RFID UHF Temperature Sensor Tags Initialization and Application

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Abstract **– Radio Frequency Identification (RFID) has found its appliance in many areas but most common use of RFID technology is for tracking various goods. In this paper the system for monitoring temperature of instruments inside the laboratory is presented. System is composed of Caen RT0005 UHF RFID tags with integrated temperature sensor, Alien 9900 UHF RFID reader and UHF RFID Alien patch antennas. Caen RT0005 tags are semi-passive tags which provide temperature logging once when they are initialized. Proposed system represents safe surveillance of expensive instruments prone to overheating. We proposed the software which provides instruments tracking inside the laboratory, initialization and writing of sensor tags, temperature tracking and alarms notification. There are two kinds of temperature alarms which can be alerted: i) when temperature increases over pre-set temperature limit, ii) when temperature is increased rapidly inside pre-set time interval. Experimental results of proposed application are induced at the end of the paper along with the advantages and disadvantages of the proposed system.**

Keywords **– RFID technology, UHF sensor tags, tags programming, temperature sensing, alarm, Caen tags, Alien reader**

I. INTRODUCTION

In paper [1] we proposed system for object tracking and monitoring by using RFID technology. We described software with the MySQL database for simple objects finding inside the laboratory. RFID system was composed of Alien RFID reader, four UHF RFID antennas and BAP (Battery Assisted Passive) tags which we use for objects tagging. In this paper we extended pre-proposed RFID system with Caen UHF RFID BAP tags with integrated temperature sensor. By using sensor tags, safer way for objects monitoring is enabled with regard to the possibility of temperature monitoring of some objects e.g. expensive instruments inside the laboratory which are prone to the overheating due to constant usage.

RFID technology is growing rapidly in many ways as an effective wireless technology for object identification. The integration of sensors for monitoring some physical parameter like temperature, humidity, pressure, etc. into semi-passive RFID tags has generated huge interest in RFID technology development [2-4]. But still there are not many manufacturers at the market who offer tags that incorporate sensing capabilities. Some of them which are worth to mention are SL900A sensory tag by Austria Micro Systems (AMS), the Easy2Log tag by CAEN RFID, and the SensTAG by Phase IV [3]. However, none of those tags are completely compliant with RFID standards and regulations and they cannot be programed/written as regular tags. RFID semi-passive tags with integrated temperature, humidity, pressure or any other sensor are not common RFID semi-passive tags since that they are equipped with sensor and are more expensive than regular tags but they contain the same identification functions as regular tags. Other disadvantage is limited life time of sesor tags due to battery usage to power its circutary which can be solved like it is proposed in [5].

RFID UHF tags are identification devices of RFID system and contain microchip attached to an antenna. They are communicating with a RFID reader by sending its identification number but they can contain an additional data like those with sensor do. RFID tags can be passive, semi-passive or active due to battery presence of absence. Semi-passive or BAP (Battery Assisted Passive) are those who have battery to power its circuitry and they are communicating with the reader in the same way as the passive tags by using backscattered communication [6].

In this work we will describe how to program sensor tags – Caen RT0005 with Alien 9900 reader. There will be presented how to use sensor tag outside of a perishable items monitoring during the transport which means that there are set into the laboratory environment. In Section II the Caen RT0005 will be described: i) how to initialize it to start temperature logging, ii) its memory banks and memory structure. Section III is about sensor tag programing with Alien 9900 reader, and Section IV and V describe experimental set-ups for programing tag testing and for testing instruments temperature logging. A conclusion and obtained results are induced at the end of the paper.

II. CAEN RT0005 TEMPERATURE TAGS

Tags with integrated temperature sensor Caen RT0005 are semi-passive UHF tags compatible to the EPC Class1 Gen2 ISO18000-6C standard [7]. They have possibility of temperature logging according to the user preferences during food transport or monitoring temperature of different laboratory instruments as we described in our paper.

To start temperature logging user needs to configure some memory registers of RT0005 tag which are part of its User memory bank. Once configured, tag can work as temperature logger as long as its battery doesn't run out. When the battery runs out or if we programmatically or manually stop its temperature logging all registers are being reset which is main disadvantage of this tag.

Main problem in tag's registers temperature logging reconfiguration is the time we need to invest in registers configuration. Constrains for writing tags are greater than for its reading [8]. Writing range is smaller than reading range and supports only one tag in the write field at the time, and it takes more time to write tag than to read it etc.

RFID Gen2 tags implement 4 memory banks: RESERVED, EPC (*Electronic Product Code*), TID (*Tag Identification)* and USER bank [9]. User memory bank contains all the configuration registers and the logging memory. RT0005 temperature tag contains 74 programmable memory registers but for the needs of the proposed system only four registers should be configured. Registers that needs to be configured are described hereafter:

1. CONTROL register which is located at the address $(000A)_h = (10)_d$ of USER memory bank. Its default value is $(0000)_h$. It is composed by the following fields: Reset bit, Button Enable bit, Logging Enable bit, Delay Enable bit, RF Sensitivity Level bits (MBIT and LBIT), Mean Kinetic Enable bit, Arrhenius Enable bit, Stop Disable. Fields of Control register can be seen at the figure below.

15..12	11	10..8	7	6	5	4	3	2	1	0
RFU	SD	RFU	ARRE	MKTE	RFSL_MBIT	RFSL_LBIT	DE	LE	BE	RST

Figure 1. Control Register of RT0005 temperature tag

Field RST (Reset) is by default set to 0, where 1 is used to reset all memory registers. BE (Button Enable) bit is 1 if user wants to enable button on the interface of the tag for start/stop temperature logging. LE (Logging Enable) needs to be set to 1 to indicate start of the temperature logging. RFSL (RF Sensitivity Level) is used to set the sensitivity level of the RF front-end and can be set to three levels: 3 is maximum sensitivity, and 1 is minimum sensitivity. Other fields are by default set to 0. For example if user wants to start temperature logging with RF sensitivity level 1 and with enabled button on the tag's interface than control register is set to binary value $(0000000000010110)_b$ or hexadecimal value $(0016)_h$. If user doesn't want to enable button on the tag's interface than register is set to hex value $(0014)_h$. The value of the control register is $(0000000000110110)_b$ or $(0036)_h$ when RF sensitivity level has its maximum value etc. All other fields are set according to needs of the user and in our case do not need to be modified.

2. BIN_ENABLE register which is composed by 16 fields and is located at the address $(0010)_h = (16)_d$. At the figure below BIN_ENABLE register's fields can be seen.

15	...	2	1	0
BIN15_EN	...	BIN02_EN	BIN01_EN	BIN00_EN
0	0	0	0	1

Figure 2. BIN_ENABLE Register of RT0005 temperature tag

In this register we set to 1 as much fields as many different temperature intervals we want to have. If we need three different intervals, than we need to enable three fields in this register by setting register to value $(0000000000000111)_b=(0007)_h$. In our case we need to monitor only current temperature which means we have only one temperature interval with sensor tag's limits, so we set register to value $(0001)_h$ which is also its default value.

3. Lower and upper temperature intervals are set in BIN_HLIMIT registers. We need to specify upper and lower limit of one register. Upper limit is upper limit of a tag 70°C and lower limit is by default set to lower limit of a tag which is -20°C as can be seen at the Figure 3.

Register	Address	Op.	Default
BIN_HLIMIT_0	0x13	RW	0x08C0
BIN_HLIMIT_1	0x14	RW	0x0000
...	...	..	0x0000
BIN_HLIMIT_15	0x22	RW	0x0000

Figure 3. BIN_HLIMIT Register of RT0005 temperature tag

Temperature is expressed in fixed point 8.5 notation so it needs to be converted to °C by using Formula (1).

$$0°C \le T_{°C} \le 70°C, \quad T_{°C} = \frac{T_{\text{fixedpoints}}}{32}$$
$$-20°C \le T_{°C} < 0°C, \quad T_{°C} = \frac{T_{\text{fixedpoints}} - 8192}{32} \qquad (1)$$

If the upper limit is 70°C than register which is located at the address $(0013)_h = (19)_d$ is set to value $(2240)_d = (08C0)_h$.

4. Optionally we can define sample time interval by setting BIN_SAMPLETIME register to value of the time in seconds. First field of the register which is located at the address $(0023)_h = (35)_d$ is set to value $(000F)_h=(0015)_d$ which means that sample time is 15s.

Register	Address	Op.	Default
BIN_SAMPLETIME_0	0x23	RW	0x0258
BIN_SAMPLETIME_1	0x24	RW	0x0000
...	...	..	0x0000
BIN_SAMPLETIME_15	0x32	RW	0x0000

Figure 4. BIN_SAMPLETIME Register of RT0005 temperature tag

USER memory bank up to 35th address now after all registers are configured looks like on the figure below:

0	1	2	3	4	5	6	7	8
0001	0300	0004	0FC2	0000	0000	0000	0000	0000
9	10	11	12	13	14	15	16	17
0000	0036	0001	0000	0000	0000	0000	0001	0000
18	19	20	21	22	23	24	25	26
0000	080C	0000	0000	0000	0000	0000	0000	0000
27	28	29	30	31	32	33	34	35
0000	0000	0000	0000	0000	0000	0000	0000	0001

Figure 5. USER memory bank up to 35th address of temperature tag

Values of the registers marked in orange (0-9) are read only. Values of registers marked in green (11-15, 17-18, 20-34) are its default values and are not edited. Registers marked in blue (10, 16, 19, 35) are configured registers with its new values.

III. PROGRAMING RFID UHF TAGS

A. Programing RFID tags

Programing/writing of the RFID tags is process which is affected by volatile RF communication of the RFID reader and tags [10] and thus is not always accurately. To increase the accuracy of writing tags the communication range should be decreased and no obstacles should be between the reader and the tag. Write command according to EPC Class-1 Generation-2 UHF RFID protocol allows a reader to write a word in a tag's memory banks. Write command is composed of following fields: memory bank which specifies which memory bank will be affected, word pointer which specifies the word address for the memory to write and data which contains a 16-bit word to be written [11].

Software for multiple USER memory bank registers programing is proposed and described hereafter.

B. Software for RT0005 temperature tags programing

Alien 9900 RFID reader and its read/write commands are used for programing sensor tags. Alien RFID reader can be programmatically controlled by using Microsoft.NET Software Development Environment [12] as is a Visual Studio which we used to write proposed software program in C# language. Program is user friendly and provides to a user simple and fast RT0005 tag's registers configuration.

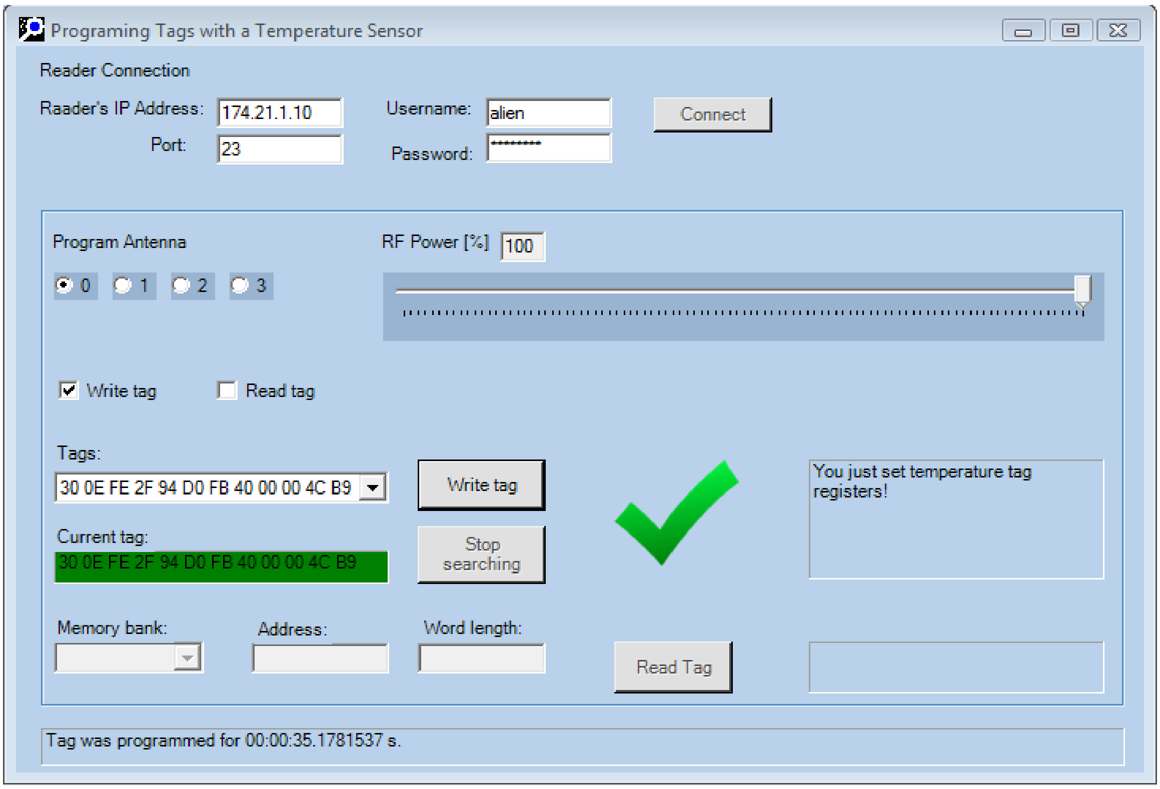
By using this program user needs to connect to a reader by entering reader's IP address and after that chooses a tag to read or to write. By pressing button *Set Temperature Logging* program calls Alien Reader command *ProgramUser*. *ProgramUser* command sets all registers in USER memory block up to 31st address. Command can be seen hereafter:

```
mReader.ProgramUser("00 01 03 00 00 04 0F
C2 00 00 00 00 00 00 00 00 00 00 00 00 00
36 00 00 00 00 00 00 00 00 00 00 00 01 00
00 08 C0 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00
00");
```

Main disadvantage of this command is that we cannot program registers which are located after 31st address. If we need to set some register that is located after 31st address we need to configure it by using another command *G2Write* which is low level programming command of Alien Reader:

```
mReader.G2Write(eG2Bank.USER,"35","0001");
```

By adding two commands *G2Write* and *ProgramUser* to write a tag time for writing tags will be extended, about what will be discussed in the section below. If user wants to check value of some register (read register value) he/she needs to specify tag's memory bank, address location, word length, press button *Start Read* and will get hexadecimal value of selected register. Main physical requirement before we can start to program tag is that tag must be at proper distance of the reader antenna, in front of the reader antenna and without obstacles between tag and a reader antenna. User interface of a mentioned program can be seen at the figure below as well as interface of a program form for temperature and alarm monitoring.



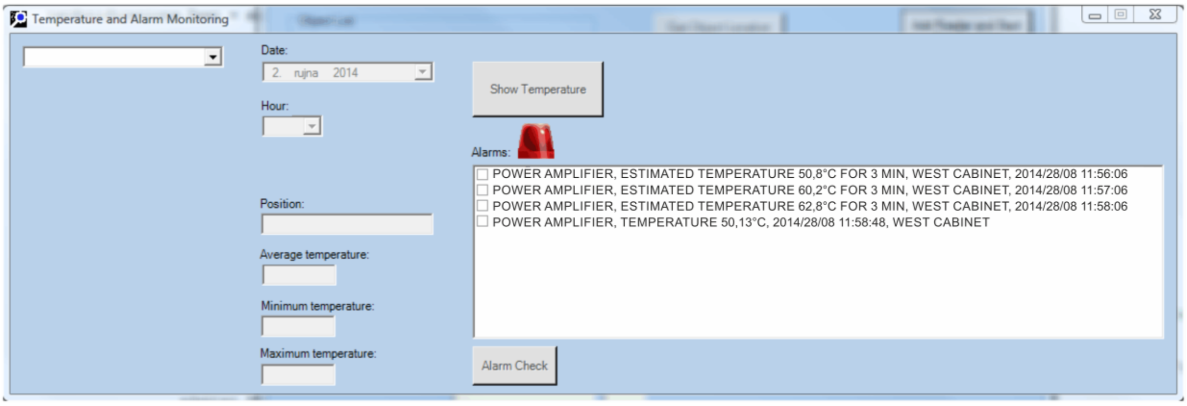


Figure 6. User interface of the form for the tag programing and of the form for temperature and alarm monitoring

IV. EXPERIMENTAL SET-UP FOR TESTING OPTIMAL TAG PROGRAMING

Tag sensitivity is one of the main features of the tag which describes minimal signal strength for reading tags at the specific location. Write tag sensitivity differs from read tag sensitivity in a few dBs [13]. Integrated circuits of modern tags consumes about 10-30μW during reading tags from a RFID reader. That means that tags need to receive about 30-100 μW from the RFID reader antenna to harvest its circuitry. Lot more power is needed during writing tags [6] which means we need to reduce distance of a RFID reader antenna from the tag.

We tested distance dependence of the RFID UHF antenna from a tag which registers we want to configure. For registers configuration we used *ProgramUser* command. For testing programing time we used two RT0005 temperature tags which we attached at the wooden stick in front of the antenna at the distances of 25cm, 50cm, 75cm, 100cm, 125cm and 150cm. Tags were randomly changed on the wooden stick and antenna was slid in front of the tag like can be seen at the figure below.

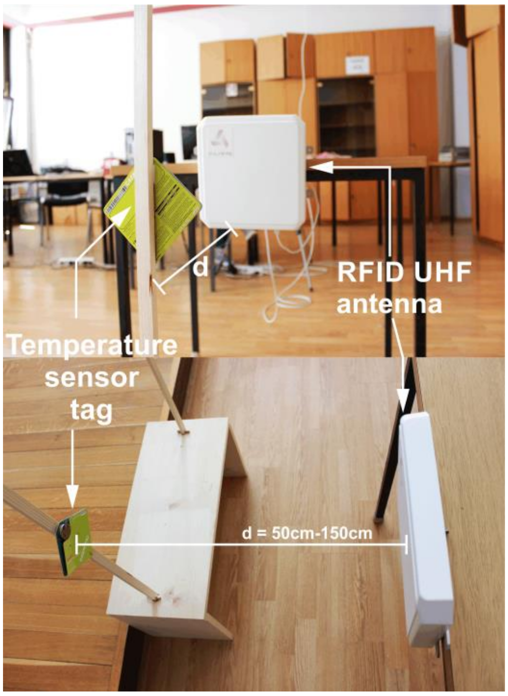


Figure 7. Laboratory set-up for programing/writing tags time testing

First we tested minimal distance of the antenna from the tag so we set antenna at the 25 cm and 50 cm distance from the tag. Shorter distances are not optimal because of the dead zones [14-16]. These dead zones are caused by the EM field cancelation since an incident wave is summed with the reflected wave caused by the EM field distribution on patch antenna. As seen in the Figure 8 [17], the field is strong at the edges of the antenna (the green areas), but weakens as we go to the centre of the antenna surface (the blue areas).

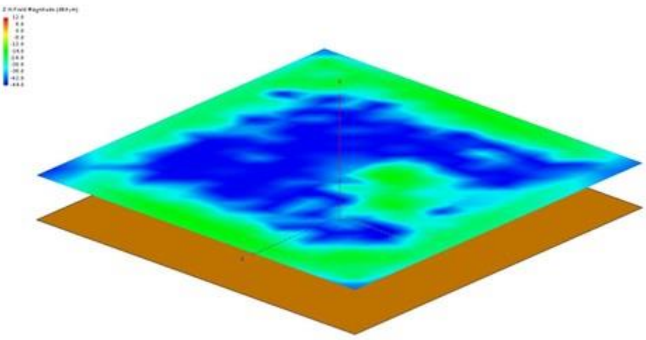


Figure 8. Magnetic field distribution of a patch antenna

Testing these two distances (25cm and 50cm) we obtained better results at the distance of 50cm. Time for programing tag at the distance of 50 cm was better for average 8,89662 s than at the distance of 25 cm. Further we tested programing times at the distances from 50 cm to 150 cm with intervals of 25cm. For each distance we have 20 programing times. Best programing time was at the distance of 125 cm which is average 3,313234 s. The testing results can be seen at the figures below.

Minimal programing time which was recorded is 0,6042 s also at the distance of 125 m. If we want to program some more registers that are placed after 31st address we need to use *G2Write* command. When we include the *G2Write* command in register configuration programing time is extended for average 6,301434 s.

V. EXPERIMENTAL SET UP FOR TESTING OF INSTRUMENT'S TEMPERATURE LOGGING

In order to present accuracy of temperature logging of tagged instruments two measurements were preformed. We monitored room temperature with thermometer and we monitored instrument’s temperature with the temperature sensor tags during one hour and during one day. During the day we logged temperature of two sensor tags. Temperature was logged every 6 seconds and was averraged for every hour of the day, what can be seen at Figure 10. During the one hour measurement one sensor tag was attached at the instrument which was at room temperature and its temperature followed thermometer temperature. Other sensor tag was attached at the instrument which was warmed up and then cooled down what represents periods of instrument's usage and standby. If we monitor room temperature only by using thermometer it can't alert us on possible situations where can come to overheating of instruments but sensor tags can. There are two alarms which can be alerted. One is based on predicted temperatures calculated from linear trend line equations. Linear trend line equation is calculated as temperature is read every 60 seconds based on previous 30 temperature data what is period of 3 minutes. Linear trend equations are calculated by least squares method. Every 60 seconds temperature is estimated for 3 minutes ahead which is time horizon for the user to act in case of alarm alert. Temperature is estimated inside interval of confidence with upper and lower 95% limit. The uncertainty of estimation is expressed as confidence interval ($CI_{\hat{y}_i}$) which is calculated by using formulas below:

$$CI_{\hat{y}_i} = \hat{y}_i \pm t_{(1+p)/2} \cdot SE_{reg} \cdot \sqrt{\nu \frac{1}{N} + \nu \frac{(x_i - \bar{x})^2}{S_{xx}}} \quad (2)$$

$$SE_{reg} = \sqrt{\frac{SSE}{\nu}} = \sqrt{\frac{\sum_{i=1}^{N} (y_i - \hat{y}_i)^2}{\nu}} \quad (3)$$

$$S_{xx} = \sum_{i=1}^{N} (x_i - \bar{x})^2 \quad (4)$$

For 95% confidence intervals term $t_{(1+p)/2}$ is $t_{0,975}$ which is the 97,5% quantile of the t-distribution for $\nu=N-2$ degrees of freedom. Standard error of regression (SE_{reg}) is an estimate of the 1-sigma uncertainty of the regression, SSE is the squared sum of the errors of the regression, N is the number of measurements and S_{xx} is measure of both the number of measurements and of the length of the interval which the trend is calculated over.

In moment of estimation if upper 95% limit of estimated temperature is higher than temperature threshold alarm is alerted. Second alarm is alerted if temperature exceeds allowed temperature threshold. At Figure 11 can be seen temperature reads of two sensor tags and thermometer. One sensor tag follows temperature of thermometer which was room temperature. All estimated temperatures of the tag were much lower than temperature threshold and no alarm was alerted. For other tag which measured higher temperatures at first point of estimation which was at 29°C estimated temperature 33,8°C wasn't high enough for alarm alert. At second point of estimation which was after 60 s estimated temperature's upper 95% limit exceeded temperature threshold and first alarm was alerted as can be seen at Figure 11. Next alarms will be at 11:57:06 and 11:58:06 until temperature of 50°C is reached.

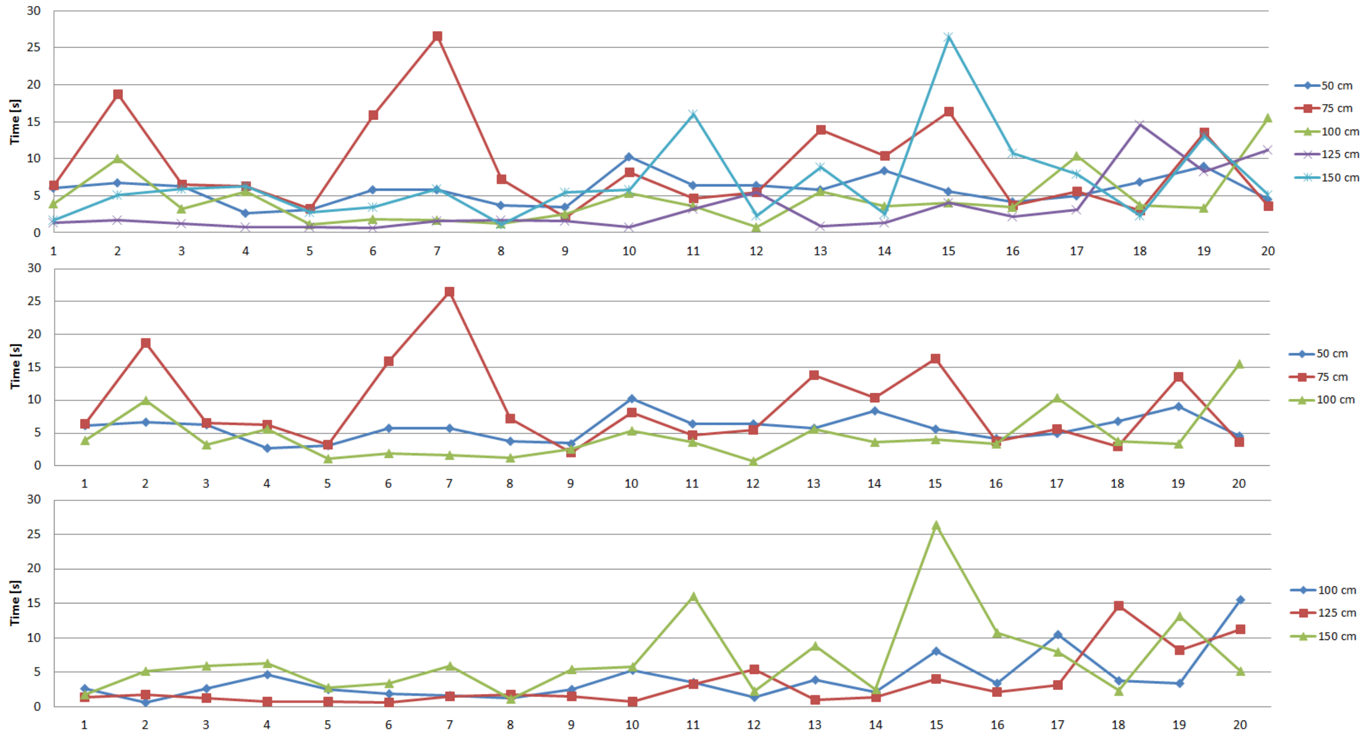


Figure 9. Time results of writing UHF sensor tag

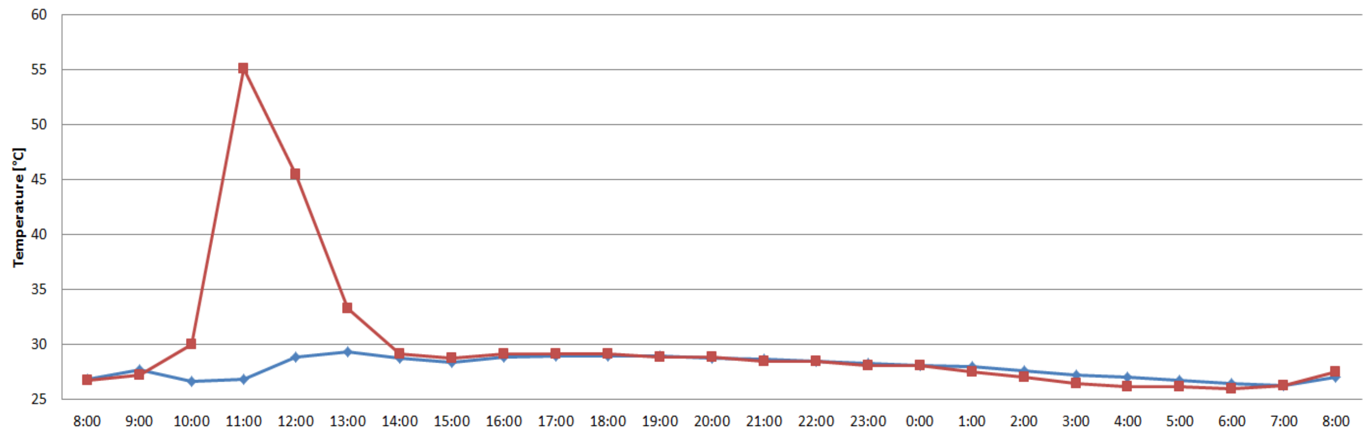


Figure 10. Temperature measurement results during one day

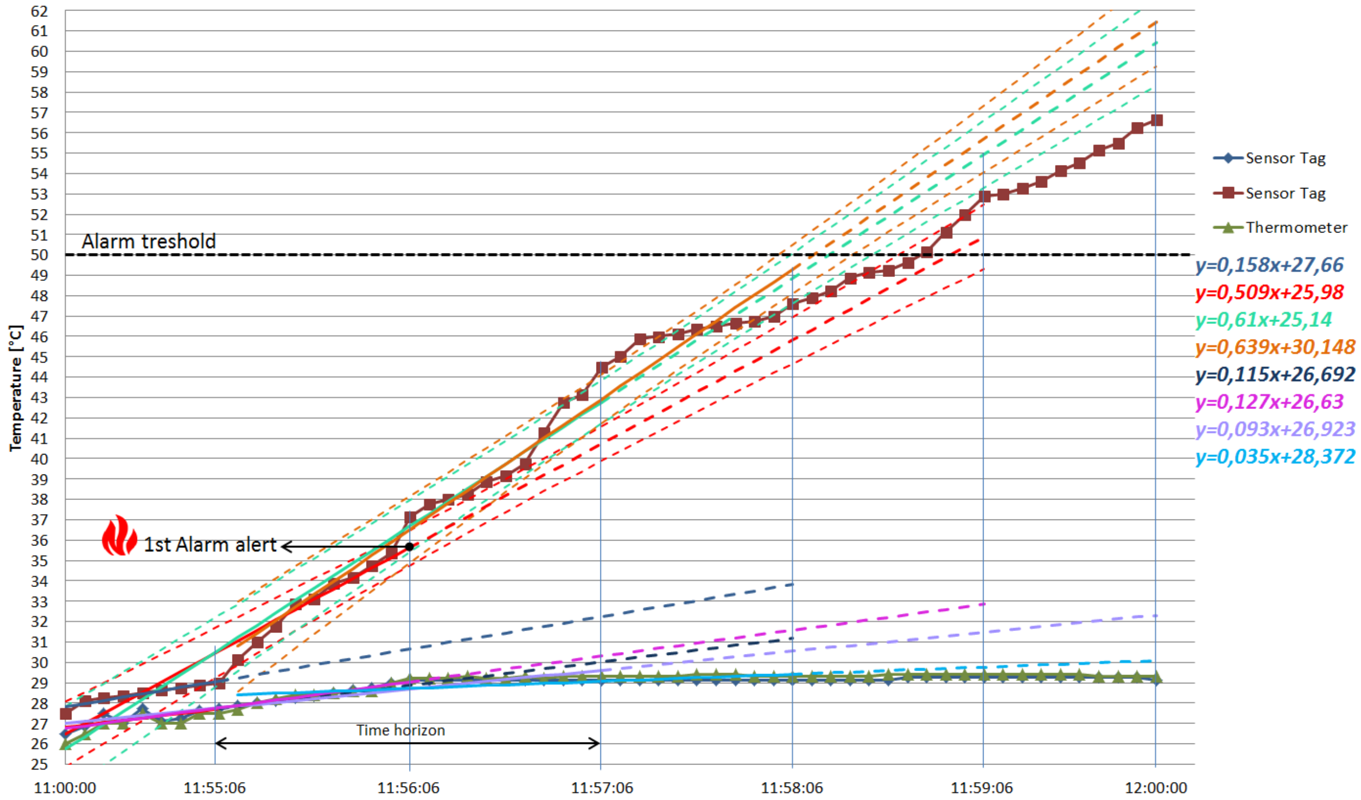


Figure 11. Temperature measurement results during one hour

VI. CONCLUSION

We presented system for precise tracking of instruments position [1] and its temperature inside the laboratory. System provides monitoring of the temperature of tagged instruments and alarm alerts because of instruments temperature inceasement. The software for tag's programing i.e. initalization of sensor tags to became temperature loggers is described and presented. Presented sysem uses semi-passive tags with integrated temperature sensor of the company *Caen RFID* and RFID reader of the company *Alien* for it's reading/writing. We tested proposed system and software program and within results we aduced advantages and disadvantages of the system. Main advantage of the system is precise temperature monitor and safe instruments surveillance by using RFID sensor tags which are compatible with C1G2 protocol and can be used with every existing RFID system compatible with C1G2 RFID protocol. Disadvantage of the system is unprecise and long time sensor tag writing and initialization to start temperature logging and system dependancy of sensor tag battery life time.

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