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Sensor systems: a hierarchical approach

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Abstract. The concept of a reference model has been well known in the communications industry for many years. This has provided clearly defined layers and interface standards which allow different organisations and across the industry to develop products independent of each other in the knowledge that their products will function correctly within the greater system. With the move towards massively parallel sensor systems networks, a similar approach needs to be adopted in order to permit concurrent developments in sensor networks. This paper summarises the need for such a reference model, and proposes a reference model applicable to sensor system.

Background.

In the 1980's the telecommunications industry recognised that the network and equipment complexity was giving rise to the breakdown of the conventional, vertically integrated equipment companies in favour of specialist companies focusing on particular components required within the overall system. In order to enable the industry to develop effectively, the CCITT, the Geneva based telecoms standards body defined a seven layer reference model with clearly defined functions and interfaces within and between each layer. This model, known as the Open Systems Interconnect (OSI) model and enabled the rapid expansion of the communications industry which culminated in the realisation of the internet.

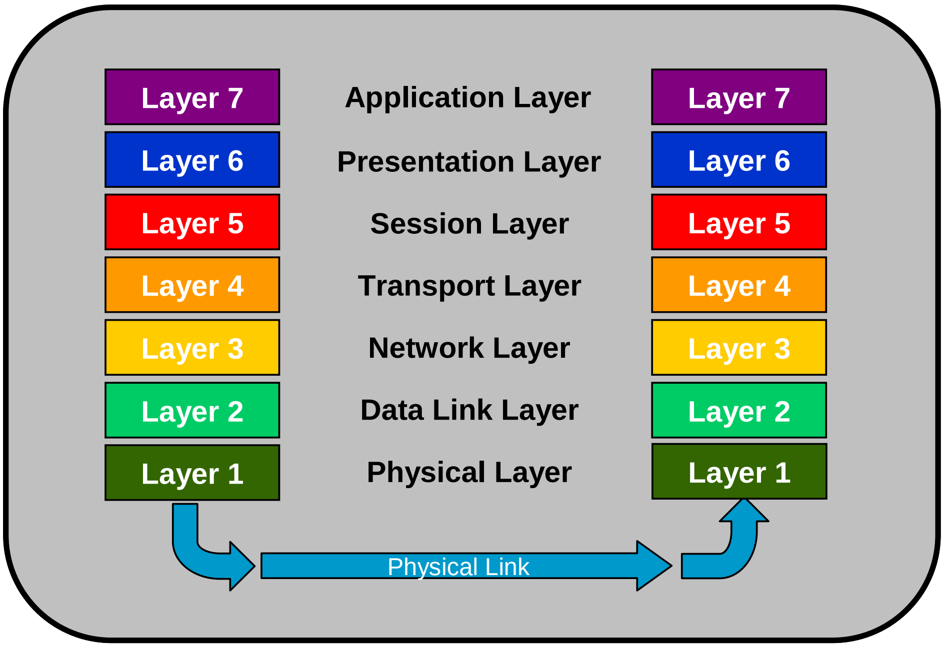

Figure 1 OSI Reference Model

With the advent of high performance, low power processing and communication platforms, it is now possible to develop complex sensor systems that integrate many different sensor technologies into a sensor system. However, in order to enable concurrent developments and maintain interoperability across the range of activities and requirements in a complex system, it is proposed that a reference model be developed. Using the approach taken by the successful OSI model, a comparable model for a hierarchical sensor system is proposed.

A sensor systems reference model

As in the case of communication systems, a sensor system is now more complex than can be effectively produced by a single, vertically integrated organisation. Consequently, the component parts and functions of sensor system need to be delineated by function and interface in order that concurrent system development can take place efficiently. The derivation of the model is based upon the OSI model but adapted for the specialist requirements of a complex sensor system. By examining the fundamental requirements of a sensor system, it can be established that all sensor systems carry out the same functions. In all cases, there is a requirement to detect a parametric change in the measureand, and after suitable conversion of the data into information, to pass that information to a 'decision making authority'.

Importantly, although the sensor system may carry out signal pre-processing or filtering, it does not make any decisions; this is beyond the remit of a sensor system. In the case of complex networks, this decision authority is often a human being, however it may be a machine system such as a automotive engine management system.

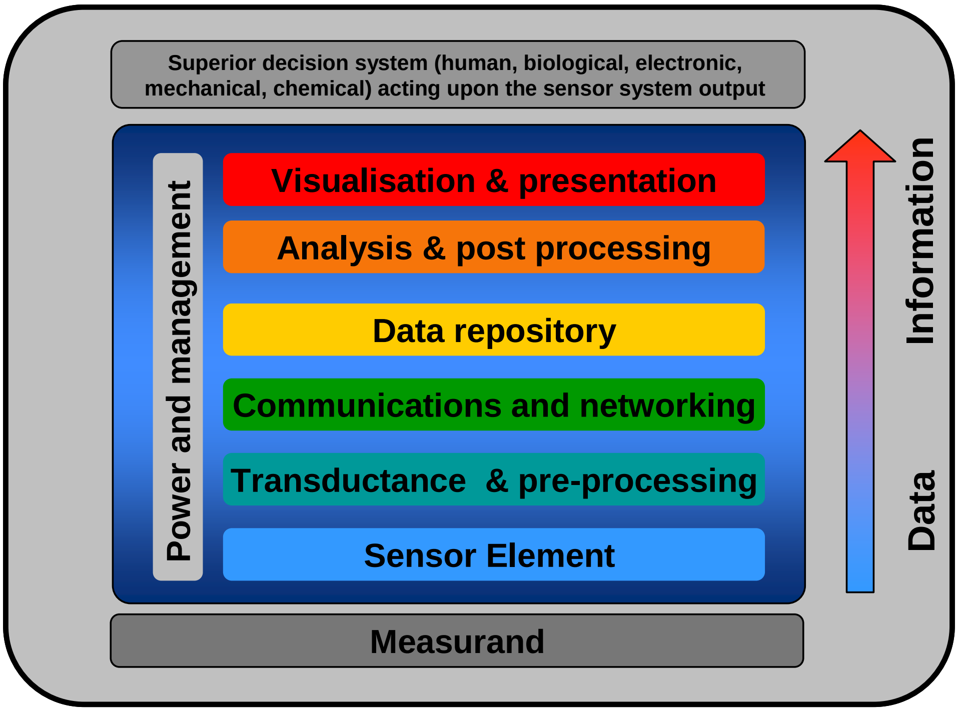

Figure 2 Sensor Systems Hierarchy

Using this generic approach, the model can be applied to a simple sensor system such as a thermometer or weather vane, or a highly complex network such as a battlefield management system or traffic management system. In order to understand the logic in developing this proposed Sensor Systems Stack, an explanation of the different layers follows.

Sensor Element

This is the foundation element of the stack and is responsible for the detection and measurement of the quantity in question. The elements operate in different ways depending on the type of sensor but are usually sensitive to a change in energy within the measurand causing a phenomenological change. This change in energy of the measurand gives rise to a secondary energy change (chemical, optical, nuclear, mechanical, electro-magnetic etc) within the sensor which is used to indicate the presence or absence of the quantity under test.

Transductance & pre-processing

Transductance is usual in a sensor device in order to convert the energy change produced by the sensor element into energy suitable for use. In modern sensor networks this is normally electrical energy although it may be another form; a simple example being a traditional mercury thermometer. Although the mercury is an effective visual indicator, it is difficult to transmit the positional information to a remote location. A second and important requirement of the transductance stage is that of signal conditioning and logging. In many cases the logging is based upon a time stamp but the measurement may be logged against another parameter such as temperature or pressure. Pre-conditioning may be functions such as removal of noise or distortion from the signal but also may be a function of the parameter such as exceeding a minimum threshold.

Communications and networking

The communication layer transports the captured sensor data from the location of the measurement to a storage location. In simple sensors, this communication is often one way; from the sensor to the storage location. However in advanced sensor devices, duplex communication protocols are used; sensor -> data store, and pre-condition rules - > sensor. Selection of the communication protocol and the sensor network architecture can have significant effects on the power demand of the network and careful consideration should be given to the performance trade-offs associated with this area.

Data repository

In any sensor system the storage of the raw data obtained from the sensor elements is essential in order to carry out post processing operations and trend analysis. In the case of simple sensor devices this can be a relatively modest data storage location, however if the sensing elements are recording video information, the storage and categorisation of this information can present significant complexities. Data reduction techniques are important in reducing the total storage requirements however, in the case of retrospective analysis to identify trends.

Analysis and post processing

Although the data repository contains data, decisions can only be made on information. The analysis and post processing function is responsible for the conversion of the measured data retrieved from the sensor elements into meaningful data upon which a decision may be made. The important difference between data and information is the introduction of context. A piece of data indicating a temperature of 35 C does not, in itself convey any information. This could indicate a hot day, a warm electronic component, or a water temperature a considerable distance from the boiling point. Only when it is placed in context, in this case a monitor of a patient's temperature can a decision be made that this indicates a very cold patient. In addition to converting data into information, this function is also responsible for post processing such as filtering, integrating or averaging such that additional information can be derived from the system.

Visualisation and presentation

The highest function within a sensor system is the processing of the information into a manner which can be understood by the superior decision system. In the case of a human operation this is likely to be presented in a manner which will stimulate one of our senses; in many cases sight or hearing. However, if the superior decision system is a control system, the correct presentation of the data may be in the form of an error message or a signal voltage. In the case of a complex sensor system such as a battlefield information system of a traffic control system, the intelligible presentation of the information can present as many challenges as the gathering of the original data. Considerable research has been undertaken to quantify the problems associated with data overload of critical operators such as aircraft pilots or vehicle drivers that demonstrates the benefit of effective data presentation.

Power and management

The final component of a sensor system is the power and management of the complete system. While researching sensor systems it was recognised that many previous attempts to analyse sensor systems identified power as a separate element within the stack components. However, it is suggested that this is incorrect as all the components of a sensor system can impact both the power consumption and the management capability of a system. Low power sensors, even zero power (energy scavenging) devices do not, in themselves modify the fundamental data or information flow through the stack. Power consumption and system management, although important from overall system functional aspects, do not in themselves modify the absolute functionality of a system.

Conclusion

The establishment of the SSSC as a dedicated centre looking at the challenges of large and widely distributed sensor systems delivers an excellent opportunity to consider the holistic problems. Over the last decade, the development of portable and highly integrated sensor platforms; the Apple iPhone being an excellent example, has delivered the capability to gather vast amounts of data upon which to generate new insights into behaviour. It is hoped that the framework suggested in this paper will provide an initial reference upon which a more rigorous methodology can be developed when developing new sensor systems.