FUSE Application Experiment 1817
Dissemination / Demonstrator document

Electronic Control System for Load Balancers

AE number: 1817
New Technology: Microprocessor
Contact TTN: COTEC
Publicity status: Update

Abstract description

Manipulación Asistida, S.A. is a 22-employee Spanish company which designs, produces and sells pneumatic manipulators called “load balancers” since 1973. Such manipulators are developed to aid handling and manipulation of heavy and cumbersome loads through manufacturing and assembly operations, allowing the operator to position or transfer the object with the minimum of effort. Typical application areas of this product are the assembly lines of automotive industries, warehouses or machine tool loading/unloading operations.

The objective of the AE was the improvement of the old manipulator, that used pneumatic technology both for driving and control functions, in order to lift heavier weights, get a more precise control of the movement, and simplify the programming procedures to customise the manipulator to the specific load to be moved.

The goals were attained developing a microcontroller-based control system. This technology was selected as the one that offered lower cost and the maximum possibilities of personalising to the specific needs of this type of product and at the same time was open to re-programming both during the work at the customer’s site to adapt it to different loads and at the factory to configure different types of manipulators. The effort of the operator was reduced from 5-8% of the total load to 2%, and the response of the system was faster, from 1.5 seconds to less than one second. The main problem to be solved, and the current limit for the increase of the performance was the unstability of the system, that required a careful adjustment of the pneumatic circuit.

This new control system has been developed in 9 months and the total cost of the project has been 43,5 KECU. The expected payback period is two years, and the average yearly return of the investment for a 3-year period is around 22%.

First User Company Profile

Company name: MANIPULACION ASISTIDA, S.A.
Company size: 14
Industrial sector(s): ME

Company size, personnel involved and expertise & experience prior to the Application Experiment

Number of employees is 22 with 3 large experienced engineers in mechanical design, 5 designers working with CAD systems and 4 specialists in pneumatics and mechanics. The size of the company has grown from the 14 employees at the time of starting the AE, one reason being that a competitor stopped his business.

Two pneumatics and balancers industrial applications specialists (Mr J. Bilbao and Mr. J.A. Pardo) were involved in the experiment.

The company is part of the Vicinay Group (1000 employees), manufacturer of heavy chains like i.e. for offshore platforms. The revenue of MA is around 2 MECU, with about 70% of this amount on handling devices.

Expertise and experience of the company prior to the AE

Manipulación Asistida, S.A. designs, manufactures and installs load balancers for a range of industrial users. The company has developed load-balancing devices for handling, palletizing and assembly operations of many different industrial applications. The company has large expertise in mechanics design and pneumatics. The company has developed and patented its own technology for load balancers and they are continuously looking for new possibilities and developments of their products, but did not have electronic design and development expertise, nor posses any experience in developing electronic solutions prior to the AE. The control system used previously for their products is a purely pneumatic circuit.

The objective of this application experiment is to improve the performance of the load balancers using an electronic control system. As first users of electronic control technology, the company will gain knowledge on possibilities and techniques to be used with this technology and its advantages over pneumatic control devices.

The company is a first user of electronic technology and has no capacity to assume in-house electronic design and development. Production of the electronic control system developed in the AE will be ordered to third companies working on electronics production.

Company business description

Manipulacion Asistida, S.A. designs, produces and sells load balancers. These load balancers are not standard, but specially custom-designed in order to solve the requirements of each application. The company offers to their customers turnkey installations to solve existing manipulation problems due to the shape, weight or breakability of the object to manipulate. Customers are mainly car manufacturers (70%). 80% of the company's customers are located in Spain.

These pneumatic manipulators are used for handling, palletizing and assembly operations involving many different components, such us: bags, boxes, bodywork components, glasses, pedal units and so on. Instead of the operator having to manhandle heavy and awkward objects, he can, with the aid of these manipulators, lift, turn, and position or transfer them with the minimum of effort. Application of these manipulators improves productivity, eliminates physical troubles for operators (back pain) and solves handling problems.

The load balancer is supplied with purpose built grippers designed for each application. For example, suction pads, pneumatic clamps, magnetic grippers and so on. Several types of load balancers are shown in the attached pictures at the end of this document.

The company's current production includes different types of manipulators covering a wide range of lifting capacities and operating areas. Floor, wall and overhead mounting positions are possible. Overhead mounting can be fixed or on moving trolley to increase working area and give clear floor space underneath. Attached pictures show different types of such manipulators.

The revenue of MA is around 2 MECU, with about 70% of this amount on handling devices.

Company markets

The load balancers produced by Manipulación Asistida, S.A. are an expert and efficient solution for a wide range of manipulating operations involved in different manufacturing processes. These pneumatic manipulators are applied through manufacturing, packaging and assembly operations, including:

Heavy parts and tools manipulation.

Car assembly operations.

Machine tool loading/unloading operations.

Palletising operations.

The company has developed load balancers for a wide range of industrial sectors, like chemical industry, paper producers, automotive industry, and so on, having in common this need of moving heavy weights with some requirements of speed and precision.

Main customers of the company, buying 70% of the handling devices are in the automotive sector, and include most of the automotive companies located in Spain, like Renault, Citroen, Peugeot, Opel, Mercedes and Firestone. The reason of this concentration is that this industry has more requirements of quick and precise movement of heavy loads – i.e. the positioning of the engine or the assembled dashboard – than the others, where sometimes the manipulator has to compete with other, more classical solutions like a crane or a fork lifter.

The nature of this market is strongly local: between 80 and 90% of the company's customers are located in Spain. There are two reasons for this lack of 'globalisation': the first is the need of providing very customised products: not only the grippers must be different for each type of load to move – glass, paper rolls, assembled equipment – but also the geometrical structure must be adapted to the available space, i.e. the more common approach of the load hanging from an upper structure cannot be used if it has to be introduced through the door of a car, and specific 'pantograph type' structures have to be developed. Hence the supplier of the equipment has to work very closely with the customer in solving the customer problems.

The second reason that restricts the competitiveness with distance is the cost of transport and installation of these heavy structures that increases with the distance to the customer.

Company competitive position at the start of the Application Experiment

At this moment the Spanish market for load balancers represents about 5.625 KECU.

Manipulación Asisitida, S.A. currently has approximately 25% of the Spanish market for such products. Main customers are located in the automotive industry with a share of 50% of the total sales of the company and a 22% cumulative increasing rate.

There are few companies competing with this type of products in this area, due to the local nature of the market explained in previous paragraph. All are using the same pneumatic technology but one that is using electrical actuators, so there are not big differences in performance, and we could say that what makes the competitive edge is the ability to supply the customer with optimum, personalised solutions: customer service is the key. In this sense, having the flexibility of an electronic control vs. the pneumatic control system can make the difference for getting higher market quota.

The need for being able to move with precision heavier loads is coming mainly from the automotive industry, due to the tendency to get bigger and bigger sub-assemblies done by external suppliers, which mean a higher weight to move to position them in place. The current barrier in terms of weight was around 100 Kg, where the conventional, pneumatic controlled, solutions have come to their limits so it seemed that a new technology was necessary to improve manipulator's performance. So the acquisition of electronic technology has been a strategic decision to get a stronger position in the market.

No specific quantitative goals were placed in terms of speed, of course the fastest the better, specially in a production chain, but as the current response time was around 1.5 seconds, there was not much margin to win, as the response of the human operator is in the same range. Faster response has more to do with operator's comfort, combined with an agile and predictive response. This parameter was more difficult to quantify beforehand, but it was felt that an easily programmable PID algorithm as microcontroller technology could provide, will offer much more possibilities than the more rigid pneumatic controller.

Where time could be saved was in the programming process previous to the handling of a set of loads of the same weight, where the operator must proceed to equilibrate the load by adjusting the pressure. This time could be saved if the balancer had a way of memorising predefined weights, so the switch from one type of load to other could be a matter of pushing a button. This was again a feature that electronic systems can do more easily that pneumatic ones.

Combining these features, a critical competitive edge would be gained due to the improvement of load balancer's performance. Such improvement and the company image will be an important competitive advantage that will increase total sales around 15%.

Application Experiment Information

Product / System name: Load balancer
Industrial Sector of Product: ME

Description of the product improved and its industrial sectors

Industry sectors:
Automotive industry.
Chemical and textile industry.
Paper producers.
Distribution companies.

The product to be modified by the inclusion of a microcontroller is the company's load balancing arm. This device is a pneumatic manipulator used to aid load handling with a purpose built gripper at the end of the arm. The manipulator is driven by a pneumatic actuator that works counterbalancing the weight of the piece attached to the manipulator's gripper. Thus, the operator can move, tilt or lower loads with a minimum of effort.

The basic operation of the load balancers is as follows:

- The operator hooks the object or piece that he wants to manipulate to the piston of a pneumatic cylinder.

- Air is supplied to a chamber of the cylinder. The air pressure in the cylinder increases until the force developed by the cylinder exceeds the weight of the object and it hangs in the air.
- Once the load has been counterbalanced, the pressure in the cylinder must be kept constant at the equilibrium value. A Pneumatic Precision regulator device is used for this purpose.
- When the object has been counterbalanced, the operator can move it as if it was weightless and he needs a minimum effort to manipulate the object.
- The attempts of the operator of lifting or lowering the object are detected as a decrease or increase of the pressure in the cylinder's chamber. The precision regulator detects these changes and acts restoring the pressure to the reference value.

One of the main problems of this method is that the operator's applied force has to be transmitted, through the manipulator structure, to the cylinder chamber. So small forces are not detected because they don't modify cylinder's pressure and there is a delay between force application and pressure modification. With the current pneumatic control system the effort that the operator has to apply to move an object is about 5-8% of the handling load.

Response time and sensitivity are essential characteristics of the balancing system. Having a short response time and better sensitivity, in fact, means that the operator develops less effort to translate a load. Current response time was around 1.5 seconds.

The objective of the experiment is to improve the regulator's response time and sensitivity using an electronic control system.

Examples of specific manipulators can be seen in the attached pictures.

Description of the technical product improvements

The objective of the application experiment is to integrate a digital control system into the current pneumatic circuit in order to get a faster response of the load balancer to the operator's attempts.

The new control system includes a stand-alone control board to manage a closed-loop system that continuously monitors the load at the end of the arm and corrects for any errors modifying the reference pressure of the precision regulator.

The main components of the control system are:

- A load cell (i.e., force transducer) is placed between the end of the manipulator's arm and the gripper, to provide a direct load reading. The load cell allows a continuous monitoring of the weight supported by the manipulator. This sensor detects any non-constant load such as those occurring when the operator attempts to move the load.
- Proportional pneumatic solenoid valve that converts an electrical input signal into a corresponding air pressure value. The output pressure of the proportional valve is used as reference signal for the precision regulator.
- The microcontroller that performs the following basic functions:
  - Read the load sensor signal.
  - Calculate air pressure value that compensates load weight and drive the proportional valve to get such pressure.
  - Detect load changes and calculate the control signal to the proportional valve in order to cancel pressure changes.
  - Provide continuous monitoring of the supported weight.
  - Provide set-up functions in order to adjust control parameters for each manipulator.

The microcontroller allows any mathematical manipulation on load cell and proportional valve signals. A PID type algorithm has been implemented for the control loop. The different parameters of the control law can be adjusted for each application so a more flexible system has been obtained.

A PID algorithm has been used to control this system. The transfer function of the controller is given by:

$$G_{cp}(s) = \frac{U(s)}{E(s)} = \frac{K_p * s^2 + K_d * s + K_i}{s}$$

The value of Kp represents the controller gain. The proportional gain Kp amplifies the detected error so as to increase the speed of response. The derivative component (Kd) acts when the error signal changes and increases the speed of response of the system during the transient period. The integral component (Ki) is used to get a better response of the system once the system gets steady state.

Some service tests were carried out in order to evaluate system performance and get a linear approximate system's model. The experimental results show that the pneumatic system performance can be modelled as a second order system with a delay. The simplified transfer function obtained from these tests was used to simulate the PID control effect and get experimental values of the controller parameters Kp, Ki and Kd. Using these values as a starting point the controller parameters were finally tuned during the final tests of the control system.

Main features of the developed digital control system are as follows:

- Power supply: 24 Vdc
- Analogue input for load cell signal connection.
- Analogue output for proportional valve control.
- Digital optically isolated inputs used to receive sensor signals and operator commands.
- Digital electromechanical relay outputs used to drive solenoid valves and communication with external devices.
- User panel including a digital display and controls.

Figure 1 shows a diagram of the microcontroller-based control system.

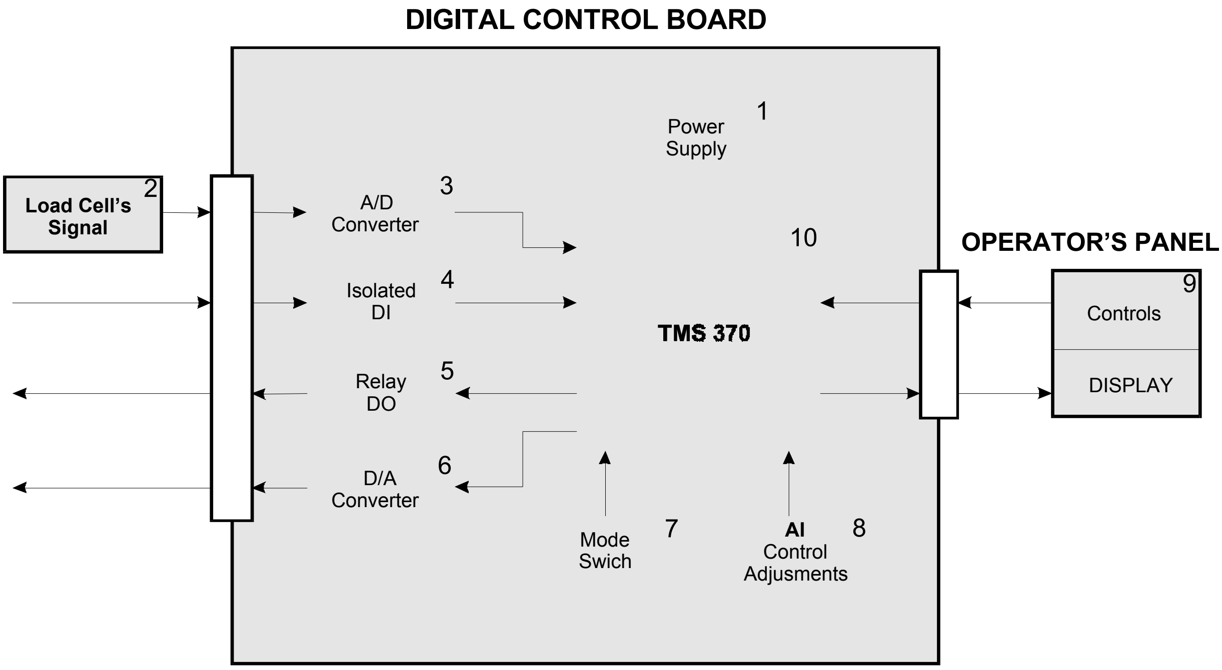


Figure 1 - Diagram of the improved control system

Main benefits obtained from the application of the microcontroller are commented below.

The main benefit is the improvement of load balancer's performance, basically in terms of speed of response and sensitivity:

- The reaction of the manipulator to the operator attempts is faster, (less than one second) when in the previous system it was 1,5 seconds. This reduces the effort required to move loads or objects.
- The sensitivity of the system has been increased. With the pneumatic control system the effort that the operator must develop to move an object is around 5-8% of the handling load. The use of the electronic control system gets a reduction to 2% of this required effort. A trade-off is here necessary between speed and sensitivity and system stability, otherwise vibrations may appear.

The developed control system is a flexible system that can be adjusted for each application. Set-up functions have been implemented in order to help operator during system installation and maintenance operations:

- The time for adjusting the pressure to the weight of a new load has been reduced from the previous 8-10 seconds to the mere push of a button.

The system can now communicate through the isolated Data Interface with the factory main computer.

- This of course was not possible with the purely pneumatic approach, and opens a wide field of possibilities - automatic adjusting, maintenance, scheduling - that now are only starting to be perceived.

The operator has continuous display of the weight supported by the manipulator.

The digital control system has been designed for fast change of the PCB.

An important reduction in size and weight has also been achieved.

Choices and rationale for selected technologies, tools and methodologies

Different solutions available for the implementation of the new control system were evaluated using the following main criteria:

- Cost of the solution taking into account the number of manipulators produced by the company: obviously, the higher the cost the more difficult to sell the new product, so the new electronic solution should not be much more expensive than the pneumatic components it replaces.
- Another obvious parameter to consider concerning cost is the number of units to sell that in the most optimistic forecasts will never surpass the range of hundreds per year. This excludes technologies, like ASIC, MCMs or MSTs that require higher production to be economically feasible, and focus the choice to off-the-shelf components. Concerning the sensing element, a standard load cell like the used for weighing equipment is perfectly suitable to the application.
- Ability of companies in the area to provide the new control system, both for fabrication and maintenance purposes: if the supplier is far from the company the problems may grow. Also, the company should have reasonable confidence in the supplier’s previous experience, to be sure that they will not use the project for learning.
- A mature technology is therefore preferred to a brand new one, if it can provide the required performance. In this case the requirements put to the electronic control are not as stringent as to require very special technologies.
- Adaptability of the solution for future applications, so the same board can be used in the factory for different types of products, or can be programmed at the user’s site for different tasks. Thus a digital, programmable technology is preferred to a hard-wired digital or analogue.

Potential solutions to the company’s requirements are:

Commercially available solutions, like digital controllers or PLCs: Commercial digital control circuits are available, and could be used in this application. However, this solution has not been selected due to the following reasons:

- The price per unit of a purpose built controller is less than the cost of the commercial available systems – it may cost around 25%, depending on the peripherals included.
- A purpose built control system includes exactly the required features needed for the application. PLCs, being a general-purpose device, normally include extra elements that are not used but have to be paid.
- A purpose built controller, being an ‘open’ solution, increases the technology level of the company, as it allows a wider scope of possibilities. The company has to explore them to decide what is the optimum solution for the current product – and what possibilities could be interesting to future developments.

Microcontrollers: These devices clearly meet the flexibility requirements for the new control system. Microcontrollers allowed all the target requirements to be achieved, so reduction of the PCB size and costs is achieved.

Furthermore, microcontrollers are programmable systems so performance of the control system can be modified easily and future product improvements implemented.

A wide range of microcontrollers were considered for the application, and although there were many possible candidates that could fit well for this application, the selected device from this assessment exercise was a 8-bit, CMOS microcontroller with on-chip EEPROM storage and peripheral support functions. Key features of the selected microcontroller are as follows:

- 8-bit devices offer superior performance in complex, real-time control applications than the too simple 4-bit ones. 16-bit devices would of course offer more performance, but it was not necessary here, as the speed of the electronic part is not critical (the pneumatic part of the control loop is always much slower). Obviously, the cost of 8-bit the devices is cheaper, as well as that of the development system that is also easier to use. Also the experience of the use of these devices in industrial applications is higher.
- 512 bytes RAM module and 512 bytes EEPROM module are useful for constants and infrequently changed variable store.
- 16 Kbytes CMOS EPROM technology provides EPROM for re-programmable and OTP program memory to be used as prototypes and for small-volume or quick-turn production.
- Integrated 8-bit A/D converter.

- Configurable I/O ports. They can be configured by the software as data, control and address lines for external memory. Any bits not needed for external memory can be programmed to be either a digital input or output.
- Built-in serial interface programmable to be asynchronous.
- ESD protection.

Although this device does not contain an integral D/A converter, required to drive the proportional valve, this function can be provided by a DAC circuit at low cost. The final design of the product will use a one time programmable (OTP) version of the device. EPROM versions have been used during development.
The digital controller consists of a PCB with 30 components distributed in two layers. The application doesn't have special size requirements, so it's no reason to use a multi-layer distribution. This also represents the lowest packaging alternative for the device.
Software development has been conducted in "C" language using the appropriate device support tools including software and emulation hardware that facilitate simplified software development, maintenance and test. Here again, the programming language choice was a question of availability of the development tools – running on standard PCs – and the existence of software modules libraries that allow a shorter development time.

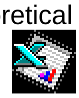
Expertise and experience in microelectronics of the company and the staff allocated to the project

This was answered in previous paragraphs. Here is a copy:

Manipulación Asistida, S.A. designs, manufactures and installs load balancers for a range of industrial users. The company has developed load-balancing devices for handling, palletizing and assembly operations of many different industrial applications. The company has large expertise in mechanics design and pneumatics. The company has developed and patented its own technology for load balancers and they are continuously looking for new possibilities and developments of their products, but did not have electronic design and development expertise, nor posses any experience in developing electronic solutions prior to the AE. The control system used previously for their products is a purely pneumatic circuit.
The objective of this application experiment is to improve the performance of the load balancers using an electronic control system. As first users of electronic control technology, the company will gain knowledge on possibilities and techniques to be used with this technology and its advantages over pneumatic control devices.
The company is a first user of electronic technology and has no capacity to assume in-house electronic design and development. Production of the electronic control system developed in the AE will be ordered to third companies working on electronics production.
Two pneumatics and balancers industrial applications specialists (Mr J. Bilbao and Mr. J.A. Pardo) were involved in the experiment. They had no previous experience on electronics.

Workplan and rationale

The theoretical and real workplan of the project can be seen in the attached Excel file:



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The total duration of the project was 9 months, instead of the 6 months planned during proposal generation. The main reasons for this deviation were:

- The workload of the company at the beginning of the project caused a delay on finishing specification task.
- During the design task it was decided to produce a first fast PCB prototype. This prototype was used for functional and integration tests. During these tests some hardware modifications were introduced. And after these tests final optimised PCB's were produced.
- During validation tests it was decided to include a different user panel. There was one month delay on receipt of this new panel.

No special technological risks were perceived for the development of the electronic unit, as the technology was a very well known and mature one, and the speed and precision requirements of the application were not critical.
The main concern was on the integration of the pneumatic, mechanical and electronic part, and the closing of the feedback loop, as this would be the moment when the right modelling of the dynamics of

the pneumatic and mechanical parts had to be assessed. This risk was minimised by allowing an easy programming of the dynamic parameters of the PID algorithm, both in the electronic part of the loop – very easy via the In-Circuit-Emulator – and in the pneumatic part of the loop, using special valves or dampers.
The key phases of the application experiment were as follows:

1. Requirements Specification:
Description: During this task a detailed specification of the new electronic control system was developed including: functional requirements, necessary set-up and adjusting functions, selection of mayor hardware components, basic design of the operator's panel, final test approach, and so on. The company's manager completed this task with assistance from the subcontractor.
Duration: Planned: 1 month Real: 2 months
Effort: Company: 4 person·days Subcontractor: 20 person·days

2. Hardware and software design:
Description: During this phase the prototype hardware of the digital control system was designed by the subcontractor. The architecture and main modules of the software were defined too by the subcontractor. The company's manager reviewed final designs.
Duration: Planned: 2 month Real: 2 months
Effort: Company: 1 person·days Subcontractor: 20 person·days

3. First prototype production:
Description: An initial PCB layout was developed and a fast prototype PCB was produced. The components were assembled on the prototype PCB by the subcontractor.
Duration: Planned: 1 month Real: 1 month
Effort: Subcontractor: 10 person·days

4. Software Development:
Description: Software functions defined during the design task were developed by the subcontractor.
Duration: Planned: 1 month Real: 2 months
Effort: Subcontractor: 17 person·days

5. Functional tests:
Description: The first prototype hardware was tested using software tests modules developed for the application. Each developed software function was tested individually.
Duration: Planned: 2 weeks Real: 2 weeks
Effort: Subcontractor: 6 person·days

6. Integration tests:
Description: During this phase, the developed microcontroller, load sensor and proportional valve were integrated with the load balancer. Once hardware integration was finished, the developed software was integrated with the constructed prototype hardware and initial system testing was conducted by the subcontractor with support from the company. Further software modifications were implemented to improve controller performance.
Duration: Planned: 1 month Real: 2 months
Effort: Company: 1 person·days Subcontractor: 15 person·days

7. Final prototype production:
Description: Due to the results of these tests the initial hardware design was modified and optimised. Final PCB layout was developed, 3 prototype PCB's were produced and components mounted.
Duration: Planned: Real: 2 months
Effort: Subcontractor: 7 person·days

8. Validation tests:
Description: Formal testing and trials of the completed prototype were conducted by the company assisted by the subcontractor. Final software modifications were implemented and the performance of the prototype product complied with the specifications.

During these final tests it was decided to design and produce a new cover for the operator's panel. Delays on the reception of this cover caused to delay project finishing.
During this task user documentation has been generated including the information needed by the company to be able to: install and set-up the developed digital control system in the load balancers, learn controller operation, to manage industrial production of the developed electronic control system and so on. This documentation has been used during company's group training task.
Duration: Planned: 2 months Real: 2 months
Effort: Company: 6 person·days Subcontractor: 12 person·days

Subcontractor 1

Name: Robotiker
Size: 100

Business
Technology Transfer Centre specialised in electronics and mechanics, including technologies as robotics, machine vision and electronics design and development.

Relevant Expertise & Experience
Electronic design, assembly and test. Integration with mechanics.

Services provided
Electronic design and assembly.

Personnel
1 engineer

Rationale for choosing / evaluation of the subcontractor
The company has selected ROBOTIKER as a suitable subcontractor to develop this control system. ROBOTIKER is a Technology Transfer Centre placed in the area of the company. One of the main areas of activity of the subcontractor deals with: robotics, electronics design and machine vision. It has large expertise with electronics design and microcontrolled control systems. This subcontractor was selected for the main following reasons:

- Prior experience of developing electronic products using the selected microcontroller.
- The ability and agreement in the objective of transferring knowledge via a co-operative development process.
- As a local subcontractor the company is able to provide technical support throughout the introduction of the prototype.

As the technology was not critical, there were of course several possible candidates to do the job. But Robotiker was selected as the optimum combination, first due to its proven record on providing a sound industrial solution and at the same time having technical knowledge transfer as part of their normal business – as advised by the TTN – that was not matched by the other possible subcontractors at the same close geographical situation – less than ten minutes distance.

More than one subcontractor? No

Barriers, Strategies and Knowledge transfer

Barriers perceived by the company in the first use of the AE technology
Manipulación Asistida, S.A. did not have any previous experience in electronics. The main barriers that have prevented the company from integrating electronics technology to improve its products include:
Knowledge and technology barriers
Manipulación Asistida, S.A has large expertise in pneumatic technology and load balancing systems. The company has developed its own technology for the pneumatic control system of load balancers. The

company knew that any improvement of load balancer's performance will be a critical competitive advantage for the company. The company also realised that electronics technology could be a way for improving their products but did not know exactly how good the improvements could be.
Also, as the company didn't have any previous experience with this technology it was unclear how to approach. The company didn't want to become electronics designer or developer, but wanted to define a digital control system that would be produced by a third party. So Manipulación Asisitida, S.A. needed first to verify the potential of this new technology and learn after how to manage a project in this new field.
At this stage, the company wanted to get an answer for the following basic questions:

- Improvements that electronics will add to the current product.
- Implications of adopting this new technology. The economic and business implications of adopting the new technology.
- If a company with non previous experience would be able to manage sub contractors in a new field.
- How to select the most suitable microelectronics solution.
- If there were local companies that could provide the company with the electronic control system developed during the experiment.

This lack of previous experience with electronics has manifested itself in technology barriers that have contributed to the overall difficulties of using a new technology.
Another problem of a small company like Manipulación Asistida, S.A. is also that they can't spend much time in new developments. The normal daily business doesn't allow the company to assume big research and development projects.

Psychological barriers

Similar to many small companies with no expertise in microelectronics, Manipulación Asistida, S.A. faced several psychological barriers. The company believes that adopting a new technology is risky. As a result the company's main effort to improve its position was to consider other solutions such as better marketing, mechanical and aesthetic improvements, rather than using new technologies.

Financial barriers

For small companies similar to Manipulación Asisitida, any investment in research, development and training can affect production and sales because resources have to be diverted away of the main business activities, representing a high risk for the company.

Strategy / steps taken to overcome barriers and arrive at an improved product

- *Preliminary technical tests:*

The first step of the company to overcome the technical barriers was to conduct a technical study of the improvements that electronics would bring to load balancer's performance. A number of experimental tests were performed using as digital control system a PC with a commercial data acquisition board in order to evaluate and verify the benefits of using electronics technology. Such testing platform showed in a fast way that a better sensitivity and response would be obtained using a digital control system, thus overcoming one of the first knowledge barriers.
These tests were carried out by the local subcontractor selected to perform the Application Experiment and before writing the FUSE proposal. *At their completion it was clear for the company that integrating an electronic control system in their products, instead of the existing pneumatic one, enhances load balancer´s performance, removing one of the first barriers*. But still the company didn't have any working experience with this technology and it was unclear how to approach.

- *Project proposal:*

The next step was conducting, with the support of the subcontractor responsible of the preliminary tests and of the TTN, a detailed feasibility study in order to:

- select the electronic technology that would be used for the digital control system
- prepare a project plan
- analyse economic aspects of using and integrating this new technology

The results of this study were documented in the form of the FUSE proposal for this Application Experiment. *This feasibility study and the preparation of the FUSE proposal have allowed the company to address and overcome the second knowledge barrier listed in previous section, and some of the psychological barriers, as the technical and economic success looked feasible*.

- *Application Experiment:*

For the Application Experiment the same subcontractor involved in the preliminary tests and proposal generation was selected. The selection of an experienced local subcontractor has ensured a continuous transfer of all expertise during the experiment.

Personnel from the company involved during the application experiment included one project manager specialist in pneumatics and load balancers industrial applications and a technician. This working team has been responsible of system requirements specification, design approval and final results validation, and the microcontroller hardware and software development was undertaken by the subcontractor, with supervision and final review of the company responsible.

This approach showed that there was no need for hiring new and expensive electronic staff but only being able to find a common language to communicate during the project, thus removing other psychological and financial barrier to use electronic technologies.

At the end of the experiment validation tests were carried out by the company's technician and project responsible. During the tests training in electronics system assembling, use and adjustment was provided for the company's team to ensure knowledge acquisition. Training process was supported with a clear and detailed user documentation of the developed control system. Such documentation includes: user manual, installation manual, service manual, detailed hardware and software design document. The generated documentation includes necessary and detailed information to produce the new control system and references of local electronics suppliers.

The adjustments required by company to accommodate the new technology in this environment will be undertaken by the programme manager. This capability forms a key aspect of knowledge development in the company and the full industrialisation of the product.

This approach assured the control of the new product by the company, removing the fear of being in the hands of a specific subcontractor. Another important issue to remark is that the contract signed with the subcontractor mentioned specifically that the Intellectual Property Rights of the application were the property of the company.

And then of course the financial help provided by FUSE made easier to the company to jump into the new technology. Being able to support the goals of FUSE - by providing our example of product improvement by a mechanical company First User of electronic technology - meant the access to a very favourable financing, that was selected as the best choice in a number of financing possibilities, and also allowed the project to start at an earlier date.

But the key factor from the financial point of view was the technical – economical assessment of the feasibility of the project performed jointly by company, subcontractor and TTN, providing the argument to invest in the electronic solution.

Knowledge and experience acquired

The knowledge and skills that were available at the company before participating in FUSE have been described in preceding sections.

This application experiment was the first experience of the company with electronics technology. The company didn't have any managerial or technical expertise in microcontroller-based application projects. As first users of electronic control the company has gained knowledge on possibilities and techniques to be used with this technology and its advantages over pneumatics technology.

The application experiment demonstrates that using microcontrollers technology brings important benefits to the company's products.

The company's knowledge acquisition process started during the preliminary test and continuous during the preparation of the FUSE proposal, when technology options were evaluated. This process has continued during the application experiment with the company acquiring knowledge from the subcontractor.

As a result of the work conducted during the application experiment, the company has gained knowledge in the following areas:

- Management of electronic development projects.
- Microcontroller based product specification.
- Understanding of the different phases involved during electronic development.
- Flexibility of an electronics control system compared with the pneumatics control.
- Microcontroller installation and adjusting operations and requirements.
- Available local companies working in the field of electronics production that would be able to supply the designed microcontroller.

Lessons learned

The most important lessons learned during this application experiment are the following:

Proposal generation

The company found that the preliminary tests carried out before the experiment and the feasibility study developed during proposal generation were key reasons for the good technical results obtained at the application experiment. These previous work allowed the company to obtain an answer for the initial question marks listed in section 11. The company's experienced indicated that these first tasks are really important for the success of the application experiment.

Correct technology selection

Another important reason for the success of the application experiment was the selection of the correct technology to improve load balancers performance. Microcontroller technology allowed the company to implement all the improvements and get a flexible control system. The company learnt about the advantages and possibilities of electronics over pneumatics methods.

The selected technology was also suitable for the technical capabilities of the local electronics suppliers. This aspect was very important because the company didn't have own resources to assume in-house production of electronics and would need third party participation. There are several local electronics suppliers with large expertise on microcontroller-based development.

The expertise gained during the application experiment will allow the company to prepare a specification for future microcontroller -based projects.

Project planning

The project was planned for 6 months and it has been done in 9 months. The company has learnt that the initial planning was no totally realistic in some aspects. The main reasons for this deviation have been the initial workload of the company that produced a delay on finishing system requirements specification and some delays on components reception at the end of the project. However, the company thinks that 9 months is a reasonable time to develop the digital control system.

For future projects more participation of the company in the design tasks should be foreseen, in order to fully understand from the beginning the possibilities and define the features to implement as early as possible. One result of not adopting this close follow-up of the electronic part of the project was the appearance of unwanted oscillations that required the use of extra pneumatic components and extended the duration of the project.

Benefits to the company business

The adoption of microcontroller technology Manipulación Asistida, S.A. has resulted in several benefits, at the technical and economic level. The new technology will allow the company to become more competitive. Up till now, when the need has arisen to improve competitiveness, the company's approach was centred on marketing or mechanical and aesthetic improvements.

Resulting product, its industrialisation and internal replication

Manipulación Asistida, S.A. intends to introduce the improved load balancer in the market in a short time after the completion of the application experiment. This industrialisation process has implications on the company's manufacturing and marketing, including:

- Modification of the design of the pneumatic enclosure currently included in the manipulator structure. The use of an electronic control system has reduced the number of pneumatic components, so a smaller pneumatic enclosure is required.
- Integration of the user panel in the pneumatic enclosure's cover.
- Contact with local electronics suppliers in order to select possible suppliers of the electronic control system.
- Improvements of the response of the system in order to guarantee the lack of oscillation under all possible working conditions.
- Exploring the use of A/D converters with higher resolution (and microcontrollers with more than 8 bits word width) in order to start the next generation of balancers able to handle much heavier loads.

The company has started these modifications at the time of writing this Demonstrator Document. The forecasted time and effort until the prototype is converted in a product in the market is around 6 months and about 4 person·month of extra effort. Overall extra cost is estimated to be in the order of 20 KECU.

Referring to the improved product marketing, the company has started contacts with some of its main customers working in the automotive sector. The company has offered to its customer a free installation of an improved load balancer at customer's facilities, to test, compare and verify the improvement that the electronics control system gives to the load balancer's performance. The company believes that this could be a good way to introduce the new product in the market.

Economic impact and improvement in competitive position

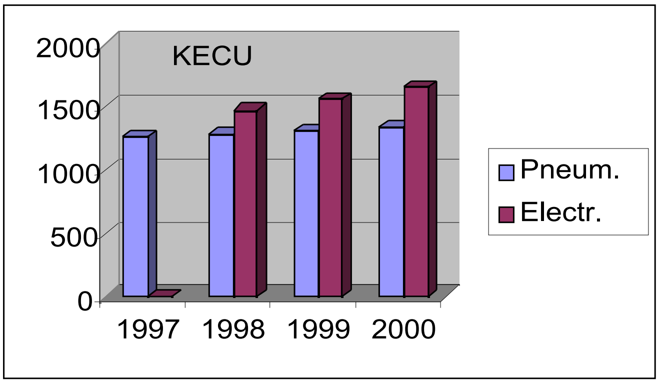
The decision to move towards electronics was seen as strategic. The use of the developed electronic control system gets an important improvement of the load balancer's performance. The more evident improvement is the reduction of the operator's effort to move a load. But furthermore, the use of the electronic control system generates other competitive advantages such those related with:

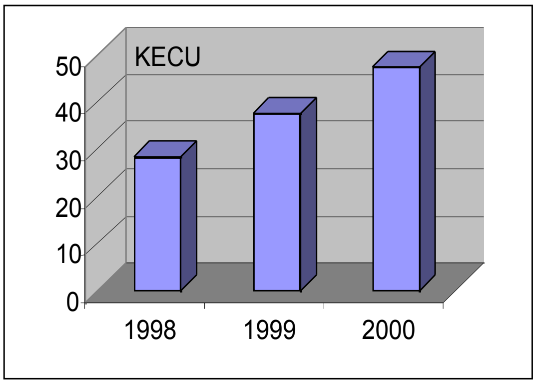
- Improved overall company's image due to the use of an own and registered electronic circuit design.
- Reduction of the effort required by the operator to move the same load.
- Operation cycle time will be reduced and productivity increased.
- Communication with factory computers to automate some tasks.
- Increase of manipulator's load capacity. Higher loads can be manipulated with less effort than now, generating new market opportunities for these devices.
- Reduction of the size and weight of the current pneumatic enclosures that represents a reduction of the manipulator's structure weight.
- Costs reduction of pneumatic components mounting operations. This reduction compensates the additional cost generated with the use of the load sensor.
- A more advanced and flexible product has been developed, enabling the company to offer a technical solution that can not be achieved with the current pneumatic technology. The programmable nature of the developed controller allows Manipulación Asistida, S.A. to modify system performance and adapt it to customer's requirements without any hardware modification.

All these improvements will open new opportunities for company's products and quite probably will result in an increase in sales. Furthermore, using the electronic control system a reduction of the production costs of load balancers can be achieved, both in materials and labour. Integration of the new electronic control system produces the following effects:

- Reduction of the number of pneumatic components.
- Reduction of the assembling and set-up time. The company's labour costs for these operations will also be reduced (15% reduction is expected).
- Costs of the PCB, load sensor and proportional valve have to be added.

Taking into account all these variations a saving in the order of 10% on the product costs can be achieved.





The chart to the left side shows the sales in the last year of the old purely pneumatic system and the two hypothesis of sales for the next three years for the old and the new system. Keeping the same sales margin in spite of the cost savings would mean an increment in profit by using the electronic technology as shown in the chart to the right.

The chart shows that the expected increment in profit due to the use of new electronic technology will pay back the overall investment of app. 65 KECU (prototype development + industrialisation) in around two years. In a three year period the investment would yield a return around 48 KECU, meaning an average yearly ROI of 22%.

Target audience for dissemination throughout Europe

The load balancers produced by Manipulación Asistida, S.A. are an expert and efficient solution for a wide range of manipulating operations involved in different manufacturing processes. These pneumatic manipulators are applied through manufacturing, packaging and assembly operations. Dissemination of the results of this application experiment will be interesting for all those companies with manipulation

operations in their production processes. This project will show them the use of load balancers and the utility of such manipulators to improve productivity and to solve handling problems.
The results of the experiment will be of interest for companies operating in a wide range of industrial sectors including: Automotive, automotive suppliers, chemical industries, paper manufacturers, distribution companies and so on.
This experiment will also be of interest for small companies operating with pneumatics technology without any previous experience in electronics and are unable to integrate themselves this new technology for their products. This was the case of Manipulación Asisitida, S.A. The results of the project demonstrate that using electronic technology will improve their products performance.
Dissemination of subcontractor relationships and formal contracts that results in knowledge transfer from the subcontractor into the company will be of special interest to the small company audience.
The knowledge to be disseminated will include data on the impacts of the technology, assessments of the benefits of improved product and the commercial gains experienced. The results of the project give a view of the benefits of integrating a new technology in existing products.

Target audience industries: ME

High resolution graphic files attachments

Pictures.d

Last modified: Juan Jose Mangas on 18/1/99 at 18:42