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ScienceDirect

Procedia Manufacturing 51 (2020) 1178–1183

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

30th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2021)
15-18 June 2020, Athens, Greece.

Design, Fabrication and Risk Assessment of IoT Unit for Products Manufactured in Industry 4.0 Factory

Martin Hirman*, Andrea Benesova, Karel Sima, Frantisek Steiner, Jiri Tupa

University of West Bohemia, Faculty of Electrical Engineering, Czech Republic

* Corresponding author. Tel.: +420377634546, E-mail *address:hirmanm@ket.zcu.cz*

Abstract

This paper deals with the design, fabrication and risk assessment of IoT unit to reliability improvement of products manufactured in the Industry 4.0 factory. The collected data from the manufactured products can provide feedback to the manufacturing company via the Internet of Things (IoT). The manufacturer can realize the optimization of the whole product and also its production process based on these data through digitization and other analyses. On the other hand, the customer can prove due to these data that the product was used within the technical conditions specified by the manufacturer. In the paper, the IoT unit with temperature and humidity sensors was designed. After that, the risk analysis of the design with a semi-quantitative risk assessment method was applied. Then, the four prototypes of the demonstration unit were made and tested. After the testing, recalculation of the risk analysis was realized. At the end, the recommendation of high risks mitigation were presented.

Keywords: IoT, Industry 4.0, Sigfox, Product life cycle, Risk analysis, Reliability

1. Introduction

Digitalization, Internet of Things (IoT) and Big data are concepts, which are parts of the basic important technologies for Industry 4.0. These technologies can be useful not only to process monitoring and measuring but also for following whole production process optimization or for product production cycle improvement. The production cycle of each product consists of five phases, which start from the development phase and end in the product decay phase. These phases should be extended about the recyclability phase for the future framework Industry 4.0 concept. The collected data from the manufactured devices can provide feedback to the manufacturing company via the Internet of Things (IoT). The manufacturer can realize the optimization of the whole product and also its production process based on this data through digitization and other analyses. On the other hand, the customer can prove due to these data that the product was used within the technical conditions specified by the manufacturer.

Industry 4.0 is the term for the realistic concept of the next industrial revolution. The main vision of this fourth industrial revolution is the emergence of smart factories.[1] The Saurabh Vaidya in her work [2] describes the aim of Industry 4.0 as fulfilling individual customer needs which affect areas like order management, research and development, manufacturing commissioning, delivery up to the utilization and recycling of products. One of the Industry 4.0 technologies is Internet of Things (IoT) which is commonly expected to use for sensors in manufacturing machines. These sensors are connected by the Cyber-physical systems (CPS) and machine to machine communication is created. It provides a continuous stream of “Big data” which has to be processed. This can be used for

10.1016/j.promfg.2020.10.165

optimization of manufacturing process [3]. The using of IoT for data collection from manufactured device during their lifecycle is not so common. The data from this application of IoT units can be used as a feedback to the manufacturing company. The manufacturer can realize the optimization of the product and also its production process based on these data through digitization and other analyses. On the other hand, the customer can prove according to these data that the product was used within the technical conditions specified by the manufacturer. The main goal of our work was verify that application of designed and made IoT unit is possible. Another goal was to make risk assessment and to eliminate the most problematic risk factor of this solution.

In our case the sensors with IoT technology are not used to the manufacturing machines but are used to the manufactured devices. This solution is one of the possible solutions for supply chain management and logistics management.

2. Design, realization and testing of IoT sensor

In the experiment, the IoT sensor for measuring temperature and humidity inside the product was designed. The theoretical risk analysis of this design was realized in the second step. The four pieces of demonstration unit was manufactured in the third step. The demonstration unit testing in climatic chamber was realized after the manufacturing of it. The evaluation of testing and recalculation of risk analysis based on the results were realized in the final step.

2.1. Design and realization of demonstration unit

The key parameter of unit were defined by brainstorming with the experts. The most important parameters were temperature and humidity because these parameters affect the final state of product most and many products has defined value range for storage and for their use. It follows that temperature and humidity sensors have to be implemented into the unit. For the possibility of higher temperature measurement (for example for some spots on device which could be more heated), the external waterproof temperature sensor has to be also implemented. Also the possibility of unit recycling and reuse was required.

The demonstration unit was based on the microcontroller Atmel ATmega32U4 which ensures the power management of IoT unit. The IoT LPWAN (Low Power Wide Area Network) Sigfox was chosen for the communication. This network has some advantages in comparison with alternative networks (LoRa, narrowband network, …). The Sigfox has a large signal coverage, see Figure 1, which is very important for using of this units type. Sigfox has free roaming, it means that device registered in one country can be freely used in another countries where Sigfox is operated. This Sigfox network is wireless network for communication by ISM radio band (industrial, scientific and medical) that is broadcasted on the frequency 868 MHz (Europe) and 902 MHz (America).

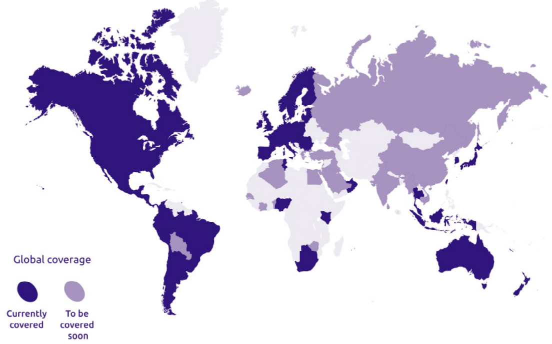

Fig. 1. Sigfox network coverage in the world (dark blue – current coverage, light violet - planned coverage) [4]

In our case, the module WISOL SFM10R1 WSSFM10R1 Sigfox Module RCZ1 was used for data sending. It is integrated radio module for IoT LPWAN Sigfox network with energy efficient “deed sleep” mode. The demonstration unit also consists of sensor element DHT22 for the measurement of temperature and humidity. The humidity can be measured from 0% to 99% RH with precision +- 2% RH. The temperature can be measured from -40°C to 80°C with precision +-0.5°C. This sensor was choose according to the low price and acceptable parameters for control measurements. The waterproof external sensor Dalas DS18B20 was used for the higher temperature part measurement. This sensor can measure temperature from -55°C to 125°C with precision +-0.5°C. For power supply is used Li-Ion battery Panasonic 18650 with maximum capacity 3400mAh for 3.7 V. According to the mode and function of sending information via IoT network Sigfox, the battery life of the device is of the order of months to units of years. For housing of the unit was used PET case manufactured by 3D printing. The individual parts of demonstration unit are visible in Figure 2. The assembled demonstration unit can be seen in Figure 3.

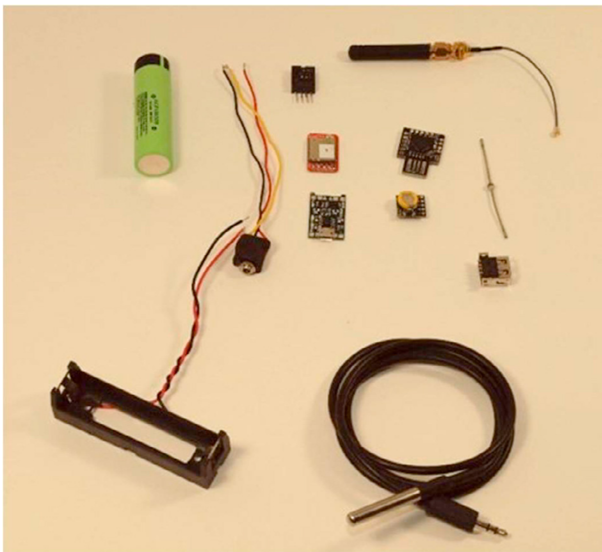

Fig. 2. The components of IoT unit prototype.

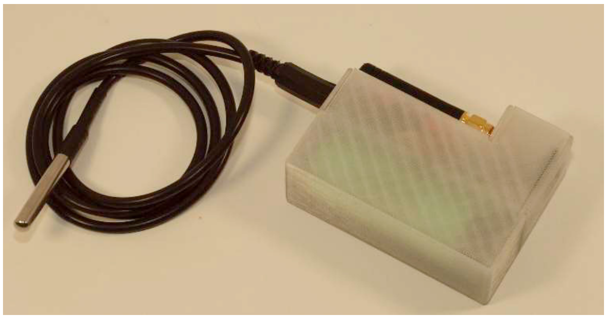

Fig. 3. The assembled IoT unit prototype.

The part of the design and manufacturing of demonstration unit was design and realization of server for collecting data with web page for easy displaying data in graphs. This website was optimized also for mobile devices as smart phones and tablets. On the website, the user can find measured values of temperatures and humidity from all demonstration units connected to the system and also the basic overview of the IoT sensor parameters. The example of realized website can be seen in Figure 4.

Fig. 4. The example of realized website.

2.2. Risk analysis of designed unit

After the designation of the demonstration unit, the risk analysis was applied. The main aim of the analysis was to identify the risks which can happen for the realized prototypes and evaluate the risk level. The semi-quantitative risk assessment method was used for the evaluation. This method evaluates impact (I) and probability of occurrence (P) for each risk.

The probability of occurrence (P) is probability that the risk happens. If the value of probability is low, the occurrence of risk is rare. The scale of this factor can be seen in table 1.

Table 1. Probability (P) classification table.

Probability of occurrence (P)	
Level	Value
Rare	1
Unlikely	2
Possible	3
Probable	4
Highly probable	5

The impact (I) describes if the impact of the risk is negligible or very high and preventive measures has to be realized. The scale of this factor can be seen in table 2.

Table 2. Impact (I) classification table.

Impact (I)	
Level	Value
Very low	1
Low	2
Medium	3
High	4
Very high	5

The scales used to characterize the probability of occurrence can be different in semi-quantitative approach [5]. The risk value can classify the impact of risk into several categories. The most common categories of risk value are low, medium, high and very high. The risk value (RV) is calculated according to the equation below [6].

$$Risk\ value\ (RV) = Impact\ (I) \times Probability\ (P) \qquad (1)$$

The risk value (RV) is between 1 to 25 which is visible in table 3. If the value is under 4, the risk is evaluated as low and it is illustrated by green color. If the RV is between 4 and 9, the risk is evaluated as medium and it is illustrated by yellow color. If the RV is between 10 and 19, the risk is evaluated as high and it is illustrated by orange color. If the RV is more than 19, the risk is evaluated as very high and it is illustrated by red color. The urgency of risks solving is determined based on the risk value.

Table 3. Table for risk assessment - RV.

	Probability of occurrence (P)				
Impact (I)	1	2	3	4	5
	2	4	6	8	10
	3	6	9	12	15
	4	8	12	16	20
	5	10	15	20	25

In our case the brainstorming methodology with experts was used to the risks identification. In this method, the group of experts meet to generate new ideas and solutions (in our case the risks identification) around a specific domain of interest by removing inhibitions. People are able to think more freely and they suggest many spontaneous new ideas (e.g. risks) as possible. All the ideas are noted down, those ideas are not criticized, and after brainstorming session, the ideas are evaluated. The identified risks for designed demonstration unit can be seen in table 4. These risks were also evaluated by semi-quantitative risk assessment method in cooperation with experts and included to the risk group.

Table 4. The list of identified and evaluated risks after the design of unit.

Risk	P	I	RV
Signal strength	4	5	20
Pulling of antenna	3	5	15
Server failure	4	5	20
Internal network failure	3	5	15
Sensor connection	3	5	15
Box material	3	4	12
Restrictions of the selected network	3	5	15
Sensors accuracy	3	5	15
Battery not inserted correctly	3	5	15
Damage of the case	3	4	12
Poor maintenance	2	5	10
Impurities	2	4	8
Water	2	5	10
Chemicals	1	5	5
Low battery	4	5	20
Data loss	4	5	20

The table shows that very high risks of IoT units can be signal strength, server failure, low battery and data loss. For these risks is necessary to provide suggestions for risk mitigations.

For the low signal strength was suggested, that the signal coverage in the expected areas of use has to be measured before using of our unit and if the problems with coverage will be founded, the different network for connection has to be used.

For server failure was suggested to prepare the backup server which will be automatically activated after the main server failure.

For low battery was suggested that the quality of battery has to be measured before the unit manufacturing and low quality pieces has to be withdraw. In addition, the analysis of this problem after the long term using of unit can be beneficial and can initiate a change in the type of battery used.

For the data loss was suggested, that data backup on the website has to be done.

2.3. Testing of demonstration unit

The four prototypes of demonstration unit was made for testing and validation. A few tests according to the standards was performed in the climatic chamber. Firstly, the cold resistance according to the standard EN 60068-2-1 (Environmental testing – Part 2-1: Tests – Test A: Cold). The setting of climatic chamber was +5°C for 16 hours. The second test was dry heat resistance according to the standard EN 60068-2-2 (Environmental testing - Part 2-2: Tests - Test B: Dry heat). The setting of climatic chamber was +55°C for 16 hours. The third test was damp heat cyclic test according to the standard EN 60068-2-30 (Environmental testing – Part 2-30: Tests – Test Db: Damp heat, cyclic /12 h + 12h cycle). The setting of the test was 40°C/97,5% RH/12 hours + 25°C/93%RH/12 hours. All data (temperature, humidity) measured by IoT units were transferred by Sigfox network to the database on server. The data were also measured by climatic chamber and these two sources of data were compared. The example of measured values from one unit can be seen in the Figure 5.

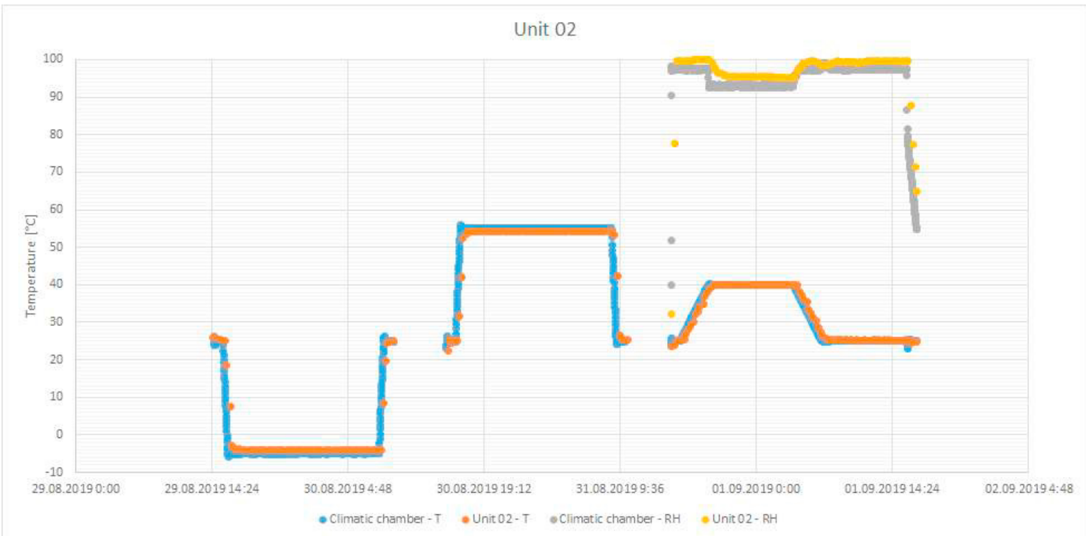

Fig. 5. The measured values by IoT unit 02.

2.4. Evaluation of testing and risk analysis

The data measured by climatic chamber are very similar with values measured and transferred by IoT units. Also the comparing of values from each IoT units showed that values are very similar, it follows that all units works similarly. In some areas are visible gaps in data measured by IoT units, but it is caused by sampling period which was 12 minutes. Another cause can be also lower signal strength in the measurement area.

The recalculation of risk analysis was realized after the results prototype units' evaluation. The list of recalculated risks can be seen in Table 5. This table shows that very high risks of IoT units are signal strength, battery not inserted correctly and low battery.

Table 5. The list of recalculated risks after the experiment evaluation.

Risk	P	I	RV
Signal strength	5	5	25
Pulling of antenna	1	5	5
Server failure	2	5	10
Internal network failure	3	5	15
Sensor connection	2	5	10
Box material	2	4	8
Restrictions of the selected network	2	5	10
Sensors accuracy	1	5	5
Battery not inserted correctly	4	5	20
Damage of the case	1	4	4
Poor maintenance	2	5	10
Impurities	2	4	8
Water	2	5	10
Chemicals	1	5	5
Low battery	4	5	20
Data loss	2	5	10

Note: This table is calculated for trained worker and using of unit in the standard environment without special external influences. In case of expected IoT unit use in harsh environment or unqualified operators it is necessary to recalculate the analysis.

For the low signal strength was suggested, that the signal coverage in the expected areas of use has to be measured before using of our unit and if the problems with coverage will be founded, the different network for connection has to be used. The lower signal or lost connection is the highest risk and have to be solved. It is possible to use multiple networks with the possibility of switching them based on the current signal strength, but this solution increases the cost of the sensor itself, which is not ideal.

For the not correctly inserted battery was suggested to improve the label for + and – side in the battery holder or designing of special holder with using of Poka-Yoke principle.

For low battery was suggested that the quality of battery has to be measured before the unit manufacturing and low quality pieces has to be withdraw. In addition, the analysis of this problem after the long term using of unit can be beneficial and can initiate a change in the type of battery used. Also for using in a larger electronic device, the unit power supply can be solved from electrical network and the battery will only serve as a backup in case of power failure.

3. Conclusions

The IoT unit for measuring the environment was realized. The experiment provided proof that application of designed and made unit is possible. The most problematic risk factors were calculated for designed unit and recalculated after the prototype testing. The suggestion of the most problematic risk factors mitigation was done.

The general conclusions from risk assessment can be also done. The users of IoT units should watch and secure the signal strength of communication network in area of their usage. If the sensor is not always connected to the electrical network, the problem with low battery should be monitored. Also the human bugs can happened during the installation or maintenance of unit, so solution to this risk mitigation should be applied.

The designed unit can be used by manufacturers in the manufactured device and collect data that can provide feedback to the manufacturing company via the Internet of Things (IoT). The manufacturer can realize the optimization of the whole product and also its production process based on this data through digitization and other analyses. On the other hand, the customer can prove due to these data that the product was used within the technical conditions specified by the manufacturer.

Acknowledgements

This research has been supported by the Technology Agency of the Czech Republic, project No. TH02010577 "Software platform for Implementation Accelerating of Process Control and Automation Systems" and by the Student Grant Agency of the University of West Bohemia in Pilsen, grant No. SGS-2018-016 "Diagnostics and Materials in Electrical Engineering".

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