A reference architecture for sensor/actuator systems
A sound architecture will make you technology independent and supplier independent.
In a time when the physical world is becoming ever-more digitized and automated, there is a growing need for dialog about the design of (business-critical) Internet of Things systems (hereinafter: sensor/actuator systems).

Technolution has developed a reference model that identifies the various elements of these systems and arranges them in a layered architecture. Our focus is specifically on a structure of horizontal layers, on functional separation, and technology independence. The goal is to give every layer a sharp interface and to keep the layers mutually detachable (or ‘loosely coupled’). This makes it possible to design and build modular and scalable systems.

The layered structure and loosely coupled interfaces guarantee the integration and reusability of existing, separately purchased or developed building blocks, which often have their own life cycle. This ensures that investments made on existing building blocks can be largely or entirely preserved.

This whitepaper describes the conceptual aspects of sensor/actuator systems as well as the SARA model (Sensor and Actuator Reference Architecture) that Technolution has developed.

It will not address such aspects as security, privacy, data integrity, and make-or-buy. However, a sound architecture can provide the flexibility and scope to choose the best technology within the context of the system, the organization, the availability of knowledge, and possibly intellectual property. A system like this will make you technology independent, because the lifespan of the system as a whole no longer depends on the life cycle of a single technology.
WHAT SYSTEMS ARE AVAILABLE?

All sensor/actuator systems (IoT systems) link the physical world to the digital world. Sometimes they do this by making a simple connection between a number of sensors and elementary presentation software, but more frequently they involve complex chains with a large number of different sensors and multiple data users.

There are therefore various types of sensor/actuator systems. The three most frequently used systems are the monolithic application, the vertical silo, and the (horizontal) layer system.

**MONOLITHIC**
A monolithic application implements all the required functionality in a single application. This works very well for small and simple systems and it requires very little direction. The drawback is that the system is difficult to manage if expansion is required. All the various aspects of the system are intimately interconnected (data, code processing, presentation). Monolithic applications are generally not scalable.

**VERTICAL SILO**
A vertical silo solution usually consists of multiple (stacked) software blocks, with system functionality focused on a single kind of sensor and/or data stream. This means that this type of system is not generic. Usually, a vertical silo uses technology from a single supplier. The advantage of this is that it requires little direction, because the whole chain is managed by the supplier in question. But at the same time this supplier dependence is a disadvantage, as is the very limited data flexibility. It is often impossible to add sensors and data streams produced by other parties.

**HORIZONTAL LAYERS**
In this type, the system is divided into detached, horizontal layers that each have a unique functionality. Each layer can be implemented with the (state-of-the-art) technology that is most suitable for that particular layer. The system has great and enduring flexibility. Several technologies can be used alongside each other, and it is possible to correlate information and processes. The disadvantage is that it requires a lot of direction; the functionality and interfaces of the layers need to be permanently monitored and assessed.

Technolution’s SARA model is based on the horizontal layer type. It keeps complex sensor/actuator systems simple by clearly separating the functions and responsibilities of the various building blocks. SARA is also able to support migration from monolithic systems and vertical software silos. This kind of evolutionary migration might start, for instance, with the renewal or expansion of a part of the system, by applying the SARA model to the design and the building.
Horizontal layer models have proved themselves in practice. The SARA model is for instance based on sensor and control systems in energy distribution, industry, and agriculture. It offers a useful frame of reference for many target groups, including system architects, project managers, and software and electronics developers. The practical basis of layered systems provides many significant advantages in industrial applications.

**PHASED INNOVATION**
Ideally, the introduction of sensor/actuator/IoT systems is a phased process, in which the parts (layers) of the system are implemented step by step. This makes it possible to keep a balance between costs and benefits, while creating scope for exploration and innovation.

**OPEN MODEL WITHOUT SUPPLIER DEPENDENCE**
Phased implementation requires that the components that are going to be used or built be flexible. The SARA model makes it possible to use the most suitable technologies and specialists. The model’s layered structure and its openness ensure that a long life cycle is possible.

**SCALABILITY**
The functional separation within the SARA architecture makes it possible to design a system for the long term while starting small-scale. Thanks to its detached layers, the system can always continue to grow, both in types and numbers of sensors and applications, as well as geographically.

**TAKING RESPONSIBILITY FOR RESULTS**
An (I)IoT system is often a patchwork of devices, networks, and applications. Expert support is recommended to operate it. A technology integrator can guarantee the integral operation and sustainability of the system. The SARA model can support you in your communications with your technology partner, who can be asked to assume responsibility for the results.
The SARA model consists of nine layers, divided into two groups: central and local, connected by a communication layer for data transport. Any system always contains one central part and one or more local parts (represented by the hourglass-shaped groups in the image). Purchased sensor/actuator networks supplied by third parties are often used in large business systems. These parties offer a closed solution of sensors/actuators, local network, and device management, which all converge in the central part of the system.

For each layer in the SARA model, aspects such as ‘make or buy’, open vs. closed source, and purchase and operational costs play a role. A useful rule of thumb is: choose the best technology per layer.
**LAYER 1**

**Sensors & Actuators**

**Purpose and function:**
Layer 1 forms the interface between the physical and digital (virtual) world. A sensor is a device that transforms a physical quantity, such as pressure, temperature, or electrical current, into an analog or digital signal. Actuators do the exact opposite: they respond to an analog or digital system by performing an action that intervenes in the physical world, like switching on a source of heating or activating an alarm.

**Application:**
Sensors are connected to sensor nodes so that they can be contacted and operated from the digital domain. Sensor nodes also contain the (wired or wireless) interfaces with the local network (layer 2). Embedded software on the sensor nodes determines the functionality and carries out communication, via the local network, with the local data platform (layer 3) to send and receive sensor data and parameters. The same is true for actuators, connected to actuator nodes.

**Specifics:**
Typical focus points for layer 1 are the desired level of accuracy of the measurement, the desired measurement interval (sensor) or control interval (actuator), reliability (robustness in a particular environment), and energy consumption.

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**LAYER 2**

**Local communication**

**Purpose and function:**
Layer 2 carries out the transport of data and information between the sensor nodes (layer 1) and the local data platform (layer 3). Because data transport can take place in various ways and using various technologies, this layer is separated from the sensor/actuator layer. This uncoupling ensures that sensors and actuators of the same type can be used in different network types and topologies.
**Application:**
Data transport can take place in various ways; wired or wireless. Examples are (real-time) Ethernet, WiFi, and LoraWAN.

**Specifics:**
Layer 2 addresses such aspects as network management, security, commissioning, and reliability. In the case of a wireless network, gateways or access points also belong to this SARA layer. Network-specific device information is collected from Device Access & Management (layer 6).

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**LAYER 3**

**Local data platform**

**Purpose and function:**
Layer 3 realizes the local storage and distribution of data in support of the local applications (layer 4). These functions are generic, give support, and are application independent. This is why they constitute a separate layer, distinct from the local applications.

**Application:**
Data distribution is the transmission and distribution of measurement and operating data, for instance with a publish/subscribe mechanism. Data storage involves offering generic services to permit the temporary or permanent storage of data on the local platform (edge computing), for instance to absorb network failures for the central data platform (buffering) and to keep a record of local log files.

**Specifics:**
The local data platform generally has a much smaller storage capacity than the central data platform (layer 8). Data storage in the local data platform is usually temporary. Depending on the application, the data is processed or enriched by local applications (layer 4) and/or forwarded to the central data platform (layer 8).

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**LAYER 4**

**Local applications**

**Purpose and function:**
Layer 4 contains the local applications that are to be implemented on the edge platform. These applications run in close proximity to the sensors and actuators, i.e. on the edges of the system.

**Application:**
Some applications are local by definition, like data forwarding to the central system. For other applications, aspects such as time, data quantity, and reliability are decisive for the choice of whether to implement the application locally (on the edge) or centrally (in the cloud).

**Specifics:**
The time aspect is usually important for a control loop. If it is necessary to be able to respond very quickly to certain stimuli, it is preferable that the corresponding decision application be implemented locally.
If the sensors generate large quantities of data, it can be sensible to process the data locally and only to forward the result of this process to the central platform.

The aspect of reliability plays a role in local alarms, for instance smoke detection. This must operate locally, because dependence on an internet connection is undesirable for fire alarms.

**LAYER 5**

**Central communication**

**Purpose and function:**
Layer 5 ensures the data transport between the local and the central system. This communication is usually performed by a third party, for instance a telecom or network provider. This means that certain dependencies have to be factored in, like costs, the quality of the connection and of service, data bandwidth, and the lifespan of the telecom technology in question.

**Application:**
The choice of a particular communication technology can determine the decisions made in other layers. A limited bandwidth can affect the choice between implementing an application locally or centrally. The less dependent the communication technology is, the better, because this means that the lifespan of this technology does not become a limiting factor for the system as a whole.

**Specifics:**
Wired internet connections, GSM data connections, or private fiberglass point-2-point connections are all possibilities. Aspects such as bandwidth, quality, latency, and coverage (in the case of a GSM connection) are decisive.

**LAYER 6**

**Device access & management**

**Purpose and function:**
Layer 6 takes care of ‘stock management’ and of access to all devices and entities that are part of the underlying local system. ‘Device management’ covers management, ‘device access’ is about the data paths from and to the central data platform (layer 8). Because device access & management as a functionality is clearly distinct from data transport, storage, distribution, and processing, it has been given a layer of its own in the SARA model.
**Application:**
Device management involves both static and dynamic device data. Static device data includes serial number, location, software version, and commissioning and authentication details. Dynamic device data consists of things such as battery status, network status (RSSI, SNR), and internal device temperature. This data is used for operational management and the analysis of sensor/actuator devices and the communication network.

**Specifics:**
Large sensor/actuator systems usually include various local systems, each with their own domain- or supplier-specific sensors and actuators. These local systems normally offer their own device management solution. This SARA layer therefore has multiple instances: there is an instance of layer 6 for each underlying sensor/actuator system.

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**LAYER 7**

**Chain monitoring**

**Purpose and function:**
Layer 7 covers the operational monitoring of the chain and the tracking of deviations. The emphasis is on monitoring the functionality and approachability of sensors/actuators and top-down/bottom-up data streams. Layer 7 contributes substantially to the correct functioning of the devices, the system chain, and the delivery of data to the central data platform and the central applications.

**Application:**
Most SARA layers already have integrated security and alarm functions to support analysis in the layer itself. Layer 7 uses an abstraction of the internal monitoring of each layer, to create one central place where the functioning of the entire chain is monitored and deviations are tracked. In critical systems and in systems that are under operational management, this is the place where chain monitoring and notification to operators takes place. This is also the layer where the quality objectives of the system are measured and reported.

**Specifics:**
Layer 7 is connected with all other layers and in thus has a special, more vertically-oriented character than the other SARA layers. The functionality of this layer is crucial for chain monitoring.

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**LAYER 8**

**Central data platform**

**Purpose and function:**
Layer 8 is the place where all data from the underlying sensor/actuator networks of the system comes together. The data is stored here and distributed as required to the various applications.

**Application:**
The central data storage in layer 8 is intended for long-term storage. This could be a simple time series of measurements, but usually it will involve large quantities of data in various database storage forms, for instance SQL, time series, or document databases. The data can be accessed from various locations through the central applications in layer 9, for instance via the RST API (data poll) or pub/sub mechanism (data push). In IoT terminology, central data storage is also called the ‘data lake’.
Data distribution takes place from and to the applications in layer 9 (the central applications). This task can be performed in several different ways, from simple applications that receive sensor data (like the REST API mentioned above), to advanced publish/subscribe mechanisms, such as MQTT or Apache Kafka. Actuator data and setpoints are also distributed to the actuators through this layer.

Data storage and distribution constitute a layer of their own, separate from the central applications in layer 9, because they are generic, give support, and are application independent.

**Specifics:**
The data in the central platform is often used by the applications of multiple parties and stakeholders. To prevent data leaks and undesired access, special attention to security and reliability is required.

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**LAYER 9**

**Central applications**

**Purpose and function:**
Layer 9 contains the central applications. In general, these are applications with overarching functionality or low timing and response speed requirements, unlike local applications that are placed in close physical proximity to the sensor/actuator and run on the edge platform.

**Application:**
The central implementation of applications offers clear advantages from the perspective of maintenance and monitoring, but of course it should not lead to problems in the field of security and timing or to excessively large data streams. Suitable applications for instance include web dashboards that provide a summary view of the system, collection functionality, or data analysis applications to detect trends.

**Specifics:**
The central applications usually run on a Cloud platform. The security and reliability of these applications is important because they provide access to the sensor/actuator chain.
PRACTICAL EXAMPLES

The diagram below shows three different implementations of sensor/actuator systems (the colored columns) projected unto the SARA model (the gray column). The Sense2Grow product and an IoT system for Tata Steel are examples of solutions designed and realized according to the SARA model.

The Cloudia BackOffice was built before the SARA model was available. Device access & management, data storage and application form a single monolithic application. There is no separation of functionalities on the central platform.

Sense2Grow is a system of sensors (for instance for temperature, carbon dioxide measurements, and smoke detection) and applications for horticulture. Tata Steel uses the IoT system for asset monitoring of industrial machinery, among other things. Cloudia establishes a connection between smart energy meters, energy providers, and consumer applications.
A sensor/actuator system is a large investment and the return is not always certain. Moreover, growing pains and technical problems can cause disruptions to production. Starting small-scale with a sound architecture and scaling up later can prevent a lot of problems.

Monolithic applications are particularly suitable for small and simple systems. They can be implemented relatively easily, but they quickly become unmanageable if the system grows. Vertical silo solutions focus on a single kind of sensor and/or data stream. Because the whole system is provided by a single supplier, they require less direction, but they do make you dependent on this partner.

A horizontally layered architecture is the most future-proof solution for complex sensor/actuator systems. The system is built using detached parts. Layers are created using the most suitable (state-of-the-art) technology from the best qualified supplier. This makes it possible to design and build open and scalable systems. An additional advantage is that a layered architecture is also suited for the migration of monolithic applications and vertical silos.

A horizontally layered architecture requires a greater degree of direction than other types of system. It is highly recommended to use a technology integrator who is able to monitor and safeguard the entire system as an architect.

The SARA model was developed by Technolution. It is based on a horizontally layered architecture and consists of nine layers. These loosely coupled layers make it possible to phase innovation and investment. Existing elements or systems can also be integrated. The open character of the SARA model prevents supplier-dependence and makes the system scalable. Moreover, the detached functionalities make it possible to ask your technology partners to assume responsibility for the results, for instance when the sensors and actuators intervene in business-critical processes.
ABOUT TECHNOLUTION

Technolution is your go-to partner for sensor/actuator systems in complex environments. Our multidisciplinary expertise in high-tech and industrial automation allows us to create asset performance management solutions that can really make a difference for your business case.

Our scalable systems offer everything you need to digitally monitor and control devices, perform analyses, and realize predictive maintenance. This allows you to enhance capacity utilization and improve the reliability and quality of production.

“Want to be sure it will work?
Contact us for a personal meeting. We are happy to come and visit you.

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