37 A DECENTRALISED CORROSION RATE PROCESSING SYSTEM (DCRPS)

J. Eri [1] **and F. Pruckner** [2]

ABSTRACT: This paper presents a recently developed system for the automatic monitoring of corrosion of steel-reinforcement in concrete. The shortcomings of the conventional automatic monitoring systems are discussed, particularly with reference to the problems encountered when using analogue signal transfer methods. Potential areas for improvement are considered. Finally, the effects of digitalisation of the measurement values close to the sensors are presented and its application in a decentralised monitoring system is examined. This system is persuasive both for the simplicity of installation and its expandability to cope with even very large reinforced concrete structures.

RÉSUMÉ : SURVEILLANCE DÉCENTRALISÉE DE LA CORROSION DES BETONS

Dans cet article nous présentons un système développé récemment pour la surveillance automatique et permanente de la corrosion des armatures dans le béton. Les imperfections des systèmes de surveillance automatique conventionnels avec leurs méthodes analogues de transfert de signal de l'endroit de la sonde au système central d'acquisition de données sont accentuées et les améliorations potentielles sont discutées. En conclusion, l'avantage d'une numérisation initiale locale et le traitement des mesures sont présentés et son application dans un système de surveillance décentralisé est discutée. L'installation du système et la possibilité d'extension à de grandes structures en béton armé seront présentés ainsi que les techniques avancées de mesure.

Keywords: corrosion rate monitoring, reinforcement, concrete, automatic monitoring

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Concrete Solutions: Proceedings of the Second International Conference, St Malo, France, 27–29 June 2006. Edited by MG Grantham, R Jauberthie and C Lanos. Published by BRE Press, Watford WD25 9XX, UK. Ref: EP71. ISBN 1 86081 915 X.

INTRODUCTION

A key factor for the functioning of our society is represented by its infrastructure including the road system with all its bridges, as well as multi-storey car parks and quays. These structures are often built wholly or in part using steel-reinforced concrete and give rise to considerable maintenance costs. To take just one example, the maintenance costs of the Austrian national motorway system (approximately 2000 km of road) amounted to €151m in 2004 of which approximately 5% (€7.55m) was used solely for bridge inspections[1].

The maintenance of the infrastructural assets will become increasingly important in the future, since a large proportion of these steel-reinforced structures are now reaching the 'critical age' of 25–35 years. Technical expertise and an in-depth understanding of concrete corrosion will be essential in order to provide both technically-advanced and cost-effective solutions to ensure the safeguarding of these civil structures. In addition, it is acknowledged that preventative measures to avoid unwanted corrosion-caused deterioration in the infrastructure are also desirable.

The current method for permanent and automatic monitoring of concrete structures has a 20-year track record. This uses a combination of sensor technology, data recording and long-distance data transmission. Such monitoring functions by connecting each sensor to a signal cable which is attached in turn to a central point (control cabinet). The signal measured is a voltage in the order of magnitude of 0–5000 mV. The transmission of these low voltage signals over relatively long distances can become unreliable because of the long cable runs; and problems may occur due to the many connection points. Alternating electrical fields, caused by power cables, can also adversely affect the signal transmission.

This paper will present and discuss a method for simplification of this automatic corrosion monitoring process – the decentralised corrosion rate processing system (DCRPS). The main feature of this system is to digitise signals at close proximity to the sensors and thereby allow for digital transfer of the signals to the central point. The functioning of such a monitoring system is presented here.

CONVENTIONAL AUTOMATIC CORROSION MONITORING

General

The purpose of permanent and automatic monitoring is stated in reference 2 and includes the collection of a range of variables at regular intervals and the registration of the change of these relevant parameters (e.g. the rate of corrosion). The following general requirements must be present within an automatic monitoring system:

- durability
- no need for frequent re-calibration
- measurement of the electrochemical properties of steel and concrete and their change over the time.
- the sensors must supply useful information.
- The measured values must be recordable and interpretable.

Monitoring to ascertain the extent of corrosion and the corrosion protection of a reinforced concrete structure will usually cover, amongst others, the following measuring parameters:

- electrochemical reinforcement potential
- protective voltage and applied protective current density when using Cathodic Protection (CP)
- concrete temperature
- electrolytic concrete resistivity
- corrosion rate
- macro-cell currents
- moisture content in concrete

A good overview of structure monitoring using various sensors can be found in the thesis of Yves Schiegg [3]. Results from a remote structure monitoring system in combination with a remote controllable CP-system are described in reference 4.

Data collection of the measured variables is performed using more or less complicated procedures, depending on the type of sensor used. The electrochemical reinforcement potential is easiest to measure with a data acquisition system (logger), along with the protective voltage and protective current density. However, capturing the concrete temperature, the macro cell current and the concrete resistivity/resistance requires much more complex electronic methods. Finally, the measurement of the rate of corrosion requires complicated algorithms and further electronic complexities.

In 1986, remote controlled structure monitoring combined with CP was installed by N. D. Burke at the bridges of the Interstate Highway 80 in New Jersey [5]. In Europe, monitoring systems have been on the market since the early 1990s [6]. Since then, successful structure monitoring systems have been installed in various places all over Europe, particularly in Italy, Switzerland, Great Britain, The Netherlands and Scandinavia.

Sometimes, however, monitoring installations are of limited use, as for example when large numbers of sensors are installed without automatic monitoring. Consequently, due to the high cost of specialist site visits, the monitoring installation has only limited practical use as a tool for early warning to initiate the right maintenance actions [7].

Shortcomings of conventional (centralised) corrosion monitoring

In concrete structures, the conventional ‘centralised’ automatic corrosion monitoring becomes less practical as the size of the structure increases, since in this process the signal cables for every single sensor has to be drawn separately from the sensor location to the central recording device (see Fig. 1). For example, the measurement signal from a reference electrode is transported using a cable-pair (one cable from the reference electrode, and one from the connection to the reinforcement) from the sensor to the recording unit. Sometimes one common connection (and cable) to the reinforcement is used for all (or several) reference electrodes, which under certain circumstances can lead to undiscovered measurement artefacts.

The more sophisticated sensors, such as those for measuring the moisture content or concrete resistivity of a structure, will often need additional electrical leads for the power supply of the electronic devices for those sensors. The resulting number of leads which are drawn to the central cabinet soon becomes excessive and unmanageable. For bridges, a span of ≥ 500 m would be the significant critical value, for a multi storey car-park a base of ≥ 2000 m^2. For structures exceeding these values the monitoring system would have to be split into several units – this can also cause problems in their ability to interoperate conveniently.

The draw-back of such a ‘centralised’ monitoring system for extended structures is obvious: both the use and installation of mechanically durable cables

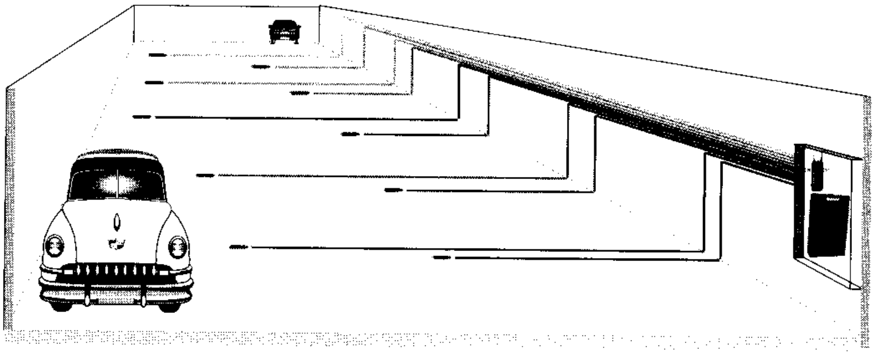

Fig. 1: *Conventional 'centralised' structural corrosion monitoring*

results in relatively high material costs. In addition, conventional data-loggers are usually equipped with only a limited number of inputs. Several data-loggers would have to be installed for large structures with a large number of measurement sensors to be monitored. The costs would increase correspondingly.

From a technical point of view, the transfer of low-voltage signals is also problematic: often noise signals are overlaid on the measurement signal. These noise signals are caused either by capacitive electrical fields or by inductive magnetic fields and usually appear in the vicinity of electric motors, light tubes or close to power cables (50 Hz noise). The lower the voltage level of the measurement signal, the higher the influence of the noise signal disturbance.

For example, when monitoring the electrochemical reinforcement potential at bridges, the transfer of the measurement signals can be influenced by disturbing noise signals due to the long leads and due to power cables often installed in the bridges themselves. When sophisticated signals, like transients (i.e. used in corrosion rate measurements) are transferred, the noise problem can make the signals totally useless.

In the case of the 'centralised' monitoring, all the measurement modules are mounted in a central cabinet. The size of a structure limits the practicability of this system, as shown in Fig. 2. In this instance, a large number of measurement leads from various sensors installed at a monitoring site of a research project are drawn to the cabinet.

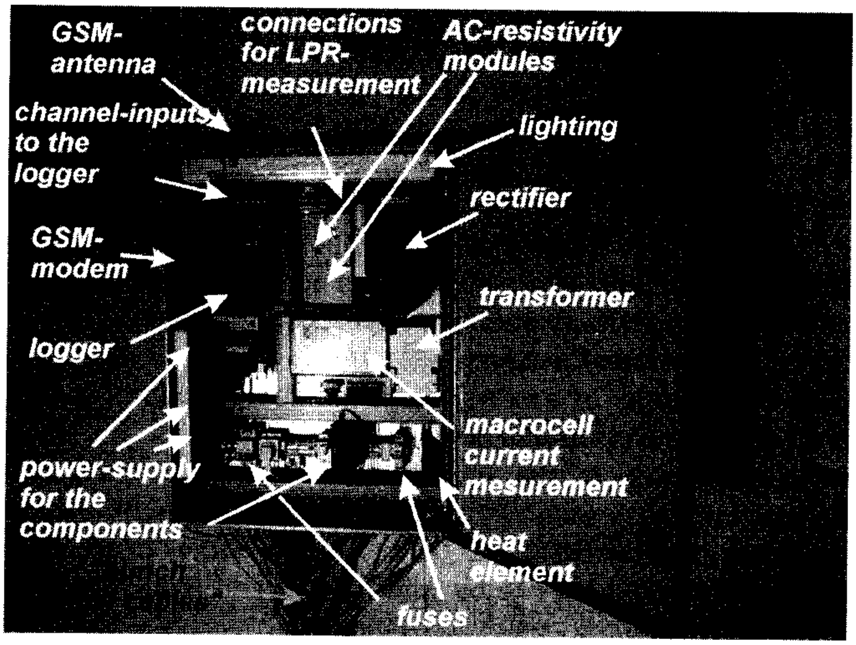

Fig. 2: *Fully instrumented measurement cabinet*

IMPROVEMENT OF THE TRANSMISSION

Short leads

The leads between the sensors and the remote monitoring unit should be as short as possible. In practice, this would mean that a data-acquisition system should be placed at each sensor location.

Shielded cables

By using shielded cables and twisted pairs, an improvement to the analogue data transfer can be achieved. However, this improvement will necessitate an increase in the cost of the cables.

Prefer current outputs for sensors with electronic output

The level of the signal needs to be higher than the noise level. A signal of 0–10 V is better (more robust) than a signal of 0–100 mV. In addition, structural monitoring systems often have a measurement resolution of just 1 mV. Therefore a larger measurement area would be desirable. Current outputs (i.e. 0–20 mA or 4–20 mA) outclass voltage outputs in robustness.

Digitalisation

As stated above, analogue signals can encounter various problems leading to erroneous data transfer. These potential causes for error can be minimised by digitising the analogue signals at the location of the sensor. Once the signal is available in digitised form it can be electronically stored, manipulated for calculations, etc. For long distance data transfer, digitised signals offer significantly more security from transfer errors when compared to analogue signals, and, additionally, digitisation allows for the transmission of many signals with just one common pair of cables. This works in the same way as a computer network – with just one cable connected to your computer you may communicate with many computers all over the world at the same time.

DECENTRALISED STRUCTURAL MONITORING

The following discussion of decentralised structure monitoring takes the Camur II as an example.

The components

The possible error sources may be eliminated to a great extent by early digitisation of the measurement signal. In order to achieve this purpose, a small electronic unit is embedded in concrete together with the sensor. This so-called “node” is connected directly to the sensor via a databus carrying the power supply as well as the data itself. (see Fig. 3)

The sensor connections to the node are galvanically isolated from the power supply and from the data net by opto-coupling. Each point of measurement is accordingly isolated from the residual installation. Mutual electrical influence is therefore not possible (see Fig. 4). The measurement nodes have their own internal serial numbers and unique auto-identification. This ensures that there is automatic identification by the monitoring software.

The components for an electro-chemical potential measurement of reinforcing steel are shown in Fig. 5 in logic arrangement.

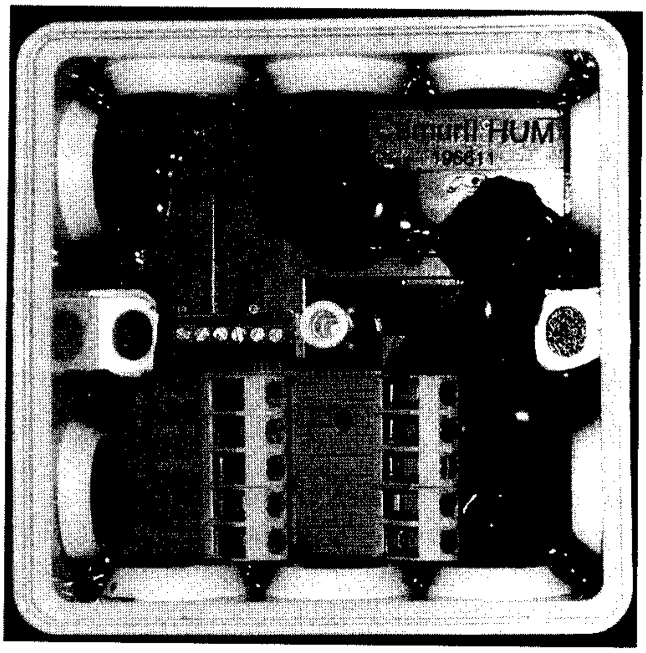

Fig. 3: *Measurement node. Green connector for sensor, white connectors for databus. May be embedded in concrete with sensor.*

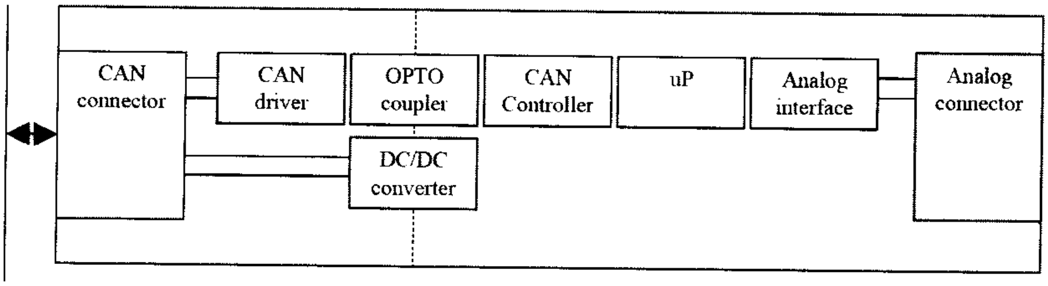

Fig. 4: *Measurement node (schematic)*

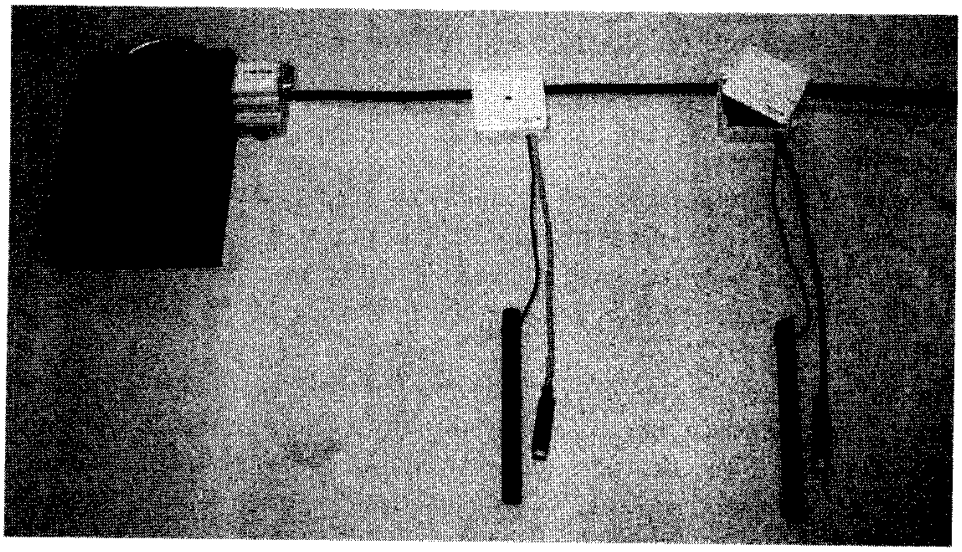

Fig. 5: *Reference electrodes/reinforcement with measurement nodes, central controller to the left*

In this instance, a commercially available manganese dioxide electrode* serves as the reference electrode. The analogue data transfer will not usually exceed a distance of 50 cm. The node is normally embedded in resin that is further embedded into concrete together with the electrical leads.

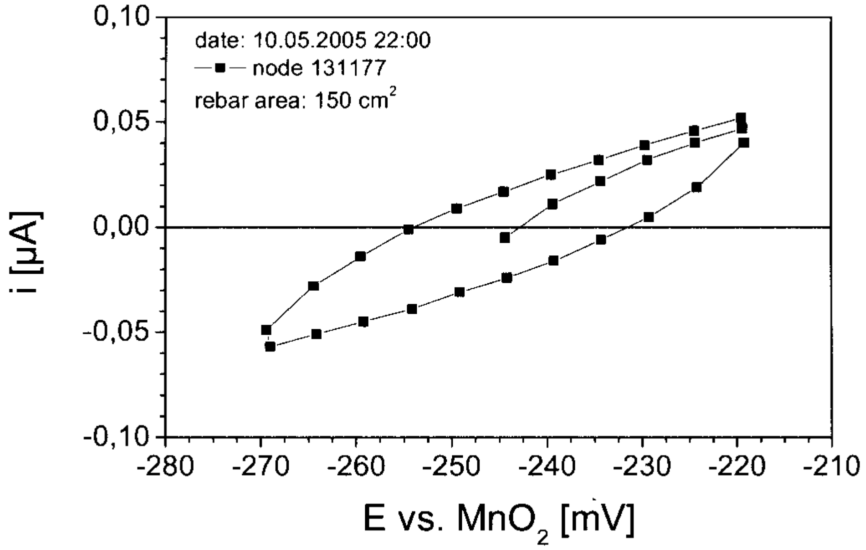

Fig. 6: *LPR-measurement*

From the LPR measurements, the corrosion rates are calculated and plotted against time. Through regular and automatic recording it becomes very easy to spot any trends and changes. In Fig. 7, we can see a clear correlation between the ambient temperature and the variation in the rate of corrosion of the reinforcing steel at the location of the sensor. This data was obtained from a car park in Oslo, Norway.

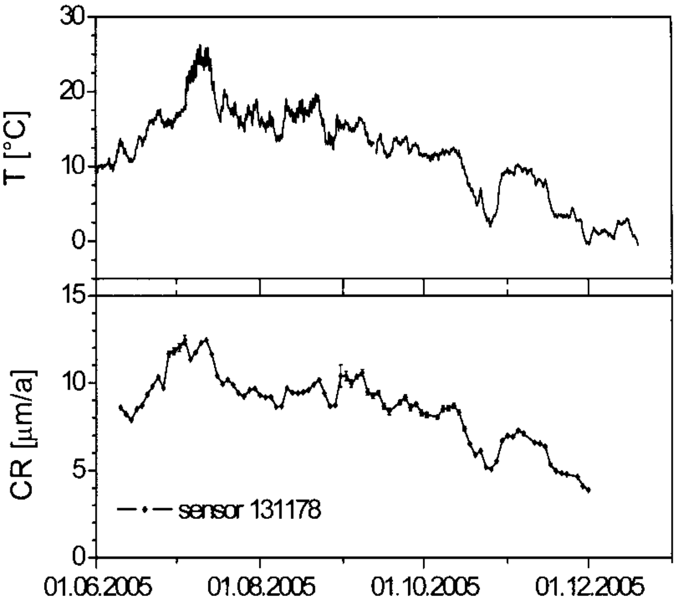

Fig. 7: *Variation of the corrosion rate with time and temperature*

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* ERE-20 Electrode, product of www.force.dk

SUMMARY

Advantages of using decentralised monitoring

As has been explained, a decentralised monitoring system offers significant advantages when compared to traditional centralised systems in several important areas:

- improved integrity of data through the reduction in transfer of analogue data
- reduced costs due to the need for less cables and because fewer and easier installation works are necessary
- less risk of errors because of the galvanic isolation close to sensor scalability – the system is easy to expand through "plug and play" principle, See Fig. 8

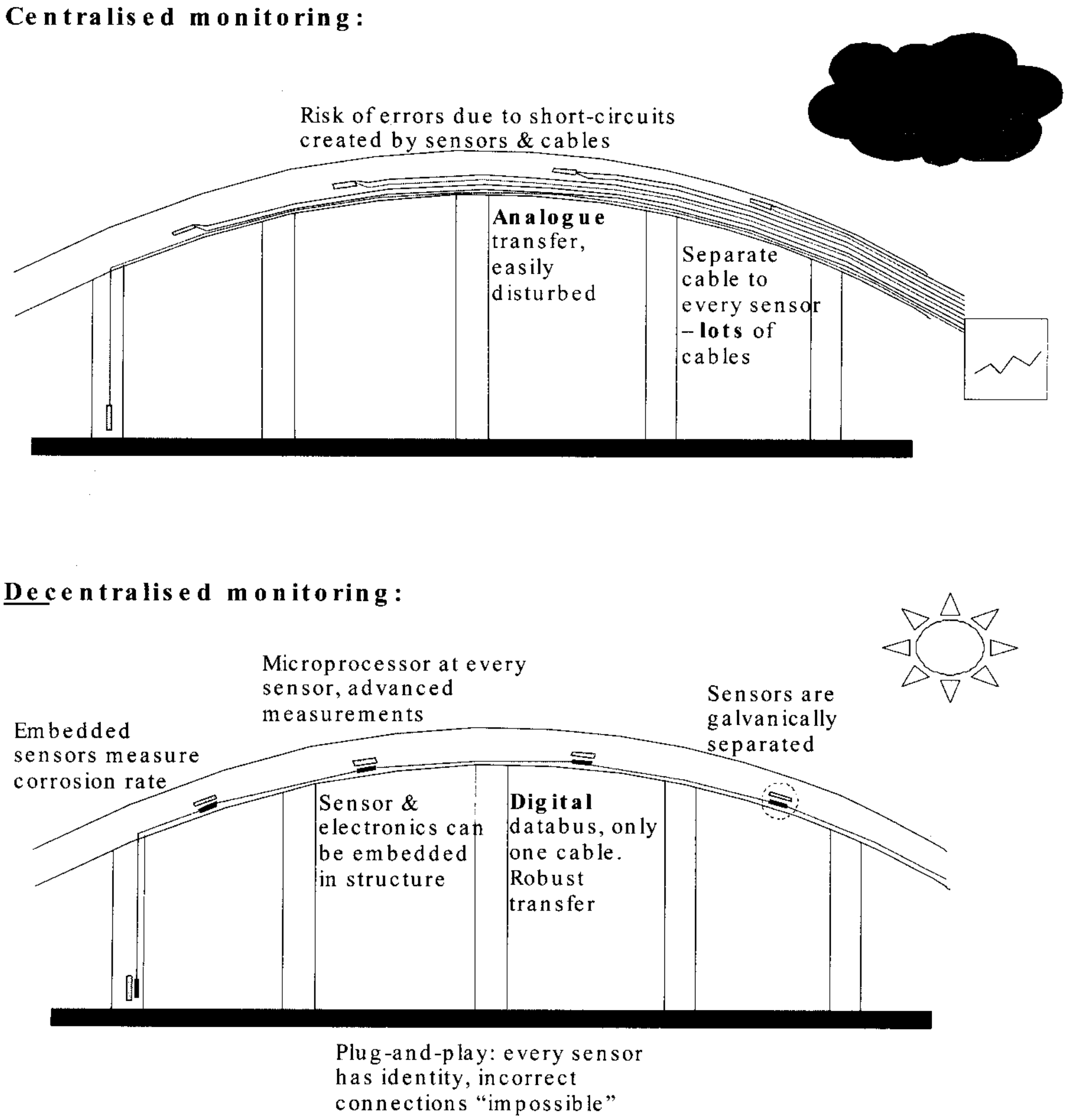
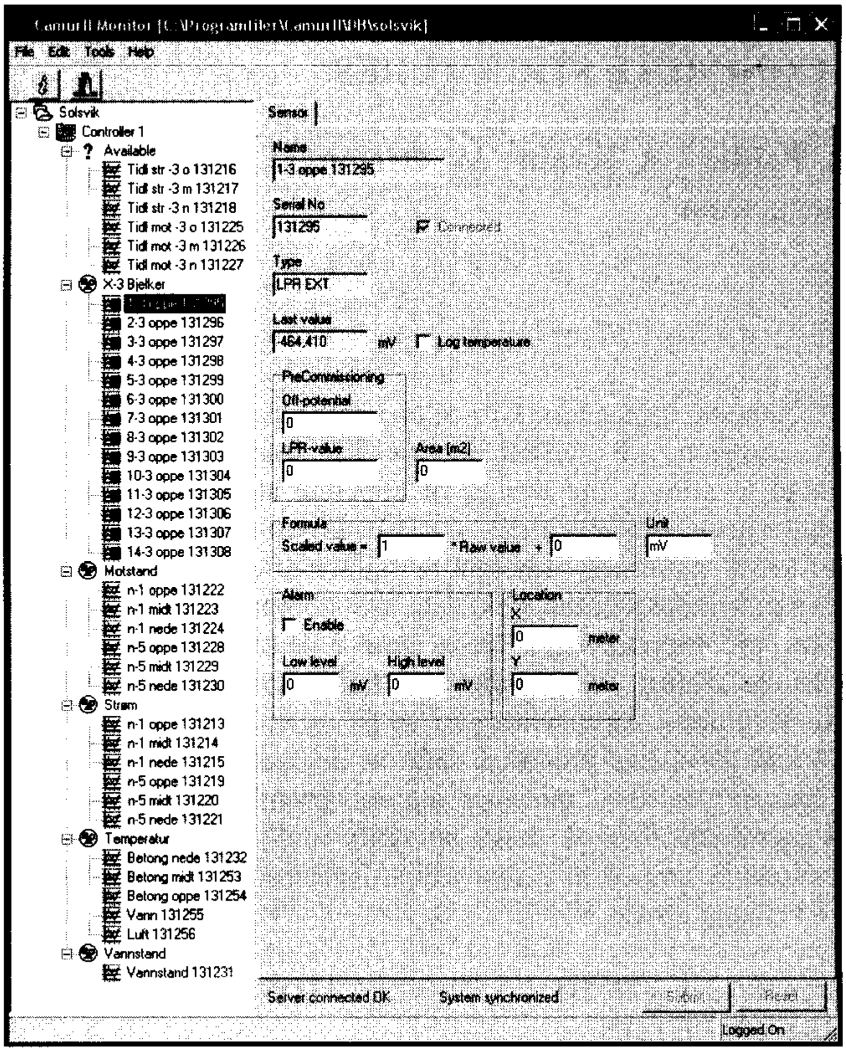


Fig. 8: *Illustration of differences between centralised and decentralised monitoring.*



- Solsvik
  - Controller 1
    - Available
      - Tidl str -3 o 131216
      - Tidl str -3 m 131217
      - Tidl str -3 n 131218
      - Tidl mot -3 o 131225
      - Tidl mot -3 m 131226
      - Tidl mot -3 n 131227
    - X-3 Bjelker
      - [illegible]
      - 2-3 oppe 131296
      - 3-3 oppe 131297
      - 4-3 oppe 131298
      - 5-3 oppe 131299
      - 6-3 oppe 131300
      - 7-3 oppe 131301
      - 8-3 oppe 131302
      - 9-3 oppe 131303
      - 10-3 oppe 131304
      - 11-3 oppe 131305
      - 12-3 oppe 131306
      - 13-3 oppe 131307
      - 14-3 oppe 131308
    - Motstand
      - n-1 oppe 131222
      - n-1 midt 131223
      - n-1 nede 131224
      - n-5 oppe 131228
      - n-5 midt 131229
      - n-5 nede 131230
    - Strøm
      - n-1 oppe 131213
      - n-1 midt 131214
      - n-1 nede 131215
      - n-5 oppe 131219
      - n-5 midt 131220
      - n-5 nede 131221
    - Temperatur
      - Betong nede 131232
      - Betong midt 131253
      - Betong oppe 131254
      - Vann 131255
      - Luft 131256
    - Vannstand
      - Vannstand 131231

Name: 1-3 oppe 131295
Serial No: 131295 ☑ Connected
Type: LPR EXT
Last value: -464,410 mV ☐ Log temperature

PreCommissioning
Off-potential: 0
LPR-value: 0
Area [m2]: 0

Formula
Scaled value = 1 * Raw value + 0
Unit: mV

Alarm
☐ Enable
Low level: 0 mV
High level: 0 mV

Location
X: 0 meter
Y: 0 meter

Server connected OK
System synchronized
Logged On

Fig. 9: *The software that controls the system discussed here as an example, has a user interface that is strongly related to the physical layout of the system.*

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