

**"Device for monitoring the health status of a limited
life critical system"**

DESCRIPTION

The present description relates to the technical
5 field of monitoring systems, and it relates in particular
to a device for monitoring the health status of a limited
life critical system.

Critical systems are defined those systems that, in
the case of an operative failure, may cause severe
10 consequences, such as:

- death or severe risks to people;
- loss or severe damaging of means and material;
- severe environmental damages.

For example, in the case that the critical system is
15 represented by an armament, such system can be defined as
critical, since a malfunctioning thereof may jeopardize a
military mission, hence the life of people related to it.

It is known that there is a series of external
factors that degrade the performance of a system or a
20 device, thereby altering its health status, even if it is
not used. Such degradation is referred to as aging.

The above-mentioned factors, which may act
individually, or in a mutual combination, are
represented, for example by storage temperature,
25 humidity, vibrations or mechanical shocks.

The critical systems, exactly in view of the consequences related to a possible malfunctioning thereof, are limited life system, since they have a life duration within which the degradation remains within
5 accepted limits.

Based on statistical considerations, it is possible to estimate predictively the health status and the life duration of a critical system, for example, in order to program the replacement of the systems at the end of
10 their life duration and/or to avoid using systems beyond their life duration. It shall be apparent that the above-mentioned statistical approach is not an optimal one, first of all, because it requires the provision of suitable and wide margins in order to ensure safety
15 requirements, secondly because it cannot take into account particularly exceptional circumstances which a critical system may be subjected to. Furthermore, the above-mentioned statistical approach requires that long and expensive test procedures are carried out.

20 The object of the present description is to provide a device that allows monitoring in real time the health status of a limited life critical system.

Such an object is achieved by a monitoring device as generally defined in claim 1. Preferred and advantageous
25 embodiments of the above-mentioned device are defined in

the appended dependent claims.

The invention will be better understood from the following detailed description of a particular embodiment, given by way of example, and, therefore, by
5 no way limiting example, with reference to the appended drawings, in which:

- Fig. 1 shows an exemplary block diagram of a monitoring system comprising a monitoring device intended for monitoring the health status of a critical system;
10 and

- Fig. 2 shows an exemplary block diagram of the monitoring device of Fig. 1.

In the Figures, similar or like elements will be indicated by the same reference numerals.

15 In Fig. 1, a non-limiting embodiment of a system 1 for monitoring in real time the health status of a critical system 2 is schematically shown.

In the particular example illustrated, without for this introducing any limitations, the monitoring system 1
20 is intended for monitoring the health status of a plurality of critical systems 2, which represent, for example, munitions 2 within a storage warehouse. In the illustrated example, each of said munitions 2 is housed in a corresponding container 3. The containers 3 comprise
25 a containment body to which corresponding monitoring

devices 10 are associated, and more precisely mechanically coupled.

In the particular example illustrated, the monitoring system 1 comprises a mobile query terminal 4, for example, a personal digital assistant device provided with a display 5 and an antenna 6, adapted to query from remote the monitoring devices 10 associated to the corresponding munitions 2. Alternatively, or in addition, at least one fixed query station 8 may be provided, which is adapted to query from remote the monitoring devices 10, for example, being provided with an antenna 7.

In accordance with an embodiment, the mobile query device 4 and/or the fixed query station 8 are configured to transmit to a remote server 9 the information acquired through the queries, for example, to transmit such information onto a remote logistic management database.

The mobile query terminal 4 and/or the fixed query station 8 are RFID reader devices (Radio Frequency IDentification devices) or similar devices.

Regarding the possible critical systems 2 to be monitored, it shall be apparent that these systems may include mechanical, electronic, electro-mechanical devices, optionally comprising also chemicals such as, for example, explosives, propellants, etc.

In Fig. 2, a functional block diagram of an embodiment

of a device 10 for monitoring the health status of the associated limited life critical system 2 is shown.

The monitoring device 10 comprises at least one measurement sensor S1-S4 adapted to measure a magnitude
5 adapted to affect the health status of the critical system 2, by outputting an electric signal carrying information relative to such magnitude. In accordance with an embodiment, the above-mentioned measurement sensor S1-S4 is a temperature sensor. In accordance with
10 an embodiment, the above-mentioned sensor S1-S4 is a humidity sensor. In accordance with a further embodiment, the above-mentioned sensor S1-S4 is a vibration and/or mechanical shock sensor. In accordance with an embodiment, the monitoring device 10 comprises a
15 plurality of measurement sensors S1-S4 of different kinds, for example, a temperature sensor S1, a humidity sensor S2, a vibration sensor S3, for example, an acceleration sensor, and a shock sensor S4. Henceforth in the present description, reference will be made, without
20 for this introducing any limitations, to the case where the monitoring device comprises a plurality of measurement sensors S1-S4.

The monitoring device 10 further comprises at least one processing unit 13, which is operatively connected to
25 the measurement sensors S1-S4 and adapted to receive and

sample the electric signals provided by the sensors S1-S4 to provide digital data related to the magnitudes measured by the measurement sensors S1-S4. For example, the above-mentioned processing unit 13 comprises a
5 microcontroller, and more preferably a low consumption microcontroller.

The monitoring device 10 further comprises at least one memory 15 adapted to store the digital data sampled by the processing unit 13 and/or digital data obtained by
10 the processing unit 13 by processing said sampled digital data. In the non-limiting example illustrated in Fig. 2, the above-mentioned memory 15 is represented as being external to the processing unit. In an implementation variant, such memory 15 could be internal to the
15 processing unit 13, or multiple memory units could be provided, for example, an internal memory unit and an external memory unit.

The monitoring device 10 comprises a power supply system 18 of the processing unit 13. Such power supply
20 system 18 can be also intended to directly or indirectly supply (in the illustrated example, by the processing unit 13) the measurement sensors S1-S4, in the case that such sensors S1-S4 require, for the operation thereof, a power supply source. In accordance with an embodiment,
25 the above-mentioned power supply system 18 comprises a

battery. In accordance with a further embodiment, the above-mentioned power supply system 18 comprises an energy harvesting device, internally or externally to the processing unit 13.

5 The monitoring device 10 comprises a passive RFID transponder 16 adapted to receive a request from an external query RFID device, for example, from the mobile query terminal 4 and/or the fixed query station 8, and to provide the stored digital data as a reply to the query
10 device 4,8.

 In accordance with a preferred embodiment, the above-mentioned RFID transponder 16 comprises a PIFA (Planar Inverted F Antenna) antenna 19, for example, made as a micro-strip on a substrate 11, which for example
15 represents a printed circuit board on which the various electronic components of the monitoring device 10 are mounted.

 The passive RFID transponder 16 may be a component external to the processing unit 13 and operatively
20 connected to the latter through suitable electric connections, or it may be a module provided within the processing unit 13, except for the antenna 19, which in any case would be external. In the first one of the above-mentioned embodiments, the memory 15 could be a
25 memory, for example an EPROM, internal to the RFID

transponder 16. In the other one of the above-mentioned embodiments, said memory 15 can be an external memory which the processing unit 13 accesses when the RFID transponder within the processing unit 13 is energized by
5 a fixed or mobile external query device 4,8. In such a case, the processing unit 13 is energized, for example, to carry out the above-mentioned reading from the same internal transponder RFID. On the contrary, in the sampling and/or processing operations of the digital
10 data, the processing unit 13 is supplied by the power supply system 18. Due to this reason, the operation of the device 10 can be referred to as semi-passive, i.e., it is active during the data acquisition and processing, and it is passive when reading such data as a reply to a
15 query by an external device 4,8. Due to the above-mentioned reason, two diodes have been illustrated in Fig. 2 between the RFID transponder 16 and the processing unit 13, and between the power supply system 18 and the processing unit 13, to the aim of pointing out that in
20 the presence of a RFID link, the transponder 16 may supply the processing unit 13, while in the absence of such link, for the acquisition and storage of the samples, the processing unit 13 is usually supplied by the power supply system 18.

25 In accordance with an embodiment, the processing unit

13 is programmed to switch between two possible energy consumption statuses, in which one of said statuses is a status having a relatively limited consumption compared to the other one, for example, a so-called powerdown
5 status. In such embodiment, the processing unit 13 is such as to normally and mainly remain in the status of relatively limited consumption to switch to the other status at preset time intervals in order to sample the electric signals provided by the sensors S1-S4. For
10 example, such sampling occurs every half hour, or every hour. Therefore, in this example it is apparent that the processing unit 13 mainly remains in the status of relatively limited energy consumption.

In accordance with an embodiment, the monitoring
15 device 10 comprises a passive movement sensor S5 operatively connected to the processing unit 13. In accordance with an embodiment, such passive movement sensor S5 is an inertial mass sensor connected to two pins of the processing unit 13, in which a mobile mass
20 following a handling of the monitoring device 10 is such as to determine an interrupt between the pins of the processing unit 13 in order to determine a reactivation of such processing unit 13 from a powerdown status.

The processing unit 13 is such as to switch from the
25 relatively limited consumption status to the other status

when the passive movement sensor S5 detects a movement having a width exceeding a preset threshold. In the above-mentioned embodiment, it is possible to provide that a vibration sensor and/or a mechanical shock sensor is sandwiched between the measurement sensors S1-S4, which is adapted to output an electric signal and in which, following said switching, the processing unit 13 is such as to sample the electric signal provided by the above-mentioned vibration and/or shock sensor and to store digital data related to the vibration and/or shock values if the latter exceed, for example, preset thresholds. In this manner, advantageously, the shock or vibration measurements are activated at each event, avoiding acquiring useless periodical measurements when the critical system is not undergoing vibrations and/or shocks.

In accordance with an embodiment, the measurement sensor S1-S4 comprises a temperature sensor. In this case, the processing unit 13 is configured and programmed to calculate the equivalent storage time of the critical system 2 at a given reference temperature, for example, at 25° C. This measurement allows understanding how much the critical system 2 has aged compared to a storage under ideal conditions; hence, it provides a measurement that is useful to know the health status of the system,

hence also the residual life of the system.

In particular, according to the above-mentioned embodiment, the processing unit 13 is configured and programmed to calculate the equivalent storage time of
 5 the critical system 2 at a reference temperature according to the Arrhenius law. Based on such law, it is possible to calculate an acceleration factor AF as:

$$AF = \exp [(-E_{aA}/k) * ((1/T_{int}) - (1/T_{ref}))] \quad (1.1)$$

in which:

10 E_{aA} = is the activation energy in J/mol (values that may be programmed and that are stored in the memory) of the degradation process;

T_{ref} = reference temperature in °K (for example, of 293.15 °K for 20 °C, or 298.15 °K for 25 °C);

15 T_{int} = is the current temperature within the critical system 2 in °K

k = is the universal gas constant (8.314472 J/mol/°K).

Advantageously, the temperature T_{int} can be a temperature esteemed based on an external temperature measurement.

20 The equivalent storage time T25 (in the no-limiting hypothesis that the reference temperature is 25° C) is obtained by integrating the acceleration factor AF upon time.

Since the processing unit 13 is such as to operate
 25 in the discrete domain of sampled data, the processing

unit 13 can be programmed and configured to calculate the above-mentioned integral at each step, i.e., after the acquisition of each sample, according to a recursive formula based on which the equivalent storage time T_{25} at the current step "t" is equal to the sum of the equivalent storage time at the previous step "t-1", and of an additional contribution accumulated in the time interval elapsed between the previous step "t-1" and the current step "t". Such contribution is given by the product of the sampling interval (for example, 0.5 hours) by the acceleration factor AF_t calculated at step t, i.e.:

$$T_{25_t} = T_{25_{t-1}} + 0.5 AF_t. \quad (1.2)$$

In the case that the reference temperature is 25° C, the acceleration factor AF may be calculated as $\exp(k \cdot (T_c - 25) / (T_c + 273))$, in which T_c represents an estimate of the internal temperature T_{int} obtained from the samples of the external temperature measured by the temperature sensor.

In the formula (1.1) of the acceleration factor AF , the temperature T_{int} represents the real temperature of the critical system 2. Since, in a non-limiting embodiment, it can be supposed that such temperature depends on a first-order transfer function from the sampled temperature T_s by the processing unit 13, it is

possible to show that the temperature T_c may be obtained as the scalar product between a vector T_s of samples having a predetermined length stored in the vector of samples T_s according to a FIFO storage technique, in
 5 which, at each step, i.e., at each sampling, the last acquired sample is inserted at the end, with a shift of the other samples in the vector T_s towards the first element of the vector (the sample of which is thus overwritten and leaves the vector), and a vector vet_e of
 10 real numbers, which represent exponential increment values.

In order to provide an example, it shall be supposed that:

- t_{sam} represents the sampling interval;
- 15 - T_1 represents the temperature stored by the sensor and sampled;
- the initial temperature within the critical system 2 is, by the sake of simplicity and without for this introducing any limitations, of 0°C .

20 Starting from the initial instant after the first step, i.e., after an interval t_{sam} , the temperature within the critical system will be $T_1 \cdot (1 - \exp^{-t_{sam}/\tau})$ in which τ represents the time constant of the system. At the next step, after an interval t_{sam} , it shall be
 25 supposed that T_2 represents the temperature stored by the

sensor and sampled. The temperature interval $T_2 - T_1$ will
 provide a contribution $(T_2 - T_1) * (1 - \text{and}^{-t_{\text{sam}}/\tau})$, while T_1
 will provide a contribution of $T_1 * (1 - \text{and}^{-2t_{\text{sam}}/\tau})$.
 Therefore, at the next step, the temperature esteemed
 5 within the critical system will be $T_c = T_3 * (1 - \text{and}^{-t_{\text{sam}}/\tau}) +$
 $T_2 * (\text{and}^{-t_{\text{sam}}/\tau} - \text{and}^{-2t_{\text{sam}}/\tau}) + T_1 * (\text{and}^{-2t_{\text{sam}}/\tau} - \text{and}^{-3t_{\text{sam}}/\tau})$. This
 represents in mathematical terms a scalar product between
 a vector T_s of sampled temperatures $[T_3 \ T_2 \ T_1]$, i.e., a
 vector T_s of temperature samples, and an exponential
 10 increment vector. Therefore, it has been noticed that
 excellent results are obtained even if the vector T_s of
 sampled temperatures is a vector of a reduced number of
 elements, for example, of about ten elements. This type
 of calculation allows saving processing time and
 15 dissipated power. Furthermore, it allows estimating the
 internal temperature of the critical system 2 from the
 external one, for example, from the temperature measured
 by the monitoring device 10 at the container 3 of the
 critical system 2, or generally at an external point with
 20 respect to the interior of the critical system 2.

Based on the above-mentioned description, therefore,
 it shall be apparent that, in accordance with an
 advantageous embodiment, in order to calculate the
 equivalent storage time, the processing unit 13 is
 25 programmed for:

- sampling the signal provided by the temperature sensor to obtain a digital sample and storing it in a vector of samples Ts having a limited and preset length according to a FIFO storage technique;

- 5 - at each sampling step, calculating the scalar product between said vector of samples Ts and a vector, for example, previously stored the device 10, of real numbers, which represent exponential increment values.

In a completely similar manner, if both a temperature
10 sensor and a humidity sensor are provided, it is possible to calculate the aging according to the Eyring-Peck-Arrhenius model (temperature-humidity combined model).

Similarly, if a vibration sensor is provided, it is possible to calculate the aging according to the reverse
15 power model.

In accordance with further embodiments, the monitoring device 10 is capable of monitoring aging, hence the health status of the critical system 2, by further models such as, for example:

- 20 - controlling thresholds (OS - out of specification): it is recorded if preset temperature, humidity, vibration, shock, pressure thresholds are exceeded;
- turning on/off: the number of the turning on/off cycles is recorded;
- 25 - operative hours: the operative hours of the relative

system are recorded.

In accordance with a further embodiment, the memory unit 13 is such as to store in the memory 15 at least one vector of data that represents a histogram and the
5 processing unit 13 comparing said digital data to thresholds is such as to store the digital data in specific elements of said vector in order to provide said histogram. It shall be noticed that, in the case that such histogram is a temperature histogram, it shall be
10 suitable to store the T_c in such histogram, for example, at each step, i.e., the esteemed internal temperature of the critical system 2 in the manner described above.

From the description given above, it is possible to understand how a monitoring device of the type described
15 above fully achieves the preset objects. Field experimental tests showed that a monitoring device of the type described above allows carrying out with a considerable autonomy an accurate and reliable monitoring of the health status of limited life critical systems.

20 It shall be apparent that, to the above-described monitoring device, those of ordinary skill in the art, in order to meet contingent, specific needs, will be able to make a number of modifications and variations, all of which anyhow falling within the protection scope of the
25 invention, as defined by the following claims.

CLAIMS

1. A device (10) for monitoring the health status of a limited life critical system (2), comprising:

- at least one measurement sensor (S1-S4) adapted to
5 measure a magnitude adapted to affect the health status of the critical system (2) by outputting a signal carrying information relative to such magnitude;
- at least one processing unit (13) operatively connected to the sensor (S1-S4) and adapted to receive
10 and sample said signal to provide digital data relative to such magnitude;
- at least one memory (15) adapted to store said digital data or digital data obtained therefrom through said processing unit (13);
- 15 - a power supply system (18) of the measurement sensor (S1-S4) and the processing unit (13);
- a passive RFID transponder (16) adapted to receive a request from an external query RFID device (4,8) and to provide as a reply said digital data to the query device
20 (4,8) by accessing the memory;

wherein the measurement sensor (S1-S4) comprises a temperature sensor, wherein the digital data comprise data related to the storage temperature of the critical system (2) and wherein the processing unit (13) is
25 programmed to calculate the equivalent storage time at a

reference temperature by calculating an acceleration factor according to the Arrhenius law and wherein in order to calculate said equivalent storage time the processing unit (13) is programmed for:

5 - sampling said signal to obtain a digital sample and storing it in a vector of samples having a predetermined length according to a FIFO storage technique;

 - upon each sampling, carrying out the scalar product between said vector of samples and a vector of real
10 numbers, which represent exponential increment values.

2. The device (10) according to claim 1, wherein the processing unit (13) is programmed to switch between two energy consumption statuses, wherein one of said statuses is a status having a relatively limited consumption
15 compared to the other one, the processing unit (13) being such as to normally and mainly remain in said status of relatively limited consumption to switch to the other status at preset time intervals in order to sample said signal.

20 3. The device (10) according to claim 2, comprising a passive movement sensor (S5) operatively connected to the processing unit (13), wherein the processing unit (13) is such as to switch from the relatively limited consumption status to the other status, when the passive movement
25 sensor (S5) detects a movement having a width exceeding a

preset threshold.

4. The device (10) according to claim 3, wherein said at least one measurement sensor (S1-S4) comprises a vibration and/or mechanical shock sensor that is adapted
5 to output an electric signal, and wherein following said switching, the processing unit (13) is such as to sample said electric signal provided by the vibration and/or shock sensor.

10 5. The device (10) according to any one of the previous claims, wherein the processing unit (13) is such as to store in said memory (15) at least one vector of data that represents a histogram, and wherein the processing unit (13), by comparing said digital data to
15 thresholds, is such as to store the digital data in specific elements of said vector in order to make said histogram usable by said external query RFID device (4,8).

6. The device (10) according to any one of the
20 previous claims, wherein said RFID transponder (16) comprises a PIFA - Planar Inverted F Antenna (19).

7. A monitoring system (1) comprising at least one device (10) according to any one of the previous claims, and at least one query RFID device (4,8) adapted to
25 operatively interact with said device (10).

8. A container (3) for a critical system (2) comprising a containment body adapted to house a critical system (2) therein, and characterized in that it comprises at least one device (10) according to any one
5 of the previous claims 1 to 6, which is mechanically coupled to said containment body.