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SCIENTIFIC PAPER

SENSOR SYSTEM FOR DETECTION OF HARMFUL ENVIRONMENTS FOR PIPE ORGANS (SENSORGAN)

C.J. Bergsten[1], M. Odlyha[2], S. Jakiela[2,5], J. Slater[2], A. Cavicchioli[3], D.L.A. de Faria[3], A. Niklasson[4], J.-E. Svensson[4], L. Bratasz[5], D. Camuffo[6], A. della Valle[6], F. Baldini[7], R. Falciai[7], A. Mencaglia[7], F. Senesi[7], C. Theodorakopoulos[8]

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Guest editor:
Prof. Dr. Erwin Rosenberg.

1. Göteborg Organ Art Center, University of Gothenburg, Sweden
2. School of Biological and Chemical Sciences, Birkbeck College, University of London, Malet St, London WC1E 7HX, UK

3. School of Arts, Sciences and Humanities, University of Sao Paulo, Brazil

4. Dept of Environmental Inorganic Chemistry, Chalmers University of Technology, Gothenburg Sweden

5. Institute of Catalysis and Surface Chemistry, Polish Academy of Sciences, Krakow, Poland

6. National Research Council of Italy, ISAC, Padova, Italy

7. National Research Council of Italy, IFAC, Florence, Italy

8. School of Conservation of Antiquities and Works of Art, Technological Educational Institute of Athens

corresponding author:
carl.johan.bergsten@goart.gu.se

The European heritage of the organ is preserved in numerous historical instruments. A major threat to this heritage are harmful indoor environments. Organic acids, also in combination with condensation phenomena, create pipe corrosion causing serious damage to the pipes. Harmful humidity conditions can create cracks in the wooden parts of the organ, making the instrument unplayable.

The EC funded SENSORGAN project (contract 022695) objectives were to make available new instrumentation for monitoring and detection of harmful environments for organs through development of sensors for real time measurement. The system contains three different sensors to detect: (i) levels of organic acids harmful to organ pipes, (ii) environments damaging to wooden parts of organs, (iii) possible dew formation inside organ pipes.

The sensors were designed in order to be placed in the organ without disturbing playing or affecting the sound. The sensors were applied in the historical organ in the Minor Basilica of St. Andrew the Apostle, Olkusz, Poland. Data collected from the sensors was analysed and conclusions were drawn for publications and mitigation strategies.

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1 Introduction

The organ belongs to the core of European culture reflecting its diverse histories, traditions and stylistic periods. The European heritage of the organ is preserved in more than 10 000 historical instruments. The pipe organ contains many different types of materials, like different types of wood, leather, brass, iron and different types of pipe metal lead-tin alloys, from pure lead to almost pure tin. This makes the organ to an object being very sensitive to microclimate changes and harmful environments. A harmful environment can damage vital

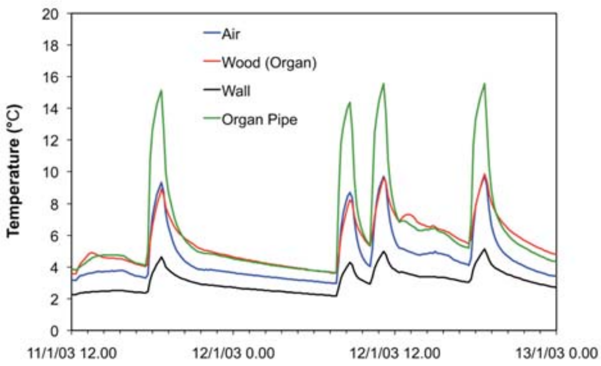

Figure 1: Temperature of the air, wall, wooden part of the organ and organ pipe measured at 5.5 m above the floor. Peaks correspond to warm-air heating at services.

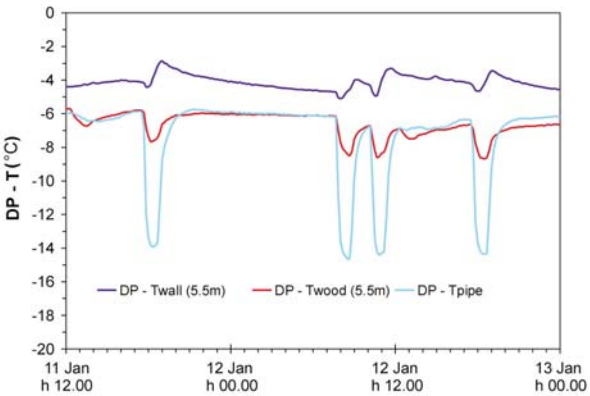

Figure 2: Dew Point (DP) spread of the wall, the wooden part of the organ and the organ pipe (all, 5.5 m). Peaks and drops correspond to warm-air heating at services.

parts of the organ, making the instrument unplayable. The organ facade, often containing invaluable art handicraft like wood carvings and sculptures, can also be damaged by such an environment. Each part of the organ responds in a different way when the church is heated or cooled. The parts with high thermal diffusivity (TD), i.e. the ratio between thermal conductivity to volumetric heat capacity, rapidly adjust their temperature to that of their surroundings, because they conduct heat quickly in comparison to their bulk thermal energy. For this reason the metal pipes closely follow the air temperature, the wooden parts with some delay, and the masonry all around does this very slowly (Figure 1).

As an example, in the case of warm-air heating, the organ and its surroundings are exposed to two counteracting factors: the increase in temperature for the warm air accumulating in the upper part of the church and the increase in moisture content for the presence of people and some evaporation forced from the plaster entering into contact with the warm air. The items characterised by high TD, i.e. the metal pipes, tend to overheat and loose most absorbed moisture; the parts with medium TD, i.e. wooden pipes, the windchest and other wooden structures tend to warm, to reduce their equilibrium moisture content and shrink, possibly with the formation of some cracks; the items with low TD and very slow heating, i.e. the wall, tends towards the dew point, suffering for absorption of water and even heavy condensation (Figure 2). For this reason the release of moisture to compensate the Relative Humidity (RH) drop and mitigate adverse effects on the organ is not a good practice, because it risks to increase too much the free water in the plaster and to favour microbiological infestation.

The previous European Commission funded project COLLAPSE (EVK4-CT-2002-00088) has shown that the escalating problem of lead based corrosion inside organ pipes is caused by organic acids, especially acetic acid, emitted from the wooden parts in the organ. The organic acids enter into the pipe foot and create a corrosive environment. This will lead to corrosion, mainly dependent on the pipe metal alloy, the temperature and humidity in the organ. The temperature and especially the RH will influence the emission rate of organic acids from the wood. Concentrations of organic acids in the same organ wind system were about five times higher during summer compared to wintertime. Higher RH levels will also speed up the corrosion process itself. Pure lead pipes are very sensitive to corrosion but a few percent of tin will have a corrosion protecting effect at lower humidity. However, at higher humidity the protecting effect of tin disappears.

An organ is often a large instrument, sometimes 5-10 meters high, and contains several divisions, each of them containing pipes. Some divisions of the organ may be close to the walls or to the source of heat or some parts may be exposed to direct sunlight. Often the wind inlet and the bellows are in a separate room behind the organ. The distributed and divided character of the organ creates different climate conditions within the instrument.

For the preservation of the organ cultural heritage there is a great need for monitoring the climate conditions in the organ and in the pipes especially after an organ restoration or a change of the heating system or the ventilation conditions in the church.

The SENSORGAN (Sensor system for detection of harmful environments for pipe organs) project[1] is a research project supported by the European Commission under the Sixth Framework Programme aimed to study the deterioration of organ pipes due to unfavourable environmental conditions in churches, e.g. crowded services and concerts, winter heating, external and indoor pollution. Variations of Temperature (T), Relative Humidity (RH) and formation of condensation contribute to many kinds of physical and chemical disruptive processes, e.g. wooden crack for exceeding dryness or corrosion of pipes for condensation. Accurate measurements of these quantities inside and outside organs will allow to study the local microclimate in relation to the use of the church and the organ itself, detecting when and where the risk of damage is highest.

The SENSORGAN project objectives were to make available new instrumentation for monitoring and detection of harmful environments for organs through development of sensors for real time measurement.

The system contains three different sensors to detect:
- levels of organic acids harmful to organ pipes,
- environments damaging to wooden parts of organs,
- possible dew formation inside organ pipes.

The sensors are designed in order to be placed in the organ or in the pipes without disturbing playing or affecting the sound. A field study was performed where the developed sensors were applied in the important historical organ from 1611 in the Minor Basilica of St. Andrew the Apostle in Olkusz, Poland (Figure 3). The data collected from the sensors was analysed and microclimatic factors creating harmful environments were studied.

Figure 3: The historical organ from 1611 in the Minor Basilica of St. Andrew the Apostle, Olkusz, Poland.

2 Materials and Methods

2.1 Dosimeter for detection of organic acids, corrosive to organ pipes

The application of dosimeters using varnish coated piezoelectric quartz crystals has been described in previous work.[2,3] In this paper lead coated piezoelectric quartz crystal dosimeters were prepared with the view to assess the extent of corrosivity of the air within the organ pipes. The work is reported within the SENSORGAN project website and it is anticipated that it will be published elsewhere.[4] Lead was used since it was demonstrated in the COLLAPSE project that exposed lead coupons provided valuable information on the damage that occurred in these environments from the action of volatile organic acids and changes in the coupons were characterised.[5]

The rationale for the use of lead coatings on piezoelectric quartz crystals is that the coating is thin (of the order of nanometres) and given the corrosive conditions of acetic acid and RH the reaction occurs more rapidly than in lead coupons which require longer exposure times and so the dosimeter provides an early warning of the incipient corrosion in lead.[2] At the start of the project lead coated crystals were placed in specially designed holders made of Delrin. These are described in detail elsewhere.[4] Measurements of crystal frequency were made before and after exposure and the change (%) calculated from these values. This application is referred to as using crystals as passive samplers. At a later stage in the SENSORGAN project the final prototype allowed the frequency change to be measured continuously during exposure. The basic operation of the piezoelectric quartz crystal (PQC) can be summarised as follows. When an alternating electric field is applied to a PQC, it vibrates at its resonant frequency (e.g 10 MHz). If a coating is applied on the crystal surface the crystal frequency will decrease. The operating system used measures a difference between the exposed crystal and an uncoated reference crystal. When the lead coating reacts with organic acids the mass of the coating will change and a frequency shift of the crystal vibration will be observed. This property is used for development of a dosimeter for detection of organic acids which are corrosive to organ pipes.

2.2 Acoustic emission sensor to indicate risk of damage to wooden parts of organs

Fluctuations in ambient relative humidity (RH) are considered to be one of the main factors contributing to the deterioration of wooden cultural objects. It has been generally recognised that wooden parts of organs are considerably endangered by this environment-induced decay. This is due to constructional restraints and the organ's position at high altitude in the church where the RH fluctuations can be particularly high when the church is heated. Cracks in the wooden parts can cause key action malfunction or leakage in the windchest which can make the instrument unplayable and a major and expensive repair work has to be performed often resulting in replacement and loss of historical substances. Usually, variations in temperature and relative humidity are measured and to assess risk of damage, a cause-effect relationship is used. However, such relationship is associated with uncertainty which for complicated objects, like organs, can be considerable. Unfortunately, the direct monitoring of damage in historic materials is a relatively neglected field of study in spite of its attractiveness. Monitoring the acoustic emission (AE) is one of the most important non-destructive tools capable of tracing mechanical damage in materials accurately in space and time.[6] The project is aiming at development of a simple, robust and economic AE sensor for direct tracing of mechanical damage in historic organs that can be used in every day practice.

In the project, the method of recording acoustic emission activity generated during development of micro-damages in wood was adopted from the engineering field to monitor mechanical fracture within the material. Usefulness of recording the acoustic emission to indicate risk of cracks in historic materials was proved in laboratory tensile tests of wooden samples. In addition, several wooden samples made of different types of wood were exposed to RH variations in a climatic chamber. Both these experiments and analysis of recorded signals made it possible to determine the active frequency range (80-500 kHz) being the most suitable for monitoring of crack propagation, especially in the presence of environmental noise. AE activity monitored during several organ concerts and services showed that the frequency of environmental noise is usually lower than 40 kHz. This allowed for development of a system to filter out signals generated during wood cracking in real time to prevent fast overload of the data acquisition system. Energy of recorded AE signals was found to be an optimal indicator of damage development which can be easily interpreted as an area of spitted wood surfaces determined during calibration procedure.

In the second phase of the project, efforts of the research team concentrated on a maximal simplification of the electronic circuits and maintenance procedures. A special focus was the design of a user-friendly interface which would enable a maximal broad application of the sensor both in museums and in field work when operated also by personnel without technical background like conservators or heritage managers.

A prototype sensor which can filter out and record signals related to damage was developed according to the results obtained and tested in the laboratory. The sensor receives a signal from a wideband AE sensor of type WD, made by Physical Acoustic Corporation. The signal is amplified ca. 4000 times by an analogue processing section integrated in the sensor. The signal is then divided into two paths:

HF band (80-800 kHz) – with RMS processor at the termination,

LF band (10-50 kHz) – with a rectifier at the termination.

Both signals are converted by a 10-bit A/D converter into digital format. The conversion results are accumulated in registers and placed in arrays with a rate varying in the range of 1-1000 seconds. During the operation, the information is displayed on the LCD panel at the front of the sensor. After the end of the process of monitoring, the stored signal can be transmitted to a PC computer via USB connection. The sensor is powered by an internal 14 Ah NiMH battery enabling proper sensor operation during periods of power failure or during a few days of field measurements.

2.3 Sensor for detection of dew or frost inside or/and outside organ pipes

One part of the SENSORGAN project was the development of a miniaturised sensor for detection of condensation inside/outside organ pipes. The need for advanced technology is evident. The sensors should monitor what happens without affecting the sound quality, or being visible, or in any way disturbing the use of the organ. Sensors should have miniaturized (micro-invasive) size, and a quick time response to environmental changes is required. Sensors should work under wetting conditions and below 0 °C as well, as frost may occur in unheated churches. Sensors should be waterproof and resistant to acidic environments (e.g. acetic and formic acid which are naturally released by wood). No interference between sensors and metal pipes, no disturbance during playing should occur. Sensors should be in some way attached inside the organ pipes and then removed, without damaging them. Uncertainty in measuring might derive when the contact angle of the water droplet on the sensor differs from the oxidized pipe surface. It is preferable to measure condensation on the actual pipe, which may be covered with corrosion products, not on the sensor.

Commercial miniaturized sensors might be used to measure T on the surface and in the air, and RH as well. Most of them would suffer a drift, or even deterioration in acidic environments. From these data it would be possible to compute the dew point. However, inside the oxidized metal pipes, the condensation may occur earlier, being favoured by the presence of hygroscopic oxides and micropores. Information about T and RH is of fundamental relevance, but not sufficient in itself to determine whether water is present in the liquid or solid phase. It is therefore necessary to perform direct measurements concerning water condensation, or frosting, on the actual target surface, not on a transducer.

An innovative optical fibre sensor was developed to this aim. The working principle is based on the change in the reflectivity of the optical fibre, following the formation of droplets, or ice crystals, on its distal end. The optical fibre is composed of a transparent core that acts as light guide and an external cladding with a different refraction index that favours total internal reflection of the light beams reaching the internal surface at grazing angles. When the light beam arrives at the opposite distal end of the fibre where the fibre is truncated most of the light leaves the fibre, and a small fraction is reflected back (Figure 4). However, when droplets, or ice crystals, form on the end of the fibre, they will disperse more light, and the reflected beam is attenuated.

In reality, we need to know what happens on the internal surface of the pipe, and not on the optical fibre, although inserted into the pipe and adherent to it. However, the wettability, represented by the contact angle of a droplet on the surface, of the oxidized metal is greater than that of pure quartz, i.e. condensation occurs first on the oxidized metal, and then on the fibre. When a film of water or droplets form on the oxidized pipe, the condensed water enters into contact with the dry fibre adherent to the surface. A set of three fibres was prepared in order to get more representative information of the target surface with three sampling points.

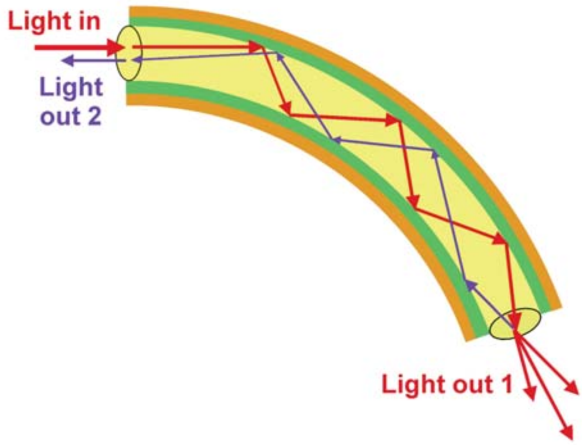

Figure 4: The optical fibre is composed of a transparent core (yellow) that acts as light guide, a cladding (green) with a different refraction index and a protection jacket (orange). When a light beam enters the fibre (red arrow), it remains entrapped for the total reflection due to the cladding envelope. The nude core disperses light at the distal end where the fibre is truncated (light out 1), but some light is reflected back (blue arrows and light out 2). When the distal end is covered with water droplets or ice crystals, the light dispersion is increased and the reflected output is decreased.

The optical fibre is illuminated with a laser diode (red light) and the reflected beam is detected with a photodetector. The advantage of this configuration is to keep the whole fibre protected with its external jacket and cladding, with only one end used as input and output and the other completely free and used as a sensor. The cladding and the jacket make it resistant to bending and to mechanical shocks. No problem is encountered with the acidic environment. The fibre is very thin (core/clad diameter: 200/230 μm) and the length is selected according to the distance from the pipe to the logger, in our case 2.5 m. The output of the photodetector is in mV.

Calibration is needed at the beginning, and then when the fibre has been broken and shortened, or whenever a change in output is recognized for whatever reason, either related to the fibre, e.g. inadvertent breakage, or the environment. Fibre calibration should be made in the absence of light entering the free distal end of the fibre. The best use is in the dark, as expected inside the foot of an organ pipe. Accurate calibration is made under some selected controlled calibration conditions, realised with RH buffering deliquescent salts kept in a climatic chamber. When the super-saturated solution method is used[7,9,10] an excess of the salts should remain in solid phase in a saturated aqueous solution at 20 °C.

Alternatively, calibration can be made under naturally or forcedly variable microclimate conditions by keeping together the fibres and a primary reference instrument to know the RH levels. In fact, it is not necessary to have a precise calibration when the aim is only to distinguish between wet and dry conditions. In such a case, essential calibration is very simple, and it is sufficient to read the outputs: (1) at usual room RH (e.g. whatever is the RH value between 30 and 60%), (2) after having wetted the top of the fibre, i.e. the sensitive terminal end. The latter can be done by immersion.

3 Results and Discussion

3.1 Dosimeter for detection of organic acids

In the first year of the project the dosimeter consisting of an array containing 8 coated crystals[2] was exposed to accelerated aged laboratory environments and at test sites in pipe organs. The recently restored organ at St Botolph without Aldgate in London and the organ at Minor Basilica of St. Andrew the Apostle in Olkusz were selected as the test sites and the crystal arrays (passive samplers) were exposed for over 24 months, initially in the windchest of the organ.

In the second year of the project miniaturisation of electronic components was completed and a special holder was designed to house the components. This allowed location of the crystals in the vicinity of the organ pipes (Figure 5) and continuous monitoring. Locations (B) and (C) show where the crystals as passive samplers were displayed; location (B) was within the windchest and location (C) near the pipes. Location (A) is where the continuous system was placed actually within the pipe. Different locations were tested to record differences, if any, between within pipe and outside the pipe and within the windchest. Figure 6(a) shows the system in operation in St Botolph. Figure 6(b) shows the placement of the system in the Minor Basilica of St. Andrew the Apostle in Olkusz.

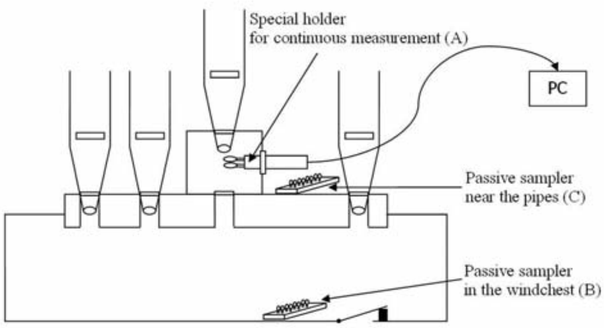

Figure 5: Schematic view of location of passive samplers (crystal arrays B,C) and continuous sampler (A) in the organ in St. Botolph.

Figure 6a: View of crystal holder located at toe of pipe raised from the toeboard in the organ in St. Botolph. Top left gives view of crystals in holder.

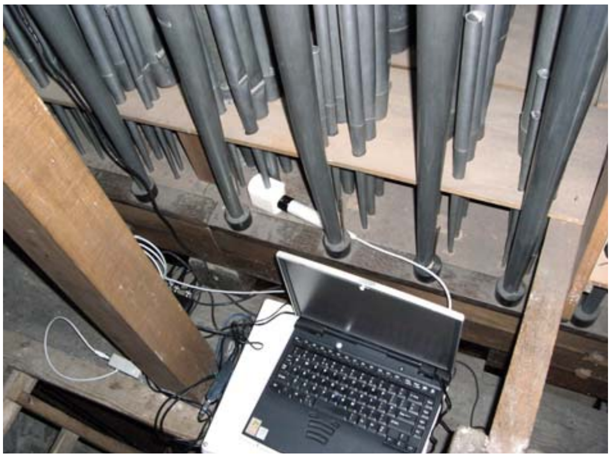

Figure 6b: System in operation in the Minor Basilica of St. Andrew the Apostle, Olkusz.

Table 1 shows the changes in the lead coating for the period winter to spring for testing using an array of coated crystals with accompanying climate data. Values of change which occurred measured on a monthly basis were similar to those obtained in simulated laboratory environments where blocks of oak (Table 2) and pine wood (Table 3) were exposed in closed cabinets at RH values 60-65% and where levels of acetic acid were up to 1ppm.

In Olkusz, level of change was lower (Table 4). Lead coupons were exposed in St Botolph without Aldgate, as previously in the COLLAPSE project, and showed on analysis (ion chromatrography) after exposure (4 months) the presence of acetate and formate on the metal surface. This indicates that the organic acid vapours have reacted with the lead surface. Crystalline products were characterised by X-ray diffraction as hydrocerussite ($Pb_3(CO_3)_2(OH)_2$) and lead oxide (PbO). This was confirmed by Raman microscopy which also indicated the presence of carbonates.

Figure 7 shows the data obtained from continuous monitoring (location Figure 5 A) using the newly developed small holder and miniaturized electronic components over a period of one month of a selected organ pipe in St Botolph.

Crystal number	Date of 1st exposure	% change	Date of exposure	% change	Date of 2nd exposure	% change
B3_3	28.11.06 14.12.06	15.60	15.12.06 18.01.07	16.32	26.01.07 12.02.07	16.97
B3_4	28.11.06 14.12.06	9.27	15.12.06 18.01.07	14.78	26.01.07 12.02.07	16.25
B4_4	28.11.06 14.12.06	22.33	15.12.06 18.01.07	23.87	26.01.07 12.02.07	24.54
B4_5	28.11.06 14.12.06	18.43	15.12.06 18.01.07	20.09	26.01.07 12.02.07	21.07
	T=18.2 C; RH=51%		T=16.7 C; RH=49%		T=15.3 C; RH=45%	

Table 1: Summary of values (% change in frequency values) of crystals in passive sampler, location Figure 5 (B) (windchest). Exposures in St Botolph without Aldgate, London, location in Figure 5 (B).

Oak Cabinet	Date of exposure and time to reach maximum value	% change
B5_3	19.12.06 8 hours	33.6
B8.8	25.02.07 3 hours	38.5
	Average values T=25 C; RH=65%	

Table 2: Summary of values (% change in frequency values) of crystals exposed in laboratory accelerated ageing cabinets containing oak wood.

Pine Cabinet	Date of exposure and time to reach maximum value	% change
B8_2	22.02.07 5.3 days	23.8
B8_3	27.02.07 3 days	19.9
	Average values T=25 C; RH=65%	

Table 3: Summary of values (% change in frequency values) of crystals exposed in laboratory accelerated ageing cabinets containing pine wood.

Crystal number	Date of exposure	% change	Date of 1st exposure	% change	Date of 2nd exposure	% change
B3_5	22.12.06 23.01.07	5.9	08.02.07 16.03.07	6.8	02.04.07 15.05.07	9.9
B4_3	22.12.06 23.01.07	6.6	08.02.07 16.03.07	7.1	02.04.07 15.05.07	9.3
B4_6	22.12.06 23.01.07	7.6	08.02.07 16.03.07	8.1	02.04.07 15.05.07	10.4
	T=9.3C; RH=74%		T=8.9 C; RH=70%		T=14.4 C; RH=57%	

Table 4: Summary of values (% change in frequency values) of crystals exposed in the Minor Basilica of St. Andrew the Apostle in Olkusz.

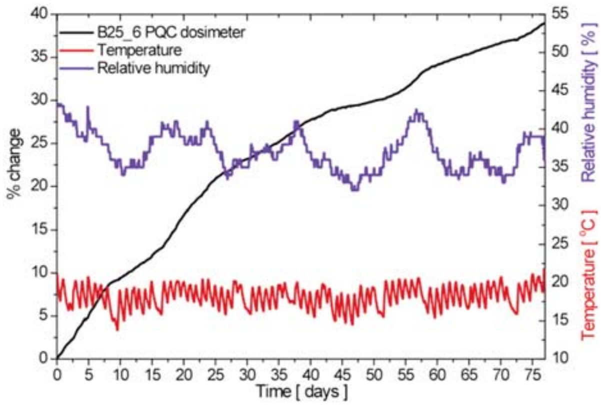

Figure 7: Record of % change in crystal frequency values recorded at St Botolph plotted against time (days) together with climate data (RH,T), location Figure 5 (A).

Crystal number	Date of exposure with continuous logger	% change
B7_8	07.02.08 - 24.04.08	13.7
B26_5	07.02.08 - 24.04.08	12.1
	Avge values T=18.1 C; RH=37%	

Table 5: Summary of values (% change in frequency values) of crystals in passive sampler, location Figure 5 (C), in vicinity of organ pipes. Exposures in St Botolph without Aldgate, location in Figure 5 (C).

Level after 15 days (Figure 7) was lower than in the windchest (Table 1 1st exposure 28.11.06 - 14.12.06, location Figure 5 B) and similar to that measured in an array placed in the vicinity of the pipe (Table 5, location Figure 5 C). So corrrosivity due to acetic acid is stronger in the windchest (location B) where change % after 16 days is up to 17% than in the organ pipes where it is about 12.5%. The environment within and outside the pipe gives similar values for change (%) in the lead coated crystals.

3.2 Acoustic emission sensor

The AE sensor developed within the SENSORGAN project was installed in the historic organ to monitor risk of damage development of its wooden part – a windchest - in the St. Andrew the Apostle Church in Olkusz during winter when the heating system operated. Signals measured by the AE sensor were recorded in 15 minute intervals. During monitoring campaign, the measurement by the prototype was accompanied by a computer based method to control proper signal identification and spectral characterisation.

Only a few AE episodes of small energy generated due to fluctuation in relative humidity during services were recorded indicating that wooden parts of the organ are at limited risk caused by the microclimate in the church as shown in Figure 8.

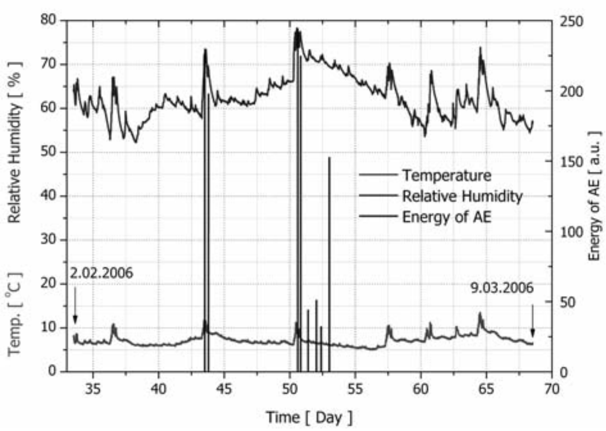

Figure 8: Acoustic emission recorded in the reference organ during the winter period.

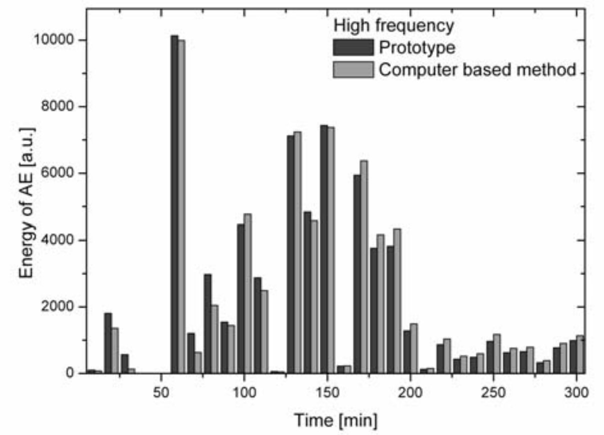

Figure 9: Energy of AE generated in lime wood sample during test in climatic chamber. RH change 70 to 30%.

Comparison of results obtained during the field campaign showed that efficiency in recording AE events by the developed sensor associated with wood cracking was ca. 90% of the value recorded by professional equipment. Similar value was obtained during laboratory tests in a climatic chamber when a wooden cylinder of diameter 13 cm was subjected to RH variation. Results of the test are shown in Figure 9.

3.3 Sensor for detection of dew or frost

Laboratory testing and outdoor field tests were performed per 6 months to control and relate the output of the optical fibre sensors to T and RH cycles under extreme conditions, e.g. in the presence of cloud and clear sky, fog, rain, the sensor and the electronic box being shielded from direct water. The output is constant (i.e. plateau value) in the RH range from 20 to 80%. At higher RH levels it starts to decrease (Figure 10) for the light dissipated by the monolayers of water absorbed onto the surface and grow at exponential rate at very high RH.[8] This is an early indication that the surface is approaching the dewing.

When liquid water (Figure 10), or ice crystals form (Figure 11), the output drops to 50-55% of the plateau value for liquid water and less for ice. The latter is however recognizable for the combination with temperature below 0 °C. For this reason it is convenient to express the output as a fraction of the plateau value: it is 1 in the safe region, it starts to drop in the alert area where water starts to be absorbed at faster rate and is halved in the case of condensation or frost. The output expressed as a percentage of the plateau value has a further advantage: to be independent from contamination of smoke or dust particles eventually deposited on the sensing surface, which might affect the fraction of back light. Condensation and frost can be easily distinguished with the help of a temperature reading.

An easy way to install and to remove the fibre was needed, without damaging the pipe foot. It is possible to enter the pipe foot through the thin hole on its bottom, which may have different size, but our target was some 5 mm diameter. The fibre is very thin, but the temporary inclusion of an o-ring, or a

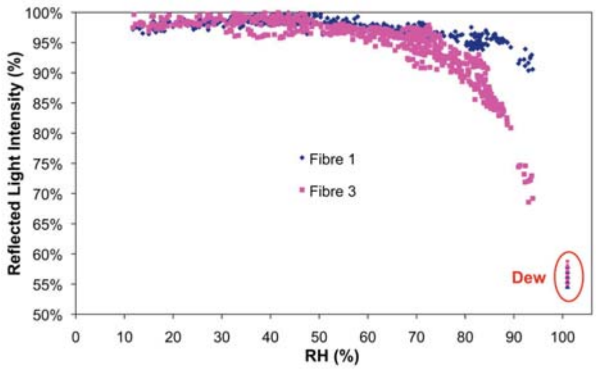

Figure 10: Normalised response of two optic fibres (blue and purple points) to relative humidity and condensation. The output shows a plateau for RH lower than 80%. At higher values the output starts to decrease. When liquid water forms, the output drops to 50-55% of the plateau level (points in the red circle).

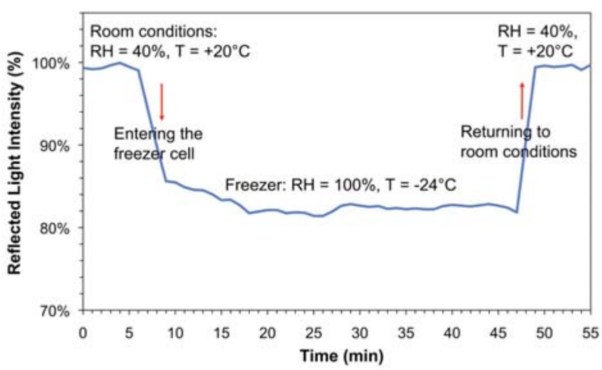

Figure 11: When the fibre is introduced into a freezing cell (T=-24 °C) the output drops for the formation of ice crystals. It returns to normal conditions when it is extracted from the cell at room temperature (T=+20 °C).

Figure 12: During the experiment, an adapter was inserted between the pipe foot and the toeboard hole in order to make easier the passage of the optical fibres and avoid any damage when handling the fibre or the pipe.

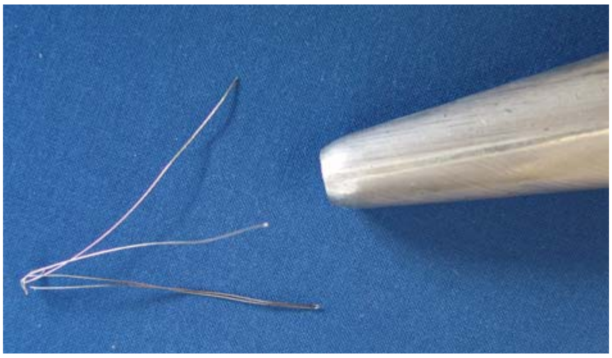

Figure 13: Detail of the spring in string steel with three arms to hold three optical fibres and be inserted into the hollow tip of the pipe foot although the hole is a few mm in diameter.

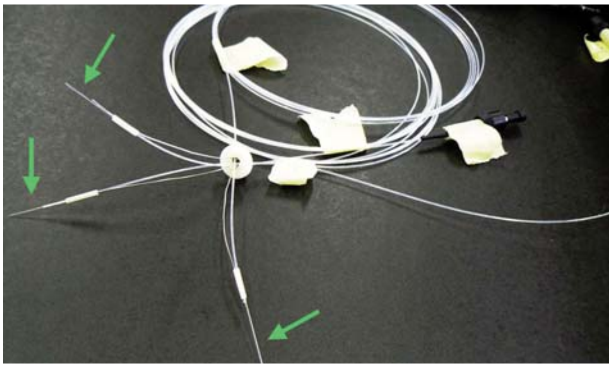

Figure 14: Array made of three optic fibres and springs to ensure contact within an organ pipe. Arrows point out the sensitive distal ends.

similar additional neck is preferable between the pipe foot and the toeboard hole (Figure 12) during the experiment. Alternatively a three leg spring (Figure 13), one leg per each fibre, can be inserted from the bottom and, once released it brings the three fibres (Figure 14) in the correct position and into physical contact with the internal surface of the pipe foot. This system is easy to mount, not dangerous for the pipe, holds the three fibres in contact with the internal pipe surface, and is easy to remove.

The optical fibre is able to monitor dewing or frosting inside a pipe organ, and has some advantages not found in traditional sensors: it is extremely thin and does not disturb the use, is not visible, it is resistant to acidic environments and detects equally well water and ice formation. It can be easily inserted into thin pipe foot holes and with the addition of a spring it reaches a good contact with the inner pipe surface. A change in signal intensity may derive after deposition of airborne particles, but the problem is easily overcome by making reference to the plateau value in the RH range 20 to 80%.

4 Conclusions

The research carried out in the SENSORGAN project resulted in development of a sensor system for detection of harmful environments for pipe organs. The system consists of three different sensors to monitor corrosion of pipes, cracking of wooden elements and condensation in pipes. The system was successfully applied in several organs to study microclimatic factors proving its usefulness in assessment of environmental conditions.

The sensors will contribute to an improved understanding of microclimatic factors creating harmful environments for organs. The sensors will also constitute a useful tool for detection of harmful environments and assessing methods to impede them in the organ field as well as in other areas of cultural heritage preservation.

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6 References

1. Project homepage: http://www.goart.gu.se/sensorgan

2. M. Odlyha, M. Svendsen-Rhyl, T. Padfield, *Microclimate indoor monitoring: damage assessment for cultural heritage preservation*, ICOM-CC Preprints 14th Triennial meeting, vol 11, The Hague, 2005, 670-676.

3. M. Odlyha, C. Theodorakopoulos, D. Thickett, M. Ryhl-Svendsen, J.M. Slater, R. Campana, *Dosimeters for Indoor Microclimate Monitoring for Cultural Heritage*, Proceedings of Museum Microclimates, p. 73-79, November 2007, ed. T. Padfield and K. Borcherson, Copenhagen (2007).

4. M. Odlyha, S. Jakiela, C.J. Bergsten, J.M. Slater, A. Cavicchioli, D.L.A. de Faria, A. Niklasson, J.-E. Svensson, T. Grontoft, E. Dahlin, M. Scharff, *Dosimetry for Monitoring in Organ pipes and in Microclimate Frames for Paintings,* Proceedings of ICOMCC Metal 2010 (submitted).5. A. Niklasson, *Atmospheric Corrosion of Historic lead Organ Pipes*, Ph.D Thesis, Chalmers University of Technology, Sweden, 2007.

6. F.C. Beall, *Overview of the use of ultrasonic technologies in research on wood properties*, Wood Sci. Techn. 36, 2002, 197-212.

7. W. Green, G.O. Maloney, Eds., *Perry's Chemical, Engineers Handbook, Sixth Ed.*, McGraw-Hill, Singapore, 1984.

8. C. Leygraf, T.E. Graedel, *Atmospheric Corrosion*, Whiley-Interscience, New York, 2000, 354 pp.

9. R.J. List, *Smithsonian Meteorological Tables*, Smithsonian Institution, Washington D.C., 1971, 527 pp.

10. R.C. Weast, *CRC Handbook of Chemistry and Physics*, CRC Press, West Palm Beach, Fla, 1977/78.