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Enhanced control architecture for achieving effective resources management within waste water treatment solution usage

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Abstract. Continuous degradation of the environment has raised up to authorities serious concerns and triggered a cycle of actions meant to reduce to the minimum the impact of social and economic actions on the surrounding environment. At the European Union (EU) level, authorities have developed specific standards and financial mechanisms in order to quickly react to unwanted environmental changes, which each EU state has to consider. This paper work presents an experimental approach that may help to reduce the impact on environment from the waste water treatment process point of view by smart usage of technological equipments and still being cost effective. The first part presents the importance of having a healthy environment and the actual situation in Romania an EU member. Secondly, a survey held to a local producer of waste water treatment solutions summarizes the identified drawbacks from the automation point of view. The third part describes the methodology and concept behind the proposed control architecture and its advantages. The fourth part introduces the authors' view of how the proposed solution can be employed to achieve a superior management of resources in order to have a smooth and problem-free process of waste water treatment. In the end, are presented the conclusions upon the importance of this research paper. Moreover, future research directions are established.
Key Words: environment, waste waters treatment, control architecture, resource management.

Introduction. "No water users, anywhere in the world, can be guaranteed they will have uninterrupted access to the water supplies they need or want..." is the beginning phrase of the latest United Nations comprehensive report on water which is meant to warn local governments to manage with great care freshwater resources (WWAP 2012). A healthy, sustainable and eco-friendly environment is directly connected to the quality and quantity of water resources and how they are administrated (Rosegrant et al 2002), which makes local authorities and population responsible for its current condition.

Water covers more than two thirds of the Earth's surface and it's vital for all life forms, but only around 2.5% of it is freshwater and available for usage (Wikipedia 2012). The gentle subject of fresh water is denoted by the fact that less than 0.3% is surface water that can be found in rivers and lakes and even more, it is uneven distributed on Earth (Shiklomanov 1993; WWAP 2012). Thus, on global scale, almost one billion people lack sustainable access to safe and clean water sources accordingly to United Nations Children's Fund and World Health Organization report (WHO, UNICEF 2012).

At the global scale, the usage of freshwater has reached 54% of resources and it is split between three main sectors: food and agriculture, which uses about 70% of water resources for growing crops and livestock in order to achieve food security; industry and energy utilizes around 20% for goods production and energy generation together with domestic use or household, nearly 10% including all the related activities (WWAP 2009). It is predicted that fast demographic growth will increase the demand of water by 50% in developing countries and by 18% in developed countries by 2025 (Unwater 2012).

Water pollution represents the outcome, from freshwater, of the above mentioned sectors with impact on the environment, ecosystems, hydrological cycle and if extrapolated, on society healthiness and sustainability as well. Water pollution and its effects represents one of the world's major concern since its estimated that 80% of the worldwide wastewaters are not treated nor collected (Corcoran et al 2010), which have been identified as leading facts to serious water related dieses and severe changes to ecosystems. Even more, confirmation of global climate changes are quantifying the freshwater stress since climate change its seen as the main driver of world water resources (WWAP 2012).

These facts clearly underline the importance of achieving a sustainable water management at different levels of society: economy, health, food, sanitation, energy, industry and environment, thus, wastewater treatment processes have become imperative.

On the map of freshwater resources from Europe, Romania can be found at the bottom of the list, being one of the country with reduced water resources (40 billiards cubic meters), but still over the global average per capita (m^3/inhabitant/year) with the following distribution of water usage: 60% used by industry, 17% by agriculture and 22% for domestic use (Eurostat 2012; EEA 2012; FAO 2012; Unwater 2012).

Being an EU member, Romania has committed to apply the Water Framework Directive in order to achieve a better quality of water resources by 2018. Figure 1 presents a quantitative evolution of wastewater collection and treatment over time (ANAR 2012).

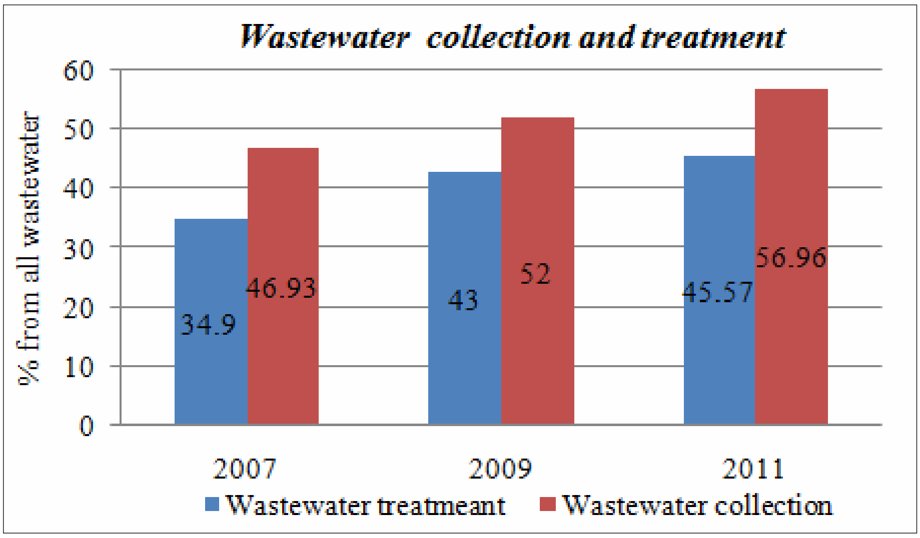

Figure 1. Wastewater collection and treatment over time (ANAR 2012).

Even though efforts are made by local authorities to obtain the expected results by the EU, there is a big difference between the degree of wastewater collecting systems availability and the level of collecting systems connected to the wastewater treatment plants considering urban and rural areas. Regardless rural areas, only up to 10% of wastewaters are collected and even lesser are treated (Ecomagazine 2010).

The problem. Some major issues generated by applying improper treatment and sanitation of freshwater and polluted water are listed underneath:

- water diseases: around 3.4 million people are dying every year from water related diseases and almost one billion don't have access to clean water (Water 2012);
- environment pollution: 70% of industrial wastes are dumped untreated in developing countries destroying specific ecosystems (WWAP 2012);
- alteration of the water cycle: thus increasing the presence of extreme weather phenomena, together with rising stress related to food security.

It is estimated that 2 million tons of sewage drain into the environment every day, infiltrating into world's water cycle, thus at the European Union level has been developed a legislation with respect to wastewater treatment and a financial mechanism meant to help local authorities to reduce the above mention issues and align with EU requirements until 2018. Considering water pollution and wastewater treatment, it can be said that

Romania is dealing with serious problems since only about 60% from all its wastewaters are collected and close to 50% from the collected wastewater is treated, from which only 22.6% accordingly to the actual European legislation as published in a report of the environment agency in may of 2012 (Environment 2012).

Some of the facts that led to such a reduced efficiency of wastewater treatment in Romania have been identified and enclosed in research papers by Vulpuşan (2010) and Vlad (2006), most important are:

- increased execution time and construction costs;
- poor quality and quick deterioration of developed solutions;
- insufficient specific data with respect to wastewater and environment properties;
- inappropriate technological treatment solution;
- modest automation performance.

Other important shortcomings of the developed water treatment plants from the automation point of view are summarized as results to a survey taken inside the electrical and automation department at S.C. ICPE BN, an important local producer of water treatment solutions with over 25 years of experience:

- reduced level of re-configurability;
- lack of distributed intelligence to equipments;
- increased execution and programming time.

Another major drawback is the noticeable difference between equipment producers and solution provides "know-how", which has an impact on overall performances of treatment plants. Considering these aspects a short question arises: "How efficient and cost effective are the currently deployed wastewater treatment solutions?"

This paper work is intended to bring enhancements from the automation and electric point of view by proposing an experimental and still in development control architecture for achieving effective resources management within water treatment solutions usage and still presenting the advantage of being cost effective.

Methodology. In order to sketch and establish the design of the new control architecture and smart equipment concepts the following actions have been undertaken:

- identification of actual water treatment plants disadvantages based on the work experience and available know-how of the electrical and automation department;
- estimate the positive impact of solving or taking a step closer to solve some of the identified problems or disadvantages;
- establish a suitable, realistic and cost effective framework for a solution capable to reach our goal in providing an enhanced control architecture;
- build an experimental testing bench and carry out specific tests in order to identify advantages and drawbacks of the proposed design;
- establish if the proposed solution is feasible and identify future research directions.

Proposed versus traditional control architecture concept. An increased number of small to medium wastewater treatment plants are about to be constructed, in order to meet European Union Water Framework Directive (2000/60/EC) by the end of 2018, and considering the medium to reduce efficiency of the available automation solutions, together with water importance to all life forms an enhanced control architecture concept is presented in Figure 2.

The above mentioned control architecture concept is mainly built from a control unit, smart equipments (sensors and units), which depending on their importance to the process can be configured as high or low priority equipments, all of them linked together by a communication protocol, used to exchange information with the control unit or among the smart equipments.

The number of high priority equipments that can be connected to the control unit is directly related to the number of available physical connections of the control unit with the outside world, instead the number or low priority equipments that could be connected to the control unit by using only the communication protocol is undefined but still related to electrical characteristics of the communication protocol. The main difference between high and low priority smart input equipments is that the first mentioned has the possibility to let the control unit know that it requires attention and trigger specific procedures on the control unit side, by using the direct physical connection, based on its own information management algorithms and configuration. Low priority smart input equipments will have to wait until the control unit asks for a report from their side. On behalf of high priority smart output equipments, the control unit has the ability to quickly trigger specific controlling sequencing using the physical connection and the communication protocol, in contrast with low priority smart output equipments which can only be triggered or controlled via the communication protocol.

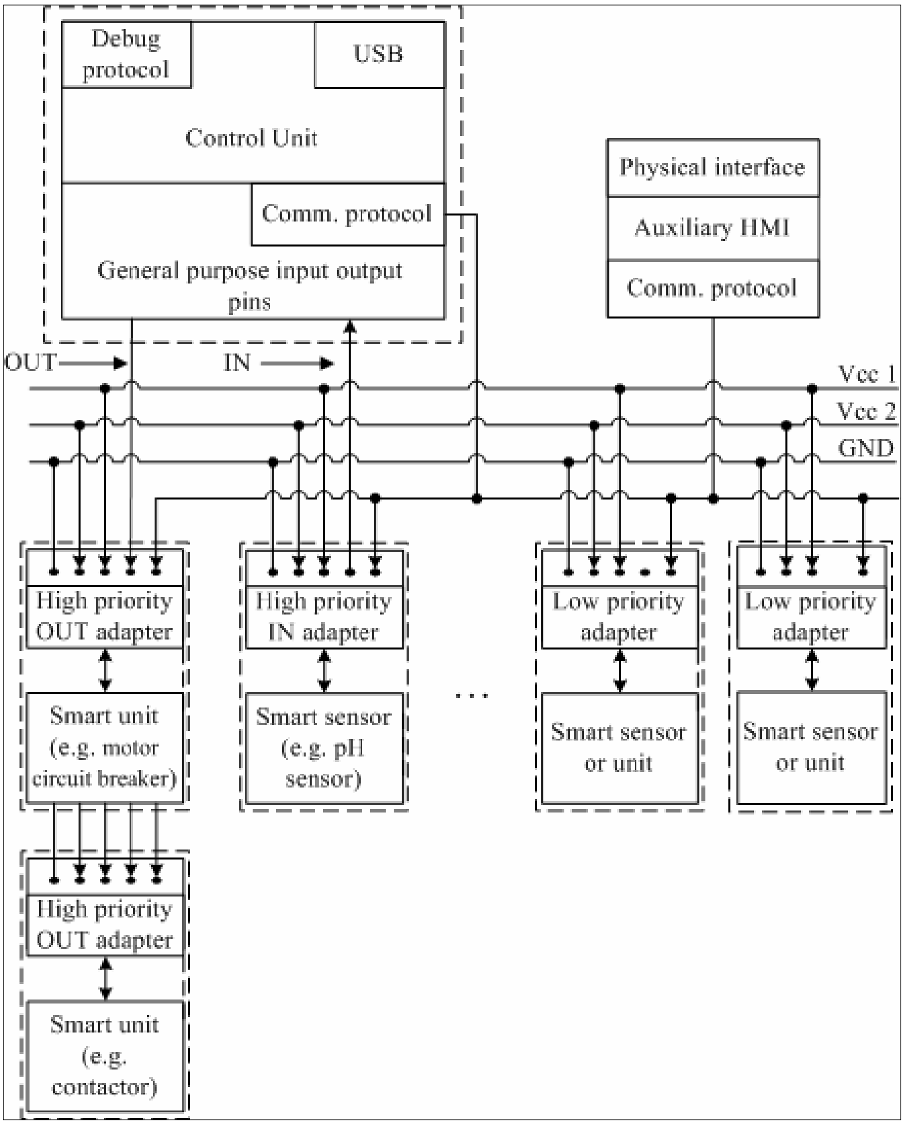

Figure 2. Simplified concept of the proposed control architecture.

In comparison with a programmable logic controller (PLC) the main control unit advantages are:

- high level of re-configurability and adaptability: is achieved by the ability of the main control unit to configure the direction (input or output) of its connections with the outside world depending of the connected equipment, at any time. PLC's connection to the outside world are predefined and cannot be changed. For example, in case of a water treatment process that requires 13 inputs and 6 outputs, the main control unit will quickly adapt its connections to process needs without involving any costs, besides the

PLC will require an additional extension module to cover process requirements, which means additional costs;

- plug - and - produce support: represents another important advantage of the proposed control architecture that will allow immediate recognition and integration of the connected equipment, resulting in reducing the execution time of the automation solution together with an increased level of information management, this kind of feature being completely unavailable for traditional PLCs. Tacking over, upgrading or fixing a water treatment station without any certain information about the applied technological solution, equipments role in the process and technical characteristics, would take an increased amount of time until the situation is clearly understood. Considering the proposed control architecture when connecting a smart equipment to the communication protocol the main control unit quickly identifies it, exchange information with the equipment and lets the user know about the available information gathered from the equipment by using the Human Machine Interface;

- direct USB connectivity: it was chosen as a communication background for programming or exchanging information between a PC HMI (in development) and the main control unit. Usually PLC's producers are providing programming methods that are using old communication protocols like RS485 or RS232 together with custom cables, adapters and firmware's all of them meaning additional costs. Among the fact that only one cheap cable is needed, USB connectivity was preferred since all notebooks supports it and this fact comes in handy when programming or maintenance is made on the site;

- interrupt driven operating systems: are capable to better use main's control unit resources and deploy increased performances reported to the PLC scan cycle. Illustrated in Figure 3, is how a PLC operates together with the important steps of the scan cycle versus how the proposed control unit works. A PLC reads the inputs from the process, executes the ladder diagram or program and adjusts the outputs, unlike the control unit which is running tasks from the program and by means of interrupts reacts to any change of inputs with a specific interrupt routine at any time, which grants reduced reaction time.

Figure 3 presents in big lines the most important steps of the two control architectures, considering two inputs and two outputs. During the *t read* time period, the PLC reads all inputs state, creates an input map and saves it in the memory for using it the next step of the PLC. Any other change of inputs outside the reading time phase is ignored. Considering our example in the input map only input 0 (IN 0) is mapped as logic HIGH, even though input 1 (IN 1) changed its state just after the reading phase ended it's considered as logic LOW and it will only be recorded as HIGH if keeps its state during the reading phase of the next scan cycle. The input map is used over the *t process* time period, where the program inside the PLC, would process the input map and based on the stored program will generate a result and store it for the next step. In our example we consider that any input which is logic high will drive the corresponding output high. The third time period *t adjust* is used to changed outputs state accordingly to the result from the second step.

Even though we report to milliseconds as time units, in case of an emergency button that is pushed after the reading phase, the process would identify the emergency command just in the second scan cycle and stop the process in the third phase of the second cycle. Also, considering input signals of high frequency, the probability of not being correctly mapped is very high, which may result in misleading information and process outcome.

Driven by a real time operating system, the proposed architecture is capable to quickly and independently react to inputs and adjust outputs by means of interrupts. Interrupts are specific special procedures which can be prioritized and assigned to inputs, but not only, and they poses the ability to stop the normal flow of a program task and trigger a handler procedure to immediately deal with the changes and adjust the program or the outputs. How the proposed control architecture deals with a similar situation in which the PLC was involved can be seen at the bottom of Figure 3. When input 0 (IN 0) change its state the specific interrupt stops the program and takes control by triggering the interrupt handler, then the output is updated accordingly and the program is resumed from where it has been stopped. Also the main control unit supports nested interrupts, this is the case when an interrupt with a high priority is generated when already inside an interrupt handler as a result of inputs state. This case is also presented in Figure 3 where after an interrupt handler was triggered as a modification of input 0 (IN 0) state, and while inside the input 0 (IN 0) interrupt handler, input 1 (IN 1) change its state and triggers its interrupt handler which by having a higher priority is solved first and then the program returns to input 0 (IN 0) interrupt handler. As a result of this, output 1 (OUT 1) is adjusted before output 0 (OUT 0) even if inputs get modified in a different order.

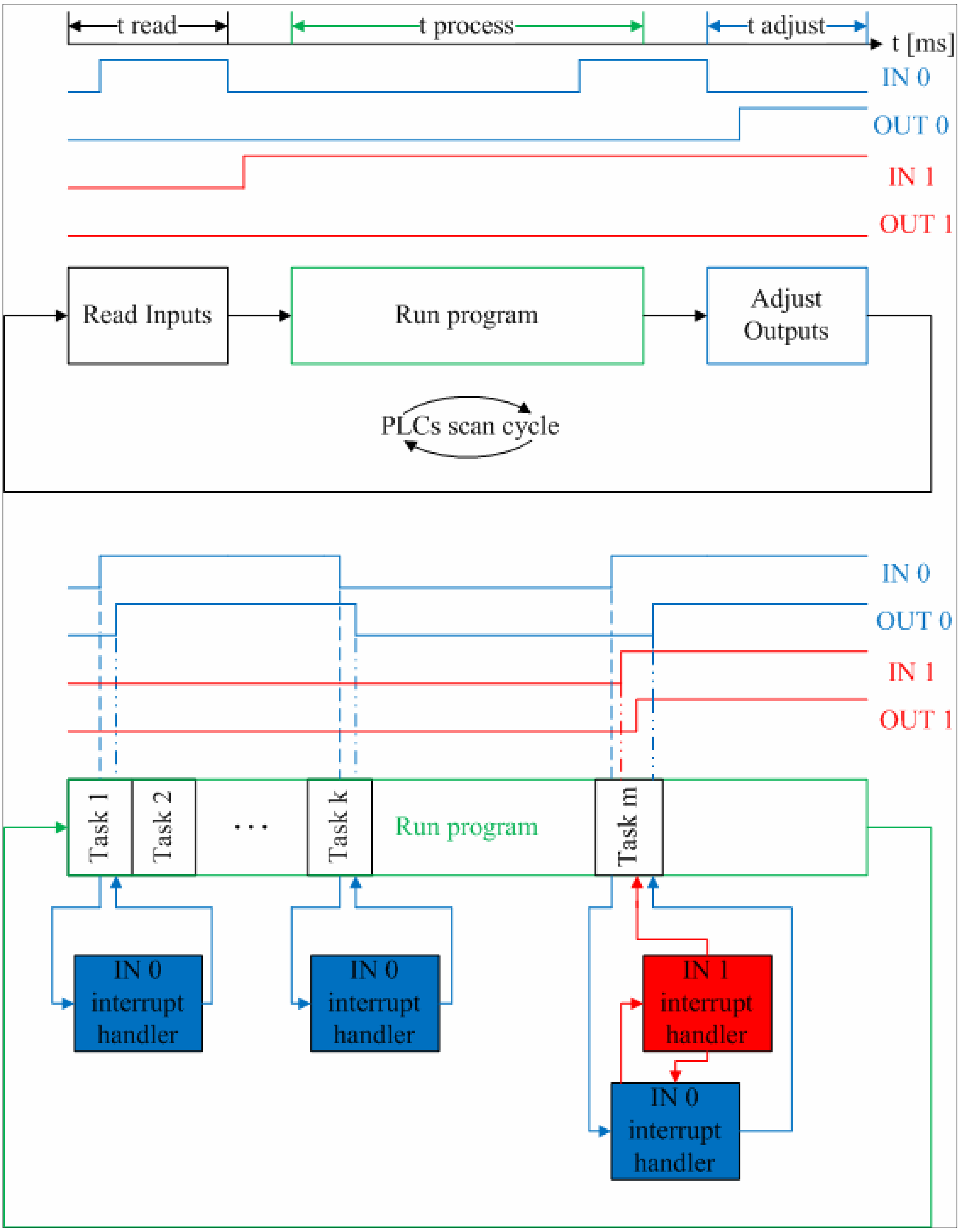

Figure 3. Programmable logic controller versus main control unit operating mode.

This control architecture overcomes the reported disadvantages of the PLC and could come in handy especially when applying chemical treatment to the water by achieving a smooth dosing control of involved chemical substances.

Smart sensors as presented in Murar & Brad (2012) and in Figure 4 are embedded solutions, where the sensor is included into a custom hardware design driven by a microcontroller forming by itself a fully functional equipment. Endowing this embedded design with distributed intelligence, by software means with respect to available hardware configuration, it was possible to increase equipment overall performances.

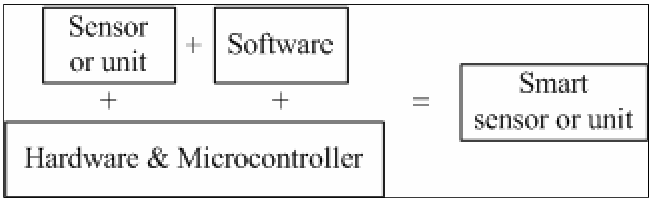

Figure 4. Smart sensor or unit framework.

Even though the performances of available sensors for water treatment, related to the process of measuring a physical quantity and converting it into an electrical signal, are high enough to met expectations, by employing this design a series of advantages are gained:

- better accuracy: is achieved since the analog signal, generated by the sensor is converted to digital information as close as possible to the source of physical parameter by the microcontroller and the result, digitally sent via the communication protocol, as opposed to traditional approach where the analog signal of the sensor has to travel long distances before reaching the analog module of the PLC. In the last case, the signal may be subject to electromagnetic perturbation especially if the cable through which the signal is traveling is not shielded or is close to power cables coming from frequency converters, resulting in misleading data;
- plug - and - produce capability: helps sensors to be identified and auto integrated by the control unit of an automation process which makes sensors even more easy to use. The only operation that the user has to do is to connect the sensor to the communication protocol than the interactive configuration process is started by the control unit and the smart sensor through the human machine interface. Plug and produce together with other functionalities are based on smart sensor distributed intelligence which can be implemented by software means by the sensor producer or third party companies;
- high level of information management: is accomplished by the ability of the microcontroller inside the smart sensor to configure itself, manage data, act and react as required by the operator during the configuration process. Up to authors knowledge, most of the automation systems are based on a centralized architectures, which has been proven to be complex and hard to debug. A decentralized automation architecture can be achieved by means of efficient information management. Having sensors capable to process data locally, keeping an advanced data log, report when asked by the control unit and, or in case of high priority smart sensor to trigger alarm signals when abnormal situation have been encountered would reduce the computational effort of the control unit, increase overall performances, reduce programming time and achieve a more manageable automation system;
- additional functionalities and configuration options: for smart sensors are implemented by software algorithms and their result will be presented in the following chapter.

Usually automation processes are receiving the electric signals from sensors and based on a look up table or a small algorithm they find the corresponding value of the measured physical quantities, still it is not a very accurate and efficient method. By applying the above mentioned smart sensor architecture, sensor producer or third party companies could implement specific algorithms in order to obtain the closest value to reality of the measured physical quantities, increasing the overall performances and accuracy.

Smart units as illustrated in Figure 4 is an under development concept similar to smart sensors, which will be applied on equipments (e.g. pumps, mixers, blowers), protection and control devices (e.g. circuit breakers, contactors, relays) that will allow achieving a series of advantages:

- preventive maintenance: is mainly achieved by avoiding equipments to failure. Inside the distributed intelligence of smart equipments, algorithms that are capable to manage product life cycle will be used for achieving preventive maintenance. Considering a relay were the producer guarantees one million on-off cycles, the preventive maintenance software will keep track of the cycles, working conditions and equipment aging and when the equipment is about to end its life cycle the operator is informed about this situation and advised to replace the equipment since it may malfunction or stop working and cause increased damage or control problems;
- execution mistakes: are caused by human error especially on repetitive jobs, like building similar automation cabinets or when working on more than one project. This type of mistakes are envisaged to be overtaken by the control unit which gathers information from all the connected equipments, identifies compatibilities issues and stop specific equipment from being controlled. In case of placing a smart contactor of 9 amps in cascade of a smart motor circuit breaker with a tripping current range of 13-18 amps, the control unit will detect this abnormal situation based on the mismatch between technical characteristics stored inside the distributed intelligence of each smart equipment. The control unit will stop any driving command of the contactor and alert the user;
- cost reduction, by means of preventive maintenance and overtaking execution mistakes that can led to equipment malfunctions or full damage;
- short control loops, by assigning smart sensors to smart equipments the information loop will be shorter, leading to a short control loop and reduced computational effort of the control unit since it will be only informed about the taken actions.

As stated earlier in this paper work the advanced PC-HMI is under development, in this way a simpler physical HMI was used to test and prove the feasibility of the presented control architecture by switching between available configuration options and selecting the desired operation of connected equipments.

Application example. In order to test the control architecture and smart equipment concept an experimental testing bench was constructed (Figure 5). Within the test bench the concept of control unit (1) is build around a high performance Atmel microcontroller capable to work at frequencies up to 60 MHz's. At the top right side of the image, a specific embedded solution for the concept of smart input equipments (3) is deployed for accommodating a temperature sensor. The human machine interface or HMI (4) can be observed on the bottom right of the picture and on the bottom left there is the signal and power distribution unit (2), which provides the support for connecting smart equipments or other devices like the HMI (4) to the control unit (1).

Considering the smart temperature sensor, employing creativity and software algorithms several configuration options and additional functionalities were deployed and they are available for selection by the user in the process of equipment configuration or process configuration:

- smart equipment configuration:
  - select the resolution of Analog to Digital Converter: 8 or 10 bits,
  - set the time and data: Yes or No,
  - keep track of working hours and operating conditions: Yes or No,
  - alert operator when maintenance dates or mean time to failure are close: Yes or No,
  - use mathematic model to identify equipment aging: Yes or No;
- smart equipment functionalities:
  - select the temperature system to be used: Celsius or Fahrenheit degrees,
  - specify temperature sampling time: from milliseconds up to hours or days,

- signalize temperature spikes and misleading data: Yes or No,
- send information to a specific equipment: select from equipment list.

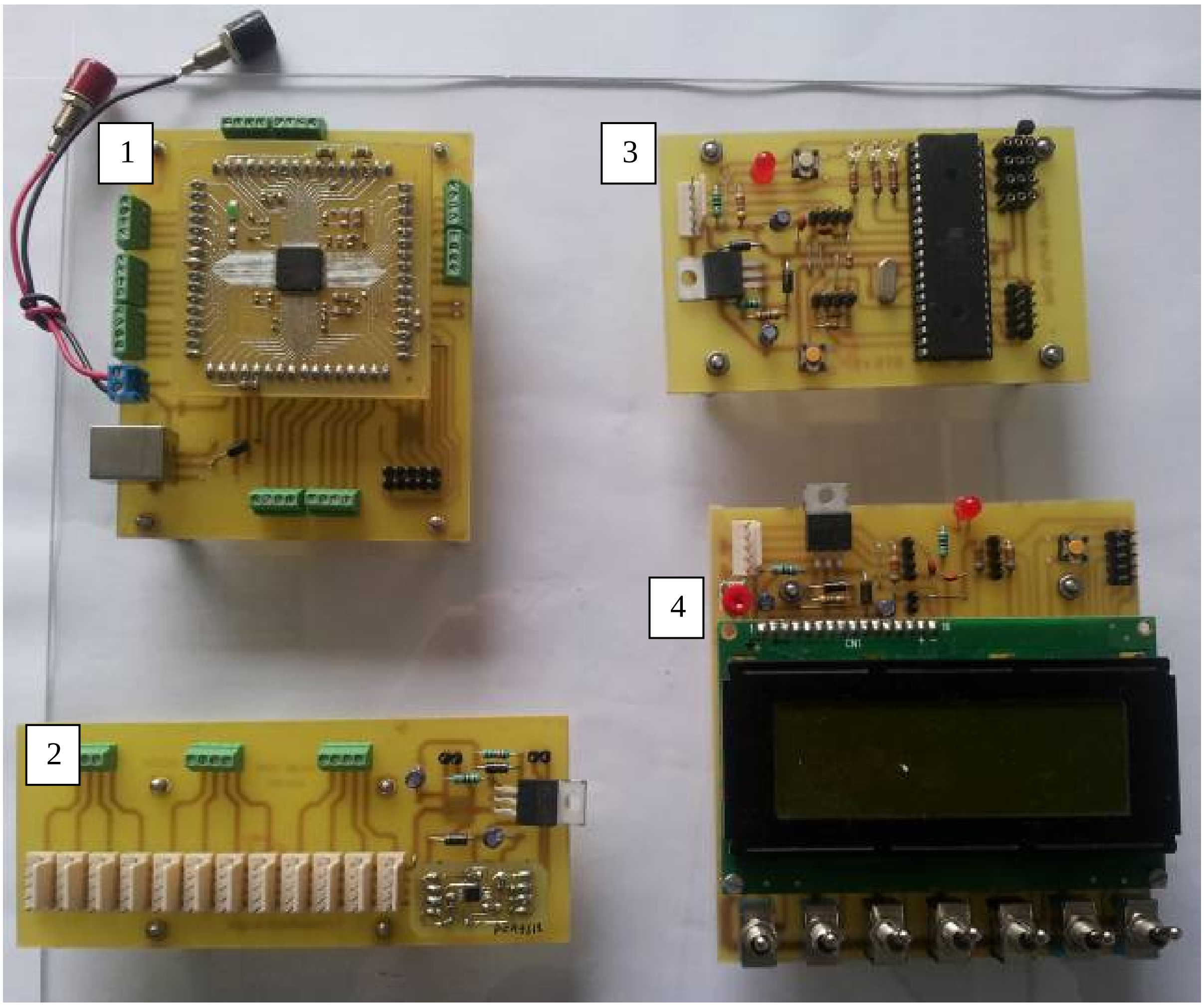

Figure 5. Experimental test bench (without connecting cables).

Testing the control architecture and smart equipment was performed without significant problems only some software adjustments were required to fully align with the presented concept, outlining the fact that enhanced control architecture and smart equipments are realistic and can be achieved with reduced costs considering the overall price of water treatment solutions and their importance.

Advantages. Among the features of this novel and experimental control architecture are: high level of re-configurability and adaptability to the connected smart equipments, plug and produce support for achieving easiness in building the automation system from both hardware and/or software point of views, USB connectivity with full functionality for portable computers to remove the need of old serial port or additional cables, interrupt driven control system and high accuracy of measured parameters for achieving a smooth and precise water treatment process, distributed intelligence, preventive maintenance, possibility to endow smart equipments with additional functionalities and configuration options are meant to achieve a superior management of resources while using the water treatment solution together with achieving a certain level of process decentralization and high scalability.

Conclusions. The concepts presented in this paper work can be easily adapted to equipments which are used in water treatment plants. They can be enhanced with additional functionalities and configuration options which are subject to the hardware constraints, creativity and programming abilities. Additional algorithms could be implemented by the equipment producers in order to reach the full potential of the equipment used and thus achieving better overall process performances.

Is envisaged that the presented control architecture can be applied to water treatment plants with a capacity of up to 2000 equivalent inhabitants. In order to successfully control bigger water treatment plants, some modifications have to be done, but the concept remains more or less the same. Even though, at micro level the benefits of applying the proposed solution may not be of great importance, applied at macro level they can gain significant importance.

The results of this experimental control architecture and smart equipments together with the advantages they bring, could help achieve a better level of efficiency and functionality of water treatment processes. The encouraging results obtained, made that even more resources to be employed for future research, in order to provide a stable and fully functional large scale automation for water treatment plants using the presented concepts.

Smart units development, for accommodating and enhancing water treatment equipments, and an advanced human machine interface based on the USB communication protocol are the next research directions that have been established to be deployed in order to achieve the full potential of this control architecture.

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