Sensor and Actuator Networks in intelligent Automation Systems

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Communication technology was in the focus of scientific investigations in the the field of automation from the early days on. Industry quickly identified the enormous market potential of distributing intelligent control units, no matter in which field, being it energy production, energy supply, rail transportation, or aviation and space technology. This article intends to review history in order to better understand the present. Principles will be highlighted, examples given, and finally current research challenges worked out to give prospectives about future paths of automation systems, which significantly will be influenced by bionics.

1. Automation

The term automation was introduced in 1936 by the Ford manager D.S. Harder [Brock 87]. Since then, its meaning has changed considerably. In the beginning, automation referred to optimization of processes in production of goods, while in engineering today automation refers generally to machinery-controlled process runs. Hence, in the past its major goal was optimizing production for highest number of pieces per time frame. Today we talk about automation when processes are controlled by machines, no matter whether human resources are additionally required or not. Also in modern production systems the goal is no more the mere rise of throughput, but process optimization in various respects, e.g. increase in quality, increase in safety and security or increase in hygiene.

The signature "hand made“ is just a feature in arts and crafts today. In terms of material goods its meaning refers no longer to high quality but more to the opposite. Machines are able to continuously deliver high quality. If we think of micro and nano technology, chip technology and many other areas of production procedures, the quality can be only kept on high levels and standards with consolidated deployment of automation technologies and methodologies. Impressive examples of advantages through automation can be found e.g. in aviation technology: modern wide body aircrafts utilize 30% less fuel compared to classical ones. Only field bus technology and the introduction of the fly-by-wire principle made this possible. It allowed the vendor Airbus to catch up and even overtake the competitor Boing within only seven years. Another example is the one-liter car engine. It will not be possible without drive-by-wire.

Mining companies in Europe were only able to reach the safety level for road tunnels in our country Austria through interconnection with field busses. They steadily collect data and send it to control stations and central offices. In this case data collection was not a technical problem at all. It could have been accomplished with decentralized control units or even with widespread internet connections for all sensors and actuators. However, the key advantages of field busses include two aspects: first of all low prices, and second and most important its specification of profiles for application areas. Especially the second point, the definition of profiles, is a question of standardization, for which industry, industrial associations, and also governments in form of grants spent lots of money. In this way a broad basis emerged, on which most notably the European industry created enormous margins. Without profiles, field busses are worthless; they would be too expensive in development and still more in maintenance. If countries that do not have strong industries in this area want to use this fundament, they need people who acquire the knowledge about profiles for them. The conception of a field bus being a small computer with long connections to sensors and actuators as well as connections to other computers is no longer enough, since field bus components will be superseded in the next years with developments in the areas of internet technological and brown ware. The performance of chips will increase year by year. Therefore, knowledge in the field bus area does not lie in components; it lies in the functional profiles and interoperability. And still there is more to it. The second large area of knowledge capital, which makes out a field bus expert, can be seen in application-specific knowledge. The collection of billions of data points via a large field bus system is not a trivial task at all, especially if various channels are connect sinks and sources. But the real challenge lies in finding the information behind the data – which can only be accomplished automatically due to the sheer amount of data [Bruck 07].

2. Intelligence and Communication

Before introducing actual examples of field bus technology and today's technical and scientific challenges it is important to understand the principles behind the scenes. Two questions are of major importance:

1. Why is it now that automation experiences its phenomenal boost? Why is it seen as an essential pillar of economy?
2. Nature solely consists of processes. Which automation principles can be found there? What can offer bionics for even smarter control units?

Purely mechanical control systems are always physical compromises since it is necessary in order to control a process A to use some mechanical system B that is subjected to physical laws and constraints. Coupling the physical components A and B is always a compromise. An example is the differential transmission in the middle of the two front wheels of a vehicle. It must be dimensioned for minimal curve radius for various velocities. A differential transmission of a tractor therefore looks different than the one for a race car.

If we separate energy and information flows in a mechanical processes and develop separate electronic control components (which are not subjected to mechanical constraints), those compromises are only necessary in very limited occasions. Let us assume now for a moment that the mechanical transmission between the front wheels as well as the steering column will be replaced by a drive-by-wire system and the propulsion engines will be integrated directly into the wheels (which in fact is a goal of the automotive industry, remember fly-by-wire). In this case, with the drive-by-wire system (field bus) any desired differential transmission algorithm can be implemented. Such a system could also additionally consider the road conditions. Compromises regarding control are no longer necessary. The economic benefits are enormous. Not only the overall energy consumption can be optimized, also the wear of tires will be reduced. Mechanical degradation is limited to the remaining parts for suspending the wheel. Maintenance will be eased and therefore available for much lower prices. The period of warranty can be drastically enhanced, because the failure rate can be calculated based on the bathtub curve.

All these considerations reveal that production lines can be built more efficient in short times with lower prices. Large portions of energy can be saved, which was not possible without field bus technology in earlier times. Automation based on field busses became a crucial business factor. Smart control units implemented as embedded systems together with communication technology are the according pillows for this trend.

Still, the question remains how nature tackled those problems. Creatures like the amoeba can be treated with respect to their control (= information processing) like a mechanical system, since they act based on physical-chemical processes, which does not allow for separation of information and energy flow. This changes when we look for example to worms. However, what about humans? In us, special information communication channels, the nerves, have evolved, which correspond to the technique of field bus systems (fly-by-wire principle). The information transportation mechanisms are however somewhat different. Nerves do not work like bus systems. But this does not contradict the basic principle of separating energy and information flow. It has nothing to do with “smart” processing of information. In computers, we differentiate various abstract layers from the hardware as lowest layer (which can itself be divided into various layers) up to device drivers, operation system, and finally the application software (which, again, is modeled itself in various layers). The same can be done with the nervous system in living creatures. Nerves themselves are in this sense the hardware. Above this abstraction the neurologists Luria [Luria 76] found several layers for the brain. Considering [Diet 08] the parallelism cannot be ignored. Nature pursues decentralized control principles, in which peripherals and centralized oriented information systems can be differentiated. Additionally, it needs to be mentioned that for humans, as the most evolved intelligent beings, the nervous system is most developed and reached the highest known complexity. It can be speculated that the principle of the human nervous system needs to be adopted, if complying smart automation systems should be constructed. But it can also be useful to look at the control mechanisms of various animals to achieve this goal. In this way bionics gains even more importance, especially in respect to the higher layers of information processing, which is a key enabling factor for the “smartness”.

3. Field Bus Systems Today

Until about twenty years ago, it was taken for granted that electrical sensors and actuators have to be connected to the control circuitry using long wires, a method which still today is widely used with PLCs (programmable logic circuits). In the U.S. the 20-mA-Interface is widely used for implementing the necessary long connections to a central computer. It is low-cost, very robust and can be sold in large quantities. However, it has major drawbacks such as very high energy consumption, many wires which are difficult to protect and hard to maintain due to missing tools. These reasons entailed a number of efforts to find different solutions, which sooner or later found their way into industrial applications. Examples are the Centronix interface, CAMAC or the large variety of proprietary RS232 solutions, which still exist partly today. These were mainly electronic solutions, where (looking back from today) the higher abstraction layers came too short. Large efforts were made to achieve correct signal transmission with low error rates, but the designers did not focus much on protocols of higher abstraction levels. The way engineers approached the design of automation networks in those days can be compared to today’s approach of many neurologists and scientists working in the area of artificial intelligence. They in fact focus on the neurons, the hardware, very closely, but do not consider the higher functional levels. Their result is often only to find out that the knowledge about the signal paths is not enough [Solm 08] to describe observed functionality. In computer science today, nobody would have such an idea. A specialist knowing to work with text processing or spreadsheet software is not interested in transistors and their connections. We as electrical engineers at that time did however not know a better approach and searched for solutions which only were based on measurement techniques and communication theory. In parallel to this electrical engineers driven development, large research efforts were brought on the way on how to remove the nuisances of bad or no interoperation in automation by a group around General Motors in the 1980ies. The team was formed by companies like HP, IBM or DEC, who put their main focus on the higher abstraction levels of the ISO/OSI model. The result, which was named MAP (Manufacturing Automation Protocol), can be seen as the first field bus protocol in industry. For the circumstances of its time it was a real paradigm shift. However, the solution was too powerful to compete on the hard-fought market. Also, the necessary hardware was everything else than low cost. The abstract levels above the hardware were far too elaborately implemented and therefore rather complex. In retrospect, the project had to fail in practice. But this was the decisive moment were it was understood that hardware and abstract information processing have to be distinguished in automation: transport, i.e. the transmission of data is only a small part of the whole story. There is much more to it. And that are functions of the remaining 6 layers of the ISO/OSI model. Today, experts know that even these 7 levels are only a part of information transmission and processing. Now it is known that the essential elements in field bus communication are the functional profiles, which serve as a kind of 8th layer. In this layer, the network variables are defined, as well as the according parameters and additional information on how the different sensor networks and field bus systems have to be connected. It has to be considered how dissimilar sensor networks and field bus systems can be coupled. It is possible to define layers number 9 and 10 for this purpose. Following this route, the changeover between field bus and PCs is reached, which e.g. can be implemented by OPC (Object Linking and Embedding for Process Control), which itself can again be seen as an even higher abstraction level.

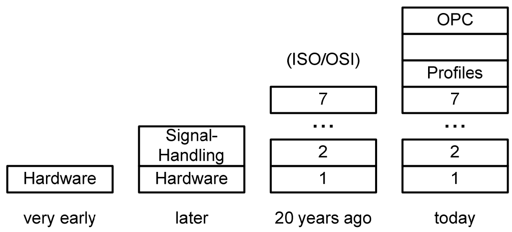

Figure 1: Development of the model of abstract layers for coupling of intelligent components

Looking at an example application where sensor data is collected and handled from lower levels to higher levels, finally revealing information about the underlying process, it becomes obvious that the actual hardware for data transmission is only a small part of the whole system that easily can be exchanged by new technologies, as it is often the case in practice. The actual know how of automation lies in the many abstraction layers above (Figure 1).

Practical sensor and actuator networks can therefore be distinguished in three large areas. The first are the already classical field bus systems like ProfiBus, Interbus, LonWorks or EIB. The second large area, which gained a foothold in the last 5 years, consists of the wireless sensor and actuator networks. The third area we see in pure sensor networks, where wired smart sensors in high numbers are integrated e.g. in walls. However, these have no economic relevance yet, a fact that surely will be changed by micro and nano technology in coming years. This third area is not further considered in this paper.

Firstly, those field bus systems shall be considered which were able to economically establish themselves in technical application fields. While fifteen years ago it was possible for one person to be an expert in many field bus types, no matter in which area it was standardized, this is not at all possible today anymore. The number of varieties has exploded in the meantime, and differences become larger and larger according to the application area due to different requirements. Only a few examples shall be given here.

About fifteen years ago, ProfiBus was developed for industry with large efforts. Although it only spanned over 3 instead of 7 layers compared to the American MAP standard (the designers had learned from the problems of MAP), it was not able to fulfill the practical needs of response times. It was a master-master system, where each master was assigned a number of slaves. A slave could be slave of more than one master at a time. The market was essentially asking for simple master-slave systems (Figure 2), relatively simple entities, in which the cycle time could be kept low very easily because the number of participants on the bus was low and restricted. Soon, companies identified this market potential and stopped the master-master development in favor of the simple master-slave system. This lead to the fast development of a large variety of tools that supported the development and integration of components for ProfiBus. Also, it was soon understood that the opinion that using Ethernet in industry automation makes no sense, which was proclaimed by academia at that time, was not accepted. On the contrary, more and more companies changed to coupling ProfiBus masters using Ethernet, although this approach was frowned upon and smiled at on many scientific conferences. Today, this approach is standardized and the means of choice to connect field busses with PCs and the Internet.

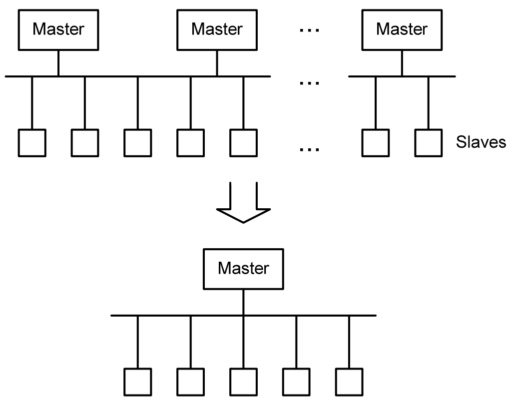

Figure 2: top: Idea, bottom: What the market required

In the meantime, ProfiBus is not only used in “normal” industrial application areas, but special versions exist also for highly explosive surroundings. It is probably the most popular industry field bus in Europe and finds a lot of reception also in the U.S., China and many other countries.

In parallel to ProfiBus another master-slave system, the Interbus was developed, which is the only field bus in ring topology. This has enormous advantages considering the two lower levels of the ISO/OSI model. No addressing is necessary. Data frames are smaller, because the entire bus works like a large shift register. Therefore, looking at data rates this system is relatively seen the fastest. Further, data can be written and read from a slave in one cycle. The operation of the bus is easily understandable, which in the beginning was a strong argument for a fast spreading of Interbus. The key problem of a failure in one component leading to a complete system breakdown, which was identified by many competitors of Interbus, was on one hand mitigated by additional circuitry, and on the other every practitioner knows that in practice this merely plays no role. Field buses in industry are mainly used in production systems. If one unit fails, the whole facility has to halt, independent of the type of bus system used.

The designers of Interbus had to learn one lessen though. The growing number of new requirements and needs regarding simple integration in applications, low maintenance costs and interconnection to other bus systems or even the internet require a higher and higher complexity of the software on the higher abstraction levels. Keeping with the lower two ISO/OSI levels like in the beginning of Interbus was no longer a choice. Management functions such as automatic error detection (error management) are an essential feature of today’s field bus systems.

Current industry field buses still mostly feature only levels 1, 2 and 7 of the ISO/OSI model, as well as higher levels. The reason for that is simple. The number of nodes on the bus should be kept low in order to maintain a high level of reliability. Further, the response time should not get too long. When a high number of nodes is required, just multiple Ethernet-linked bus systems are used. In this case however routing is not yet an issue. Another aspect, which in fact is an issue, is security. Today a common assumption is that by using firewalls the security issue is solved. Up to now, the danger of system manipulation by the own staff members is only seen in the banking sector. All this makes implementations of the functionality in layers 3 to 6 of the ISO/OSI-Model unnecessary.

Nevertheless, in building automation the circumstances are very different. Here, many nodes in close proximity have to be arranged in different groups at the same time. Just imagine the bus nodes that have to cooperate between different rooms, but in case of fire they have to behave in a completely different way. Master-slave systems are not allowed here for safety reasons. Integration and maintenance have much higher requirements than in an industrial surrounding. Components of building automation networks are usually installed by unskilled workers during the construction phase of a building. For maintenance, no skilled personnel stand by at the operation site but have to be requested when a network malfunction occurs. In the case of fire, certain functions also have to be guaranteed. And last but not least, neighbors should not be able to manipulate the system. This is the reason why in LonWorks for instance all 7 levels of the ISO/OSI model are implemented. And this is also the reason why soon a number of different profiles (the quasi-level 8) were specified for different LonWorks applications and still are being specified. Therefore it is not astonishing that LonWorks is very complex on one side, but flexibly applicable to different applications, from buildings to the factory floor. A second bus system, which is widely used in Europe, is EIB (European Installation Bus). It has specifically been designed for buildings. A number of technical arguments in favor or against LonWorks and EIB respectively have been exchanged, but all these do not get to the point why LonWorks is usually found in large and EIB in smaller buildings. Both systems offer a large suite of functionalities. The actual reason can be found in the way how bus systems are evaluated and certified.

LonWorks has not only been designed for buildings; today it can be found in the lighting system for aircrafts as well as in large cold storage rooms, fire alarm systems etc. Flexible application is its hallmark. Engineers should be able to apply it everywhere and network electrical components with it. This however implies that the designer has a considerable amount of know how when he or she is able to apply LonWorks to very different applications. This approach is not yet economic for small houses. A normal craftsman does not have this specific knowledge. Only large companies are able employ experienced LonWorks staff; and these specialists are only found on the sites of large projects.

Very different circumstances can be found with EIB. EIB companies certify their products and design them in such a simple way that every crafts enterprise can use and work with them. This however restricts flexibility. Only certified components can be connected, and usually it is not possible (or very complicated) to connect heating system A, lighting system B and alarm system C. Of course for both EIB and LonWorks, Internet gateways exist. But Internet connections always imply a certain restriction in functionality and can cause security breaches.

Another application area for automation bus systems is the automotive and rail sector. The first bus system that has been standardized in this area is CAN (Conrol Area Network). It was originally designed for truck trailers. Today, a large set of different CAN protocols for very different applications exist. CAN stands for high fault tolerance and short reply times. It is a bus that does not work with addresses. Instead, every node sends its identifier with its message. Each bus member checks individually whether the information from a specific node is interesting for it or not. So, what philosophy lies behind this approach? Two ideas form the basis of CAN that makes it stand out from other automation busses. First, everyone should be able to easily and safely retrofit a node in his or her own car without setting up node addresses or anything like that. Second, a strong emphasis lies on fault tolerance. The no-addresses issue could be solved by ring topology, but that is not a good choice for safety reasons. Another approach is using identifiers instead of addresses. During production of bus components the identifier has to be determined in such a way that in one network all identifiers are different. CAN uses this approach, and since the decision for identifiers is a basic principle in CAN, the identifier is also the first part of a CAN message. An identifier hierarchy allows for prioritizing messages. The identifier “000…0” has the highest priority. The system is zero dominant, which means that if two messages are sent simultaneously by two nodes, the one with the earlier “0” wins. Since the bus medium prioritizes zeros over ones, the message is not destroyed in such a case. The node that detects another node overruling its identifier sequence on the bus simply stops its transmission. It tries again after the higher-priority node has finished the data transfer. Using this principle, the more important data streams, e.g. those of the brakes, prevail over the lower important ones. This works perfectly in cars and trucks. CAN circuits and components soon became very inexpensive due to the large volumes in the automotive industry. This lead other industry sectors to start using CAN. Interestingly, it is very successful in spinnery, a fact that is probably related to the short response time. There is however one problem: in a car, there are relatively few bus nodes on one CAN bus. So, it is easy to distribute the priorities. In spinnery however, there are many nodes and many of them have in practice the same priority. So, some nodes would actually send all the time, and some would be forced to keep quiet. How has this issue now been solved? That was relatively easy. CAN stretches, like the before mentioned industry busses, over layers 1, 2 and 7. In layer 7 it is recorded how many frames each node was able to send. If problems are detected, priorities are dynamically re-arranged.

CAN can be found in many applications today, in cars, fuel dispensers or even in operating theatre. Therefore, a number of profiles have been developed and standards formulated. Many development tools have been developed in the meanwhile, many of them at universities. The row of field busses like ProfiBus, Interbus, LonWorks, EIB or CAN could be further continued. However, these examples should be sufficient to serve as basis to deduce the open problems in chapter 4.

Briefly, the second large class of sensor and actuator networks, the wireless sensor and actuator networks shall be covered. They play a growing role in building automation as it is possible to design the systems in such a way that also unskilled people are able to set up a functional network. This reduces the costs for maintenance, which in turn allows new marketing strategies for such network components. It should however be noted that here usually low numbers of nodes are involved. Networks with about 20 nodes are manageable, and not too strong requirements are made for the response times. Up to now however no clear market leader has been identified in this area, a fact that shall be reflected upon in the next chapter.

4. Open Problems – Challenges in Research

The chapter should highlight that different applications for particular field bus systems require different profiles. All of them have distinct properties and justification for particular applications. They cannot be harmonized. They are discriminative in a way that even demands different functionalities in the lower layers of the ISO/OSI model. However, the last claim needs to be restraint since profiles are located above layer 7, which requires different implementations of the upper layers in a top-down design. This however is not true for the lower ones, if specific performance of the lower layers can be guaranteed. And this is exactly today’s discussion: Can hardware be found that is economically applicable in many different bus systems allowing for different implementations of the higher layers? One possible answer could be Ethernet, which is under constant development and, through its deployment in the PC world, economically priced. Can these hardware components be used in field bus technology in order to build up different implementations of the higher layers and most notably profiles? Everything points at “yes”, but in the history of field bus technology many technically reasonable solutions have been presented, which were then no longer followed due to economical reasons. The conclusion is still open, although the trend goes to Ethernet (and its hardware) to be utilized on a broad basis for the lower layers in field bus systems.

The last point also refers to wireless networks. The developments in this area are also still in progress, especially focusing on energy efficiency while preserving communication abilities. The duration of such nodes reached already several years, but shall be enhanced up to five years [Mahl 07] in order to allow for cost efficient application like transportation [Mada 07].

In addition to the requirements of cheap hardware and enhanced performance, four principles for further research and development emerged in field bus technology:

(1) Reduction of installation and maintenance costs

(2) Safety

(3) Security

(4) Interpretation of the enormous amounts of data

The problem of reducing installation and maintenance costs is of great significance in building automation, since conditions there are most dramatic. The physical placement of nodes is usually performed by very cheap, semiskilled workers and the number of nodes is in a dimension of more than 2.000 up to 60.000. The problem of integrating and maintaining such a number of components in an economic way on a PC is left to the integrator. This is not just a realization question to an engineer, but a scientific challenge. This is because modern technology did not find a suitable solution which supports the integrator with this problem on the construction site satisfactory.

Safety is a topic which was tackled in automation only rarely and sometimes even in an amateurish way. An example give the first suggestions for safety relevant electronic circuits when micro processors came into place: it was demanded to build up the circuits redundant in a way that one side is allowed to contain a micro processor, but the other needs to have a discrete built circuit. Times changed this fundamentally, but still safety is often avoided since it is seen to imply higher costs, sometimes more than double costs. However, experts know this is absurd, since safety is not about doubling hardware or software, but functionality, which results in additional costs of the product often in a range of 5 to 10%. Second, in case of electronic components, the failure rate has to be seen different to mechanical parts, since electronic components have a constant failure rate over their live time, already starting from the beginning. This means the percentage of failures is the same after many years as in the beginning. So, in order to reduce failure rate, one has to invest in redundancy.

The case with security is even worse. In automation this topic is widely untouched; some proponents say a firewall at the system border is sufficient. It is certainly not, e.g. in many critical infrastructures attacks come from inside, e.g. from active or fired employees. For mechanical systems this was hardly a problem, but in case of electronic systems it is no problem to connect a small device to an internal field bus, which cannot be detected easily, but controlled in order to terrorize a company. However, in many areas like industry automation or automation in transportation this topic is kept behind the scenes these times. Only in building automation some considerations have been further investigated: what would happen if some bad guy enters a building and attaches a wireless box to the field bus system which controls the HVAC system, illumination, etc. He could annoy the working or living people in the building a lot. But, as mentioned before, it is of no concern today, research results are present in small number but it is questionable if they will find integration in practice or if they will be further investigated. Maybe other solutions will be found which are economically more reasonable.

After this, the last and maybe most interesting topic is reached: how can the enormous amounts of data in a building, e.g. an airport or a shopping center be usefully interpreted without the need for massive support of humans? This question already implies that a system is sought that can substitute the capabilities of humans in this respect. But what respect is it when referring to building automation? The applications are HVAC systems, illumination, security systems, and – in the vision of many researchers – context aware systems for many applications to increase safety, security, comfort, energy efficiency, etc. The requirements on a meta level are the same in all applications: perceiving information and interpreting this information with respect to the context of the system. But what is the context? The context is a theoretical construct by humans. Therefore, for a machine in order to be able to derive the context, it is necessary to give it the same perceptional function as a human. This problem can also be only tackled with using bionic's principle to study nature's solutions. In the case of human's functional capabilities there are scientific disciplines concerned with, namely the humanities. For engineers, humanities have the touch of subjective, maybe imprecise sciences. The latter is simply an illegitimate prejudice by people not from the field, whereas the first impression is a consequence of the matter with which many fields in humanities are concerned: the subjective self [Solm 08]. From a technological side, some strides towards understanding and preparing for implementation of humanities' concepts have been made. A key result, which was already presented above, is that human perception is organized in many layers. Starting from sensors there are dedicated brain areas for mono-modal interpretation of sensory input, followed by multi-modal processing in order to generate a holistic mental impression of perception. In further layers (which cannot be assigned to brain areas anymore) perception is evaluated with respect to the selfish use of perceived objects, objects are associated with other objects or actions, and objects and actions are ordered into timely sequences (Figure 3). On this level, expected outcome of actions can be anticipated which allows for reasoning about possible action tendencies. Humans are supported in generating these layers through their parents, their other caregivers and, last but not least, by their own body which allows for trying out all kind of actions and lets them subjectively experience results of actions – or results of more or less sophisticated action plans. For technical systems that reach "smartness" on this level, it cannot be afforded to let them learn in a way children do. A technical system needs to possess a combination of pre-defined "mental content" in the presented structure [Diet 08] and learning capabilities [Bruck 07] for its particular application area. Research in this direction is still in its infancy; however, it will change the impact of automation in our daily life widely.

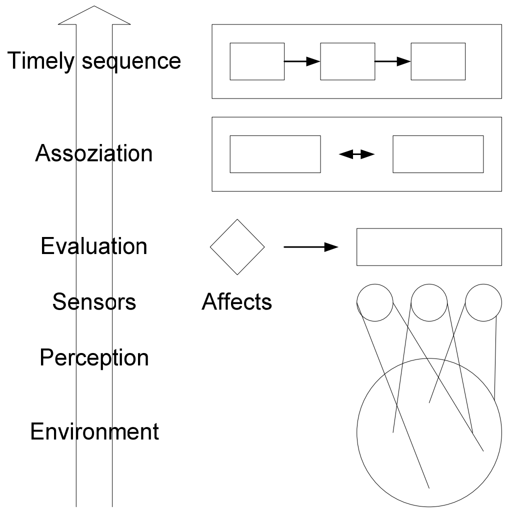

Figure 3: Hierarchy of perception, shown are the lower layers up to timely sequences

5. A new area of automation: energy distribution

Automation systems have evolved from small, bounded automation applications, such as production on the factory floor or communication between truck and trailer to larger and larger interconnected systems, such as large commercial buildings. In recent years, a completely new application area for automation systems has emerged: management of energy flows in electric power grids. Traditionally, the power grids throughout the world were designed as strict hierarchical systems with a few large power plants at the top and a tree-like transmission and distribution grid, which had the only task to transport the energy from the central generation sites to the consumers. Given severe under-capacity problems, the necessity to reduce CO_2 emissions and rising energy prices, this traditional structure is considered as out-dated by most experts in the field. The development goes in the direction of "smart grids", which get more and more economically viable (Figure 4).

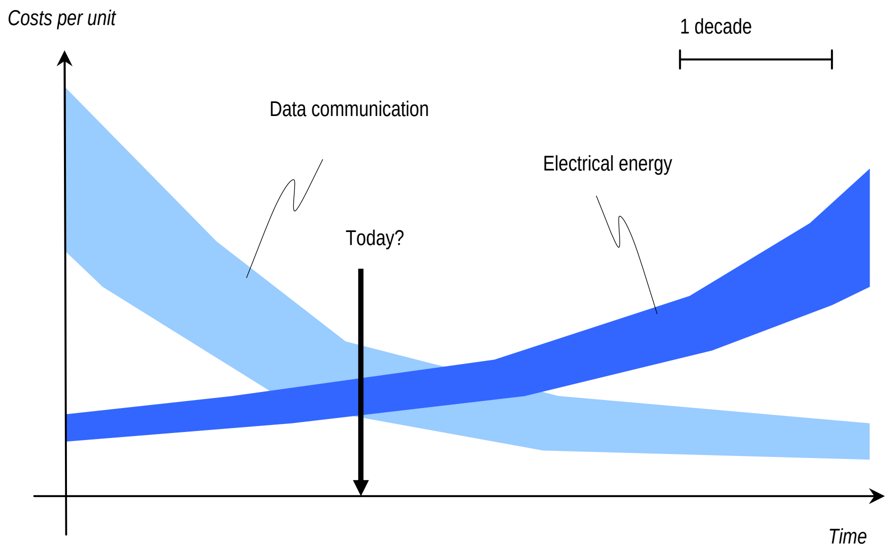

Figure 4: Estimated development of costs for communication and energy

Strong drivers are working towards more information and communication technology in the power grids. On the electrical engineering side, efficient components and generation from renewable energy resources are the most important ones. On the IT side, the introduction of an automation infrastructure, so to say a "field bus for energy grids", is of high importance. Of course, information technology is not an end in itself in this context, but a means for more efficient, sustainable and cost-effective provision of electrical energy and ancillary (i.e. supporting) services. The vision of the future power grid with an increased level in utilization of information technology is that of a "smart grid". The term "smart grid" is currently promoted by the European technology platform of the same name, which is formed by many stake-holders in the field. Similar activities are ongoing in the U.S.

Control measures on the demand side, i.e. remote switching of customer's appliances, play a role in most "smart grid" visions. They are seen as a supporting tool to match supply and demand under the condition of supply from fluctuating renewable energy resources, whose generation patterns do not match the demand curves. It however also makes sense to adjust the generation to the supply by featuring generation technologies where this is possible, e.g. for residential combined heat and power (CHP) systems. Comprehensive control of distributed energy resources, either generators or loads, will be necessary. For this, information exchange between the grid participants is needed. The future smart grid will be characterized by an intensified flow of information compared to the state-of-the-art power grid, where the dominating flow of energy is only accompanied by sporadic (monthly or yearly) meter readings.

The implementation of upcoming requirements will involve innovative technical solutions that significantly differ from standard measures for grid update. Electricity grid investments are done for long-term time horizons. Thus, new components should to be designed in such a way that future technical demands, which are not predictable today, can be fulfilled. A brute force approach for this, which has been widely used in the past, is over-dimensioning. This however is economically unfeasible today. The key for this upcoming design decision is the intelligent grid. Autonomously acting components stay operative even in grid failure situations; their context-awareness enables them to adjust to different situations. Due to the ability to learn from collected data, the grid will be able to solve problems locally if possible and even handle new, previously unknown situations. Large technical challenges are implied in this vision. The communication systems have to be highly reliable (real time control is operated on their basis), have to cope with millions of nodes (e.g. remote meter reading of every customer), and span over huge geographic areas. Depending on the application, they have to provide real time capabilities and guaranteed response times of a few seconds over dozens of kilometers. Very inhomogeneous existing infrastructures have to be coupled for this reason in order to gain a continuous layer 1 and 2 connection. But the real challenge will be the management of such a huge network. The lessons learned with the old field bus systems can help here, however the system will be so big that many new solutions will have to be found. At last, the electric power grid is the largest technical structure humankind has built so far.

6. Conclusion

Communication technology for automation has evolved from systems that solved the mere issue of bus communication over a single wire to technologically complex solutions that implement all levels of the ISO/OSI communication model and even more levels above. The academic questions to be solved in this context have changed from classical electrical engineering issues such as data transmission over a two-wire-system to problems of network setup, configuration and maintenance, which are more related to data modeling in computer science. The demands and requirements for automation systems are steadily changing. In the context of smart future automation networks, it is very promising for academia and industry in Pakistan to collaborate in this field and jointly develop innovative products that stand out even on a world market scale.

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