RFID SMART TEMPERATURE SENSOR.
APPLICATION IN MONITORING AND TRACEABILITY OF HEMODERIVATES.

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Abstract

In this paper, the development of a new smart temperature sensor adapted to monitoring hemoderivates production is presented. The sensor serves as an identification mechanism, while at the same time, is capable of registering temperatures. The design makes use of RFID technology in order to meet operation specifications; which would be impossible with other technologies. The development of a reader with a data treatment and manipulation computer is also presented. These developments form part of the TermoQUIRON project funded by JCCM.

Key words: smart sensor, RFID, traceability, hemoderivates.

1. INTRODUCTION

The term "smart sensor" was coined in the mid 1980's when microelectronic development started to allow for the integration of microcontroller systems/digital signal processors (MCU/DSP) along with silicon sensor devices. Basically, a smart sensor is the combination of a sensitive element at various magnitudes (temperature, pressure, acceleration, position, humidity, pH, etc.) and an electronic subsystem which has signal conditioning capabilities provided by a microprocessor/microcontroller system that is equipped with signal management abilities, data storage and digital communications functions.

Radio Frequency Identification (RFID) made a comeback during the radio electronic era, although Mario Cardullo figures as the patent owner in the North American Office of Patens since January 1973 [3], [14]. This patent defines the base elements of a RFID system. These elements can be transcribed to modern systems with slight advances. RFID technology basically consists of the transmission of an identification signal (series number, internal code, etc…) to a base station (reader), using a radio frequency link.

The main peculiar difference between conventional radio communications and RFID technology resides in the transmission, which is usually carried out by modulating the carrier signal sent from the base station (reader). The identifier (TAG) uses a part of the carrier signal to extract its energy, which allows creating a totally passive identifier.

The advancements of these two technologies have gone hand-in-hand with microelectronic developments. Along with these, it is important to make mention of a few others, specifically: higher integration level, calculation power, consumption and cost reduction, increased features, integration of microelectric mechanical systems (MEMS), etc. These developments allow new and previously unimaginable uses of smart sensors and RFID technology [11], especially in the traceability and monitoring areas.

This paper presents the development of a new smart sensor design to guarantee hemoderivates production quality all the way from the preparation phase through to the transmission phase.

2. HEMODERIVATES

The production of blood derivates can be seen in the following steps:

a) Extraction: This phase is carried out in stationary blood banks or in mobile extraction units, which can provide service to a designated coverage area. This is also the stage in which each bag is identified with a bar code that the system base station associates with a donor, the date and blood type.
b) Stabilization and storage: After the extraction, the bags of blood are chilled and kept in 20-24ºC during 3-18 hours using a butanediol tray.
c) Fractioning: it is a centrifugal process in which the blood components are separated into red globes concentrate, platelets concentrate and plasma bags.
d) Separate storage: The red globes concentrate is stored in a refrigerator at 4ºC-6ºC anywhere from 1 to 40 days. The platelets are kept in an incubator between 20ºC and 24ºC from 1 to 5 days and the plasma is kept in a freezer for 1 to 365 days at –60ºC to –20ºC.

It is fundamental to respect the established storage temperature limits within each phase in order to guarantee the quality [1] of the subproducts. It is very important to keep a record of the temperature evolution of each bag throughout the process to achieve this goal.

Given the characteristics of the bags, the conventional data logging systems are inadequate due to their size, connection requirements, complexity and management costs. To fill this need, new smart, RFID tag sensor data logging system has been designed, that has the following characteristics:

a) Compact size, so that the tag can be placed on the bag.
b) Large data capacity storage.
c) Possibility of alarms processing and treatment.
d) Price and consumption reduction.
e) User-friendly.
f) Mechanical/thermal/chemical strength and durability.

3. RFID SMART TEMPERATURE SENSOR

Due to the application requirements, a new highly compact, semi-active, impenetrable smart temperature sensor has been especially designed. It was established that the new sensor must:

a) have the most compact microprocessor available.
b) contain a high capacity, non-volatile memory for data storage.
c) use short range, wireless communications to download data and set up parameters.
d) include a temperature sensor with a precision range of 0.2ºC
e) use an energy source which provides an operating life of 2 or 3 years.
f) be impenetrable and durable.

A block diagram of the proposed sensor is shown in Fig. 1.

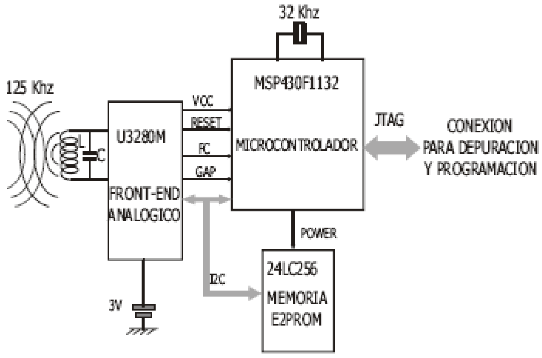

Figure 1. RFID smart temperature sensor block diagram.

3.1. Component description

In the following paragraphs the basic components which make up the sensor are explained. The significant characteristics of the application are described below.

3.1.1. Microprocessor

Given the characteristics of the application, choosing the main nucleus of the sensor has been a determinant factor in the success of its development. So, in selecting a microprocessor various aspects were taken into account, of which a few should be noted:

- Ultra-low consumption.

- Most compact design.
- Processing capacity and memory.
- Peripheral components for communication and other functions.
- Low cost and availability.
- Development tools and documentation.
- Including a temperature sensor in the microprocessor and a data acquisition system.

Using the previous characteristics as guidelines, a comparison was made between products offered by three manufacturers: Microchip Inc. presents NanoWat technology devices, while Texas Instruments Inc. has developed the MSP430 family of 16 bit, ultra low consumption RISC microprocessors, and also the EM6812 family from Microelectronics Marin. The most self-controlled alternative is the EM6812 as can be seen in [2], but the chosen solution was the MSP430 [7], and more specifically the MSP430F1132 because of such factors as price, availability and development tools offered. The most important characteristics of the MSP430F1132 are:

- 1.8V-3.6V energy supply range.
- Ultra low consumption: 200 µA in active mode, 0.7 µA in sleep mode and 0.1 µA in off/storage mode.
- 16-Bit RISC architecture with 125 ns cycle.
- 10-Bit A/D converter, 200 Ksps.
- Serial programming. JTAG treatment.
- Flash memory 8KB+256B and 256B RAM.
- 20 pin chip TSSOP or SOWB.
- Price < 2 euros.

As shown in Fig. 1, a I2C bus connects the microprocessor with the rest of the components. A 32.78 KHz quartz crystal is used to achieve the lowest possible consumption, and an available stable time base. Furthermore, the internal temperature sensor of the microprocessor attains cost and energy minimization. The synchronization of the demodulation of received data from the reader is simplified by using the frequency carrier that the analog interface delivers. The EPPROM memory energy source is managed by the microprocessor, connecting exclusively when reading and/or writing processes must be carried out.

3.1.1. EPPROM Memory

A small, low consumption, non-volatile storage system requires alarms, parameter configuration and registered data storage. The choice is clear at this point, the EPPROM memory with I2C serial buses must be selected for this project. In line with application necessities, it is estimated that 32 KB is sufficient. For this, the 24CC256C Model is chosen. Its characteristics are detailed below:

- Low consumption, 2 mA writing cycle, 200 µA reading cycle, 100 mA sleep mode.
- Series I2C™ interface.
- 5 ms writing cycle maximum.
- 8 pin chip SOIC, TSSOP, MSOP.

A very simple, but extremely efficient, data compression procedure is required in order to optimize memory space and reduce energy consumption. The method employed is based on storing new data if the difference between two consecutive samples exceeds a preestablished threshold. This way, when the bag temperature stabilizes, which will happen in a few hours, the sensor will not have to store new data. This strategy not only reduces memory requirements and power consumption, but also shortens data download time.

3.1.3. U3280M analog front-end

A number of wireless alternatives with radiofrequency (RF) and infrared were analyzed in order to determine the data transfer procedure between the sensor and the reader. The RF choice is justified because, during communication, it supplies energy to the reader without taking power from the battery of the tag, which lengthens its life. Furthermore, the RF option allows the device to be totally impenetrable and permits it to carry out long distance communication, no matter how the sensor is oriented.

Within the frequency bands reserved for RFID applications in Europe [3], the 125 KHz carrier design is clearly a sound choice because it facilitates the realization of a more compact analog front-end, even though specific integrated devices already exists for this function. More over, this frequency's energy consumption is significantly reduced when compared to carriers at 13.56 MHz or above.

Taking into account the previous factors, it is clear that the U3280M [18] is a justified option for front end communications between the reader and the sensor. Fig. 2 shows the internal structure of the device; its most important characteristics are described below:

- Communication interface and wireless energy supply.
- Power supply management from the battery.
- Clock extractor.
- Detection of fields and gaps in the signal.

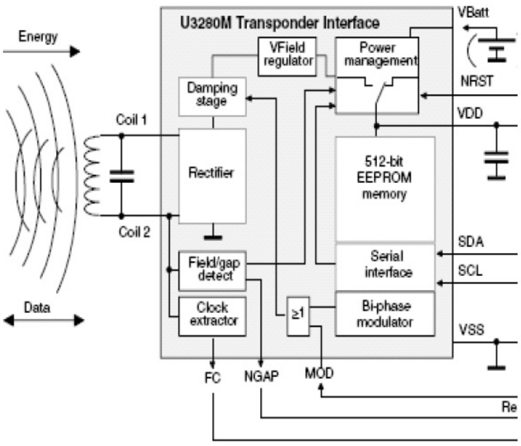

Figure 2. Structure of the analog front-end U3280M.

As was shown in Fig. 1, the U3280M interconnects µC through a I2C serial bus. The bus is also used as a communication channel between the µC and the EEPROM memory. The resonant circuit [19], [20] formed by the L coil and the C condenser, together with the U3280M rectification and internal regulation stage, make possible the supply of energy from the reader to the sensor.

Data is transferred from the reader to the tag through carrier amplitude modulation (100% ASK) [13]. The reverse of this process, sending information from the tag to the reader, is made possible through modulation of an electric charge in the coil. The reader antenna picks up amplitude variations from the modulation in the sensor coil, which after being amplified, filtered and demodulated, are converted into a digital serial signal.

Reader-sensor data transfer is carried out through a stationary frame package protocol with CRC16 error detection at a rate of 3,900b/s with Manchester codification supported by a F/32 subwave.

A simple arbitration system with command/recognition/reply functions is used for the link level.

3.1.4. Power supply

Achieving compact size, long life, durability and low cost has been one of the most critical points in the design. This is also the reason to have chosen RFID technology. In order to accomplish this, the electromagnetic connection reader-tag provides the power supply to the sensor whenever it is inside the field. The rest of the time a 3V lithium battery supplies power. Due to its low cost, the CR2032 (20mmx32mm) model has been selected for this project. Furthermore, employing more compact models does not add significant advantages due to the size restrictions of the sensor, which are imposed by the diameter of the antenna and the thickness of the integrated components.

A detailed study of consumption has demonstrated that the sensor has an estimated life of more than 3 years when used twice a week.

3.2. Encapsulating Process

It is necessary to encapsulate the board (PCB), the battery and the coil, so that the sensor can be safely and simply managed. The most appropriate way to encapsulate would be to use an injection mold, as used in manufacturing integrated circuits [9].

Precautions must be taken to ensure that temperature and pressure are correctly adjusted to the lithium battery limits (this is the most restrictive element). Moreover, the plastic material must be biocompatible with the application. Because investment costs are high, the prototype encapsulation process, as seen in Fig. 3, is finished with an outer coating of epoxy resin using an ABS plastic container.

Figure 3. Smart sensor before being covered with epoxy.

3.3. Sensor Firmware

The program implemented in the microprocessor must perform the following main functions:

- Measure temperature in regular intervals.
- Filter measurements and determine if they should be stored in the non-volatile memory.
- Decode and interpret the commands and data that arrive from the reader through a RF link.
- Manage power.

In order to save power, the microprocessor stays in stand-by mode while the EEPROM Memory remains deactivated. Every second and internal timer wakes up the microprocessor and initiates a new work cycle. During this phase it takes a temperature sample and the average of previous samples. If the same amount of time has passed in the acquisition period, and the system verifies that the sample average is different from prior samples, the data is stored.

When the sensor is placed within the reader's RF field, the microprocessor keeps the sensor permanently waiting to receive requests from the reader. When this field disappears, the sensor returns to data acquisition mode. The first EEPROM Memory positions have been reserved to maintain sensor configuration data. The following packs should be pointed out: 8 byte (64 bits) unique identifier, sample intervals, temperature sensor reset to zero, state of activity.

The rest of the EEPROM Memory is used for data storage, taking into account that every register stores in time increments of seconds from the initial reference and the temperature value in tenths of a degree.

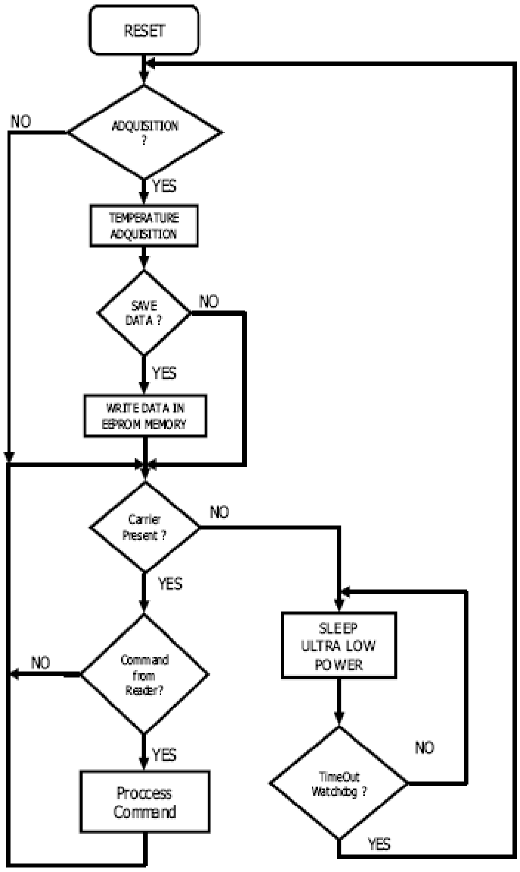

Figure 4. Flowchart diagram of the sensor firmware. The transfer of the compiled program is made possible by an ITAG connection in the sensor.

Every time an acquisition process is reinitiated, a special register that indicates the initial date/time reference is inserted. This information is transmitted by the reader to the sensor when the ACT (sensor activation) button is pushed. Part of the EEPROM Memory is reserved to determine whether or not the sensor should take measurements. By simply pushing the DES button, the sensor is deactivated and stops taking measurements. The flow chart diagram in Fig. 4 shows the main structure of the program. The application has been carried out in C and assembled under IAR work environment conditions.

4. BASE STATION

The process of setting up the sensors and data unload is performed by an electronic device designed for the application (READER). Just as is shown in the block diagram in Fig. 5, this is a system based on an 8 bit microprocessor that contains a RF link interface with the sensor and communication channels connected to the computer. The set has been mounted on a plastic box and has three indicating led buttons to simplify its operation (Fig. 6).

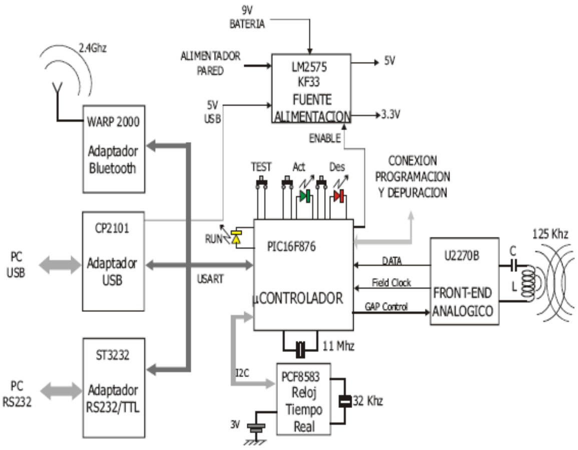

Figure 5. Block diagram of the reader.

Sufficient functional capacity has been implemented in the reader so that it can operate autonomously; as part of the extraction work has to be carried out by mobile extraction units.

With the three buttons and indicators, the user can: activate a sensor, check work status and deactivate it to stop the registration and save energy. Each time the user pushes the ACT button, the reader sends a deactivation order to the sensor indicating the date and time supplied by the real time clock, and as it is totally portable, no connection is needed to perform its functions.

4.1. Hardware Description

Aside from the microprocessor [8], the key component of the reader is the U2270B integrated circuit [17], as can be seen in Fig. 6. This device contains an analog front-end that, in addition to generating the 125 KHz wave, has amplifying components, filters and differentiators to convert the modulated signal of the tag into a digital signal. Using software, the microprocessor unscrambles this signal in order to compose, interpret and send the package, it then transmits and modulates the 125 Khz wave, employing a U2270B control line.

Three channels have been made available so that the reader can communicate with the outside world: USB connection, auxiliary RS232 connection and wireless Bluetooth technology. The device includes a real time clock with a battery back up to achieve autonomous operating capabilities. A precise date and time reference is fundamental in the initiation of the data registration of temperature. Three options are available to supply power to the reader: a 7.30V wall adapter, USB Port, or a rechargeable NiMh PP3 battery.

Figure 6. Final packaging of reader.

4.2. Firmware Description

The reader is the component responsible for data interchange between the computer and the sensor. Moreover, this device has been equipped with enough self-controlled elements so that it can function without the need for a computer connection. For this, the program installed in the reader should carry out two main functions:

- Physically and logically exchange protocols from the computer to the sensor.
- Self-controlled activation/deactivation and verification of the sensor status.

As described in Fig. 7, the program implemented in the reader receives data packages through a serial channel (Bluetooth, USB, RS232), formats and sends them via ASK Modulation to the sensor. The sensor continually processes the signal to decode the data, verify its integrity and send it to the computer.

The routine in charge of decoding the data coming from the sensor is especially critical. As the data link is very unstable, this routine has to verifying the integrity [5] through

CRC16, but the system also implements a protocol layer on the transportation level in charge of message retransmission and validation. This program has been completely written in assembler code, using the Microchip inc. MPLAB development environment.

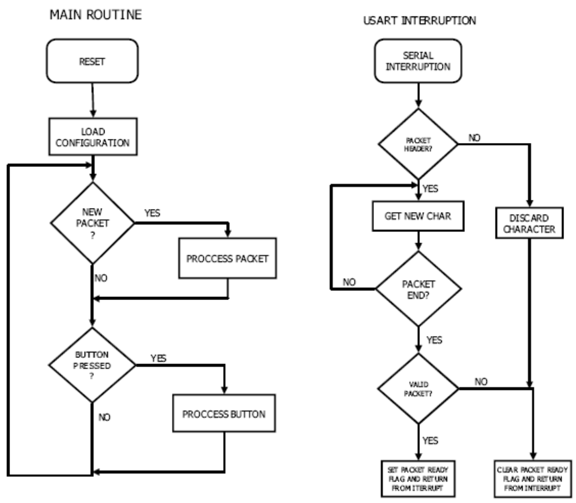

Figure 7. Main Firmware Reader Flowchart.

5. SOFTWARE MANAGEMENT AND PARAMETER SET-UP OF THE SENSORS

A program has been created to function under the Windows™ operating system, the latter acts as an interface between the users and the sensors by utilizing the connected readers as a gateway to RS232, USB, or Bluetooth. It is important to mention the following functions that the program performs:

- Sets sensor parameters. Assigns identifiers, calibrates temperature, etc.
- Recuperates data stored in the sensors.
- Creates a graphic presentation of the collected data.
- Adapts and inserts data into the data base of the blood bank.

The data collected by the sensors and the codes assigned to the bags are associated to the same application. The bags in the blood banks are labeled with bar codes produced. Then, a bar code reader captures the information on the bags and sends it to the computer. These data are finally stored in the blood bank database.

6. RESULTS

Examples of registered extractions from March/April 2006 are shown in Fig. 8. The cooling dynamics occurs in two phases which can clearly be seen in the graphs.

One conclusion we have drawn from these results is the importance of taking the cooling plates (butanediol) out of the refrigerator for at least 30 minutes to allow for stabilization. By not following this protocol, we have observed that during the separation phase, temperature can reach below 18°C. The final analyses and results of the separation and transfusion provide us with very interesting data (with regards to quality for the subproducts) when it is properly stored.

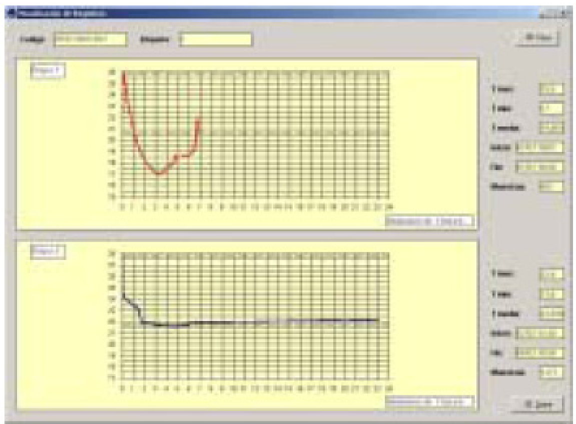

Figure 8. Graphical Evolution of the two stages.

7. CONCLUSION

The design of this new smart sensor will keep us at the forefront of hemoderivate product storage and production technology. This technology provides product quality assurance before the blood bags are used by discarding the ones that turn out to be defective because of insufficient conservation standards. In effect, this allows us to avoid many blood transfusion risks. Furthermore, it opens a new door in health and transfusion research with regards to the effects of storage and production.

More information can be found at http://autolog.uclm.es

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