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D3.1 Robotics and Sensor Integration

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Executive summary

This deliverable **D3.1 State of play in Robotics and Sensor Integration** is the result of task **T3.1** (Robotics and sensor integration) which aims to provide information on existing devices, services, standards, systems and applications currently adopted within the application domain relevant to the BEMO-COFRA project.

BEMO-COFRA strives for the realization of a large-scale distributed monitoring and control framework that eases the supervision and the optimization of physical processes. In this scenario, the most common manufacturing processes, referring to an actual manufacturing plant provided by COMAU, are covered in this document.

The purpose of this survey is to lay down the basis for the definition of the legacy section of the architecture (i. e., the section of system that includes devices, services, systems, etc. used in todays manufacturing plants). The idea is to allow the project´s partners to get to know the type of technologies they will interact with.

The description of newly developed communications systems and protocols used in the modern industry is also part of this deliverable. This is extremely important to establish the type of system(s) that will be used in the BEMO-COFRA project.

Additionally, this deliverable describes the main types of sensors and actuators used in the factory floor and gives their classification, based on the type of information they deal with. As such, this review presents the main standards, platforms and protocols used in Wireless Sensor Networks, which are then compared.

BEMO-COFRA seeks the development of an innovative distributed framework which allows the monitoring and control of large-scale complex sub-systems. As a result, the research on Robotic and Sensor Integration state of play becomes a major concern. Valuable information includes the type of technology they are hosted in a manufactyring plant and the way this could be changed.

2. Introduction

2.1 Overview of the BEMO-COFRA Project

The new order in modern industry is the demand for flexibility in production activities that must adapt to a continuously changing world. As a consequence, the manufacturing industries will have to be more flexible and better adapting to shifting consumption patterns. The key issue to survive the worldwide competition will be the capacity of launching new and innovative products on the market.

This cannot be achieved without a solution that allows addressing the main weaknesses of present manufacturing systems, which highly affect overall efficiency and reduce competitiveness:

- Process integration: limited integration among the processes involved in the engineering and management of the plants.
- Flexibility: difficulties to provide an adequate flexibility of the production plant therefore reducing the capacity of complying with continuously varying product mix and volumes.
- Scalability and reconfigurability: production systems are not designed to be easily reconfigurable.
- Manufacturing efficiency: the monitoring of productivity is affected by low diagnostics capacity; there are usually neither efficient instruments to detect engineering errors and to prevent installation problems, nor efficient data logging to enable preventive maintenance.

The future factories will have to be necessarily characterized by production systems with the capacity to ensure efficiency, performances and robustness, with the constraint of high production variability. To reach such objectives, the engineering of networked monitoring and control solution represents a major concern.

BEMO-COFRA aims at providing generic solutions to these challenges faced in the manufacturing industry by addressing the main weaknesses of present manufacturing systems, which highly affect overall efficiency and reduce competitiveness.

BEMO-COFRA features a Service oriented Architecture (SoA) and a middleware able to expose smart objects, legacy devices and sub-systems' capabilities by means of web services thus supporting syntactic and semantic interoperability among different technologies coexisting in the overall monitoring and control framework. Wireless Sensor and Actuator Network (WSAN) devices, legacy sub-systems and devices will thus be able to interact and cooperate, orchestrated by a manager in charge of enforcing a distributed logic with the overall monitoring and control network.

2.2 Purpose and context of this deliverable

Deliverable D3.1 Robotics and Sensor Integration State of the Art document describes the current status of automotive manufacturing robots, its communication systems and other peripheral devices that can be found on the factory floor. Additionally it ialso presents the role of sensoring and controlling systems.

This document focuses on the welding process, one of the most important parts of the automotive industry, and where some problems such as singal loss may occur.

The document also presents a study of the most modern technologies from Wireless Sensor and Actuator Networks. This is a major concern for BEMO-COFRA´s success as a great deal of the solution´s flexibility of depends on the type of network chosen.

Finally, the main features in the sensor and robotics integration are descrined; Two main types of sensors are presented. This offers a general idea on what can be changed in the future by Bemo-Cofra.

2.3 Scope

The main ideas introduced in this document may be summarized in the list below:

- Identification of the most common manufacturing robots and processes used in automotive industries;
- Research of other communicating devices used by most industries while focusing in Comau´s case;
- Communication systems and protocols used in modern plant industries;
- Most common platforms, protocols and standards used in Wireless Sensor Networks;
- Description of the main types of sensors and actuators used in the automotive industry.

3. Robotics

3.1 Robotics Characterization in the Automotive Field

According to the ISO 8373, an industrial robot is an automatically controlled, reprogrammable, multipurpose manipulator. It is programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications (IFR, 2012).

A typical robot has a movable physical structure, a motor of some sort, a sensor system, a power supply and a computer "brain" that controls all of these elements. Essentially, robots are man-made versions of animal life – they are machines that replicate human and animal behavior. Robots are distinct from other movable machines, such as cars, because of their computer element. Also, they are distinct from ordinary computers in their physical nature – normal computers don't have a physical body attached to them (HARRIS, 2012).

Modern industrial robots are true marvels of engineering. A robot the size of a person can easily carry a load over one hundred pounds and move it very quickly with a repeatability of +/-0.006 inches (HOOPER, 2012). Furthermore, these robots can do that activity 24 hours a day for years on end with no failures. The benefits of robots to industry include improved management control and productivity and consistently high quality products. This performance is achieved because they can work tirelessly night and day on an assembly line without any loss in performance.

In the context of general robotics, most types of industrial robots would fall into the category of robot arms. Modern industrial arms have increased in capability and performance through controller and language development, improved mechanisms, sensing, and drive systems. Since the early to mid 80's the robot industry has grown very fast primarily due to large investments by the automotive industry (RRG, 2012).

Typical applications of industrial robots include welding, painting, ironing, assembly, handling, palletizing, product inspection, testing, gluing or sealing, and press. All accomplished with high endurance, speed, and precision (RRG, 2012). Most of these applications are shown in the next sections where it will be detailed how each industrial robot works.

3.2 Devices Classification in a Framing Station

The introduction of robot arms performing many tasks in the automotive line has changed the concept of production itself. It is now hard to separate automation from large-scale production. However, devices of all kinds and purposes, pwrhaps except the robots, are now integrated in a network, providing many types of services and helping sub-systems to control a number of processes. Furthermore, the process of robotisation is necessarily attached to devices that may offer support to the machine, such as communicating I/O failures, over temperatures or phase loss. In general, this kind of equipment plays an important role in productivity and performance, in this section, few devices used in the client´s factory floor will be presented and described, however, they can also be found in most modern automotive industries.

3.2.1 Armor Start

A general 280/281 ArmorStart is an integrated application, pre-engineered, accounting and for the full voltage reversal. The ArmorStart offers IP67/NEMA Type 4 enclosure design that is suitable for water wash. The quick couples for I/O, communications, and motor connection reduces wiring time and eliminates wiring errors. The ArmorStart offers a standard, four DC inputs and two outputs for the use with sensors and actuators, respectively, to monitor and control the application process. The ArmorStart's LED status indicator and built-in diagnostics allows maintenance and troubleshooting (ROCKWELL, 2006).

- Technical Features:
  - On-Machine ™ from the solution Maximum reverse voltage;
  - Horsepower range from 0.5 to 10 Hp (0.37 to 7.5 kW);
  - IP67/NEMA resistant Type 4 enclosure degree of protection;
  - Modular design Plug and Play;
  - Quick-disconnect connectors for communication, I / O, motor and three-phase input power;
  - Bushing card input: Input AmorConnect ® conduit or average power;
  - Four inputs and two outputs (expandable with ArmorPoint ®);
  - LED status indicator;
  - DeviceNet ™ communications;
  - DeviceLogix ™ technology components;
  - Peer-to-peer (ZIP).

Figure 1: Armor Start (www.ladder.com.br)

The features of the Zone Control ArmorStart are ideal for horse-power (0.5 to 10 Hp) transport motor. The ArmorStart has built-in DeviceNet Communications, DeviceLogix technology, and adds the parameters of the zone interlock (zip) allowing an ArmorStart to process data coming from up to four other DeviceNet nodes without going through the network scanner.

- General Description (ROCKWELL, 2012):
  - Inputs: The entries are simple key (two inputs per connector), which are from DeviceNet power (24VDC) with LED status indicator;
  - Outputs: Two processors with dual output connectors are provided as a standard. The outputs are obtained from the control voltage, which is 24 VDC, with LED indication;
  - Fault Diagnosis: The fault diagnostic capabilities built into the distributed motor controller ArmorStart, helps identify a problem and therefore the solution becomes easier and faster.
  - Fault diagnostic examples: Short Circuit, Overload, Phase loss, Loss of control voltage, Detection of the control voltage fuse, I/O Failure, Detection of power output fuse, Over temperature, Phase Imbalance, DeviceNet power loss, EEPROM failure and Hardware Failures.

Power

Safety ArmorStart® Distributed Motor Controllers

Bulletin 280D/281D

Sensor Media ⌘

Description		ArmorStart I/O Connection	Pin Count	Connector	Cat. No.
	DC Micro Patchcord	Input	5-pin	Straight Female Straight Male	889D-F4ACDM-►
				Straight Female Right Angle Male	889D-F4ACDE-►
	DC Micro V-Cable	Input	5-pin	Straight Female	879D-F4ACDM-►
				Right Angle Male	879D-R4ACM-►
	AC Micro Patchcord	Output	3-pin	Straight Female Straight Male	889R-F3AERM-►
				Straight Female Right Angle Male	889R-F3AERE-►

Figure 2: Input/output t Connectors (http://www.ab.com)

3.2.2 Armor Block

Figure 3: Armor Block (http://www.ab.com)

The ArmorBlock ® Guard I/O ™ provides all the advantages of distributed I/O to traditional security systems, but has IP64, IP65 or IP67 packages (as identified on the product label) that can be mounted directly on your machine. OE Safety I/O On-Machine reduces connection time and cost of starting controllers for security applications, eliminating the electrical boxes and simplifying cable installation. The family ArmorBlock provides blocks I/O that can be mounted directly on equipments near sensors or actuators. The connection of I/O for sensors and actuators becomes easy, mainly because has quick-disconnect pre-wired cables (ALLEN-BRADLEY, 2012).

The Guard I/O can be used with any safety controller that communicates on DeviceNet using CIP Safety for the control and monitoring of safety circuits. Guard I/O detects circuit failures at every point of I/O and provides detailed diagnostics directly to the controller. CIP Safety, can easily integrate safety and standard control systems using standard messages in the same cable (ALLEN-BRADLEY, 2012).

The ArmorBlock Guard I/O module 1732DS consists of I/O Digital 24V DC DeviceNet networks.

- General Description:
    - I/O point level diagnostics and LEDs: quickly identify a problem and reduces machine downtime;
    - I/O connectors for dual channel M12 “quick disconnect” allows a single cable connected between the ArmorBlock Guard I/O and a safety device Dual Channel;
    - Supports both standard and safety control;
    - Versatility: Can connect to both standard and safety rated sensors;
    - Easy Configuration: via RSLogix™ 5000 or RSNetWorx™ for DeviceNet;
    - Supports devices in single or dual channel inputs and outputs;
    - Profile Setup EDS (RSNetWorx for DeviceNet) or RSLogix 5000;

- Additional outputs standard solid state can be configured as pulse test sources, outputs for standard PLC control, 24 Vdc source, or control and monitoring of muting lamp;
- Added capability for standard control: Use test outputs for added diagnostics, panel lamps, standard actuators, etc. and connect standard proximity switches, sensors and push buttons to unused safety inputs;
- Simplified Installation: a single M12 cable connection to dual-channel devices on inputs and outputs: using quick disconnects.

In summary, the ArmorBlock Guard has an important role in the general architecture of an automotive line, mainly because it controls and monitors safety devices. Additionally, its robust construction enables reliability in harsh environments, which is that of an industrial case. ArmorBlockGuard I/O is especially suited for robotic, point-of-operation, guard-monitoring, and all remote control applications.

3.2.3 Rockwell GuardLogix

This section will introduce basic design differences between a standard PLC and a Safety PLC (Guardlogix). A PLC has one microprocessor which executes the program, a Flash area which stores the program, RAM for making calculations, ports for communications and I/O to detect and control the machine. In contrast, a safety PLC has redundant microprocessors, Flash and RAM that are continuously monitored by a "watchdog" circuit and a synchronous detection circuit. These are the main differences of both architectures (ALLEN-BRADLEY, 2011). Besides standard PLC inputs provide no internal means for testing the functionality of the input circuitry.

By contrast, Safety PLCs have an internal "output" circuit associated with each input for the purpose of "exercising" the input circuitry. Inputs are driven both high and low for very short cycles during runtime to verify their functionality. When it comes to output context, the standard PLC has one output switching device on the other hand a safety PLC digital output logic circuit contains a test point after each of two safety switches. Each of the two safety switches is controlled by a unique microprocessor (ALLEN-BRADLEY, 2011).

If a failure is detected at either of the two safety switches due to switch or microprocessor failure, the operating system of a safety PLC will automatically acknowledge system failure.

Figure 4: GuardLogix Safety PLCs (http://www.ab.com)

Some benefits of safety PLCs are (ALLEN-BRADLEY, 2011):

- Flexibility: Safety PLCs are programmable systems;

- Productivity: The flexible programming of Safety PLCs permits control engineers to create maintenance modes of operation with "limited shutdown" capability. This means that the MTTR (Mean Time to Repair) is improved by reducing time to restart systems in the troubleshooting and improving productivity;
- Wiring Simplification: Safety input and output devices are wired directly to Safety I/O modules. Safety PLC systems can reduce the amount of wiring and commissioning effort required to install and start up production equipment;
- Diagnostics: Safety PLC systems perform internal and external diagnostics checks many times per second;
- Integration: Safety PLCs enable machine makers to think of safety as part of the normal control of the machine, not just a piece that is added on at the end. Some safety systems are so integrated, they can perform all of the standard machine control (sequential, motion, …) plus safety control, all from one unit;
- Reliability: Safety PLC systems are designed specifically for very high MTBF (Mean Time Between Failure) and very low PFD (Probability of Failure on Demand);
- Expandability: Additional I/O modules can be added to the system and application code can be easily modified and expanded by control engineers.

3.2.4 Point I/O Rockwell

In-Cabinet (IP20) distributed I/O can be placed throughout an application and requires an enclosure. In-Cabinet Modular I/O products allow the selection of the exact blend of I/O interfaces and communication adapters to fit current needs. In addition to a wide range of analog, digital, and specialty modules, it provides in-cabinet I/O options for extreme environments, I/O for safety systems, and intrinsic safety (IS) I/O that can be distributed throughout hazardous areas (ROCKWELL&AB, 2012).

Bulletin 1734 POINT I/O™ is ideal for applications requiring flexibility and low cost of ownership. Granularity of one to eight points lets the engineer acquire only the I/O needed. The compact design makes installation easier in limited panel space. The family includes POINT Guard I/O™ safety-rated I/O modules that can be used side-by-side in a standard POINT I/O system. Network connectivity includes ControlNet™, DeviceNet™, EtherNet/IP™, and other open networks. Some modules feature DeviceLogix™ Smart Component Technology, integrating low-cost logic solving capability in your I/O for faster sense-to-actuation times (ROCKWELL&AB, 2012).

- Technical features:
  - Modular design independently selects the I/O, termination style and network interface;
  - Removable wiring system saves time and money during installation and troubleshooting;
  - Comprehensive diagnostics and configurable features makes POINT I/O™ easy to apply;
  - Auto Device Replacement (ADR) lets OEMs add features and I/O with minimal effort;
  - Add-On-Profiles in RSLogix 5000 programming software provide smooth integration into Integrated Architecture systems.

3.2.5 RsView 32

Monitoring and controlling automation machines and processes demands versatility and the scalability to connect to a host of open technologies. RSView® 32™ is an integrated Human Machine Interface for monitoring and controlling automation machines and processes. Its versatility shows with seamless integration to other Rockwell Software and Microsoft products as well as third-party applications (ROCKWELL, 2011).

Core functionality provides the versatility to accommodate a range of integration needs. RSView32 is an open system that allows plant floor data to be shared with other manufacturing systems throughout the enterprise. This provides a link to real-time manufacturing information for the enterprise. Designed for Microsoft® Windows® environments, RSView32 interacts easily with the Rockwell Software integrated product line, Microsoft products, and other third-party offerings.

Figure 5: RsView 32 (http://www.rockwellautomation.com/rockwellsoftware)

- RsView Features (KEPWARE, 2012):
  - Interaction with other Rockwell Software products:

  It is possible to build a customized suite, only for those products that best serve the needs of specific applications. For instance, select RSLogix ladder tags right from within RSView32. When working in FactoryTalk Transaction Manager, go online with an RSView32 project and select just the tags you need.

  - Sharing data with Microsoft products:

  RSView32 tag configuration, alarm configuration, and logged data are all ODBC compliant. Log data directly to an ODBC data source such as Microsoft SQL Server, Oracle, or SyBase, and the data in a trend can be graphically viewed.

  - Compatibility with Rockwell Automation products:

  RSView32 and RSLinx offer a combination of tools to capture, control, and convey plant floor data. This combination provides performance with the Allen-Bradley ControlLogix PLC family of products, which are very common at Comau.

  - OPC:

  Using OLE for Process Control (OPC), RSView32 can be connected to any communication device for which an OPC-compliant server or driver is available. RSView32 can function as both a native OPC client and OPC server, and RSView32 supports browsing for OPC server addresses.

- Additional Products related to RsView32:
  - RSView32 Active Display System™ is a true client/server application that adds on to and extends the reach of your RSView32 HMI software. With RSView32 Active Display System, it is possible to control RSView32 projects from remote locations.
  - RSView®32™ WebServer allows anyone with a valid RSView32 user account to access snapshot views of graphic displays, tags, and alarms through any standard web browser.

3.2.6 CompactLogix

It is made for mid-range applications; this small controller offers the features and flexibility without the overhead of larger systems. It provides cost-effective integration of a machine or safety application into a plant-wide control system because it integrates safety, motion, discrete and drive capabilities in a single controller. Typical applications include complex machine control, batch processing and building automation. Some features are listed below:

- Supported Network: DeviceNet, ControlNet, Ethernet/IP
- Sends and receives messages to and from other devices (this includes access to messages to the controller via the RSLogix 5000)
- May be configured as a master or a slave in serial communication network. Uses the serial port for the information and remote controllers.
- Advanced system connectivity to EtherNet/IP™ networks for CompactLogix™ 5370 platforms
- Full support for standard EtherNet/IP networks and limited support for ControlNet™ and DeviceNet™ networks across all CompactLogix platforms

Figure 6: CompactLogix

3.2.7 General Architecture at Comau Brazil

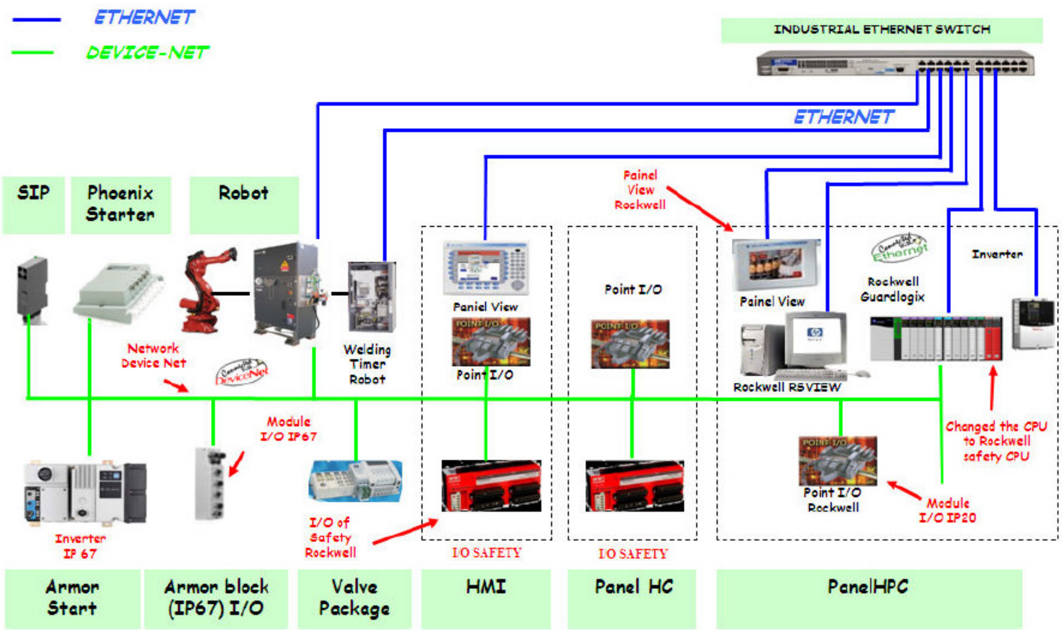

Figure 7: General Architecture (Deliverable 2.1 State of play in production monitoring and control systems_v1.0)

The figure above shows the network architecture at COMAU Brazil with some devices already seen in the last sections. There is a secured network named Plant Automation Network (PA) which connects the plant floor equipments. This network is protected by a firewall preventing information about production can pass through the entire network. Extending the plant floor equipment as well as throughout the PA Ethernet network there is a Process Control Network where communications is primarily local within this network but includes communication back to applications servers typically located in the local data center on the PA network. The Ethernet and Devicenet networks functionalities are well explained in the section 3.6.

3.3 Common Processes in the Automation Domain

Assembly lines have been elaborately refined by automatic control systems, transfer machines, computer-guided welding robots, and other automated equipment, which have replaced manual operations, while leading to high efficiency. The next section of this document describes the main types of processes in the automotive field, which may be divided in four groups:

- Handling of Large-Sized Parts
- Foundry and Interpress
- Painting and Gluing
- Body Welding

3.3.1 Handling of Large-Sized Parts

Industrial robots are used in a variety of tasks. Typical applications include assembling, gluing, laser integration and material handling. Industrial robots that are used to inspect pipelines, storage tanks, and boilers are usually mobile and capable of withstanding harsh environments. In particular, the automotive industry is generally dependent of these robots, large and heavy steel parts are the main type of raw material, and manual force is not an option. For this reason, the handling process and robots play an important role in the automotive industry; some examples are presented in this section.

Part handling devices in general, are expected to lift, transfer and locate parts prior to the process to be made. The sheet metal panels require special care in transportation because of its flimsy character. Damages caused by any mishandling affects overall aesthetic quality of the vehicle. Repair is difficult as well as undesirable. So, the motion employed for transfer must employ soft touch part lifting. The system decelerates again as it reaches final position. All these motions must be carried with maximum possible speed and positioning accuracy for desired productivity and quality. A transportation system comprises of different types of material handling equipment depending on applications, parts and subassemblies, shape and process, and production capacity of the facility. Some of the main robot and automation companies and their handling robots are represented below.

Figure 8: GUDEL RoboFlex RF-4 (www.gudel.com)

Figure 9: KUKA KR 150-2 (www.kuka-robotics.com)

Figure 10: FANUC M-9000iA (www.fanuc.com)

MANUFACTURER	MODEL	AXES	PAYLOAD	REPEATABILITY (mm)	MAX. REACH
COMAU	Smart NX1	6	600Kg	0.2	3.03m
KUKA ROBOTICS	KR 150-2	6	60Kg	0.06	2.04m
GUDEL	RoboFlex RF-4	6	6Kg	0.03	0.81m
FANUC	M-9000iA	6	700kg	0.3	2.83m

Table 1: Features of handling robots from different manufacturers

3.3.2 Foundry and Interpress

The basis for all casting processes in an automotive foundry is to feed the liquid metal into the hollow of a mold with the required format, followed by cooling, to produce a solid object. This operation is performed by injecting a substance in its melting temperature in a special mold, or matrix. Within the matrix, the matter takes the shape of the mold. The finished piece can pass through a press before being stored on pallets (FRANCHIN, 1999).


Figure 11: COMAU SMART NX1 (www.comau.com)

The COMAU Smart NX1 Model (COMAU, 2012) (Figure 10), for example, has a payload capacity of up to 800Kg and reaches more than 3,8m. It is a six axes heavy duty robot suitable for a wide range of applications.

The presses are used for shaping, cutting, drilling, coining and leaking parts. In these processes there is always a hammer (puncture) which is moving from a hydraulic system (hydraulic cylinder) or a mechanical system (where the rotational motion is transformed into a linear system via connecting rods, cranks or spindles). The workpiece is positioned on a press, which applies an external pressure on it, or removes portions of it to obtain a new form. The transfer of pressure from the press to the workpiece is performed by a special mold called matrix on which the part is placed to take shape (FRANCHIN, 1999).

Some casting processes include the inclusion of other material portions of the fused portion in order to increase the mechanical strength of the final product.


Figure 12: COMAU PressBooster (www.comau.com)

The COMAU SMART NH PRESSBOOSTER (COMAU, 2012) (Figure 11) is designed for loading and unloading operations and it is able to handle both small items and components of large dimensions. It is available in the model for floor or shelf installation with a maximum arm reach of 3526 mm a wrist torque up to 12,50 nm and a payload up to 100 kg.

Some of the most widely used automotive foundry robots are shown below:

MANUFACTURER	MODEL	AXES	PAYLOAD	REPEATABILITY (mm)	MAX. REACH
COMAU (COMAU, 2012)	Smart NX1 600	6	600Kg	0.2	3.03m
KUKA ROBOTICS (KUKA, 2012)	KR 60	6	60Kg	0.06	2.04m
ABB (ABB, 2012)	IRB 140	6	6Kg	0.03	0.81m

Table 2: Features of foundry robots from different manufacturers

There is a variety of options available according to the industry's need. The number of axes is usually the same and their reach varies depending on the payload.

Some of the most widely used automotive press-to-press robots are shown below:

MANUFACTURER	MODEL	AXES	PAYLOAD	REPEATABILITY (mm)	MAX. REACH
COMAU (COMAU, 2012)	Smart NH PRESS-BOOSTER	6	100Kg	0.2	3.5m
KUKA ROBOTICS (KUKA, 2012)	KR 120-2	6	120Kg	0.06	3.5m
ABB (ABB, 2012)	IRB 6650S	6	200Kg	0.13-0.9	3m
FANUC (FANUC, 2012)	M-410*i*B	4	160-700Kg	0.5	3.143m

Table 3: Interpress Robots

3.3.3 Painting and Gluing

Car body Painting and gluing are the key processes in automotive manufacturing, directly influencing the exterior appearance and quality of the final product. For this reason, it is important that the robots are flexible, with fast axis speed and acceleration and high accuracy. How these tools work in the case of some known models is shown next.

- **Painting**

Using robots in spray painting consists in setting a spray paint gun to the actuator of the robot. In the application of spray paint, the flexibility of robots becomes evident, which can store a specific program for each type of part to be painted. Many robots used in this application have no sensing system. This is because the part that is worked is placed at a given distance and direction from the base of the robot, and can be performed in either stationary or moving objects. In the case of static objects, the robot starts the operation only after receiving a signal confirming that the part that is painted is properly positioned (FRANCHIN, 1999).

Figure 13: FANUC P-200E (www.fanuc.com)

Figure 14: ABB IRB5400 (www.abb.com.br)

The next table shows the main features of the robots from some manufacturers:

MANUFACTURER	MODEL	AXES	VELOCITY	PAYLOAD	REPEATABILITY
FANUC ROBOTICS (FANUC, 2012)	P-200E	6 OR 7	1,5m/s	15Kg	0.5mm
ABB (ABB, 2012)	IRB 5400	7	1,5m/s	25Kg	0.15mm

Table 4: Features of painting robots from different manufacturers

- **Gluing / Sealing**

Many automakers are using glue to bond some parts together on modern vehicles. Automotive structural adhesives are advanced materials called epoxies that can be customized to bond to almost any surface and endure a wide range of temperature extremes. Figure 14 is an example of robot used for gluing.

Using glue in auto manufacturing isn't a way to cut corners or make an inferior car. Modern adhesives offer a lot of engineering advantages over traditional methods of fastening two parts together. In fact, adhesives usually form a bond stronger than the materials they're bonding together. Adhesives could be the key to building lighter, more efficient cars, and when new materials such as carbon composites are used, adhesives might be the only way to bond them as carbon fiber panels cannot be welded together.

Figure 15: COMAU NH4 200 (www.comau.com)

Of course, auto adhesives aren't perfect – there are a few environmental concerns and some applications for which they just don't work very well.

The next table shows the main features of the robots from some manufacturers.

MANUFACTURER	MODEL	AXES	PAYLOAD	REPEATABILITY	RECH
COMAU (COMAU, 2012)	NH4 200 – 3.1/SH	6	200KG	0.15mm	3.15m
ABB (ABB, 2012)	IRB 2400	6	20KG	0.11-0.15mm	1.55m
FANUC ROBOTICS (FANUC, 2012)	M-710iC /20L	6	20KG	0.15mm	3.11m

Table 5: Features of gluing robots from different manufacturers

As showed in the last two tables, the main features are similar, so we can say that these models differ more on specific features.

3.3.4 Welding Processes and Robots in an Automotive Line

Welding and joining technologies pervade commercial and defense manufacturing, and are a significant source of value-added in the manufacturing process. Occurring late in the manufacturing stream, the joining process is typically the final step in assembly and plays the major role in ensuring structural performance (WIKIPEDIA, 2012). Additionally, the emergence of near-net-shape processes to produce sub-components has raised the importance of assembly processes as the next area for increased production efficiency. The role of welding and joining in the repair and life extension of manufactured products is even more critical since these processes are frequently used to repair structures and components that were not originally welded. The two main types of welding processes will be described below, spot and arc welding.

Spot welding is a technique commonly used to bond metals shaped into sheets no thicker than few millimeters. Spot welding can create precise bonds without generating excessive heating that can affect the properties of the rest of the sheet. This is achieved by delivering a large amount of energy in a short time in order to create controlled and reliable welds (FRANCHIN, 1999).

Arc welding is a process used to join two pieces of metal along a continuous contact area. The two pieces of metal are heated along the area of contact, which melts this part and after a cooling process the molten metal solidifies, uniting the two parts (WIKIPEDIA, 2012).

For a better explanation, these two processes will be discussed more deeply, starting with the Spot Welding process that involves three stages; the first of which involves the electrodes being brought to the surface of the metal and applying a slight amount of pressure. The current from the electrodes is then applied, then, the current is removed but the electrodes remain in the same place in order to cool the material. Welding times range from 0.01 sec to 0.63 sec depending on the thickness of the metal, the electrode force and the diameter of the electrodes themselves (FRANCHIN, 1999).

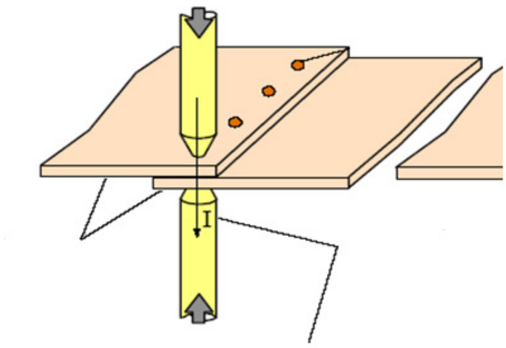

Figure 16: Spot Welding example

The equipment used in the spot welding process consists of tool holders and electrodes. The tool holder works as a mechanism to hold the electrodes firmly in place and also support optional water hoses which cool the electrodes during welding. Tool holding methods include a paddle-type, light duty, universal, and regular offset. The electrodes generally are made of a low resistance alloy, usually copper, and are designed in many different shapes and sizes depending on the application. (FRANCHIN, 1999).

After the current is removed from the workpiece, it is cooled through the coolant holes in the center of the electrodes. Both water and a brine solution may be used as coolants in spot welding mechanisms.

The spot welding process using common robots may be summarized in few operations:

- Fast robot arm, with the soldering gun fixed to approach the point to be welded;
- Exact positioning of the welding gun;
- Attachment of electrodes to the point being welded;
- Sending electrical current through the electrodes and the material being welded;
- Opening the electrodes;

The most common application of spot welding is in the automobile manufacturing industry, where it is used almost universally to weld the sheet metal to form parts of a car. Spot welders can also be completely automated, and many of the industrial robots found on assembly lines are spot welders.

The Arc Welding process is used to permanently join metal parts. Moreover it is widely used for many applications in various industries. Nonrmally, to create an electric current, two electrodes with different potentials, fed by the welding equipment are needed. The arc welding gun has only one electrode, with the object to be welded serving as the second electrode. Metal objects are heated by an electric current, which flows through the electrodes in the welding gun and through a range of air until it reaches the object. When using a robot to perform an arc weld, the welding gun is attached to the same actuator and the electrode is fed through a conductor, parallel to the robot arm. The soldering gun also disperses a special gas in the heated area to prevent against oxidation, which would worsen the quality of the weld.

The process of arc welding requires the use of high quality robots with sophisticated software capable of performing the following operations:

- Maintain a constant orientation relative to the electrode and the surface to be welded;
- Keep the soldering gun moving at a constant speed;
- Ability to perform "weaving" movements in order to achieve a good junction between the two metal bodies and ensure the quality of the weld.

Bellow some examples of spot and arc welding robots and comparative tables used to highlight the differences between the manufacturers are shown.

- **Spot Welding Robots**

The spot welding robots perform complicated movements, such as tracking pieces contours and reach inaccessible spots without damaging the parts being welded. Thus, many applications use welding robots with 6 degrees of freedom - three for positioning and three for direction or attitude toward the piece. Although the moves required for spot welding robots are complicated, the only point that requires a great precision is the point where the weld is done making it possible to control the use of point-to-point during the path of the robot between weld points. To avoid collisions between the robot and the parts that are welded during its movement between two welding points, the robot must be accompanied by a large number of positions for which he must pass through their way to the next welding point. The teaching tasks spot welding is a complicated process (FRANCHIN, 1999).

Figure 17: COMAU Smart NJ 130 (www.comau.com)

The next table shows more features of the spot welding robots based on some manufacturers' specifications:

MANUFACTURER	MODEL	AXES	PAYLOAD	REPEATABILITY	REACH
COMAU (COMAU, 2012)	Smart NJ 130	6	130Kg	0,07mm	3m
KUKA ROBOTICS (KUKA, 2012)	KR 150 L110-2	6	110Kg	0,06mm	3,1m
FANUC (FANUC, 2012)	R-1000iA	6	80-100Kg	0,2mm	2,230m
ABB (ABB, 2012)	IRB 6620	6	150Kg	0,03mm	2,2m

Table 6: Features of spot welding robots from different manufacturers

Operations under spot welding process, integrating the robot are:

- Fast movement of the robot arm, with the fixed welding gun to approach the point to be welded;
- Approaching of the welding gun electrodes to both sides of the part to be welded and positioning exactly opposite to the welding point;
- Attachment of the electrodes to the point to be welded;
- Transmission of electrical current through the electrodes and the material to be welded;
- Hold;
- Opening of the electrodes;
- Driving the robot arm to approach the new welding point;
- The main advantages involved in using robots in points are:
- Improving welding quality;
- Precise positioning of the weld, ensuring strength;
- Saving manpower and time.

The main disadvantages are the failures that can occur in the process due to physical deterioration of the electrodes and the tedious process of teaching.

- **Arc Welding Robots**

The arc welding gun has only one electrode, with the object to be welded serving as the second electrode. The metal objects are heated by an electric current, which flows through the electrodes in the welding gun and through an air empty space to the object being welded. The welding gun also scatters a special gas to prevent the heated area against oxidation, which would affect the quality of the weld (FRANCHIN, 1999).

The next table shows more features of the arc welding robots based on some manufacturers' specifications:

Figure 18: COMAU Smart Arc 4 (www.comau.com)

MANUFACTURER	MODEL	AXES	PAYLOAD	REPEATABILITY	REACH
COMAU (COMAU, 2012)	Smart Arc 4	6	5Kg	0,05mm	1,951m
KUKA ROBOTICS (KUKA, 2012)	KR 16 arc HW	6	16Kg	0,05mm	1,636m
FANUC (FANUC, 2012)	M-710iC/20L	6	20Kg	0,15mm	3,110m
ABB (ABB, 2012)	IRB 1600ID	6	4Kg	0,02mm	1,5m

Table 7: Features of arc welding robots from different manufacturers

Some applications of arc welding machines in the automotive industry are: fuel injectors, ignition controls, air bag assemblies, switch gear assemblies, anti-lock brake solenoids, motor assemblies and armatures, lighting assemblies.

The arc welding robot process requires the use of high quality with sophisticated software capable of performing the following operations (COMAU, 2012):

- Fast movement to the contact area to be welded;
- Transmission of signals for causing the spread of the gas and applying voltage to the electrode;
- Precise movement along the weld path while maintaining a constant empty area with air;
- Preserving a constant direction relative to the electrode surface to be welded;
- Keep the welding gun moving at a constant speed;
- Ability to perform "weaving" movements in order to achieve a good joint between two metal bodies and ensure the quality of the weld.

To meet the above requirements, the arc welding robot process needs the following characteristics:

- Offer five to six degrees of freedom;
- Continuous path control, for moving exactly along the trajectory and welding speed regulation;
- High repeatability.

The problem with arc welding occurs when the bodies are heated, leading to distortions that cause a slight displacement of the bond line during the welding process, which may be significant in long welds where the heat is not quickly dispersed from the weld area.

3.4 Network responsiveness Requirements

In a factory floor, the response time varies depending on the application requirements and the hardware used in the manufacturing process (PLCs, Robots, Sensors,…). Then, many factors can influence the responsiveness, such as poor design, hardware limitations, problems with the operation system or the network. A fast hardware could not be the better responsiveness as well as a simple hardware could reach better responsivness. The rationale behind the responsiveness principle is that the system should deliver results of an operation in a timely and organized manner.

In this section, only for clarification issue, we provide examples of the devices responses time and its features and the network interfaces used at COMAU Brazil:

- **ETHERNET:**
  - 100 Mbps/ full duplex: robot/plc
  - Auto: IHM
  - Consumer: max. Delay: 10 ms
  - Interval: 30 ms
  - Producer: 2 words (1 word = 32bits)
- **DEVICENET:**

Framing Station:

General: Allen-Bradley

Type: 1756-762s Control Logix 5562S Safety Controller

- Serial Port:
  - Baud Rate: 19200
  - Data Bits: 8
  - Parity: None
  - Stop bits: 1
  - Control Line: No Handshake
  - RTS Send Delay: 0 (x20 ms)
  - RTS Off Delay: 0 (x20 ms)
  - DCD Wait Delay: 0 (x1 sec)
- System Protocol:
  - Protocol: DF1 Point to Point
  - NAK Receive Limit: 3
  - ENQ Transmit Limit: 3
  - ACK Timeout: 50 (x20 ms)
  - Error detection: BCC
  - Embedded Responses: Autodected
  - Enable duplicate detection
- User Protocol:
  - User Protocol: ASCII
  - Buffer: 82 bytes

Framing Device: Type: 1756-DNB 1756 Devicenet Scanner

- Input Size: 40 (32-bit)
- Output Size: 30 (32-bit)
- Status Size: 32 (32-bit)
- Requested Packet Interval (RPI): 20 ms

Safety Framing Station: Type: 1791DS-IB8X0B8 8 POINT 24 VDC SINK SAFETY INPUT, 8 POINT 24 VDC SOURCE SAFETY OUTPUT

- Safety Input: RPI: 20 ms
- Safety Output: RPI: 25 ms
- Connection Reaction Time Limit (ms): Safety Input: 80 ms; Safety Output: 65 ms

General Operation: Type: 1756-L63 Control Logix 5563 Controller

- Serial Port:
  - Baud Rate: 19200
  - Data Bits: 8

        - Parity: None
        - Stop bits: 1
        - Control Line: No Handshake
        - RTS Send Delay: 0 (x20 ms)
        - RTS Off Delay: 0 (x20 ms)
        - DCD Wait Delay: 0 (x1 sec)
    - System Protocol:
        - Protocol: DF1 Point to Point
        - NAK Receive Limit: 3
        - ENQ Transmit Limit: 3
        - ACK Timeout: 70 (x20 ms)
        - Error detection: BCC
        - Embedded Responses: Autodected
        - Enable duplicate detection
    - User Protocol:
        - User Protocol: ASCII
        - Buffer: 82 bytes

Station:

- Type: 1756-DNB 1756 Devicenet Scanner
- Input Size: 45 (32-bits)
- Output Size: 35 (32-bits)
- Status Size: 32 (32-bits)
- Requested Packet Interval (RPI): 20 ms

3.5 Communication and Integration between Manufacturing and Control Devices

Modern industry is characterized by numerous devices and systems, each one presenting different communicating processes. The following section describes the most common standards, protocols and concepts responsible for coordinating such systems, and which may be relevant to the BEMO-COFRA project.

3.5.1 PROFIBUS

Profibus belongs to a group of protocols that share the concept of Fieldbus. This concept shares the idea that, the information is not centralized in one place of a production line, such as the PC manager, but distributes over the entire network (from the shop floor to the uppermost levels of management).

As Profibus can be used at various levels of the industrial process, a a series of different profibus types emerged. A brief description of these derivatives can be seen below (SMAR-US, 2012):

- Profibus DP: this was the first version created while focusing on the factory floor where the volume of information is considerably higher. Also because of that, there is a need for high speed communications to avoid delays in the treatment of events and responses.
- Profibus FMS (Field Message Specification): This version is a Profibus DP evolution. It is more powerful and is intended for communication to the cell level (PLC mostly).
- Profibus PA (Process Automation): This is the modern version of Profibus. It is clearly the most interesting version due the possibility to make the data travel on the same physical line of DC power, saving time installation and gaining performance.

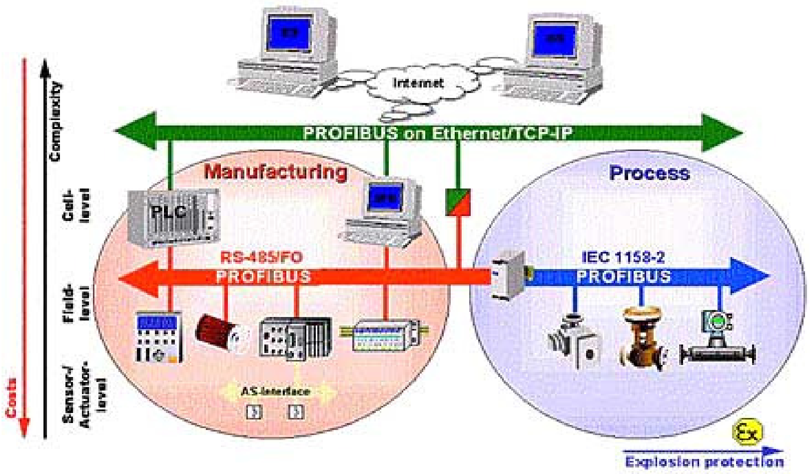

Figure 19: PROFIBUS scheme (www.smar.com)

The architecture of the PROFIBUS protocol ensures to each station involved in the data exchange, has a long enough period of time to perform the tasks of communication. The industrial communication Fieldbus networks are specially designed for interconnections between controllers, sensors and actuators located in the layers of a lower level (shop floor). The higher a level is in terms of message flow, the greater the response time required for information transfer. Many factors are involved in the composition of message delay and include, access times and queues Mechanism (MAC - Medium Access Control), transmission time and protocol processing time.

MAC Mechanisms (MAC bus access) are implemented at layer 2 of the OSI model. This is known as the Fieldbus Data Link (FDL) in the case of PROFIBUS. The FDL besides being responsible for controlling access to the bus and the token cycle time, it is also responsible for data transmission services to the application layer (SMAR-US, 2012).

PROFIBUS uses different subsets of level 2 services in the form of the profiles (DP, FMS, PA).

SERVICE	FUNCTION	DP	FMS	PA
SDA	Send Data with Acknowledge	NO	YES	NO
SRD	Send and Request Data with reply	YES	YES	YES
SDN	Send Data with No acknowledge	YES	YES	YES
CSRD	Cyclic Send and Request Data with reply	NO	YES	NO

Table 8: PROFIBUS profiles

Profibus FMS is widely used by Comau Europe, but for the Brazilian subsidiary, the DeviceNEt solution is being used.

3.5.2 DEVICENET

DeviceNet is a low-level industrial application layer protocol for industrial automation applications (REALTIME, 2009). It connects sensors and actuators with higher-level devices such as Programmable Logic Controllers (PLC). Built on the standard CAN (Controller Area Network) physical communications standard DeviceNet uses CAN hardware to define an application layer protocol that structures the task of configuring, accessing and controlling industrial automation devices. Briefly, it was designed for maximum flexibility between field equipment and interoperability between different manufacturers.

DeviceNet is an open automation standard that carries two main types of information:

- Cyclical data from sensors and actuators directly related to the control;
- Acyclic data indirectly related to control, such as configuration and diagnostics.

The cyclic data represents the information exchanged periodically between field equipments and controller. On the other hand, the acyclic data are in general represented by diagnosis of field equipment. The physical layer and access network technology is based on the DeviceNet CAN (Controller Area Network) and the upper layers are CIP (Common Industrial Protocol protocol see figure 19) which defines an architecture based on objects and the connections between them.

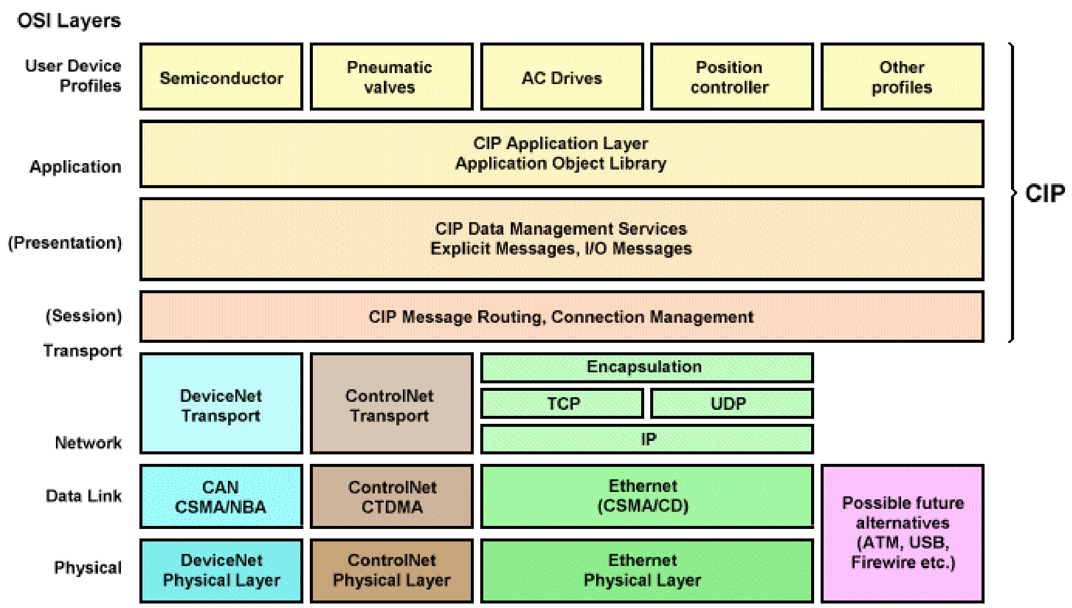

Figure 20: CIP Protocol Familly

CAN is a serial communications standard for intelligent devices to communicate with each other (REALTIME, 2009). Unlike many other communication standards that provide fast data rates with thousands or millions of data bytes in a single frame, CAN has a bit rate that reaches at most 1 MegaBaud. Most industrial applications do not even require such speed; they usually use the lowly 125 Kbaud (REALTIME, 2009). Additionally, other standards move thousands of bytes in a single frame, CAN only moves 8 bytes of data per frame.

A DeviceNet network can contain up to 64 devices where each device occupies a node in the network, addressed from 0 to 63 (REALTIME, 2009). DeviceNet uses peer to peer (P2P) communication in combination with a priority mechanism and the arbitration schemes inherited from CAN protocol is performed bitwise. The data transfer occurs according to the producer/consumer model.

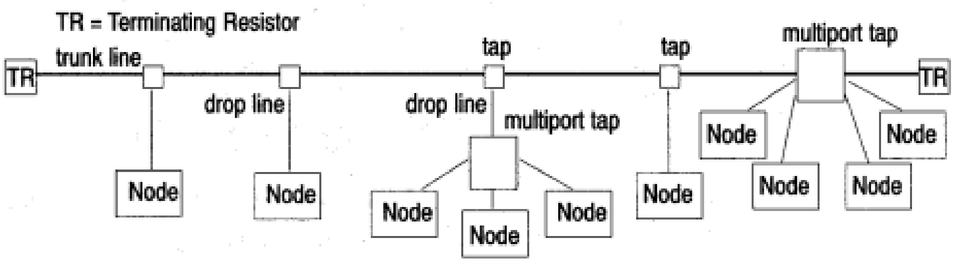

Figure 21: DEVICENET model (http://www.ieeta.pt/)

Although DeviceNet allows many different devices to communicate, it also has physical limitations such as the supported maximum distance between nodes for instance. The following rules must be obeyed so that the cable system is operational:

- The maximum distance between any device in a branched junction to the trunk cannot be greater than 6 meters;

The distance between any two points in the network cannot exceed the Maximum distance permitted cable for baud rate and cable type used as shown in the Table below. The distance refers to distance between two devices or termination resistors.

TRANSMISSION SPEED	MAXIMUM DISTANCE (THICK CABLE)	MAXIMUM DISTANCE (THIN CABLE)	LENGTH OF DERIVATION	
			Maximum	Accumulated
125Kbps	500m	100m	6m	156m
250Kbps	250m	100m	6m	78m
500Kbps	100m	100m	6m	36m

Table 9: DeviceNet Features

Rockwell Automation has developed an application for configuring a DeviceNet bus. The software performs calculations needed to check lengths of cable, currents, etc...

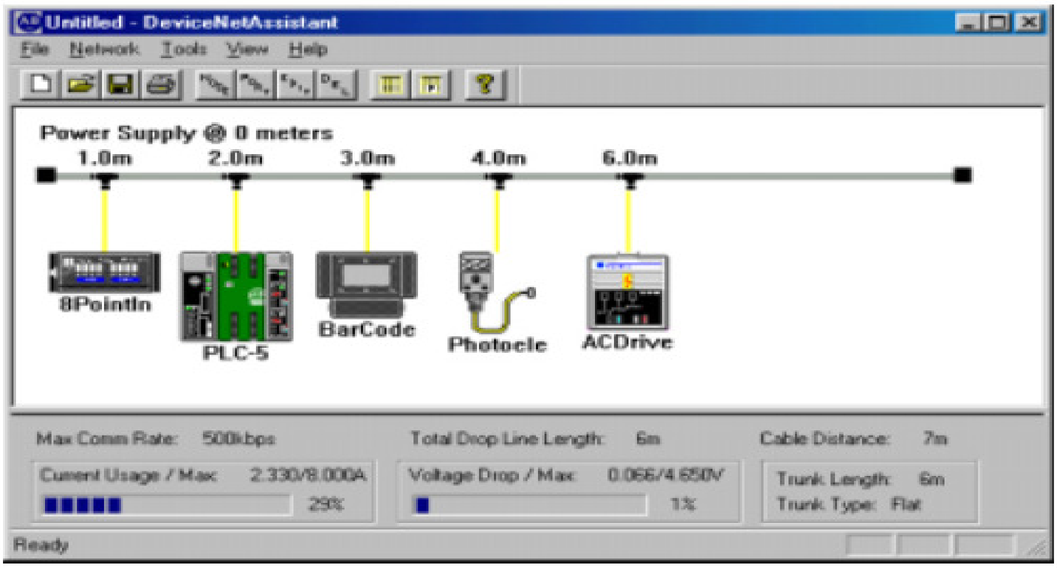

Figure 22: DeviceNet Assistant (http://www.ieeta.pt/)

It uses CSMA / NBA - Carrier Sense Multiple Access with Non Destructive Bitwise Arbitration or CSMA/CD + AMP (Arbitration on Message Priority). This protocol provides the characteristic where any node can access the bus when it is free. If there is contention, bitwise arbitration will occur based on the priority of the message. Following this idea, a node only initiates the process of transmission, when the environment is free. Each node that starts a process of listening to each bit sent in order to check if the data sent is equal to the received data. The bits with a dominant value overwrite recessive bits.

In this type of network, the data is identified by its content and the message does not require explicit source address and destination. Also there is no concept of master, that is to say, any node can transfer.

The PLC or scanner has the master role and performs a polling of the slave devices. These only respond when asked, in this system the master is fixed and there is only one master per network. The host connection to the network device can be through a serial line RS232 using the Communication Adapter 1770 - KFD. The connection can be made anywhere in the network.

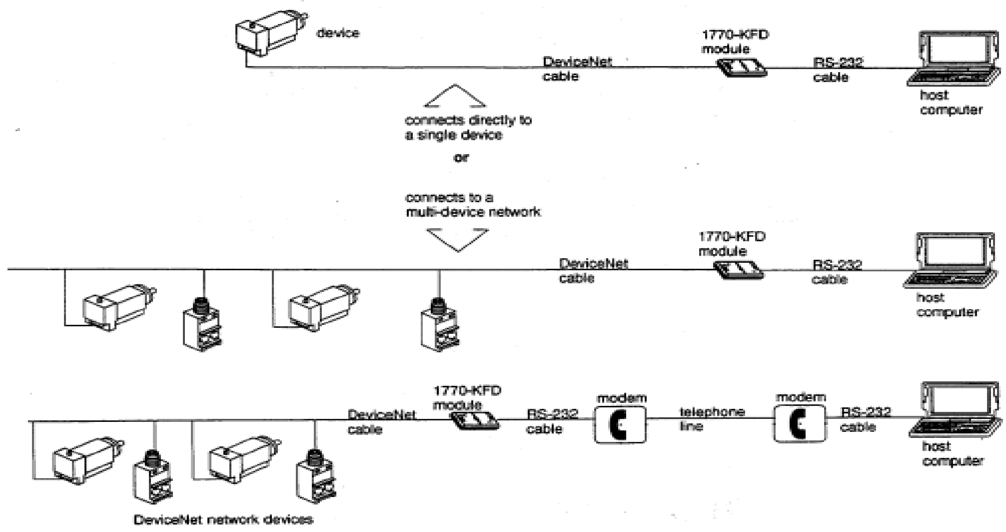

Figure 23: Network Example (http://www.ieeta.pt/)

To summarize, DeviceNet is an open technology, whose application layer uses CIP. Along with ControlNet and EtherNet / IP, it has a common structure for objects, that is to say, physical and data link layer are independent. This standardized application layer, combined with hardware and software interfaces open platform is a universal connection between components in an automation system, from the factory floor to the Internet level.

3.5.3 MODBUS

The MODBUS protocol was designed in 1979 by "Modicon", today known as "schneider electric". It was created to establish communication between master-slave / client-server devices. MODBUS devices communicate using a master-slave technique that allows only the master device to initiate transactions. The slave devices are assigned to respond according to the request of the master, or according to the task at hand.

There are three types of MODBUS Protocols (MODBUS, 2006):

- MODBUS TCP/IP: The MODBUS TCP/IP is used for communication between supervision systems and PLCs. The Modbus protocol is encapsulated in TCP/IP protocol and transmitted over ethernet standard networks with media access control for CSMA/CD.
- MODBUS PLUS: The MODBUS PLUS is used for communication between themselves in PLCs, I/O modules, starter's electron engines keys, human-machine interfaces etc. The physical environment is the RS-485 with transmission rates of 1 Mbps.
- STANDARD MODBUS: The STANDARD MODBUS is used for communication between PLCs and input devices / output data, intelligent electronic instruments (IEDs) as protective relays, process controllers, valve actuators, transducers, etc. The physical medium is the RS-232 or RS-485 in conjunction with the master-slave protocol.

During a communication on a Modbus network, the protocol determines how the device would know a devices address, recognize a message addressed to it, how to determine the type of action to take and how to extract the data or other information contained in any message. If a response is required, the protocol also determines how the device builds and sends a message.

The master can address messages to an individual slave or send messages to all (broadcast). Slaves return a message only to the queries addressed specifically to them. Message broadcast does not generate any answers. Although it has been the basis for many others, the protocol is outdated, and therefore few industries use it today.

3.5.4 ETHERNET

Ethernet is the most popular and widely used technology of wired local area networks (LAN) in the world. It was developed by Xerox in the 70's, in collaboration with DEC (Digital Equipment Corporation) and Intel, which lead to the standard´s development in the 80's. The Ethernet network has gone through a long evolution over the last years constituting a network of best range and performance for a wide range of applications. In the last years there was an increasing interest in the industry over the Ethernet network as a possible alternative on the factory floor and process control. But Ethernet was not designed to work in industrial automation. It has been successfully modified to provide basic requirements of data communications between industrial processes (HARRIS, 2012).

Ethernet, which later became the basis for the IEEE 802.3 network standard, specifies physical and data link layers of network functionality. The physical layer specifies the types of electrical signals, signaling speeds, media and connector types and network topologies. The data link layer specifies how communication occurs over the media — using the CSMA/CD technique — as well as the frame structure of messages transmitted and received. Nowadays we have the IEEE 1451 standard, which defines how the sensors and actuators can be connected directly to a control network, including Ethernet. This standard opens an alternative to Ethernet in applications that do not require safety or power through the cable network (B&B ELETRONICS, 2012).

By using standard Ethernet, automation systems from different manufacturers can be interconnected throughout a process plant. Industrial Ethernet takes advantage of the relatively larger marketplace for computer interconnections using Ethernet to reduce cost and improve performance of communications between industrial controllers.

Depending on the real time and cost requirements, the technologies follow different principles or approaches. This comparison tries to group those approaches in three different models by looking at the slave device implementations (ETHERCAT, 2011):

MODELS	FEATURES
MODEL 1 (‘BEST EFFORT’ APPROACHES)	• Completely TCP/UDP/IP Based; • Using ordinary Ethernet Controllers and Switches limits the real time performance by unpredictable delays in infrastructure;
MODEL 2	• Parallel channel to TCP/UDP/IP - data transported directly in the Ethernet frame by a dedicated process data protocol; • TCP/UDP/IP timing controlled by process data driver; • Using ordinary Ethernet Controllers and Switchers limits the real time performance by unpredictable delays in infrastructure;
MODEL 3	• Parallel channel to TCP/UDP/IP - data transported directly in the Ethernet frame by a dedicated process data protocol; • TCP/UDP/IP timing controlled by process data driver; • Special realtime Ethernet Controllers and Switches - dedicated hardware on slave device side providing better performance due to better hardware integration;

Table 10: ETHERNET Features

Below are shown the most popular Ethernet standards:

- Ethernet-**IP** (**I**ndustrial **P**rotocol) (ETHERCAT, 2011) – developed by Rockwell Automation and managed by ODVA (Open DeviceNet Vendors Association). Its main features are:
    - CIP (Common Industrial Protocol) – common object library for Ethernet/IP, ControlNet, DeviceNet;
    - Follows **Model 1**;
    - Consumer / Producer Model;
    - Simplify Maintainability;
    - Enhance flexibility;
    - Very efficient for slave-to-slave communication but requires broadcast communication and thus filtering in each device;
    - Same technology used on the Internet and on the enterprise network;
- Modbus-**IDA** (**I**nterface for **D**istributed **A**utomation) (ETHERCAT, 2011) (MODBUS, 2006) – Supported by Schneider Automation, AG-E, Jetter, KUKA, Lenze, RTI, Sick and Phoenix. It is a serial communication protocol published by Modicon in 1979. Its main features are:
    - Simple and robust;
    - It has been developed with industrial applications in mind;
    - Follows **Model 1**;
    - Client / Server Model;
    - Communication on an Ethernet TCP/IP network;
    - Not real time approach;
    - Widely used;

- EtherCAT (ETHERCAT, 2011) (BECKHOFF, 2012) – (Ethernet for Control Automation Technology) is the real-time Ethernet technology from Beckhoff. Its main features are:
    - Star topology can be replaced with a simple line or tree structure;
    - Up to 65,535 devices
    - network: size almost unlimited (> 500 km) and operates with or without switches using twisted pair physical layer or fiber-optic cable variants 50 to 2,000 m;
    - hot connect/disconnect of bus segments;
    - Follows **Model 3**;
    - Frame processing 'on the fly';
    - With EtherCAT Slave Controller the network performance does not depend on the performance of the slave devices;
- Profinet (ETHERCAT, 2011) (PROFIBUS&PROFINET, 2012) – PI (Profibus International) – Siemens Ethernet solution with 3 varieties: CbA (Component based Automation, follows **Model 1**), RT (soft Real Time, follows **Model 2**) and IRT (Isochronous Real Time, follows **Model 3**). Profinet RT and IRT can be named Profinet I/O. Its main features are:
    - Flexible network topology but requires a top-down approach and restrictions apply when designing a network with a required performance;

  - WLAN and Bluetooth communication can be integrated transparently into the solution, including for real-time data;
  - Integrates Redundancy solutions;
  - Uniform integration on fieldbus systems;
  - Fast Forwarding;
- PowerLink (ETHERCAT, 2011) (ETHERNET-POWERLINK, 2011) – developed by EPSG (Ethernet POWERLINK Standardization Group) integrates features and abilities from Ethernet, CANopen, and a newly developed stack for real-time data communication. Its main features are:
  - Safety-oriented real-time protocol;
  - Use of Polling approach: the master send a poll request to each slave;
  - Hubs (no switches);
  - Follows **Model 2**;
  - Limited line topology and performance is topology dependent;
  - Broadcast: every node receives every frame;
  - Ring redundancy, partial ring redundancy, cable redundancy, and Managing Node redundancy;

Asynchronous phase for integrating nodes without real-time capability into the network;

3.5.5 INTERBUS

INTERBUS has been developed as a fast sensor/actuator bus system for transmitting process data in industrial environments to increase productivity of machines and plants, while at the same time cutting costs. It transmits data between control systems (e.g., PCs, PLCs, VMEbus computers, robot controllers etc.) and spatially distributed I/O modules that are connected to sensors and actuators (e.g., temperature sensors, position switches). It utilizes a single cable to interconnect all devices, no matter the level of complexity, and allows its users the advantage of reducing overall control system installation and maintenance costs (HMS, 2012).

Today the INTERBUS technology is known as mature and solidly and is fully standardized according to the European Standards EN 50254 and IEC 61158. It is one of the leading Fieldbus systems in the automation industry (very popular in automobile production). At the moment, more than 600 manufacturers are involved in the implementation of INTERBUS technology in control systems and field devices (CITRANO et al., 2011) and there are over 16 million installed INTERBUS nodes available (PROFIBUS, 2012).

Due to the increasing change of Fieldbus technologies towards Ethernet for users and the integration of the technology INTERBUS, the creation of efficient and investment-protecting migration ways are of essential meaning. Thus an optimum integration of INTERBUS into PROFINET has been created (PROFIBUS, 2012). Today's stable INTERBUS technology may simply continue to be technically maintained.

The INTERBUS system provides not only excellent performance characteristics, such as fast, cyclic and time-equidistant data communication, but also simple handling, comprehensive diagnosis functions to minimize downtime, as well as a high degree of immunity to interference by using fiber optics (PROFIBUS, 2012).

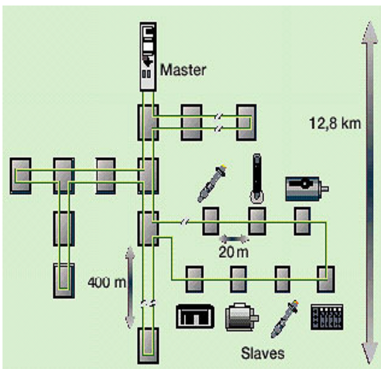

Figure 24: INTERBUS scheme (http://www.phoenixcontact.com)

It is these characteristics, in combination with the inexpensive connection of sensors and actuators that have led to the rapid acceptance of the fieldbus system.

INTERBUS is a ring system, i.e., all devices are actively integrated in a closed transmission path. Each device amplifies the incoming signal and sends it on, allowing higher transmission rates at longer distances. Unlike other ring systems, the data forward and return lines in the INTERBUS system are led to all devices via a single cable. This means that the general physical appearance of the system is an “open” tree structure. A main line exits the bus master and can be used to form seamless sub networks up to 16 levels deep. This means that the bus system can be quickly adapted to changing applications (PHOENIX, 2012).

The INTERBUS master/slave system enables the connection of up to 512 devices. The ring is automatically closed by the last device. Countless topologies can be created since the system can be adapted flexibly to meet the user’s requirements by adding or removing devices Branch terminals create branches, which enable the connection and disconnection of devices (PROFIBUS, 2012). The coupling elements between the bus segments enable the connection and disconnection of a subsystem and thus make it possible to work on the subsystem without problems, e.g., in the event of an error or when expanding the system.

INTERBUS FACTS	
NETWORK TYPE	Master/Slave Fieldbus Communication system
TOPOLOGY	Active ring topology with branches
INSTALATION	Shielded twisted pair cables with 9-pole DSUB connectors
CABLE LENGTH	Max. 400m between 2 remote bus devices and up to 13km with RS-485 and 50km with fiber optic
SPEED	500kbit/s or 2Mbit/s max.
STATIONS	1 Master and up to 511 Slaves (Max: 512 nodes)
DATA	Max. 4096 Bit I/O data
NETWORK FEATURES	Fast and efficient Fieldbus communication system optimized for cyclic I/O data transfer
ADDRESING	Master/Slave, cyclic and PCP messages
SYSTEM FEATURE	Possibility to define 256 own PCP objects + own VFD-object Supports PMS services: PCP V2.0; Initiate, Abort, Reject
ERROR DETECTION	CRC checksum
DETERMINISM	Deterministic but no during error correction

Table 11: Interbus Facts

To connect each of the sensors and actuators in an economical way a transmission technology adapted to several common conditions of operation was developed. This is called the INTERBUS loop. The INTERBUS loop connects terminals to a loop through a simple unshielded cable. Using two wires, data information and the supply voltage are provided simultaneously. Data communication occurs in the form of current signals independent of charge. By this method, the INTERBUS loop becomes as free from interference that makes unnecessary a shielded cable.

As is required in other systems the data is not assigned to the individual stations. Instead, data is assigned automatically by means of the physical position of the stations in the system without using switches. The ability to assign meaningful names to physical addresses by software, allows equipment to be added or removed without readdressing existing equipment. This plug and play function is a decisive advantage with regard to reducing the installation complexity and increasing the ease of maintenance of the system (CHEN, 2012). The problems and possible malfunctions that might occur through manual setting of the device address during installation and service are often underestimated.

3.5.6 AS-I (ASINTERFACE, 2012)

In 1990, in Germany, a consortium of companies developed a successful bus system for networks of sensors and actuators, called the Actuator Sensor Interface (AS-I). Some of the most notable members are Allen-Bradley, Siemens, Schneider, Turck, Omron, and Eaton Festus. The AS-Interface is a serial interface, bi-directional, which is considered a simpler solution in industrial networks, applied to the lowest level of automation, belonging to the category Bus Sensor (SMAR-BR, 2012).

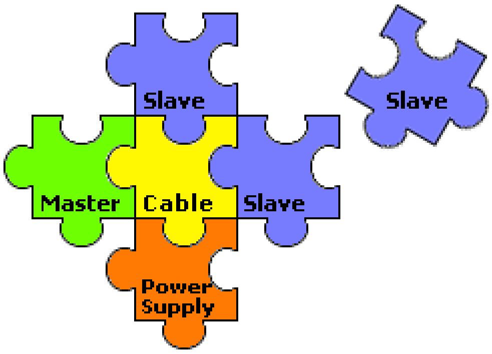

Figure 25: AS-I Network (Ref: http://as-interface.net/)

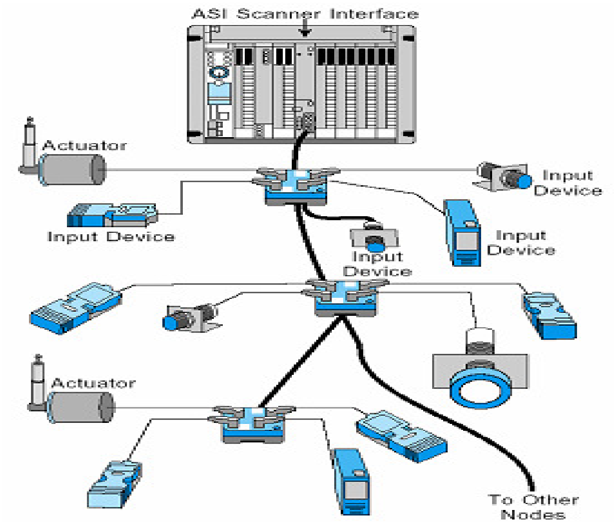

Figure 26: AS-I Network (Ref: http://as-interface.net/)

Its main advantages are:

- Optimized for connection of sensors and actuators;
- Cost efficiency;
- Operation in severe environmental conditions;
- Reliable and safe;
- Ability to update data in real time;
- Universal application;
- Simple installation and expansion;
- Openness to higher hierarchical levels of the network;
- Protected against electromagnetic interference;

The main features of AS-I are:

- Standard: EN 50295 (European Standard CENELEC 1998), IEC62026-2 (International Electrotechnical Commission);
- Topology: Tree, star, ring structure;
- Physical environment: without cable shielded and pair not twisted with two wires for data and energy (24-30VDC/8A);
- Maximum cable length 100 m or 500m with repeaters;
- Master module can be a Master PLC, a PC, IPC, or even a Gateway;

- Maximum number of slave devices equal to 31 with auto-sensing;
- Number of points: Up to 4 sensors and 4 actuators per slave (Max 31 * 4 = 124 bi-directional, max 31 * 8 = 248 binary signals);
- Addressing: Each slave has a given address. The address is set by the master or programming tool;
- The message is sent from the master to a single address with immediate response from the slave;
- Bit rate: Transmits 4bits/slave/message. All slaves are called sequentially by the master and get 4 bits of data. Each slave responds immediately with 4 bits of data;
- Transmits analog data (using several cycles of scanning);
- Cycle time scanning with 31 slaves = 5 ms;
- Error detection: The incorrect messages are identified and relayed;
- Master initializes the network;
- Identification of participants: Asynchronous definition of the parameters to slaves;
- Bus and slaves diagnosis and easy maintenance;
- Error messages to the host computer (short circuit, overload, loss of auxiliary supply, communication errors);
- Addresses definitions in replaced slaves
- Performs the cyclical transmission of data to the computer or the slaves.

The Master has to service the following interfaces:

1. Interface to the AS-Interface network: Controlling the AS-Interface cycle, controlling the combined data exchange, supplying of configuration and diagnostics data, execution of controlling commands from the host system, if necessary.
2. Operator interface to configuration, monitoring, and diagnostics of the network.
3. Interface to the higher-level system: Supplying and accepting of user data, parameter data, configuration and diagnostics data, and control commands.

The integrated circuit ASIC (Application Specific Integrated Circuit) responsible for interpreting data network from/to the sensors may come embedded into the active module I/O (for connection of conventional actuators and sensors) or embedded directly into the new sensors and actuators.

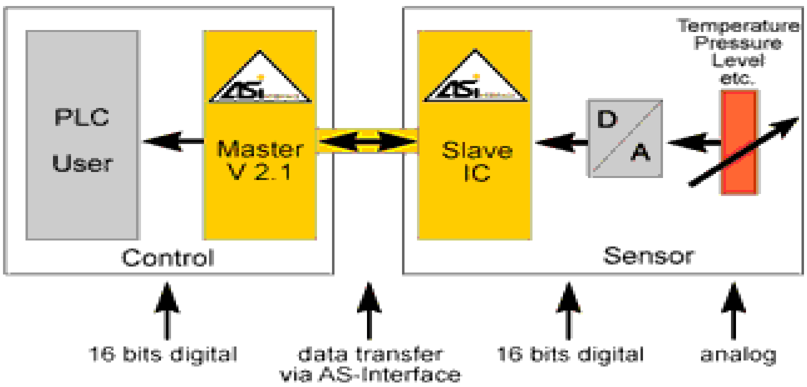

Figure 27: – Master/Slave communication (http://as-interface.net/)

ISO/OSI layers	Function	Implementation with AS-Interface
Layer 7: Application	provides network services for the user	messages, cycles, profiles, automatic address assignment
Layer 6: Presentation	converts from network to application data formats	–
Layer 5: Session	opening and closing of connections	–
Layer 4: Transport	transparent data processing for network transitions	–
Layer 3: Network	address processing, data path switching	–
Layer 2: Data link	data structure, data frame, data safeguarding, error procedures	data telegram, start bit, stop bit, protection, error processing
Layer 1: Physical	mechanical and electric connection for information transfer	Cable, power supply, data de-coupling, APM, energy supply

Table 12: The ISO/OSI reference model

4. Sensor Integration

Sensors are used in everyday objects such as touch-sensitive elevator buttons and lamps. There are many applications for sensors of which most people are never aware. These applications may include cars, machines, aerospace, medicine, manufacturing and robotics.

A sensor is a device which receives and responds to a signal and its sensitivity indicates how much their output changes when the measured quantity varies. These devices are responsible for a great part of the machines success in comparison with handy work, and therefore they play a major role in industrial activity.

This section provides a brief introduction to the classification of sensors and its roll in an industrial field and few types of sensor networks. Additionally, in order to provide a basic notion for future implementation, multi and single radio platforms are analyzed and together with the most common types of sensors used in the Brazilian BWA line.

4.1 Main Sensors in Integration

Since robots are usually physically interacting with the environment, two main types of sensors are commonly used in order to improve quality in a robotic system:

- Proprioceptors for the measurement of the robot's (internal) parameters;
- Exteroceptors for the measurement of its environmental (external, from the robot point of view) parameters.

4.1.1 Proprioceptors

Proprioceptors are sensors measuring both kinematic and dynamic parameters of the robot. Based on these measurements the control system activates the actuators to exert torques in order to articulate the mechanical structure that will perform the desired motion. The usual kinematics parameters are the joint positions, velocities, and accelerations. Dynamic parameters as forces, torques and inertia are also important to monitor for the proper control of the robotic manipulators (OMEGA, 2008).

From a mechanical point of view a robot appears as an articulated structure consisting of a series of links interconnected by joints. Each joint is driven by an actuator which can change the relative position of the two links connected by that joint. Based on Proprioceptors measurements the control system activates the actuators to exert torques in order to articulate the mechanical structure that will perform the desired motion (GENTA, 2012).

- Kinematics Sensors
  - Potentiometers:

    They are seen as true proprioceptors, measuring the relative position of the various parts of a robot are often implemented by measuring angles. The simplest way to measure an angle is by using rotational potentiometers (GENTA, 2012). A potentiometer is a device that allows measuring a position by measuring a voltage.

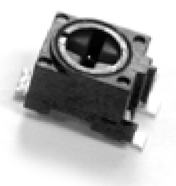

Figure 28: Potentiometer (http://www.piher-nacesa.com)

    The Potentiometer can be attached to the robot using the mounting arcs surrounding the center of the sensor. The arcs provide flexibility for the orientation of the Potentiometer, allowing the full range of motion to be utilized more easily. When mounted on the rotating shaft of a moving portion of the robot, such as an arm or gripper, the Potentiometer provides precise feedback regarding its angular position. This sensor data can then be used for accurate control of the robot.

- Encoders:

Encoders are digital position transducers which are the most convenient for computer interfacing. These are rotational position sensors made of an annular portion of a disc with alternate transparent and opaque sectors. A light source and a light detector (a LED and a phototransistor) are located at the two sides of the disc, and detect the passage between them of the opaque and transparent sectors. To measure the value of the rotation angle an absolute encoder must be used (GENTA, 2012).

Figure 29: Encoder (http://www.automationdirect.com)

- Tachometers:

Tachometers are instruments that measure directly angular velocities; they are based on several different principles but usually are better suitable to measure speeds that are not too low. Tachometer generators are small generators yielding a voltage that is proportional to the angular velocity: they are quite widespread in many different applications (GENTA, 2012). Magnetic, optical and laser tachometers have all their field of application.

The frequency of the output of an incremental encoder is proportional to the rotational speed and to the number of divisions of the disc. Encoders with a large number of divisions are needed to measure low speeds in this way.

- Accelerometers:

Acceleration sensors are based on Newton's second law. They are actually measuring the force which produces the acceleration of a known mass. Different types of acceleration transducers are known: stress-strain gage, piezoelectric, capacitive, and inductive.

- Dynamic Sensors

- Piezoelectric:

The most common dynamic force detector is the piezoelectric sensor. It produces a voltage when it is "squeezed" by a force that is proportional to the force applied. The fundamental difference between this devices and static force detection devices such as strain gages are that the electrical signal generated by the crystal decays rapidly after the application of force. This makes these devices unsuitable for the detection of static force (ELETRONICSBUS, 2012).

Figure 30: Piezoelectric (http://www.kistler.com)

The high impedance electrical signal generated by the piezoelectric crystal is converted (by an amplifier) to a low impedance signal suitable for such an instrument as a digital storage oscilloscope (ELETRONICSBUS, 2012). Digital storage of the signal is required in order to allow analysis of the signal before it decays.

Depending on the application requirements, dynamic force can be measured as either compression, tensile, or torque force. Applications may include the measurement of spring or sliding friction forces, chain tensions, clutch release forces, or peel strengths of laminates, labels, and pull tabs.

- Torquemeter:

A torquemeter is a device for measuring and recording the torque on a rotating system, such as an engine, robot. Static torque is relatively easy to measure. Dynamic torque, on the other hand, is not easy to measure, since it generally requires transfer of some effect (electric or magnetic) from the shaft being measured to a static system (ZHAO et al., 2010).

Figure 31: Torquemeter (http://www.romdevices.com)

One way to achieve this is to condition the shaft or a member attached to the shaft with a series of permanent magnetic domains. The magnetic characteristics of these domains will vary according to the applied torque, and thus can be measured using non-contact sensors.

Newer types of torque transducers add conditioning electronics and an A/D converter to the rotating shaft. Stator electronics then read the digital signals and convert those signals to a high-level analog output signal, such as +/-10VDC (ZHAO et al., 2010).

Finally, another way to measure torque is by way of twist angle measurement or phase shift measurement, whereby the angle of twist resulting from applied torque is measured by using two angular position sensors and measuring the phase angle between them (ZHAO et al., 2010).

4.1.2 Exteroceptors

Exteroceptors sensors are used to protect the interface between worker, robot and equipment. These products also help the robot fuse objects together in an efficient, safe and productive manner (OMEGA, 2008).

- Contact Sensors:

  Contact sensors are used to detect the positive contact between two mating parts and/or to measure the interaction forces and torques which appear while the robot manipulator conducts part mating operations.

  The interaction forces and torques which appear, during mechanical assembly operations, at the robot hand level can be measured by sensors mounted on the joints or on the manipulator wrist (OMEGA, 2008).

  - Force-Sensitive:

  The force-sensitive sensors (conductive elastomer, strain gage, piezoeletric) measure the contact forces.

  - Displacement-sensitive:

  The displacement-sensitive (opoeletronic, capacitive) sensors measure the mechanical deformation of an elastic overlay.

- Proximity (“near to”) sensors:

  Proximity sensors detect objects which are near but without touching them. These sensors are used to near-field (object approaching or avoidance) robotic operations (OMEGA, 2008).

  Inductive sensor:

  Inductive sensors are based on the change of inductance due to presence of metallic objects.

Figure 32: Inductive Proximity Sensor (http://www.sick.com)

  - Hall effect:

    Hall effect sensors are based on the relation which exists between the voltage in a semiconductor material and the magnetic field across that material (OMEGA, 2008).

  - Capacitive:

    Capacitive sensors are potentially capable of detecting the proximity of any type of solid or liquid materials.

  - Ultrasonic and Optical:

    Ultrasonic and optical sensors are based on the modification of an emitted signal by objects that are in their proximity (OMEGA, 2008).

Figure 33: Ultrasonic Sensor (http://www.sick.com)

- "Far away" sensors:

  This kind of sensor is responsible for feeling the environment. The monitored area is more comprehensive than with Proximity sensors.

  - Range sensing:

    Range sensors measure the distance to objects in their operation area. They are used for robot navigation, obstacle avoidance or recover the third dimension for monocular vision.

  - Vision:

    A vision sensor (camera) converts the visual information to electrical signals which are then sampled and quantized by a special computer interface electronics yielding a digital image. Solid state CCD image sensors have many advantages like small size, light weight, robustness, and more adequate electrical parameters. This is why they are suitable for robotic applications (ELETRONICSBUS, 2012).

Figure 34: Vision Sensor (http://www.sick.com)

4.2 Wireless Sensor and Actuator Networks

Wireless sensor and actuator networks (WSANs) are a new technology of sensor networks. These networks are composed of small equipment (sensors) and actuators which, in turn, each incorporating processing, sensing and communication with each other (wireless) (MELODIA et al., 2012). The sensor nodes do not need to compute much data and for this reason energy use becomes more efficient. On the other hand, the actuators generally require more processing and communication, as a consequence more energy is needed and this means a longer battery life (XIA, 2007). Regardless, both components have their limitations (processing, energy, etc.).

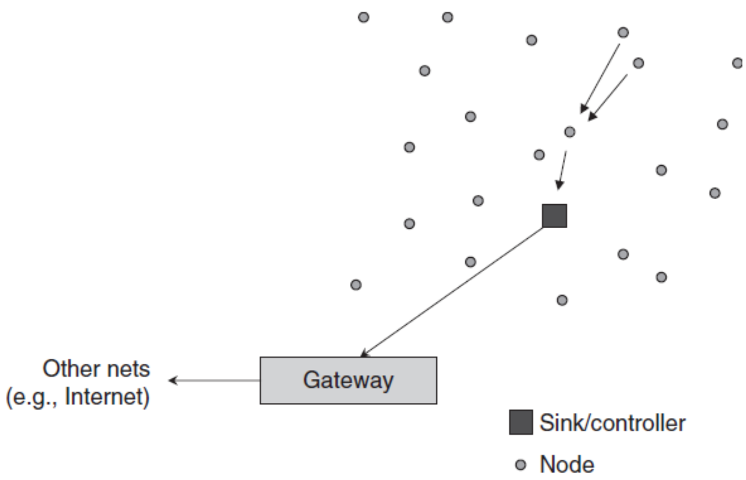

Figure 35: Traditional single-sink WSAN (VERDONE, 2008)

A system consisting of sensors and actuators is responsible for collecting data, e.g., to sense the environment. The data is forwarded, from wireless links (usually RF) to a sink (display or controller). These monitors can process data locally or send them to other networks through a gateway.

Since WSAN allows more flexible installation and maintenance it is used to monitor and control equipment in hazardous and difficult-to-access environments (MAZUMDER, 2010). The native mobile support is the big difference to the wired network, greatly facilitating communication. In their various shapes and forms, they have greatly facilitated the enhanced automated, remote, and intelligent monitoring of a large variety of physical systems. The data obtained in the physical world is sent to controllers/actuators and used to change aspects of the physical environment. In this way, with the ease of wireless communication, the interaction with the physical world is facilitated, as it was mentioned previously.

In industrial control settings, for example, wireless networks can be installed for a fraction of the cost of wired devices and can provide unprecedented flexibility, with high density sensing and deployments in unsafe areas that may be impossible to instrument with standard wired approaches (such as inside waterways, or in high-temperature oil refineries) (DESHPANDE et al., 2005). These WSANs are to be developed by BEMO-COFRA with support for flexibility, reliability, availability and manageability characteristics that are of paramount importance to support dependable operations in harsh environments (BEMO-COFRA, 2011).

Despite all advantages, WSANs face new challenges for control applications. In general, a wireless channel has harsh properties such as path loss, multi-path fading, adjacent channel interference, Doppler shifts, and half-duplex operations (MAZUMDER, 2010). Given these problems, applications can suffer from packet loss and time-varying delay. These problems can degrade the performance and cause system instability (KARLOF, 2002). Another key point is the security issue, especially in wireless sensor networks. This type of network has its peculiarities, so traditional techniques cannot be directly applied to it. In brief, many sensor network routing protocols have been proposed, yet none could be excellent in all aspects (SICS, 2012).

As previously mentioned, the industrial automation scenario presents great threat to wireless communication, however, the proposed standards in this part where designed with special features for surviving the harsh environment. This section aims at the most relevant standards used to interconnect devices in wireless sensor and actuator networks.

4.2.1 IEEE 802.15.4 Standard

The IEEE 802.15.4 standard was created to accomplish a series of necessary requirements in Low-Rate-Wireless Personal Area Network (LR-WPAN). This kind of network has particular features that allows it be well suited for industrial automation scenario.

Among those features, it is important to mention that LR-WPAN has a reliable data transfer and a short operating range, but the greatest advantage is its low cost and easy installation. In addition, it offers an extended battery life and energy saving which consolidates it as one of the best options for adoption in automation domains. The Standard divides the devices in two types. Reduced-function devices (RFD) that communicate only with similar ones and Full-function Devices (FFD) that communicates with both types. (BESTER et al., 2009)

Most automation scenarios require long range communication, high reliability and minimal data to be transfered, e.g.: energy consumption of a welding robot. Machinery automation for instance, can be seen as a scenario where the assembly lines rely on several machines that hold, cut, turn and move materials. Despite a cable structure being more reliable in certain terms, it is nonetheless more expensive. It becomes impossible to move around a machine without having to stop all the production line and besides that, cables and wires are often impacted by exposures to all sorts of products and fragments. In this inhospitable environment, it is common to have to replace or repair the cables every three or four months (CITRANO et al., 2011).

Using IEEE 802.15.4 wireless at the factory environment, this problem of moving and handling machines all over the place is solved. Wherever the machine is going to be, the sensor will connect in the network either way and transmit the data. Maybe this is the most important reason for the adoption of wireless technology in this industry (WEXLER, 2003). Flexible installation can save many minutes of walking every day by remotely moving a switch or controller as needed which also truns system reconfiguration much quicker.

From the standard architecture, to the flexibility of adding in features unique to a specific customer's use, IEEE 802.15.4 can be an ideal wireless solution for countless industrial applications. It offers choices, low cost, low power consumption, and reliable and secure performance.

4.2.2 ZigBee

ZigBee is a well known standard created to work directly with the IEEE 802.15.4 protocol and consequently with low power devices. This technology serves very well the Bemo-Cofra project requirements (ALLIANCE, 2012).

It was designed to allow a reliable wireless communication with low energy consumption and low data rate transmission, being specially dedicated to the purpose of monitoring and control. The standard divides devices into three distinct types, each one have your well defined role in the network as can be seen below (LEGG, 2004):

- ZigBee coordinator: Every ZigBee network has a single coordinator and is probably the most important device due the number of functions it offers. Because of its functionality and its coordination of the entire network, the coordinator should always be powered on.
- ZigBee router: It works just like a common router. It keeps a routing table and, besides the fact that it is an optional device, it has the important function of contributing to the mesh routing and controling the allocation of local addresses to the end devices.
- ZigBee end device: The main function of end devices is to exchange information with the master nodes (usually routers) and because of its simplicity, it cannot send data to other devices. Due to that the need for power and memory is relatively minor.

Communication is typically done through xbee modules connected in any board or microcontroller, as the Arduino example in figure 33. In Bemo-Cofra, each of these modules will be placed on welding robots in order to monitor their behavior.

Figure 36: Xbee Module (www.rogercom.com)

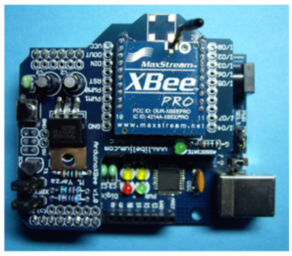

Figure 37: Xbee and Arduino (www.emartee.com)

It is possible to mount a ZigBee network in three different topologies. Star, cluster tree and mesh. For the Bemo-Cofra project, it is only interesting to focus on mesh topology that directly involves the concept of routes, commonly taking several paths from source to destination over the network. Among its features it is essential to quote that every node is capable of connecting to all of its neighboring nodes and usually in case of some of them being added later, the network must automatically reconfigure itself (LEGG, 2004).

These characteristics make this type of topology extremely suitable to the Bemo-Cofra purposes and guarantees to attend the requirements of a future WSAN. The specified maximum range of operation for ZigBee devices is 250 feet, way further than that used by Bluetooth devices, although security concerns may not prove to hold true for ZigBee devices as well.

4.2.3 6LoWPAN

In the concept of the Internet of Things (IoT), there is nothing more promising than the 6LoWPAN standard. It has the ability to interconnect various devices using the IP protocol version 6. This question is critical for a number of factors ranging from the amount of IPv6 addresses to the security methods it already implements.

For the Bemo-Cofra 6LowPan offers the opportunity to assemble the architecture based on IPv6 and thereby be ready for new technologies and devices that may become available in the coming years. IPv6 brings to an embedded device network security which includes through the optional support for IP Security Authentication and Encryption which is commonly used by web-services, technology widely present on the project.

Some key factors to implementation of IP on IEEE 802.15.4 networks (SHELBY, 2009):

- Header:
  - Standard IPv6 header is 40 bytes [RFC 2460];
  - Entire IEEE 802.15.4 MTU is 127 bytes [IEEE];
  - Often data payload is small.

- Fragmentation:
  - Interoperability means that applications need not know the constraints of physical links that might carry their packets;
  - IP packets may be large, compared to IEEE 802.15.4 max frame size;
  - IPv6 requires all links support 1280 byte packets [RFC 2460].

- Allow link-layer mesh routing under IP topology:

- IEEE 802.15.4 subnets may utilize multiple radio hops per IP hop;
- Similar to LAN switching within IP routing domain in Ethernet.

- Allow IP routing over a mesh of IEEE 802.15.4 nodes:
  - Options and capabilities already well-defines;
  - Various protocols to establish routing tables.

- The 6LoWPAN frame format:

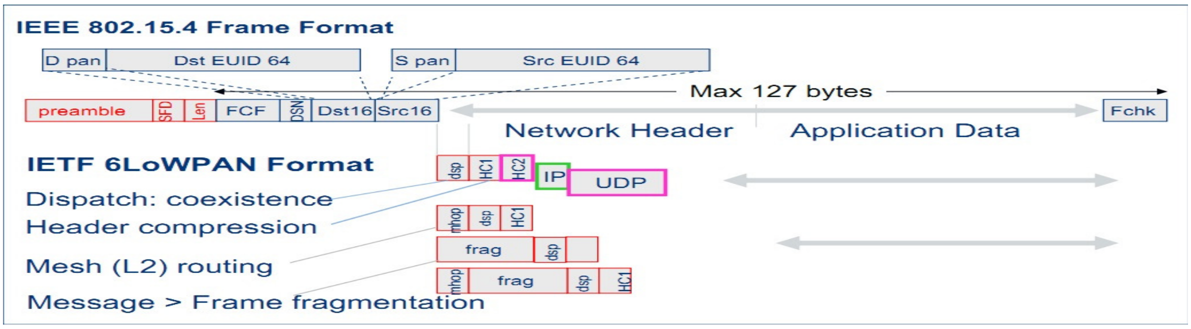

Figure 38: 6LowPan Frame Format (Z. Shelby)

It is good to know that operating systems like Tiny OS and Contiki, both references in embedded devices and sensor nodes, have adopted 6LoWPAN.

The protocol turns IEEE 802.15.4 into the next IP-enabled link and provides open-systems based interoperability among low-power devices and IP devices. Besides that, it has great ability to work with the resource constraints found in WSANS networks.

4.3 Single-Radio and Multi-Radio WSN platforms

Wireless sensor networks attracted much interest due to their versatility and wide applicability, and huge market potential. Recently, WSNs have been considered as the core technology of the emerging Internet of Things (IoT), in which objects with intelligence connect with each other through heterogeneous communication networks and work collaboratively (ZHAO et al., 2010).

The main difference between single-radio and multi-radio WSN is that the first one can operate in just one network protocol and the last one can operate in different protocols, such as Bluetooth + ZigBee. The single-radio platforms also can operate in multi-channels: frequencies are limited by the protocol specification. The use of the multi-radio platforms has been increasing due to need for interaction between different technologies that are becoming more popular. Others differences between these technologies are showed in the next table.

SINGLE-RADIO	MULTI-RADIO
LOW-COST	High-cost
SIMPLEST HARDWARE	Complex hardware
NON-FLEXIBLE	Flexible
LOW DATA RATE	Highest data rate
USUALLY HALF DUPLEX	Full duplex
LOW THROUGHPUT IMPROVEMENT	High throughput improvement
COMPLEX TIME SYNCHRONIZATION	Static or dynamic channel assignment

Table 13: Multi-Radio and Single-Radio Comparative

Multi-radio platforms is higher-cost and more complex than single-radio because their higher functionalities. Usually these platforms are more robust and have a Linux-compatible operation system. The best throughput is achieved using techniques of channel assignment which can change the network topology and the direction of the radio transmission.

The next sections are showed some comparative data about single-radio e multi-radio hardware platforms and the concepts about single-radio and multi-radio software platforms.

4.3.1 Single-Radio Hardware Platforms

The next topic is about the Wismote, a single-radio platform. The preference for this platform as an example is due to its popularity and recommendation for experts. Then others similar technologies are showed in a comparative table.

4.3.1.1 Wismote

WiSMote (ARAGON, 2012) is a Sensor Node IPv6 open platform designed for Research & Development into Wireless Sensor Networks (WSN) developed at the LCIS (Laboratoire de Conception et d'Intégration des Systèmes) in partnership with Arago Systems. It embeds Contiki, a small footprint, highly portable, multitasking Operating System which supports IPv6 (6LowPAN) protocol.

Its main features are:

- Based on a 16-bit RISC architecture;
- Based on IEEE 802.15.4 transceiver providing 250Kbps data rate and targeting 2.4GHz ISM band applications;
- Powered by two AA batteries or USB;
- Unique Serial ID and an external serial Flash memory (256KB flash and 16KB RAM) for data logging;
- Easy-to-install development environment like , for example, Eclipse IDE;
- 250 kbps data rate;
- Onboard Antenna;
- Up to 3 onboard sensors: temperature, luminosity and 3-axis accelerometer ;

- 40 pins expansion connector;
- Extension capabilities: Humity plugin and RS485 interface plugin;

Figure 39: Wismote Board (www.aragonsystems.com)

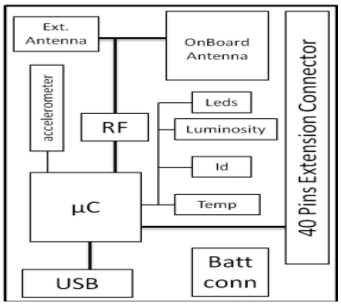

Figure 40: Wismote block Diagram (www.aragonsystems.com)

4.3.1.2 Comparative Table of Single-Radio Platforms Based on BEMO-COFRA Requirements

HW Platform	Pros	Cons
Libelium WASPMote	• It can be used also as multi-radio node (wifi, bluetooth, RFID, ZigBee, GSM/GPRS) • Multiple sensors can be integrated to the board • Processor ATmega1281 (8MHz)/ 8KB (SRAM), 128KB (Flash) • SD card support (up to 2GB)	• 6LoWPAN and Contiki are not supported • No package
STM32W	• Contiki and 6LoWPAN are supported • Sensors accelerometer + temperature • ARM® Cortex™-M3 processor (up to 24MHZ)/ up to16KB (RAM), up to 256KB (Flash) • Robust WiFi and Bluetooth coexistence	• No package • Contiki 2.5 only supports one type of node (MB851revB)
Zolertia Z1	• Contiki and 6LoWPAN compliant and ZigBee™ ready are supported • Packaged nodes • Phydget support (sensors) + Zolertia sensors • MSP430 processor 16-bit MCU 16MHz / 10K/92K (RAM/ROM) • Digital sensors (accelerometer and temperature)	• Minor problems with contiki 2.x
WISmote	• Contiki and 6LoWPAN are supported • Accelerometer 3 axes(Optional), Luminosity, Temperature (Analogue and Digital) • Phydget support (sensors) • TI MSP430F5437x processor (16bit and 16MHZ) / 16k/256K (RAM/ROM)	• No package is provided
Sensinode K320	• Package included • 6LoWPAN is supported • RF interface (2.4GHz IEEE 802.15.4 and Sub-1GHz IEEE 802.15.48)	• Contiki is not supported • No sensors integrated • 8051 Microcontroller Core

Table 14: Comparative table of single-radio platforms

4.3.2 Multi-Radio Hardware Platforms

In the next topic we talk about the BeagleBoard, a multi-radio platform. The preference for this platform as an example is due to its popularity, its variety of applications and recommendation for experts. Then others similar technologies are showed in a comparative table.

4.3.2.1 BeagleBoard (BeagleBoard.org, 2012)

The USB-powered BeagleBoard is a low-cost, fan-less single board computer that unleashes laptop-like performance and expandability without the bulk, expense, or noise of typical desktop machines.

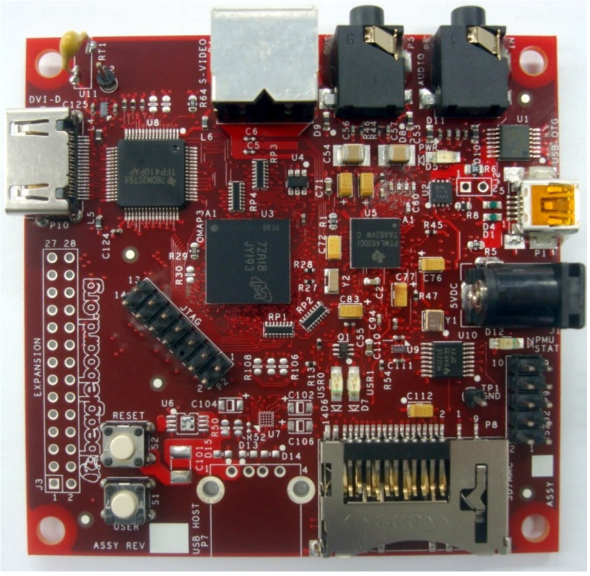

Figure 41: Beagleboard platform

The general-purpose processor performance of the Beagle Board exceeds that of other low-cost computing platforms on the market today, such as the OLPC XO-1. Additionally, the processor contains 2D and 3D graphics acceleration capabilities as well as a DSP optimized for multimedia processing. A typical configuration of a Beagle Board system would draw power off of a USB port on standard laptop or desktop PC used for developing and downloading the low-level Beagle Board software, but additional peripherals would allow the Beagle Board to operate as a multimedia computer on its own.

OMAP3530 processor highlights:

- Over 1,200 Dhrystone MIPS using the superscalar ARM Cortex-A8 with highly accurate branch prediction and 256KB L2 cache running at up to 600MHz
- OpenGL© ES 2.0 capable 2D/3D graphics accelerator capable of rendering 10 million polygons per second
- HD video capable TMS320C64x+ DSP for versatile signal processing at up to 430MHz
- USB power via complete chip-set with minimal additional power-consuming logic
- Expansion capability and power options
- DVI-D for connecting digital computer monitors
- Compatibility with a huge collection of USB peripherals including hubs, keyboards, mice, WiFi, Bluetooth, web cameras, and much more

- MMC+/SD/SDIO interface for memory or wireless connectivity
- S-Video out for connecting your NTSC or PAL television or wearable visor
- Stereo audio in and out for a microphone and headphones or speakers
- Power via typical USB chargers for cell phones from your laptop, from an automobile adapter, from batteries, or even from a solar backpack

4.3.2.2 Comparative Table of Multi-Radio Platforms Based on BEMO-COFRA Requirements

HW Platform	Pros	Cons
BeagleBoard	• ARM® Cortex TM -A8 MHz at 1 GHz • 512MB of low-power DDR RAM • On-board four-port hub with 10/100 Ethernet • It's possible add a dongle to use another network interfaces (WiFi, Bluetooth)	• No sensors already integrated • Doesn't have multiple network interfaces already integrated
Meshlium	• 256 MB (DDR) RAM / Processor 500MHz • Up to 32GB storage (SD/MMC) • Wifi Mesh Dual Band 2.4 GHz / 5GHz Radio, Ethernet, Bluetooth, Zigbee, GPS, GPRS/GSM connections • Linux system, Debian • Aluminium enclosure with IP65 protection	• No Bluetooth 4.0 (just only 1.1) • Response to ethernet ping = 60s • No sensors integrated
Snowball	• Bluetooth 4.0 Included • 3D Accelerometer/Magnetometer, 3D Gyrometer and Pressure sensor • Android, Meego and Ubuntu complaint • 1GB Mobile LPDDR2 SDRAM x32 / Dual Core Arm Cortex A9 (1GHz) + MALI 400 GPU • 10/100 Ethernet and WIFI Bluetooth® (BT4.0) GPS Combo Module • 3D Accelerometer/Magnetometer, 3D Gyrometer and Pressure sensor	• No package
Rasperry PI	• Broadcom BCM2835 700Mhz • 256MB RAM • 10/100 wired Ethernet RJ45 (The Ethernet is driven via USB 2.0, so the upstream bandwidth would not support Gigabit.) • It's possible add a dongle to use another network interfaces (WiFi, Bluetooth) • Price	• No sensors already integrated • Doesn't have multiple network interfaces already integrated

Table 15: Comparative table of multi-radio platforms

4.3.3 Single-Radio Software Platforms

For controlling the sensor nodes, the hardware needs an embedded operation system. Tiny OS and Contiki are chosen due to their popularity and the possibility of using at BEMOCOFRA project. The next topics describe them.

4.3.3.1 CONTIKI

Contiki is a small open source, highly portable, multi-tasking operating system used in networked equipment with computation restrictions, from 8-bit computers to embedded systems on microcontrollers, including memory-efficient networked embedded systems and wireless sensor networks. This is considered the main operating system for the next billion connected devices: the internet of Things (TINYOS, 2012).

Contiki provides a simple event driven kernel with optional preemptive multithreading, interprocess communication using message passing signals, a dynamic process structure and support for loading and unloading programs, native TCP/IP support using the uIP TCP/IP stack (uIP provides the protocols TCP, UDP, IP, and ARP) (SICS, 2007). Additionally, the interaction with a network of Contiki sensors can be achieved with a Web browser, a text-based shell interface, a networked virtual display with VNC or Telnet or dedicated software that stores and displays collected sensor data.

The native TCP/IP support, mentioned earlier, allows tiny devices to communicate with each other and the outside world using very little power. One of the main innovations in Contiki is the ability to communicate using the Internet protocols (IPv4 and IPv6) even in resource-constrained systems (TINYOS, 2012). Contiki supports 6LoWPan header compression, IETF RPL IPv6 routing, and the IETF CoAP application layer protocol, among many other protocols and mechanisms.

On the other hand, support for loading and unloading programs are implemented using a run-time relocation function and binary format that contains relocation information. When a program is loaded into a system, the loading program can be aborted. This occurs if the loader could not allocate sufficient memory based on information provided by the binary. If the program has been loaded successfully, the loader calls the program's initialization function (KARLOF, 2002). The initialization function may start or replace one or more processes.

In order to provide sensor network lifetime, it is crucial to control and reduce the power consumption of each sensor node. Contiki provides a software-based power profiling mechanism that keeps track of the energy expenditure of each sensor node. It detects when the network is down, being able to power down the node. Power conservation mechanisms depend on both applications and network protocols. The Contiki kernel contains no explicit power save abstractions, instead, it permits the application specify parts of the system that implement such mechanisms (DUNKELS et al., 2004). The event scheduler, exposing the size of the event queue, help the application decide when to power down the system. It occurs when there are no events scheduled. When the processor wakes up in response to an interrupt, the poll handlers are run to handle the external event.

Contiki has been used is a variety of projects and therefore many applications can be mentioned such as road tunnel fire monitoring, intrusion detection (VOIGT, 2004), wildlife monitoring, and in surveillance networks (FINNE et al., 2008). Many key mechanisms and ideas from Contiki have been widely adopted in the industry. The uIP embedded IP stack, originally released in 2001, it is today used by hundreds of companies in systems such as freighter ships, satellites and oil drilling equipment. Contiki and uIP are recognized by the popular nmap network scanning tool.

About the technical specifications, to execute applications, for a device running Contiki is that it has a small microcontroller with a few tens of kilobytes of memory, a wireless low-power communications device such as an IEEE 802.15.4 CC2420 chip, a set of sensors, and a battery. Despite providing multitasking and a built-in TCP/IP stack, Contiki only needs a few kilobytes of code and a few hundred bytes of RAM. A full system, complete with a graphical user interface, needs about 30 kilobytes of RAM. And a typical Contiki configuration consumes 2 kilobytes of RAM and 40 kilobytes of ROM (SICS, 2007).

4.3.3.2 Tiny OS

TinyOS consists of an operating system, a development environment with open source, a model and a programming language. The OS is very simple and compact, designed to support some of the requirements of WSNs (wireless sensor network), which can be intensively concurrent and may need minimum hardware requirements and energy savings (PETRIU, 2002). It meets some RSSF challenges well and has become the platform of choice for sensor network research. It supports a wide range of applications and research fields, therefore used by hundreds of groups around the world.

TinyOS has good compatibility with other technologies used in sensor systems. Some examples are listed below (LOUREIRO et al., 2004):

- Support for the epic, mulle, and shimmer2 platforms;
- Support for 6lowpan, an IPv6 networking layer within the TinyOS network (extensive interoperability, established security, established network management tools, transport protocols, most “industrial” (wired and wireless) standards support an IP option);
- Support for simple, uniform low-power networking across many protocols;
- Support for security on the CC2420 radio;
- Improvements to many existing services and protocols, including the inclusion of a new dissemination protocol (DHV), improvements to CTP, improved TOS Threads documentation, and numerous bug fixes.

The sensor nodes are inherently concurrent (multiple events can occur at the same time) since they are monitoring real-life experiences. Several events may become concurrent, the tasks that will respond to these events should be performed efficiently and the operating system must be designed so that all of them can be met on time (LEVIS et al., 2007). Thus, TinyOS, operating system designed for low-power wireless devices has been built to work with limited resources and facilitate the development of software components focused on efficiency and modularity.

To allow competition, TinyOS has an event model that uses little memory space. This model achieves a gain of 12 times compared with the model of context switching (LOUREIRO et al., 2004). This is a positive point for the operating system, since sensors have limited energy and processing.

As a service provider, it provides interfaces and components that implement the core services of a WSN application. Examples: set of interfaces for various types of sensors that can be used in a sensor node, energy management, among others. The power manager, in turn, allows the machine to go into "sleep" mode whenever the task queue is empty. For this reason, the machine gets very low energy expenditure prepared for an incoming event.

In response to global supplies consumption concerns, the Bemo-Cofra system will be focused at energy consumption. The application-specific nature of TinyOS ensures that no unnecessary functions consume energy, which is the most precious resource on the node. However, this aspect alone does not ensure low power operation. For example, three aspects of TinyOS low power operation support: application transparent CPU power management, power management interfaces, and efficiency gains arising from hardware/software transparency. The sleep mode reduces the power usage, as it was mentioned previously. The use of split-phase operations and an event driven execution model reduces power usage by avoiding spinlocks and heavyweight concurrency (e.g., threads) (LEVIS et al., 2007).

The scheduler alone cannot achieve the power levels required for long-term applications; the application needs to convey its runtime requirements to the system. TinyOS addresses this requirement through a programming convention which allows subsystems to be put in a low power idle state. Calling the stop command causes a component to attempt to minimize its power consumption, for example, by powering down hardware or disabling periodic tasks. This strategy works well: with all components stopped, the base system without the sensor board consumes less than 15 μA, which is comparable to self discharge rate of AA alkaline batteries. The ability to replace software components with efficient hardware implementations has been exploited to yield significant improvements in energy consumption in our platform. The hardware implementation of these software components consumes less than 100 μA and allows for much more efficient use of microcontroller sleep modes while providing a 25-fold improvement in communication bit rate (LEVIS et al., 2007).

4.3.4 Multi-Radio Software Platforms

Below, is showed some operation systems that are used in multi-radio platforms with ARM microprocessors. The Arm architecture has grown increasingly popular in the past few years as manufacturers are creating more low-powered tablets powered with Arm chips. These OS are adapted versions of well-known OS.

4.3.4.1 Ubuntu

Ubuntu is the most popular linux distributions for ARM microprocessors. The ubuntu versions to ARM can be found at Ubuntu ARM Team (Ubuntu wiki, 2012). Many companies, as Texas Instruments and Toshiba, contribute for the OS development. Ubuntu Core is a sub-set of Ubuntu technologies ideally suited for the next generation of connected screens where Internet connectivity is the key. It takes advantage of the extensive hardware, architecture and component certification work done by Canonical so that manufacturers can build great experiences on set-top boxes, in-vehicle infotainment systems and digital devices for the home. Also, ARM processors are already a key presence in the data center powering devices such as networking routers and storage controllers. With the availability of higher performance, multi-core capable processor cores, the breadth of applications that can be addressed by ARM technologies is broadened, requiring advanced server-capable operating systems. These data centers can use Ubuntu Server to power advanced workloads such as distributed data processing or cloud infrastructure.

4.3.4.2 Android

Android platform is a software stack for mobile devices including an operating system, middleware and key applications. This OS is widely used around the world.

The Linaro.org (Linaro.org, 2012) releases builds of an android version for Panda, Snowball, Beagleboard, iMX53, iMX6, Origen, and Versatile Express platforms named Ice Cream Sandwich. Its main features are (Igloo Community, 2012):

- HDMI display support (with limitations)
- Graphics acceleration with the Mali 400 GPU
- Bluetooth support (with limitations)
- Ethernet and Wireless connectivity
- microSD card support
- ADB over network and USB
- GPS support
- Multimedia acceleration (with limitations)
- Sensors support (accelerometer, magnetometer, gyroscope, barometer)

Other version of android is the Embinux Embedded Linux Platform (E-ELP) (SQL STAR INTERNATIONAL INC., 2012) and was designed and optimized for Wireless Handsets, Mobile Phones and Smart Consumer Electronics Devices. Android port for Beagle Board was announced by Embinux Team on beagle board mailing list. Its main features are:

- Hardware support to OMAP 1, 2, 3, MSM 7X, 8X, DaVinci, MIPS reference platform
- Storage (IDE/Flash/SD)
- Network (Ethernet 802.3, WiFi 802.11a/b/g, WiMAX 802.16)
- Display (Serial Console, Framebuffer, Touch Screen, LCD)

- Multimedia (OSS and ALSA supported audio chipsets, Camera Interface)
- I/O (Serial, IrDA, SDIO, USB), GPIO
- External DSP Interface
- Timers and Watch

4.4 Types of Sensors in Comau´s Framing Station

A major concern in the automotive industry is that of high precision and efficiency, both are characteristics closely related to the machines used in the process. In order to improve quality, sensors have been used systematically, and as a result, regular machines are becoming more efficient. The systems are now supplemented with various sensors to achieve consistent results, for instance, more accuracy and security. This section presents the most common sensors that are being used in the client´s floor: inductive proximity sensors.

Inductive Proximity Sensors detect metal objects without touching them. This technology is used in applications where the metal objects to be detected are within an inch or two of the sensor face. This kind of sensor can be used in the harsh environments on automotive welding equipment. (Rockwell Automation, Inc, 2012)

Inductive Proximity Sensors – BALLUFF:

	Figure 42	Figure 43	Figure 44
HOUSING SIZE	18 mm	18 mm	18 mm
NOMINAL SENSING RANGE	12 mm	12 mm	12 mm
SUPPLY VOLTAGE	10 – 30 Volt DC	10 – 30 Volt DC	12 – 30 Volt DC
RATED OUTPUT CURRENT	200 mA	200 mA	200 mA
FREQUENCY	2500 Hz	500 Hz	150 Hz
IP RATING	IP 67	IP 67	IP 67
CONNECTION TYPE	M12 Connector, 4 wire type	S4 M12	S4 M12
AMOUNT IN CURRENT USE	280	1155	115

Table 16: Comparative table of Sensors

Figure 42: REF. BES-M18ML-PSC12E-S 04G-W (Pennine Components Ltd., 2012)

Figure 43: REF. BES 516-326-S4-W (Balluff Inc., 2012):

Figure 44: REF. BES M18MI-PSC80B-S04K (Balluff Inc., 2012):

5. Conclusion

The document describes the current status of the automotive manufacturing robots and the role of sensors/controlling systems at COMAU´s factory floor. A study on the modern technology of Wireless Sensor Networks and its integration with robots is also presented in order to support the idea of the BEMO-COFRA project.

First of all, a brief overview on the main areas of an automotive line and its robots is presented. However, the welding process is a major concern because of its relevance in this kind of scenario. Furthermore, information on our client´s floor such as its network requirements, PLC´s and other important devices are also investigated.

Moreover, the main sensor network protocols, standards and platforms are presented, illustrating its key role on the task of monitoring physical or environmental conditions, specifically in an automotive line. This part of the document focusses in the technology to be applied in the BEMO-COFRA network architecture.

In addition, the most common types of sensors and their role in robotic quality are discussed in the assembly line production context. The last section is concerned with the integration and behavior of these devices, which are divided into two groups, based on the type of information that is required.

The information in this document has special application on the network architecture that will be projected based on what was collected in terms of devices, therefore creating a bridge between COMAU and all the partners. Additionally, by providing an analysis of the WSAN's technologies, it opens the possibility of creating laboratorial tests using this type of network.

Finally, our visit to COMAU´s factory was beneficial in many ways. The main contribution was the possibility of creating a test lab directly in our client´s floor, which the advantage of predicting unexpected behavior of the prototype, differently from a local lab.

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