all relevant potential failure modes.

FMEA combines several advantages:

- It is a team-based, structured, detailed, bottom-up approach
- It is a component-oriented method
- It considers all possible component and system failure modes individually
- It identifies possible failures during system or process development.
- Time and resources for FMEA are allocated during development, when changes are easier and less expensive to make.
- Results can be presented in an easy-to-understand format
- The available analysis team is familiar with the method as well as with the ITEM FMEA tool, which was eventually used in the analysis.

The methodology is described in MIL-STD-1629A, which has been published by the United States Department of Defense in 1980. The standard establishes requirements and procedures for performing the FMEA. This analysis method is well understood at the system and hardware levels, where the potential failure models usually are known and the task is to analyze their effects on system behavior.

C. Goal of the Smart Eye RAMS Analysis

In its current implementation, the "Smart Eye" TDS is intended for traffic supervision tasks like, for instance, counting the number of vehicles per minute, measuring their speed or detecting traffic congestions. This is safety-related only from a holistic point of view since critical traffic situations lead to dangerous driver reactions. In the ADOSE project (EU-IST-FP7-216049, funded by the EC) the sensor is one of the novel approaches for driver assistance systems (ADAS), specifically applied for pre-crash warning and vulnerable road-user (VRU) protection (bicycles, pedestrians).

With regard to field applications, such a RAMS analysis is mandatory as part of the overall validation of the protection system.

As mentioned in the above section, the term "RAMS" covers various quality attributes of a system or product, which are relevant for dependable systems. The traffic data sensor is connected to an IP network where a security violation like intrusion into the network is highly improbable. Due to its use, a safety threat in consequence of a malfunction of the camera is not likely. And in its current version it represents a prototype, for which maintenance issues are yet of minor importance.

Therefore, the RAMS analysis was performed with the goal of improving the quality of the new traffic data sensor technology. Taking into account the above mentioned considerations, the focus of the analysis was laid on two dependability attributes:

- Reliability and
- Availability.

Finally, as a result, recommendations for quality improvement were derived.

IV. Performing the FMEA

A. *Scope of the Analysis and Assumptions*

The application of the FMEA was restricted to the interior of the device – from the inside of the protective glass to the Ethernet and power supply sockets.

Several close-to-reality assumptions were made in order to reduce the scope of the analysis:

- The protective glass must be cleaned.
- As the device is heated the temperature in winter is never below 15°C, so the effect of a steamed-up lens or protective glass is not part of the analysis.
- For summer, we assumed that the maximum temperature inside the white housing is between 70 and 80°C.
- The device is installed between 8 and 10m above the motorway. The classifications IP66 (protection against dust and strong water jet) allowed us to neglect effects caused by dust or water intruding the housing.
- For use as an in-car sensor, EMI protective measures were assumed to fulfill the standard criteria.
- The device has a lightning protection system for outdoor use.

In general, environmental influences which are well-known and avoidable by means of established measures were not considered.

B. *Block Diagram and Components*

For the FMEA of a complex system, it is necessary to split the device in subsystems, blocks and components. We used two degrees of granularity:

a. *rough analysis based on big hardware blocks*

b. *detailed analysis for each single hardware component*

The following figure shows the block diagram.

PPI........Parallel peripheral interface
JTAG....Joint Test Action Group, a name for IEEE 1149.1

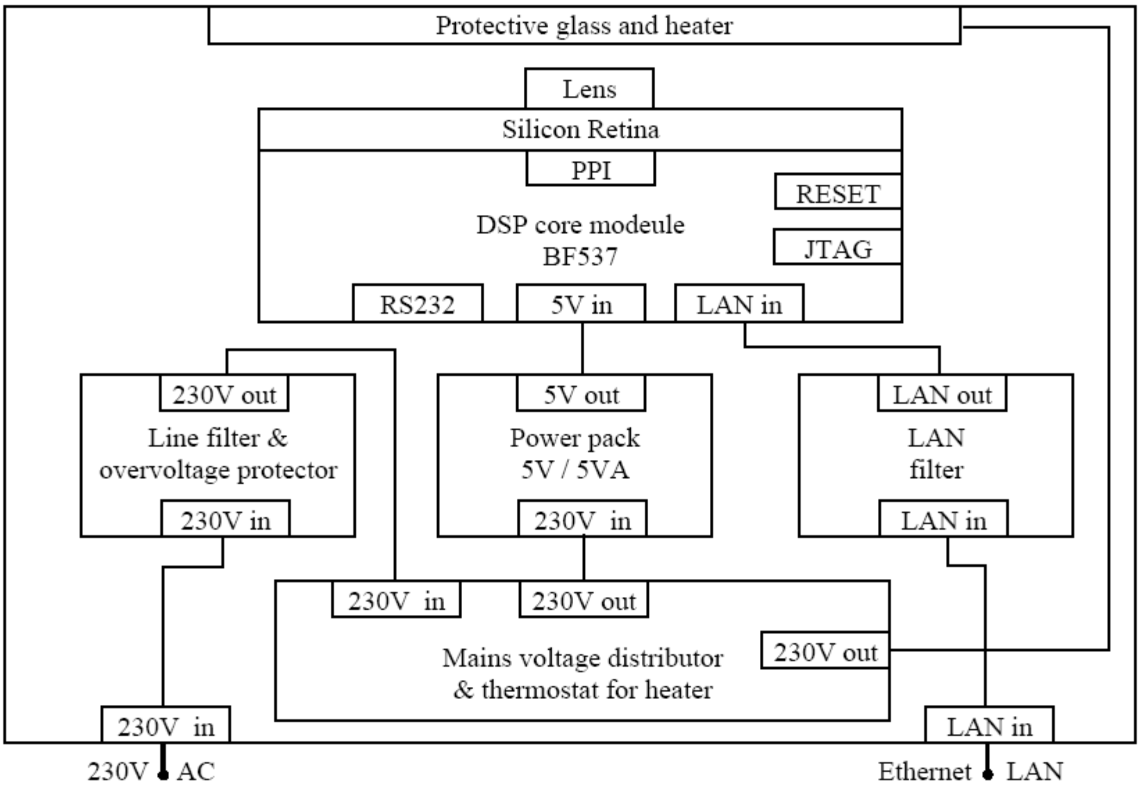

Figure 3. Block diagram of the Smart Eye Sensor

C. Execution of the FMEA

The FMEA was performed following the steps described in MIL-STD-1629A. The task comprises the collection of all potential failure modes for each component or block, respectively, the identification of failure causes and the investigation of their effects.

The failure modes for the FMEA are usually collected in one or several workshop-style sessions, in which at least the designers, the developers and quality experts participate, and so it was in the case of the Smart Eye Sensor. We took a 2-step approach:

- The first analysis was based on the coarse blocks as depicted in Figure 3.
- The second step analyzed single components like resistors, ICs, capacitors, etc

The result was a FMEA sheet in compliance with MIL-STD-1629A.

TABLE I. FMEA SHEET FOR THE ETHERNET CABLE

Name: Ethernet cable *Failure rate (25°C): 0,119* *Failure rate (75°C): 0,394*

Failure mode	*Cause*	*Local effect*	*Failure detection*	*Compensating provisions*	*Remarks*
No connection	Production defect Assembly error Bent with a much too small radius	No data	No function	None	The cable is bent with a much too small radius!
Incorrect connection	Production defect Assembly error Bent with a much too small radius	Incorrect data No data	Incorrect function No function	None	The cable is bent with a much too small radius!

D. Estimation of Failure Rates

In addition to the qualitative analysis done in the FMEA, qualified values for component and block failure rates allow to calculate the reliability of the entire device.

E. Reliability Handbooks

For estimating the failure rate of the subsystems and the components there are several handbooks like MIL HDBK-217 [2], Telecordia SR-332 [5], IEC/TR 62380 [6], IEC 61709 [7], or Siemens SN 29500 [8].

We decided to use MIL-HDBK-217 [2], the Military Handbook for “Reliability Prediction of Electronic Equipment”, published by the US Department of Defense. It contains failure rate models for the various part types used in electronic systems, such as ICs, transistors, diodes, resistors, capacitors, relays, switches, connectors, etc., and allows detailed failure models with respect to environmental conditions, component quality factor, load situation, and temperature. These failure rate models are based on the best field data that could be obtained for a wide variety of components and systems; this data is then analyzed and combined, with many simplifying assumptions thrown in, to create usable models.

F. Failure Rates of the Smart Eye Sensor

In a very first step of reliability estimation we found out that - based on the assumption of a fixed installation on a stable gantry and careful manufacturing processes as well as quality control - the reliability of the mechanical components exceeds that of the electronic ones significantly. Failure rates were therefore estimated only for the electronic components, not for mechanical ones like lens holder, sealing, etc. For future mobile applications, this assumption has to be proven beforehand, in particular with respect to mechanical robustness in long-term field test.

As mentioned above, the Standard MIL-HDBK-217 was used for the electronic components. This standard gives failure rates based on the precise type of the component and on several component-type-dependant dimensionless parameters, called "factors".

For instance for a fixed electrolytic tantalum capacitor, the resulting failure rate λp is defined as follows:

$$\lambda_p = \lambda_b \bullet \pi_{CV} \bullet \pi_{SR} \bullet \pi_Q \bullet \pi_E \,. \qquad (1)$$

λ_b Base Failure Rate, obtained from a table which applies to a defined temperature specification of the capacitor, with a 10°C ambient temperature range per row, and stress factors 0.1 to 0.9 (ratio of operating to rated voltage) in the columns.

π_{CV} Capacitance Factor (high capacitance corresponds to high failure probability; example values: π_{CV} =0.7 for 91nF, π_{CV}=1.3 for 1100µF).

π_{SR} Series Resistance Factor (to the power supply, values between 0.066 for >0.8 Ω/V and 0.33 for <0.1 Ω/V).

π_Q describes the influence of the Quality class - the values vary between 0.001 and 10.0; MIL-HDBK-217 assumes "Lower quality" for commercial components ($\pi_Q = 10$).

π_E Environment factor, which takes into account the operating conditions like "Ground, Benign", "Airborne, Inhabited, Cargo" and many others as they occur in military use. Values range between 1 (ground/benign) and 530 (cannon/launch).

For the Smart Eye Sensor, we assumed the following operating conditions:

- For environmental conditions the device was classed with "Ground, Fixed" ($\pi_E = 2$).
- Failure rates of all electronic components, all blocks and the whole device were calculated for two different temperatures*:* 25°C and 75°C.

For the remaining factors, the classification was component-type-specific.

G. *Failure model of the Silicon Retina*

It was not in all cases possible to find corresponding components in MIL-HDBK-217 [2]. There are components in the device, which could only be roughly approximated with MIL-HDBK-217, above all the brand new silicon retina chip. This very specific custom-designed chip doesn't correspond to any one of the mass production components for which the MIL standard gives failure models. Generally, there is little empirical reliability data available for specific ASICs (Application Specific Integrated Circuits).

But we found two failure models with sufficient similarities to the silicon retina chip:

- Approximation with "analogue circuit with as many transistors as possible". The problem is, however, that in practice such huge analogue circuits are not common, therefore the extrapolation beyond experience by using this seemingly appropriate failure model from the MIL standard is not really justified.
- Approximation with a CMOS-matrix-like configuration. There is certain similarity here because of saving the values in a big matrix of analogue storage. On the other hand, the whole circuitry outside the analogue photo-sensitive detection of changes in illumination (e.g. for arbitration or message routing) is digital, which doesn't closely correspond to this failure model in MIL-HDBK-217 [2].

Considering the arguments mentioned above, we decided for the second option, as we regarded it as the closer approximation. But we have to admit that - based on the limited experience with that new chip - there is not sufficient evidence so far if our assumption was justified although it seems to be plausible.

V. RESULTS OF THE ANALYSIS

The reliability of the components was computed by multiplying the calculated failure rate of equivalent components with their number ("Parts count method").

TABLE II. FAILURE RATES FOR THE SMART EYE COMPONENTS (IN FAILURES PER MILLION HOURS)

Component/Block	*λ (25°C)*	*λ (75°C)*
Over-voltage protector for Ethernet	0,2586	1,1382
Over-voltage protector MA05	0,3910	1,4192
DAC (U2, U3)	0,0299	0,1389
Diode (D1)	0,0078	0,0345
DSP core module -BF537	0,2031	0,7056
Ethernet socket	0,0060	0,0202
Ethernet cable 1	0,1197	0,3941
Ethernet cable 2	0,1197	0,3941
EXOR gate (U5)	0,0198	0,0288
FIFO memory	0,0832	0,0902
Clamp 1	0,0036	0,0190
Clamp 2	0,0360	0,0119
Clamp heater L, N	0,0041	0,0136
Clamp in L, N	0,0049	0,0164
Clamp out L,N	0,0049	0,0164
Capacitor (C1-C13)	0,0046	0,0277
Capacitor (C1-C27)	0,0046	0,0277
LAN socket	0,0060	0,0202
Main cable socket	0,0045	0,0151
Power pack EGSTON	0,5882	0,5882
Digital interface board	0,0434	0,0434
Sensor board	0,0715	0,0715
RS232 Level converter	0,0299	0,0479
Shielding glass heater with thermostat	0,7121	0,8201
Silicon Retina	0,3112	0,3253
Voltage regulator (U4, U5)	0,0050	0,0594
Voltage regulator (U6)	0,0050	0,0277
Plug JP6 (3 pins)	0,0041	0,0136
Plug JP6 (8 pins)	0,0060	0,0202
Plug JP1, JP2 (2 pins)	0,0036	0,0119
PlugJP3 (10 pins)	0,0068	0,0226
Plug JP3 (14 pins)	0,0082	0,0275
Plug JP4 (2 pins)	0,0036	0,0119
Plug JP4, JP5 (6 pins)	0,0053	0,0177
Plug JP5 (6 pins)	0,0053	0,0117
Plug contacts for DSP-board	0,0312	0,1042
Pin row 21 pins (ST1, ST2)	0,0109	0,0364
Current Supply Socket (MP1, MP2)	0,0036	0,0119
Tantalium capacitor (CP1-CP3)	0,0309	0,0555
Tantalum capacitor (CP1-CP4)	0,0384	0,0690
Transistor (T1)	0,0009	0,0026
Resistor (R1-R7)	0,0207	0,0322
Resistor (R1-R5, R7, R8)	0,0207	0,0322
Optical sensor module	0,7985	1,9215
Digital interface module	0,5495	1,3297
Block: connecting terminal board	0,0211	0,0702
Block: Ethernet cable	0,2394	0,7882
Block: housing	0,7277	0,8554
Block: Silicon Retina module	1,5511	3,9568
Block: power supply and data connector	1,2378	3,1454
Smart Eye total	**3,7771**	**8,8160**

As mentioned in the previous chapters, the reliability analysis was performed for two different temperatures and for two different granularities of system decomposition. TABLE II. gives an overview on the calculated failure rates λ (in failures per million hours) for the single components, for the blocks, and for the entire system at operating temperatures of 25°C and 75°C:

We may assume that the real failure rate values are comparatively better than the calculated ones because of the following factors:

- The MIL-HDBK-217 values are conceived as conservative because they were derived in the 1990s when the quality of electronic components was generally lower than today with advanced production processes.
- The real average temperature inside the device is significantly below the assumed maximum of 75 degrees, which is reached only on hot summer days during daytime; in winter aging of components is significantly delayed.
- Not all component failure modes listed in MIL-HDBK-217 lead to a failure of the whole device.

So it can be rightly supposed, especially when our optimization proposals are implemented, that the real values will be even better than the calculated ones.

MTTF means the average time to a system failure. If $\lambda(t)=\lambda$, i.e. if λ is constant over time, then MTTF is the reciprocal value of the system failure rate:

$$MTTF = 1 / \lambda \,. \qquad (2)$$

The following bar chart gives a good overview on the resulting mean time to failure (MTTF) of the Smart Eye Sensor.

As we can see in Figure 4. , the operating temperature plays a very important role for the reliability and the MTTF, respectively. This is a consequence of the significantly accelerated aging of electronic components at high temperature levels.

Another interesting fact can be observed: The values for the coarse analysis are not essentially different from those obtained in the detailed analysis; in fact they are only about 25% lower. This is much less than the difference caused by different temperature assumptions.

The other dependability attribute our analysis was dealing with is the availability, which takes into account the reliability and the repair time MTTR (Mean Time to Repair).

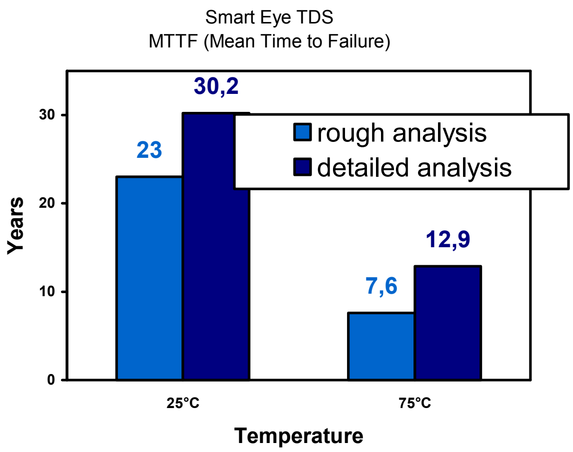

Figure 4. Calculated MTTF for the Smart Eye Sensor

Availability is defined as follows:

$$Availability = MTTF / (MTTF + MTTR) \,. \qquad (3)$$

The repair time was not a part of our analysis. If it can be kept below one day, then the availability is in the range of 99.97 %, which should be far better than what is required for the purpose of the system as a traffic surveillance sensor. In case of in-vehicle use in safety-critical applications, a reliable fault-detection mechanism is necessary to signal malfunction and the need of early replacement to the driver.

The FMEA yielded moreover 2 urgent issues for improvement:

- A coaxial cable is bent with a much too small radius.
- A power supply module is specified for 50°C only, it has to be replaced by a device rated for at least 85°C.

VI. Conclusions

Our analysis of the new traffic sensor has shown several interesting results; some of them need further study, others indicate potential for optimization of the RAMS analysis.

First of all the strong correlation between MTTF and device temperature has to be emphasized. Based on the good reliability modeling in MIL-HDBK-217 with respect to temperature, we showed clearly that reducing the temperature inside the Smart Eye Sensor can contribute significantly to a reliability improvement.

Interestingly, we observed that an analysis based on coarse blocks differs only by about 30% from a detailed, component-based calculation. This shows that - for a first analysis - the granularity plays a minor role.

So, for a further refinement of the reliability prediction, we have to model the annual and daily temperature curve: The device is heated up to 75°C only on hot summer days, in winter and during the night the temperature level is moderate. Although temperature cycling can increase the incidence rate of certain failure modes (e.g. loose bond wires, solder joint fractures) the majority of electronic devices exposes an increased failure rate at higher temperatures. Therefore, the resulting reliability will presumably be closer to the calculated value for 25°C than to that of 75°C.

The silicon retina sensor has advantages not only when used as a traffic data sensor but for various applications. If it serves as a pre-crash sensor as in the ADOSE project mentioned earlier, it is safety-relevant. Then, a RAMS analysis has to cover also safety aspects.

Acknowledgment

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