Monitoring System for Tests of the Mg Implants

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Abstract –In the article authors are providing requirements analysis for the informational systems for medical trials. The author considered types of the experiments which could be conducted remotely with the Mg implants and designed an experiment for the in vivo tests of the Mg stem. In the paper the authors present three level architecture for the monitoring system the corrosion and solubility of Mg implants and model for data integration and transmission. Also suggested the model for the data integration and transition in to repository.

Keywords —critical systems, implants, monitoring, data analysis, hardware and software systems, robust models.

1 Introduction

Implementation of IoT-technology in the research process allows users to collect, process and visualise data. Especially in critical fields as for example the testing of new materials for artificial implants, an IoT approach can present new opportunities for speeding up and get more accurate data.

Internet of medical things (IoMT), a connected infrastructure of medical devices, software applications and health systems and services, transforming greatly the sector of medical trials improving the quality of data and its interoperability[1]. It enables machine-to-machine interaction and real-time data streaming between an almost infinite range of medical device and involve multiple participants, such as doctors and patients, hospitals, and research institutions in multi.

New regulations, digitisation, data analytics, artificial intelligence, automation and the development of value-based health care represent some of the numerous challenges as well as opportunities facing the medical technology industry [2]. And one of the biggest challenge is interoperability, including complying with various national and international standards and protocols around the exchange and use of data.

Real-time monitoring systems could be implemented as for in-vivo and for in-vitro test systems and complement to the existing approaches in both stages. Within the international Erasmus+ KA2 project BIOART (Innovative Multidisciplinary Curricu-

lum in Artificial Implants for Bio-Engineering BSc/MSc Degrees [3] in NU "Zaporizhzhia Polytechnic" are developed new Mg alloys for implants [4]. To test these new materials it is required to create a new robust testing system, which could provide researchers with prompt and reliable information on their material tests. For development of the requested monitoring system there is required integration of the biomedical data, material science data and IoT.

2 Investigation of the in-vivo and in-vitro real-time monitoring approaches

Mg has a particular material property which makes it suitable for using as an implant material: it is soluble in a watery environment. If the solubility rate of the material can be controlled it opens up a range of possibilities in the implant-surgery as it would avoid a second surgery for taking the temporary implants out again, making in more comfortable for the patient, and giving an economic advantage in avoiding extra medical costs.

The aim of the current research is to accurately determine the solubility rate of the material and to match it with other retrieved data. The rate is measured by putting stems of Mg in water and monitoring its state under pressure. After a predetermined time the stems are taken out and their characteristics (weight and corrosion state) are measured. The stems should dissolve in a controlled concrete time. The continuous real-time measurement data of the this process should be collected at a server and then used for decision making in in-vivo tests. In in-vivo test the state of the implant is monitored by making X-rays or tomography. The base hypothesis is that the rate of dissolving is the same in-vitro as in-vivo. By measuring and comparing a prediction of the dissolving time will be possible.

The combination of a test-method(s) and appropriate techniques for assessing solubility in-vitro and validating it in-vivo is the basis for the research. Underneath there is an overview of the different state-of-the-art solubility tests and currently used measuring techniques.

For the actual monitoring during the in-vitro test an EIS-technique is used for reasons of efficient measuring and digitalizing of signals over a longer period of time.

In the work [5,5] there is provided an overview solubility test-methods for Mg alloys:

- Short term immersion test (hydrogen evolution) in NHCO3/CO2 – buffered simulated body fluid (SBF) at 37°C – up to 14 days.
- Electrochemical impedance spectroscopy and immersion tests in DMEM supplemented by 10% (v/v) fetal bovine serum (FBS) pre-conditioned at 37°C up to 28 days.
- Long-term immersion test (up to 365 days) in Dulbecco's Modified Eagle Medium (DMEM) supplemented with 10 vol.% fetal bovine serum buffered with 4-(2-

hydroxyethyl)-1-piperazineethanesulfonic acid (HEPES) at 37°C and refreshed periodically.

Assessment techniques for in-vivo corrosion:

- SEM (Scanning Electron Microscopy) and WDS (Windows Deployment Services) for the morphological imaging of retrieved implants and on-the-spot semi-quantitative chemical composition analysis.
- FTIR (Fourier-transform infrared spectroscopy (FTIR) is a technique used to obtain an infrared spectrum of absorption or emission of a solid, liquid or gas. An FTIR spectrometer simultaneously collects high-spectral-resolution data over a wide spectral range. This confers a significant advantage over a dispersive spectrometer, which measures intensity over a narrow range of wavelengths at a time.
- Histology: also known as microscopic anatomy or microanatomy, is the branch of biology which studies the microscopic anatomy of biological tissues. Histology is the microscopic counterpart to gross anatomy, which looks at larger structures visible without a microscope.
- USG: Medical ultrasound (also known as diagnostic sonography or ultrasonography) is a diagnostic imaging technique.
- X-ray radiography - non-invasive hard tissue imaging, produce 2D image of gross tissue (combination of hard and soft tissue), image nearly all biomaterials, similar to USG, qualitative analysis by visual observation of radiographs, quantitative analysis by means of image processing software
- μCT - Enhanced capabilities of X-ray radiography with possibility to generate a complete 3D image, as a product of stacking discontinuous 2D slices, of an implant and its surrounding tissue
- MRI - non-invasive medical diagnostic tool for real-time soft and hard tissue imaging

Real-time in-vitro corrosion monitoring of absorbable metal implants [6]:

- Electromechanical-based monitoring systems - quantitatively measure corrosion rate and electrochemical properties of corroded surface in short-time (accelerated process);
- Electrochemical impedance spectroscopy (EIS): EIS is a highly sensitive characterization technique used to establish the electrical response of chemical systems in a nondestructive manner. EIS systems characterize the time response of chemical systems using low amplitude alternating current (AC) voltages over a range of frequencies. Using an electrode setup consisting of a working, reference, and counter electrodes a known voltage is passed from the working electrode through an electrolytic solution and into the counter electrode. Quantitative measurements are produced by the EIS and enable the evaluation of small scale chemical mechanisms at the electrode interface and within the electrolytic solution. Therefore, EIS is useful in determining a wide range of dielectric and electrical properties of components in research fields studying batteries, corrosion, etc.

- Sensor-based monitoring systems - accurately measure certain corrosion parameters using specific sensors, e.g., H_2 sensor, Mg ion sensor, possible use for real-time and continuous in-vivo corrosion monitoring as the sensor is connected to a data acquisition device.
- Micro-dialysis-based monitoring system: Micro dialysis is a minimally-invasive sampling technique that is used for continuous measurement of free, unbound analyte concentrations in the extracellular fluid of virtually any tissue. Analytes may include endogenous molecules (e.g. neurotransmitter, hormones, glucose, etc.) to assess their biochemical functions in the body, or exogenous compounds (e.g. pharmaceuticals) to determine their distribution within the body or fluid.

3 Design of the in vivo-experiment

Advances in microelectronics, in particular, such as miniaturization, computing power increase per given area of silicon, reduced power consumption, increased efficiency of radio frequency telecommunications and monolithic system-on-chip (SoC) integration are leading to data acquisition equipment which is becoming increasingly portable and unobtrusive, permitting uninterrupted real-time monitoring in a variety of scenarios [7].

For the setup of the experiment (Fig.1) there was chosen an immersion test which resembles body conditions. The Mg stems are put in a row in a plastic tube which is pressurized with a saline solution by a pump. The saline solution is kept at a constant temperature of 36.6°C to mimic body conditions.

The saline solution dissolves the Mg from the stem and as such will change its electric properties. The impedance change of the solution is measured in real-time and logged. After each test period a stem is removed and measured for weight and visual (microscopic) inspection to assess the rate of dissolving. The other stems are kept in the saline solution for the next test.

The pressure and flow of the saline will be controlled to assess the influence of the different parameters. The H_2 which is set free form the reaction $Mg + H_2O => MgO + H_2$ is collected in a gas reservoir to measure the dissolving rate.

The control system is managing the temperature of the saline, pump pressure, periodic pictures of the stems, data from the sensors. It is developed on the Xilinx platform [9], which makes its flexible for integration with the user application and verification of the system functioning.

Web-interface is providing access to the experiments measurements in the real time, allowing user to change the conditions of the experiments and manually control measurements.

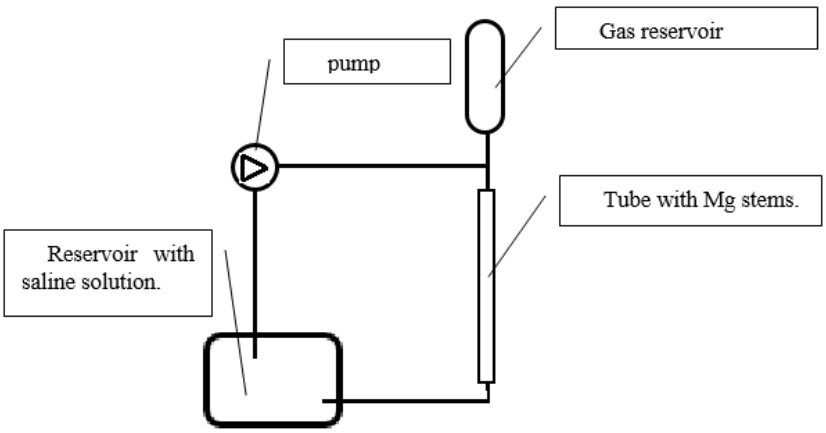

Fig. 1. Experimental setup for immersion test on Mg -stems

4 Monitoring system for Mg implants

A feature of modern monitoring is the extensive use of various instruments, sensors and communication infrastructures capable of transmitting and processing data in real-time. At the same time, a data collection system with low energy costs and the ability to simultaneously service a large number of IoT devices is necessary for efficient collection and processing of data on end nodes of information systems based on IoT.

For the monitoring system we will consider a three layer architecture [10] which contains device level, server level and application level (Fig.2).

At device level data is collected from different sources, but in general it could be divided into two types: sensor-information and images. Both types can be collected at in-vitro tests. For in-vivo tests mostly only imaging data (X-ray, tomography, scans..) can be used, and in the case of surgical extraction of implants other data (loss of material…) can be measured too.

At sever level, the technique to classify real-time data from several different sources involves the following eight steps: data normalization; prediction future points; analysis of residuals; probability calculation; conflicts definition; data fusion; classification; estimation of classification accuracy.

At application/end user level tools are needed for the collection, the analysis, and the representation of results of the experiments.

Device level	Server level (Cloud level)	Application level (End users applications)
Data classification and aggregation Control system adjusting	Data collection/Stream publication/	Web and mobile applications for collection, analysis, and presentation results of the experiments

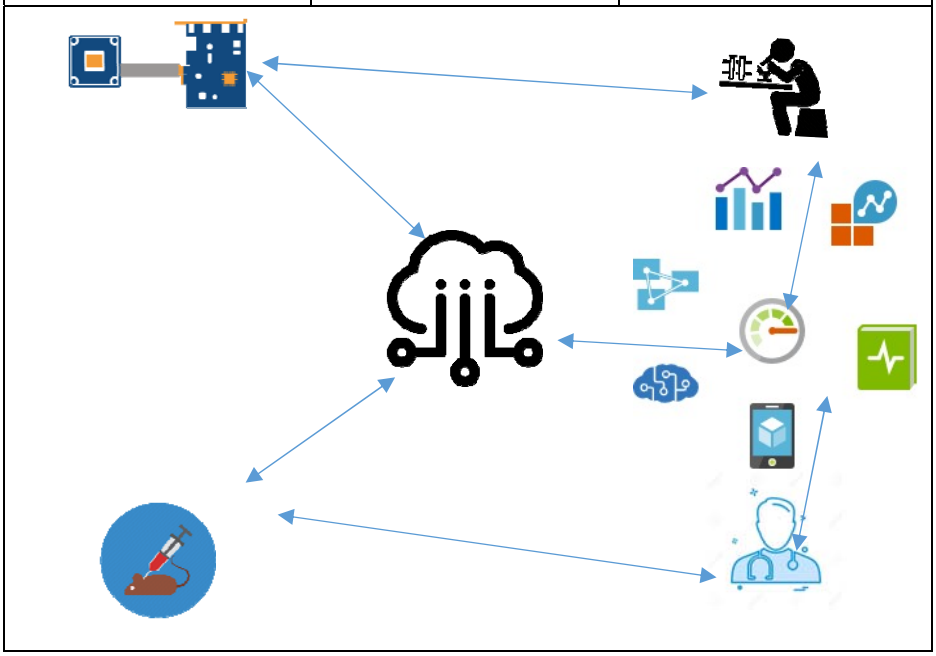

Fig. 2. Architecture of the monitoring system

Data which is received from sensors during the tests is also used for the manipulation of the test control system.

Data resulting from in-vivo tests should be used later for the further in-vitro tests. There should be possibility for continuous update of all the information and the matching of the different types of data.

For the testing of the Mg implants a monitoring system is developed, which is described in Fig.3. We are implementing a single model of combining all data which makes it possible to develop a high quality system for supporting medical trial decisions. In the system we integrate medical, biomedical, physical and clinical data .

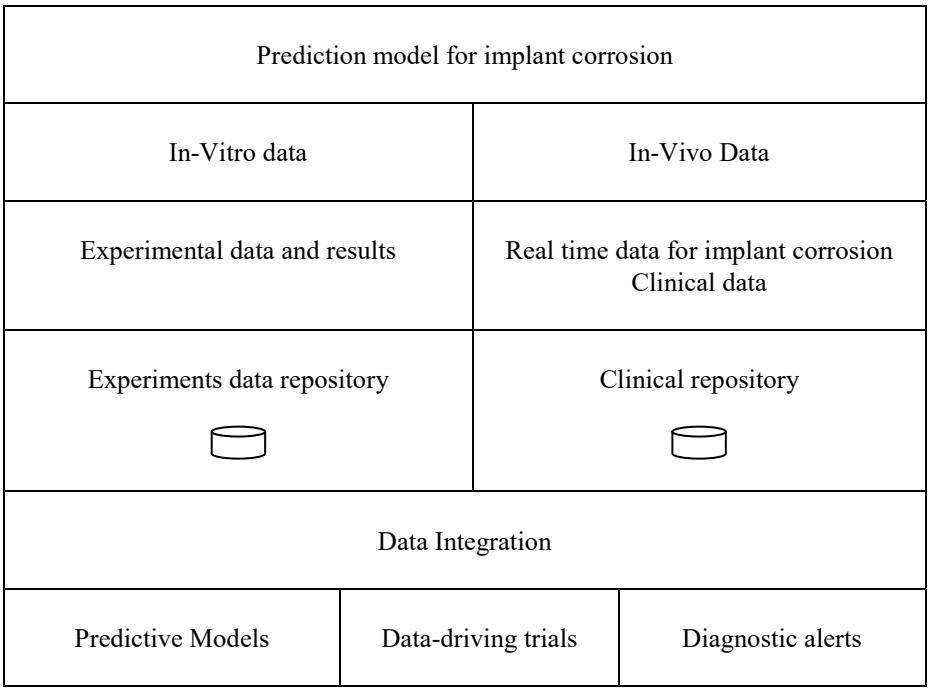

Fig. 3. Integration model for the trial data

Data integration model will be considered as a multidimensional cube:

$$M_{data} = H(D, A), \tag{1}$$

where $D = \{d_1, d_2, \ldots, d_i\}$ is set of dimensions (d_1 – "set of material properties of the sample", d_2 – "set of trial conditions", d_3 – "source of information", d_4 – "time dimension"), $A = A_{d1} \cup A_{d2} \cup \ldots \cup A_{di}$ – set of attributes:

$$A_{di} = \{a_1^i, a_2^i, \ldots a_g^i\}, \tag{2}$$

where i = 1, 2, 3 – set of attributes of dimension *di*.

Each cell of the hypercube of data corresponds to the only possible set of measurement attributes containing unique experimental data for set of measurements in concrete moment of time.

As developed test system is system with limited resourses we need periodical data transfer to the cloud, and for the data transfer period from the testing system to the cloud we will use [11]:

$$\eta' = (1+\omega)(\tau B + \sigma C)\left(\frac{\tau}{S} - \frac{1}{\upsilon_{net}}\right), \tag{3}$$

where ω – safety factor; B – volume of the modified data within specified period; C –volume of the recorded data or Δ period; τ – the predicted device operating time; σ – predicted volume of the recording data; υ_{net} – mean speed of data transmission S – available volume.

For realisation of the interoperability repositories should comply following requirements:

(1) it should be a digital system able to manage N-dimensional hyper-cubes and allow data analytics;

(2) it should be accessible and interoperable at the software level from the external channels;

(4) it should have managing mechanism;

(5) the realisation of the data exchange should be organised regarding to the health information technology standards[12] to have possibility for the further in-vivo monitoring.

The main regulation standards for file format are xml and json, for electronic health information architecture is ISO 18308:2011 [14], for messaging of healthcare data are HL7 v2.x [15], v3, FHIR [16], openEHR [13], for clinical documents (Clinical Document Architecture – CDA), for medical imaging and communication (DICOM) [17], and for patient health summaries (Continuity of Care Record – CCR) [15].

5 Conclusion

In the paper authors suggest an architecture of the real-time monitoring system which allows to check the state of the artificial implants based on Mg alloys.

Starting from a predictive model on the dissolving rate of the Mg in the human body, data from in-vitro tests and in-vivo checks is combined to validate and update the predictive model.

The architecture of the monitoring systems contains aggregation data from different sources, processing, automated control of the testing equipment, and decision support system for the researcher.

The setup for in-vitro experiments was constructed, which could be used as the remote experiments for research and education purposes.

The aim is to have a robust and validated prediction for the dissolving of the Mg-implants in the body.

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