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Development of a wireless temperature measurement board for surface-temperature measurement, even for non-flat surfaces - Feasibility study -

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ABSTRACT: *The purpose of this research and development project is to develop a flexible temperature measurement board, which continuously measures the temperature values even on non-flat surfaces. The measured temperatures should be sent to personal computers, mobile phones and tablets via Bluetooth. This feasibility study describes the proceeding and the difficulties associated with laboratory tests.*

KEYWORDS: *Temperature sensor, wireless communication, flexible measuring board, non-flat surfaces.*

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I. INTRODUCTION

The aim of this development project was to develop a mobile and flexible circuit board for measuring surface temperatures. The main advantage or novelty of this development is the use of temperature sensors in conjunction with a flexible printed circuit board and the radio-based transmission of the measured temperature data. The newly developed board has a microprocessor, a Bluetooth module and a power supply on-board; so that a cabling of the circuit board with measuring devices is eliminated.

Another advantage of the new developed prototype is the potential use for temperature measurement on curved surfaces. Due to the missing cabling (connection between measuring board to measuring device), the new system can also be used on slowly rotating components. Areas of application are automotive construction, aircraft construction and classical mechanical engineering. The areas of application and the functional diagram are shown In Fig. 1.

By slight variations in the construction of the prototype, a use in biomedical technology is quite possible. The use in this application requires a constructive redesign of the design (shape and size), the adaptation technology and possibly the temperature sensors (specific measuring range).

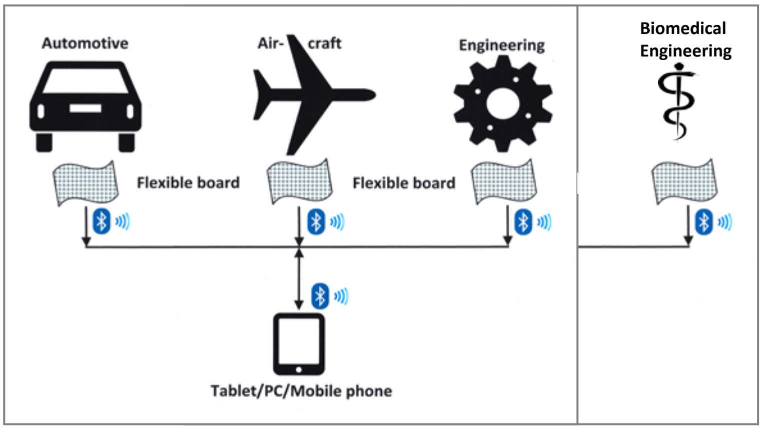

Fig.1: Areas of application and functional diagram of the developed prototype

II. MEASUREMENT METHOD

To measure the surface temperature of static and dynamic components, a novel flexible printed circuit board has been developed. The flexible temperature measuring board is equipped with a (variable) number of temperature sensors. The developed laboratory sample used temperature sensors of the type MCP9808 [1]. Due to the large number of temperature sensors, temperatures and temperature changes should be recorded, analyzed and displayed over a large area. At the prototype, a large number of temperature sensors were used on a relatively small area, Fig. 2. The area of the layer and the number of temperature sensors should be freely selectable in a later series production. The prototype developed and used here has a measuring area of 100 mm^2 and a number of 25 temperature sensors. A special feature of the developed prototype is the detection and processing of the individual temperatures by an on-board microcontroller. Also the recorded temperature values are transmitted by an on-board Bluetooth module to a handheld and/or another mobile evaluation device. The developed laboratory sample used a microcontroller of the type ATMEL ATmega 328 [2] and a Bluetooth module of the type OBS421i-14 [3]. All the necessary electronics and power supply are located directly on board. Therefore a wiring to the component which shall be measured can be omitted. This ensures high flexibility in measurement.

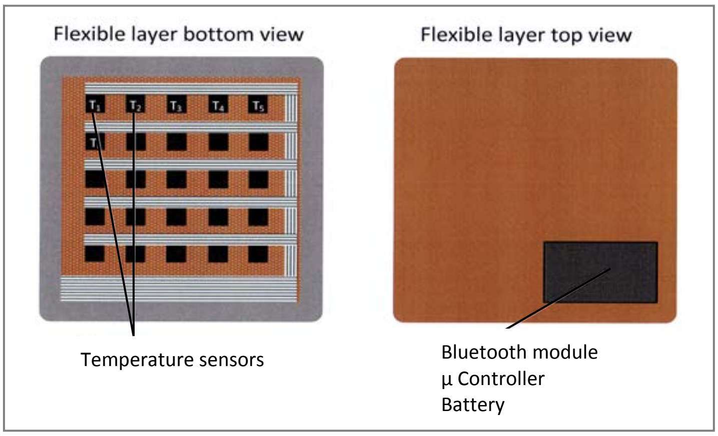

Fig. 2: Illustration of the flexible temperature measuring board

III. LABORATORY EXPERIMENTS

Before the temperature sensors of the developed prototype could be tested for function and accuracy, standard or reference temperature values had to be created. The reference temperatures (target temperatures) were realized by a precision heating plate [4]. The temperature values of the reference heating plate were again checked with calibrated probes [5] and measuring instruments [6] according to DIN EN 60584-1 [7] and to DIN EN 60584-3 [8]. The heating plate surface was divided in analogy to the surface of measuring board. Thus, the 25 temperature areas of the heating plate were exactly assigned to those of the board, Fig. 3. The division into 25 geometrical areas made it possible to make differentiated statements about the temperature distribution on the surface. The temperatures were measured exactly in the center of the respective 25 fields (red measuring point).

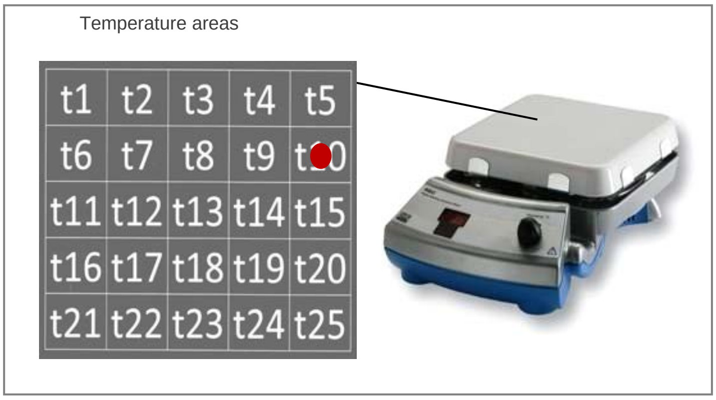

Fig. 3: Precision heating plate with specified temperature areas

As an example for a large number of laboratory measuring series, table 1 shows an average measurement series for determining the reference temperatures at a nominal temperature of 50 °C. The check of the temperatures (heating plate) was carried out 10 times at the temperature values of: 50 °C, 60 °C, 70 °C, 80 °C, 90 °C, 100 °C, 110 °C and 120 °C. Thereafter, the mean values of the respective measurement series were determined as standard or setpoint temperatures. These setpoint temperatures were then available as comparison values (reference values) for the evaluation of the measurement sensors of the prototype.

Table 1: Determination of the reference temperature values at 50 °C

Series of measurement for T= 50 °C , heating plate (preset output value) Measuring with calibrated temperature instrument							
Check -point	**Measured Value [°C]**	**Heating plate Value [°C]**	**Difference Value [°C]**	**Check-point**	**Measured Value [°C]**	**Heating plate Value [°C]**	**Difference Value [°C]**
t_m1	49.3	50.0	-0.7	**t_m14**	49.0	50.0	-1.0
t_m2	49.3	50.0	-0.7	**t_m15**	49.4	50.0	-0.6
t_m3	49.3	50.0	-0.7	**t_m16**	49.1	50.0	-0.9
t_m4	49.4	50.0	-0.6	**t_m17**	49.3	50.0	-0.7
t_m5	49.5	50.0	-0.5	**t_m18**	49.5	50.0	-0.5
t_m6	49.2	50.0	-0.8	**t_m19**	49.4	50.0	-0.6
t_m7	49.4	50.0	-0.6	**t_m20**	49.7	50.0	-0.3
t_m8	49.5	50.0	-0.5	**t_m21**	49.1	50.0	-0.9
t_m9	49.1	50.0	-0.9	**t_m22**	48.9	50.0	-1.1
t_m10	49.4	50.0	-0.6	**t_m23**	49.1	50.0	-0.9
t_m11	49.3	50.0	-0.7	**t_m24**	49.2	50.0	-0.8
t_m12	49.6	50.0	-0.4	**t_m25**	49.1	50.0	-0.9
t_m13	49.1	50.0	-0.9				

When determining the reference temperatures, there were slight deviations to the setpoint temperatures of the heating plate. The maximum measured temperature deviation was -2.2 % of the setpoint. The deviations in the individual temperature fields were taken into account in all further considerations and measurements. The current values measured with the temperature sensor on the heating plate were defined as new reference values for the further laboratory test series with the developed prototype.

The measurement series with the prototype-board, shown in Fig. 4, were each corrected by the determined deviations of the individual temperature fields.

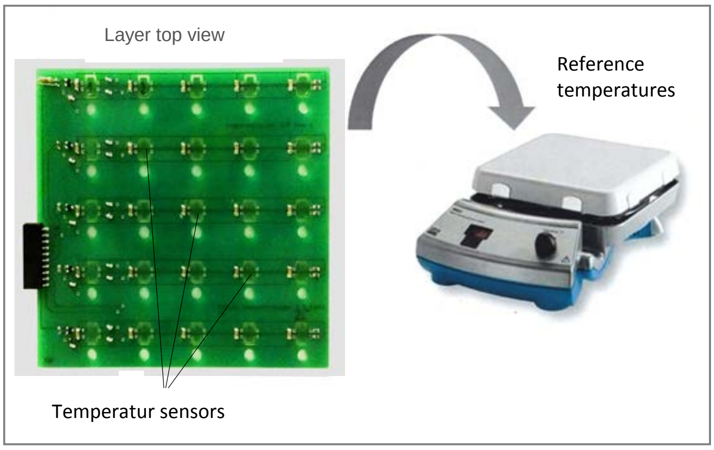

Fig. 4: Temperature measurement with prototype-board on a precision heating plate

As an example for a large number of laboratory measuring series, table 2 shows a mean value series for determining the functionality and accuracy of the developed prototype, at a nominal temperature of 50 °C. The measurement of the setpoint temperatures (heating plate) was carried out at the temperature values of: 50 °C, 60 °C, 70 °C, 80 °C, 90 °C, 100 °C, 110 °C and 120 °C, respectively 10 times (n=10).

After taking into account the previously determined deviations, the mean values ($t_{m}i$) of the respective measurement series, were determined as measured values of the prototype.

Table 2: Measurement of the temperature values with the prototype-board at 50 °C
- Determination of deviations -

Series of measurement for T= 50 °C , heating plate (new reference value) Measuring with prototype-board							
Sensor	**Measured Value [°C]**	**New Reference Value [°C]**	**Difference Value [°C]**	**Sensor**	**Measured Value [°C]**	**New Reference Value [°C]**	**Difference Value [°C]**
t_m1	49.0	49.3	-0.3	**t_m14**	49.3	49.0	+0.3
t_m2	49.2	49.3	-0.1	**t_m15**	49.0	49.4	-0.4
t_m3	49.0	49.3	-0.3	**t_m16**	49.2	49.1	+0.1
t_m4	49.1	49.4	-0.3	**t_m17**	49.5	49.3	+0.2
t_m5	54.5	49.5	+5.0	**t_m18**	49.4	49.5	-0.1
t_m6	49.4	49.2	+0.2	**t_m19**	49.3	49.4	-0.1
t_m7	49.3	49.4	-0.1	**t_m20**	49.3	49.7	-0.4
t_m8	49.3	49.5	-0.2	**t_m21**	47.8	49.1	-1.3
t_m9	49.3	49.1	+0.2	**t_m22**	49.0	48.9	+0.1
t_m10	48.9	49.4	-0.5	**t_m23**	49.0	49.1	-0.1
t_m11	49.0	49.3	-0.3	**t_m24**	49.3	49.2	+0.1
t_m12	49.4	49.6	-0.2	**t_m25**	52.3	49.1	+3.2
t_m13	49.4	49.1	+0.3				

Table 2 shows three significant measured value deviations. The measured value deviations from the actual value to the reference value were determined in all 10 measurement series in the measuring field's t5, t21 and t25. After analyzing the errors, the temperature sensors were replaced by new sensors in all three measuring fields. After replacing the temperature sensors in that field´s, no significant measurement errors were detected.

IV. DISPLAY OF MEASURED VALUES

In order to read and display the temperature data, an App was developed and programmed on an Android system. The layout, the user interface, the activities and widgets have largely been defined and programmed. In this project the software Android Studio 2.2.3 was used to program the project-specific App. The tablet, with the preinstalled Android version 5.1.1 and the hardware for radio-based data transmission, has been purchased. Fig. 5 shows the screens for viewing and evaluating the transmitted temperature data.

These views are essentially intended for the end user. More views for the programmer are prepared and can be unlocked. The end user control screens have deliberately been simplified and reduced in size. Essentially the settings or configurations of the temperature measurement with limit value and alarm setting, the representation of the temperature distribution as temperature screen and the representation of the temperature profiles as graphs are shown.

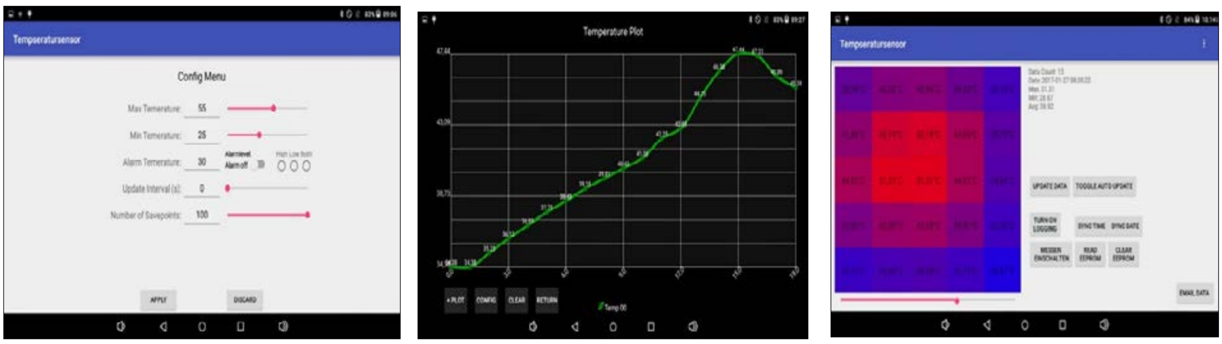

Fig. 5: Presentation of results in two variants on mobile devices

V. OBJECTIVES AND ADVANTAGES

The aim of this development project was to create a flexible measurement board which enables the measuring of temperature values at statically and dynamically structural components to be compiled in the lab using commercially available sensors. The stimulation for that development was that there was no comparable system on the German market.

The main advantages of the new device-system are:

- Temperature-measurement-board with power supply, microcontroller and wireless module onboard
- No cabling between sensor and evaluation unit
- Temperature data transfer to PC and/or Tablet and/or Smartphone
- Transmission of data at longer distances
- Alert in the event of limit exceeded
- Support for technicians on site at their measurements tasks
- Time savings for the service technician
- Curve trends related to analysis of thermal stress
- The use is even possible on curved surfaces and slowly rotating surfaces.

VI. APPLICATION AND REQUIREMENT

The market for the newly developed product consists of applications in the automotive industry, the aircraft industry and classic mechanical engineering sectors. Due to the above-mentioned features and advantages of the prototype, it is ideal for use in these applications. Especially in the three applications mentioned, an analysis of thermal stress on components is often required. Also, there are often curved surfaces that are poorly accessible with standard measuring devices. Due to the missing wiring, between sensor and the measuring unit, the flexible printed circuit board is an ideal measuring device for measuring slowly rotating components.

An example of application in the automotive industry could be the temperature measurement on the engine block. Without having to lay any annoying measuring cables in the car. An application example in aircraft construction could be the determination of friction temperatures on the wing. Again, the missing wiring of the measuring board supports the flexible use. In analogy to the aircraft, the temperature measurements on the wings of wind turbines could also be possible; on- and offshore. The missing wiring of the measuring board proves to be particularly helpful, because through the additional rotating movement of the wings, a wiring would be very cumbersome if not impossible. Another application could be the field of biomedical technology. Again, the above benefits apply. However, in order to be able to use the prototype in these application areas, a reduction of the size and an adaptation of the temperature range is planned to be tested.

Due to the wireless transmission of the temperature data, the measuring system shown in Fig. 6 is ideally suited for service technicians. An error analysis or exceeding of temperature values on components and objects can be transmitted via radio. An elaborate measurement with temperature measuring devices and temperature sensors, directly at the measuring object, can be bypassed.

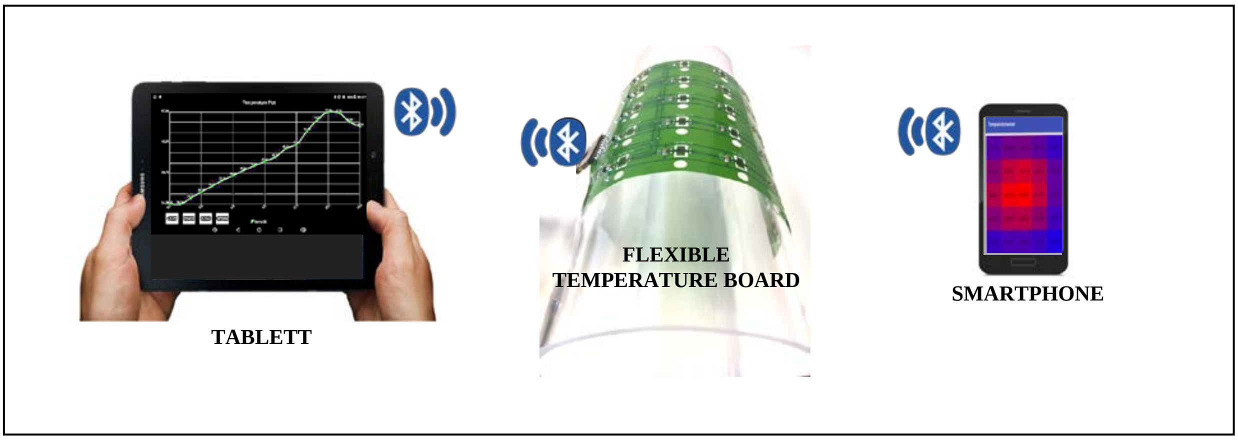

Fig. 6: Prototype of flexible temperature board with tablet or smartphone as display

VII. CONCLUSION

The feasibility study aimed to develop a flexible temperature measuring board, which can be used without wiring to the test object. By laying the voltage source and the Bluetooth module on the board, the use on rotating measuring parts is also conceivable. The developed prototype was currently only tested in the laboratory. The results of the laboratory measurements were promising. In further experiments must be clarified whether the contact point from the measuring sensor to the tested object may possibly be improved by a heat transfer medium. The transmission of the measurement data and the evaluation on the tablet or mobile phone works flawlessly. Following the pending laboratory tests with the heat transfer media, a series production could be started. The new development is intended for the service area. Service technicians can save a lot of work for preparation the measurement object because a cabling of the tested object is eliminated by the radio transmission. Areas of application are automotive construction, aircraft construction, and classical mechanical engineering to medical technology applications.

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