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Development of a wound dressing with wireless communication to analyze relevant parameters for veterinary medicine Feasibility study part 1 -sensor-

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ABSTRACT: *The purpose of this research and development project is to develop a wound dressing which continuously measures the pH value and temperature value parameters of a wound for use in veterinary medicine. The measured parameters should be sent to mobile phones and personal computers via Bluetooth. The pH value and temperature value are important parameters used in assessing the healing success of a wound. This section, Part 1, describes the difficulties associated with laboratory tests using an ISFET sensor and the laboratory simulation of wound ichor.*

Keywords: *pH sensor, wireless communication, temperature sensor, veterinary medicine, wound bandage*

I. INTRODUCTION

Today, acute wounds suffered by animals must be dressed at regular intervals. An important reason for changing a dressing is to examine and assess the wound. Visual control is currently the only possible method by which a veterinarian can obtain early indications of problems concerning the healing process as well as any opening of the wound, bleeding or inflammation. In order to ensure that bacteria and other germs do not increase in these warm, humid conditions, the dressing and wound must be controlled regularly. From a veterinarian aspect, this necessitates increased initial expenditure because the equipment, accommodation and treatment for certain animals can be extensive and expensive; costs which are then passed on to farmers and breeders for example. In addition, all treatment provided represents a source of stress for the respective animal and expense for the animal owner.

II. OBJECTIVES AND ADVANTAGES

The aim of this development project is to create an adaptable dressing for wounds which enables the pH and temperature values of the respective wound to be compiled in the lab using commercially available sensors. There is currently no comparable system on the German market. Wound assessment, as described in the "Abstract" above, does not exist. Wound assessment is still carried out in the conventional way (local veterinarian completing examinations on site).

The advantages of the new device system are:

- Support for veterinarians regarding the treatment
- Alert in the event of fever or varying inflammation parameters
- Curve trends related to analysis of the healing process
- Cost savings for animal owners, dressing is changed only if the parameters change
- Cost savings because the animal can be treated ambulant and not necessarily in a clinic
- Shortened healing process through supervised and optimized wound care.

III. APPLICATION AND REQUIREMENT

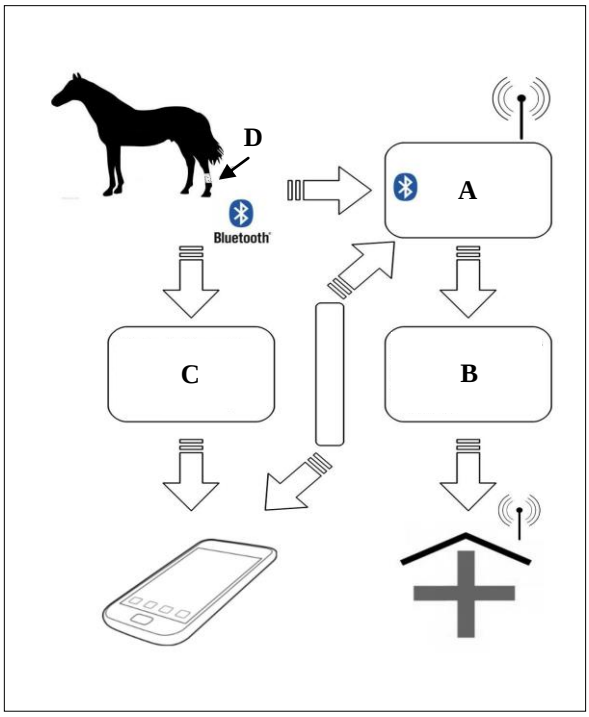
The market for such a product already exists in the form of veterinary medicine. In Germany, for example, there are more than 1.2 million horses and ponies [1] and a substantially higher number of farm animals. Just simply taking those into consideration, the newly proposed development could be used in the case

of inflammations and wounds. Approximately 11933 veterinarians [2], animal breeding companies and farmers represent potential customers.

IV. APPROACH

Our idea was based on placing ISFET-based planar pH sensors and temperature sensors into a wound bandage so that it would be possible to measure the pH value and temperature value of a wound. The analog values would then be compiled by a microcontroller circuit linked to a Bluetooth module. The Bluetooth module will be integrated in the adaptable wound bandage. The wireless communication module would then send the data compiled to a so-called Host, at regular intervals, which would then record the pH and temperature data sent from the wound bandage. As soon as defined, critical, limit values are exceeded; the communication module sends an alarm in the form of a text message or an e-mail. The Host can also be configured to communicate with mobile phones or smartphones. Furthermore, it should be possible to access all the measured data directly by smartphone in the form of trend curve data. The security of the transmitted data is guaranteed by current coding procedures and by the allocation of transmitters and receivers, **Fig 1**.

V. FUNCTIONAL DIAGRAM



A) Conversion of Bluetooth on GSM (Global System for Mobile Communications) or Webserver SSL (Secure Sockets Layer)

B) Automatic dispatch of inflammation parameters (pH value and temperature value) via text (mobile phone) or E-mail (PC)

C) Direct reading of the parameters (pH value and temperature value) on the mobile phone

D) Wireless communication of data from wound bandage on horse

Figure 1: Functional diagram of the R+D project

VI. SENSOR

For the purpose of this project, we used an Ion-Selective Field Effect Transistor ISFET for measuring the pH value. The advantages of an ISFET sensor, compared to common glass pH electrodes, are its glass-free (unbreakable) components, its miniature size, the lack of built-in buffer solutions, its non-directional installation method and, in our case, the integrated temperature sensor [3]. The difference between an "ordinary" field effect transistor (FET) and an Ion-Selective Field Effect Transistor (ISFET) is explained by the different structure of the gate. While the gate of an FET is of a semiconducting material, the gate at an ISFET is of an Ion-sensitive layer (IS) which comes into direct contact with the measured liquid, **Fig. 2** [4]. The lower the pH value of the measured liquid, the more hydrogen ions are delivered to the gate. The output signal of the ISFET is a potential difference which varies with the change of logarithm of detected ion activity (H^+-Ion). This causes an increased current flow (I_{SD}), which can be measured and converted to a pH value.

1) Reference
2) Gate SiO_2 oxide
3) Insulation
4) Channel
S) Source
D) Drain
B) Bulk

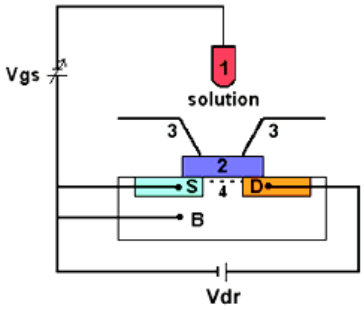


Figure 2: Schematic representation of an ISFET structure

VII. LABORATORY EXPERIMENTS

The ISFET sensor used had to be calibrated according to pH standards in advance prior to completing the laboratory measurements in order to ensure reliable and comparable measurements. The laboratory measurements and ISFET sensor were evaluated for pH and temperature measurements [5] by means of a calibrated gauge. **Fig. 3**, **Fig. 4**, and **Fig. 5** show measurements for the pH calibration in respect of the ISFET sensors used in the experiments.

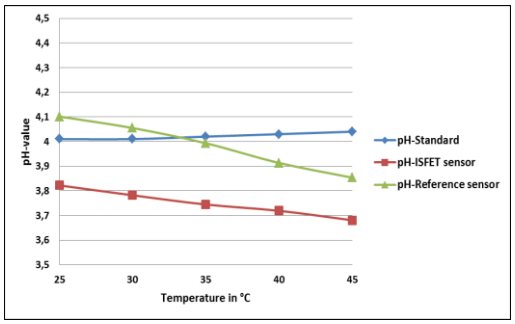


Figure 3: Calibration with pH 4.01 standard

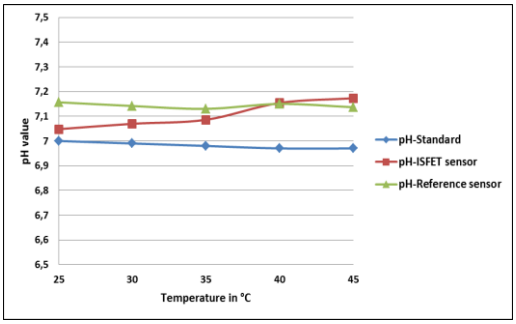


Figure 4: Calibration with pH 7.00 standard

The graphs depicted in Figures 3 to 5 indicate a deviation of the pH value, ISFET sensor to pH value comparator system, of maximally pH 0.3. An accurate calibration was not possible over the temperature range from 25°C to 45°C. A max. inaccuracy of pH 0.3 was accepted for the development of a prototype.

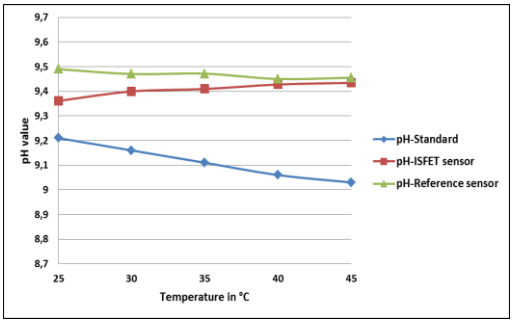


Figure 5: Calibration with pH 9.21 standard

In order to emulate the conditions of a wound in an animal's body, it was necessary to develop a laboratory experiment in which there was a simulation of the wound fluids coming into contact with a wound dressing. The pH value of the ichor was simulated by means of various pH buffer solutions. The ichor or transmitting medium was emulated by a wound gel [6], **Fig. 6**. A special wound gauze [7] was used to simulate the wound dressing and provide a permeable barrier between the sensor and wound. The wound dressing and wound gel were purchased as commercially available medical products. The wound dressing enabled the transmitting medium (gel) to be kept on the wound and prevent the gel from running out of the wound, **Fig. 7**. In addition, the wound dressing prevented the pH sensor from making contact with the wound. This prevented the possibility of other injuries being caused by a sensor.

As a result of the permeable structure of the wound dressing, the pH value of the wound can be established through the transmitting gel and the application of the ISFET sensor. The experimental setup reflects the composition of a wound dressing (bandage) relatively closely. The photos below illustrate part of the laboratory experiment and the resources used.

Figure 6: ISFET sensor in wound gel

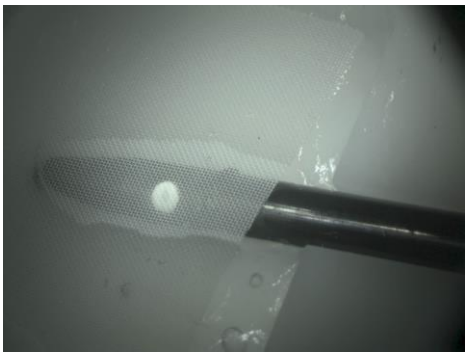


Figure 7: ISFET sensor in wound gel with wound dressing

The wound gel was mixed with substances having various pH values and deployed as an artificial ichor. An alignment of the pH value between the wound gel and pH value of the standard solution occurred after approx. 8 minutes in the case of all pH values. The delay does not play an important role with regard to the measurement in the wound because the wound dressing, when finalized, will perform scanning and transmission of the wound parameters on an hourly basis. The following standard pH values were used for the laboratory experiment: pH 4.01, pH 7.00, and pH 9.21 [8]. It was attempted to ensure that the gel and standard solution mixture was homogeneous. During the course of the experiments, it became apparent that the gel started to clot slightly from a pH value of 7.0. The homogeneity of the gel changes as a result of clotting and the measurements became inaccurate. Since pH values can be expected in the range 7.5 to 9.0 with regard to wounds [9], the wound gel used could no longer be applied to complete realistic experiments.

Following the above experience, four other medically approved wound gels were purchased and used in experiments. Hundreds of sequences of laboratory test measurements were completed. All the laboratory tests produced similar results and tendencies. Clotting of the gel is highly probably from a pH value of 7.0, **Fig. 8**.

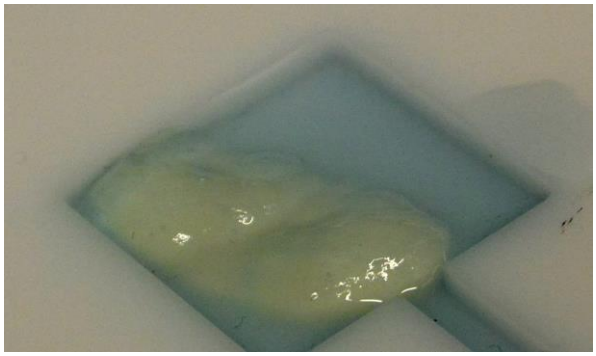


Figure 8: Clotting and flocculating in wound gel

Also, as a result of the gels, a slight deviation of the pH value (standard solution) occurs in relation to the pH value measured (actual ISFET value). The maximum pH value deviation was approx. 8% from the set value in the case of all the gels used in the laboratory tests. However, since the wound gels were only used as an ichor substitute for the laboratory tests and are not relevant in respect of the wireless communication wound bandage to be developed, these deviations can be considered irrelevant. When used in real-life situations, the ISFET sensor will have direct contact with the wound on the injured animal. The transmission of the pH value of the wound to the ISFET sensor will therefore occur directly and more quickly.

Measurement of the temperature value of the respective artificial wound (ISFET sensor) indicated no deviations to the calibrated comparator system [10]. The laboratory tests were performed in the temperature range from 25 °C to 45 °C. The temperature measurements using the ISFET sensor proved fully uncomplicated and problem-free. No further consideration was paid to measuring the temperature.

VIII. CONCLUSION

The first part of the development project was to determine whether an ISFET sensor was suitable for use in the wireless communication of measurements of the pH and temperature values for wound parameters. The following conclusions can be drawn regarding the first part of the project. Due to its miniature design, the ISFET sensor is perfectly suited for measuring the pH and temperature values of wounds on animals. As a result of the glass-free design, the ISFET sensor can be easily integrated in wound dressings. The connection of the ISFET sensor to an evaluation system proved uncomplicated and technically reliable.

Error-free transmission of the wound temperature values by the ISFET sensor was realised successfully in the laboratory tests. Direct transmission of the laboratory results proved possible in practice (prototypes). Due to the uncomplicated, easily evaluable series of temperature measurements, further examination regarding temperature measurements with an ISFET sensor were dispensed with.

The ISFET sensor also proved applicable with regard to measuring the pH value of wounds. Following a relatively extensive calibration phase for the ISFET sensor, it was ready to be used for the laboratory tests. The slight delay in transmission of the pH values was proven to be caused by the transmission medium, namely the gel. Also, the measurement inaccuracies related to pH values in excess of 7.0 were proven to be caused by the gel. In practice, however, the ichor is the transmission medium and it can be expected that this error source of the inaccuracies, the gel, will be omitted.

Therefore, it was decided that the ISFET sensor would be used for measuring the temperature and pH value of the wound during the further course of the project. The Ion-Selective Field Effect Transistor (ISFET) will be implemented as the sensor technology for the wound dressing with wireless communication function to be developed.

The second part of the development project concerns the evaluation and presentation of the wound parameters (wound temperature and pH value) and the development of a wireless system to transmit the measured values to mobile communication equipment and/or computers.

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