Project no. COOP-CT-2006-032493

Project acronym SORMEN

Project title: Innovative separation method for non-ferrous metal waste from electric and electronic equipment (WEEE) based on multi- and hyper-spectral identification

Instrument: Cooperative research project

FINAL ACTIVITY REPORT

Period covered: from 2/10/2006 to 2/01/2009

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Duration: 27 months

Project coordinator name: Jone Echazarra
Project coordinator organisation name: Robotiker

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PUBLISHABLE EXECUTIVE SUMMARY

This project develop a new technology for the separation of non-ferrous metal Waste from Electric and Electronic Equipment (WEEE) based on multi- and hyper-spectral identification. This new technology will overcome the shortcomings posed by current methods, which are unable to separate valuable materials very similar in colour, size or shape. The project will provide a **reliable technology to automate scrap processing in the recycling sector for non-ferrous metals** from WEEE which is nowadays essentially manual, labour intensive and time consuming.

The relevance of the project to the European SMEs is really outstanding. The level of automation and specialisation of SME recyclers is very low. Besides, WEEE is one of the most complex waste streams requiring management. This is due to the fact that EEE covers a wide variety of products ranging from mechanical devices such as hair dryers to highly integrated systems as computers and mobile phones. Non-ferrous metals, including precious metals, represent approximately 13% of the total WEEE weight.

The recycling sector will benefit from the development of this new technology, since waste fractions of small size (10-50 mm) after shredding, magnetic, mechanical and densiometric sorting still contain significant quantities of non-ferrous metals (e.g. Aluminium, Copper , Zinc, Brass, and Lead) and Stainless Steel which **the current technology does not lend appropriate to identify and separate**. As the price of recycled materials depends largely on purity, these fractions are currently sold at much lower price. This project will allow to sort those materials and in consequence to sell them individually at a higher price, increasing the added value of recycling process.

The **final goal of the SORMEN project** is to build a new technology machine able to separate non-ferrous metal waste fractions of small size from EEE based on multi- and hyper-spectral identification.

The main innovations are as follows:

- A multi- and hyper-spectral identification device for recycling applications.
- A new separation method will be developed for distinguishing individual non-ferrous metals from a scrap of many different materials
- An automatic machine with low maintenance for fractions between 10-50 mm.
- A machine able of processing around 1 tonnes / hour, at a market target price of around 90.000 €.

The development of this new method will increase the value of recycled materials sold in the market and reduce recycling cost, thus improving overall SME economic profit. Additionally, it will contribute to reduce external costs, namely costs derived from destruction and landfilling, and complying with European directives.

The SORMEN project involves German, Belgian, Finnish and Spanish partners in a jointly effort to improve the recycling industry. The Consortium of this project consists of five SMEs and two RTD performers. The involver contractors are two WEEE recycling companies (INDUMETAL, Spain, and IGE HENNEMANN, Germany), one manufacturer of recycling equipment (HEVAC, Spain), one imaging system vendor (SPECIM, Finland), two RTD

performers: a specialist in machine vision and image processing techniques (Robotiker, Spain) and a specialist in illumination and spectral imaging (CSL, Belgium).

The coordinator is Robotiker, a Spanish RTD specialised in machine vision applications and has previously worked on numerous European projects. The person in charge of the project is Mrs. Jone Echazarra, jone@robotiker.es, tel. +34 94 600 22 66.

During the project, the work performed has consisted in the following tasks, briefly described:

- Preliminary tests and users' requirements. The end users provided the developer partners with different types of samples of their usual mixtures to be separated. These materials were studied from two different points of view. On the one hand, the mechanical aspects of the machine were analyzed, i.e., size, weight, height and physical nature of the particles to face up to the proper design of the mechanical and pneumatic elements. On the other hand, main resources were devoted to the classification algorithm, which is supposed to use the information contained in the wavelengths out of visible range, to distinguish between elements similar in colour, shapes or size in visible spectrum. This is the case of aluminium and stainless steel. The algorithm has been finally defined and it is in development stage at this moment.
- Design of the system. The different modules that constitute the whole system were designed. The feeding, transportation and separation modules were carefully described and dimensioned. The control algorithm of the whole system was also designed in order to make sure that the proper synchronization of elements is feasible, which is a key point in the integration.
- Development of the modules. Once the design of the elements had been carried out during the first year, the manufacturing of the elements was finished. The camera was provided by Specim; the illumination module was provided by CSL; the feeder, transportation and separation module was manufactured by Hevac, as well as the electric box that manages the different elements.
- Integration of the modules. Once the modules were available in Robotiker facilities, every module was tested according to its expected requirements, the detected problems were solved and the integration of the modules was accomplished in order to build the whole prototype, and get it work as a whole.
- Exploitation and dissemination issues. The first actions in dissemination and exploitation matters were carried out during the first year, while the main key actions for second year were planned. There is a webpage where all the articles and presence of the project is shown..
- Management and coordination actions. The mandatory documents that gather management issues have been properly fulfilled and sent to the EC. Several meetings have been held during this second reporting period and the coordinator has circulated previously the agenda and discussion matters, has moderated the discussion in the meetings and afterwards, has circulated the minutes with the conclusions and planned actions.

The results achieved at the end of the project are satisfactory. It has to be remarked the good results of the classification algorithm, which is capable of separating perfectly several metals in a mixture. Special attention has to be paid to the possibility of classifying aluminium and stainless steel, which at this moment is not achieved in market machines. The problem with these elements is that they are not possible to be separated in the visible range, and therefore, other wavelengths were to be used. This is a major output of the project that enabled a PhD, a patent and many articles.

1. PROJECT OBJECTIVES AND MAJOR ACHIEVEMENTS DURING THE PROJECT

1.1. Overview of general project objectives

The main objective is to develop a new technology for the separation of non-ferrous metal Waste from Electric and Electronic Equipment (WEEE) based on multi- and hyper-spectral identification.
As stated in Part B, the general objectives of the project are gathered in the following table:

Category	***Quantified objective***
Technical	*Increase recovery of non-ferrous metals by 30-40%*
	Achieve production rates in the range of current commercial recycling machines (around 3 tonnes/hour)
Scientific	*A multi- and hyper-spectral identification device for recycling applications.*
	Automatic identification and separation of waste fractions between 10-50 mm very similar in colour, size and/or shape
Economic	*Develop a technology that could be marketed in one machine for a target price up to 90.000 Euro*
	Reduce recycling costs by 10 -15%
	Increase value of recycled fractions up to 50%
Societal and Policy	*Dramatic reduction of landfill*
	Reduction of energy consumption
	Better use of natural resources
	Improvement in competitiveness of European SMEs recyclers

Technically speaking, the final goal of the SORMEN project is to build a new technology machine able to separate non-ferrous metal waste fractions of small size from EEE based on multi- and hyper-spectral identification. It has been identified three main modules: setting up, identification and separation. The spectral imaging technology is applied in the identification module, but the other two are also essential for the good performance of the machine.

Therefore, the main innovations in SORMEN project will be:

- A multi- and hyper-spectral identification device for recycling applications.
- A new separation method will be developed for distinguishing individual non-ferrous metals from a scrap of many different materials.
- An automatic machine with low maintenance for fractions between 10-50mm.
- A machine able of process up to 3 tonnes/hour at a price of around 90.000€.

1.2. State of the Art Review.

The state of the art review implies a general overview over the idea of the project and the technologies used in it. It has been followed and brought up to date along the entire project, because it is also necessary in order to face properly the exploitation and dissemination tasks.

Existing Recycling machines

The existing machines available in Europe for metals separators have several serious limitations. Depending on the size and weight of the particles, some materials cannot be separated, so the final scrap is still a mixture of different metals.

Some manufacturers of metal separators, such as STEINERT and SSE (in Germany) have started to commercialise colour-sorting systems. These new systems can separate out, from the material flow, particles that are visually different from the rest of the material. The relevant criteria are colour, brightness, size and shape.

STEINERT has a system called FFS that has a colour camera capable of recognising differences in colour and shape in the material to be separated. Depending on the material the performances can be quite different and the size of the particles varies between 3 and 250 mm.

SSE has a system called Metal X SpectraSense. This system is able to recognise and evaluate small differences in colour. This machine can be applied for sorting of pieces as small as 2mm. The most frequent fractions, like 10-50mm and 50-100mm, can be treated with a higher purity and capacities than the small ones.

In Spain, PICVISA is another company that has manufactured a similar system, that separates some metals but in this case, at a low speed of the conveyor belt (3 m/min) and consequently, lest capacity of recycling. It is ECOSCRAP, a recyclable materials segregation system based on 2D image processing technique. Non-ferric metals as copper, brass and aluminium are segregated according to a colour analysis and identification system, which control the separation devices.

Other existing commercial systems are:

- <u>MetalSorter</u> (TORATEC). Its main features are:
  - induction
  - metal separation, such as stainless steel
  - 3 m/second
  - Blowing for classification of identified elements

- <u>OpticalSorter</u> (TORATEC). Its main features are:
  - Different cameras for different sorting tasks
  - Effective use of latest sensor technologies
  - Low air consumption using latest valve series
  - Air conditioned modules and cabinets
  - Machine width of 600mm-2400mm

- Different resolutions for different tasks available
- Up to 4 CCD cameras in line for higher resolution
- High capacity optical sorting of material sized 2-20mm
- with a 2400mm wide machine
- the detected particles are blown out

▪ EcoGlass (TORATEC). Its main features are:
  - The machine can be used for removing the CPS (Ceramics, Porcelain, Stones) impurities in the glass, as well as for colour sorting of glass by means of high resolution colour cameras.
  - Via fast acting valves, nozzles are activated to blow out the pieces in question
  - Sorting of glass according to their colour and brightness
  - Nozzle grid of 5mm

▪ Mikrosort (COMMODAS)

Using the latest technology in opto-electronic sorting of non-ferrous metals, developed by the CommoDaS group, copper, brass, zinc, aluminium, stainless steel and waste residues such as rubber and plastics are separated by colour.

For types of metal which cannot be distinguished by colour a combination of opto-electronic and electromagnetic sensing allows almost pure sorting of non-ferrous metals.

By using the high number of parameters and flexible adjustment options available, MikroSort® machines solve numerous tasks in sorting and separation of material streams according to monochrome and true colour recognition, also allowing separation according to size and shape. The systems operate in a size range from 1mm to 100mm with a throughput capacity of up to 20 t/h.

Conclusion

The major limitation of the mentioned solutions is that they only separate by colour, brightness, size and shape in the visible range. However, there are several metals and alloys that may have the same colour, shape and size in the mixture of WEEE. This is the case of Stainless Steel, Aluminium and Nickel or Copper, Brass and Tin. Furthermore, other non metallic particles similar in colour can be present in the waste stream due to previous recycling processes, such as plastics of different colours. This implies that recycled final scrap still has mixtures of several metals, and therefore, it has to be sold at a much lower price in the market than pure metals. For example, if the copper has 95% purity, it is sold at 85% of the price of pure copper. Small amounts of impurities mean considerable reductions in the sale price.

SORMEN project aims at going beyond the state of the art by providing a useful tool capable of using the information acquired in the wavelengths out of the visible range and to process it in the convenient way as to discriminate the materials that seems undistinguishable in the visible range. This advanced algorithm will be executed in an integrated machine, which will constitute a key element in the recycling process.

1.3. Work performed and Main achievements

During the project, the following work has been carried out. In this section a general overview is presented, meanwhile in the following section, workpackage per workpackage, it will be thoroughly detailed. The actions undertaken are:

- The different mixtures coming from the two end users (INDUMETAL and IGE Henemmann) were provided to the developers in order to check the dimensions and physical nature of any of them. These materials were studied from two different points of view. On one hand, the mechanical aspect of the machine were analyzed, i.e., size, weight, height and physical nature of the particles to face up to the proper design of the mechanical and pneumatic elements. On the other hand, main resources were devoted to the classification algorithm, which is supposed to use the information contained in the wavelengths out of visible range, to distinguish between elements similar in colour, shapes or size in visible spectrum. This is the case of aluminium and stainless steel. The algorithm has been finally defined and it is in development stage at this moment.
- An initial set of mixtures were chosen for the algorithm development. This mixture contains aluminium and stainless steel, among other elements. These two elements are impossible to be distinguished in visible spectrum. The added value of the hyper- and multi-spectral technology, along with the proper classification algorithm, will be to separate these materials.
- The global solution was designed. It is constituted of three modules: feeding and transportation, identification and separation. The elements for the modules have been designed. These are:
    - The camera for multi- and hyper- spectral acquisition
    - The illumination system (patent pending design)
    - The feeding system
    - The transportation elements
    - The separation system: blowing pumps controlled by an PLC
    - The software algorithm for elements classification
    - The control algorithm

The detailed description of these modules is fully given in D2- Design of the system.

- Exhaustive Tests. The end users provided the developer partners with different types of samples of their usual mixtures to be separated. During the first year, preliminary tests were carried out to experience with the hyper spectral technology and to evaluate the proposed methodology in the separation of different metals in the mixture. Those preliminary tests provided good results in the classification, but the imaging data was acquired with a camera and illumination different from the final ones. In fact, these were some of the possible improvements. Once these elements were available for testing, a lot of data was acquired in order to validate the good results obtained in the preliminary tests.

- Development of the classification algorithm. Once the imaging data is acquired, the classification algorithm was improved and finalised. The results in the separation of critical material, such as stainless steel and aluminium, were much better than in previous stage.
- Development of the modules. Once the design of the elements had been carried out during the first year, the manufacturing of the elements was finished. The camera was provided by Specim; the illumination module was provided by CSL; the feeder, transportation and separation module was manufactured by Hevac, as well as the electric box that manages the different elements.
- Integration of the modules. Once the modules were available in Robotiker facilities, every module was tested according to its expected requirements, the detected problems were solved and the integration of the modules was accomplished in order to build the whole prototype, and get it work as a whole.
- Exploitation and dissemination issues. The first actions in dissemination and exploitation matters were carried out during the first year, while the main key actions for second year were planned. There is a specific deliverable produced in the second year that comprises all the actions that took place.
- Management and coordination actions. The mandatory documents that gather management issues have been properly fulfilled and sent to the EC. Several meetings have been held during this second reporting period and the coordinator has circulated previously the agenda and discussion matters, has moderated the discussion in the meetings and afterwards, has circulated the minutes with the conclusions and planned actions.

The contractors' participation has been as follows:

- IGE Hennemann and Indumetal provided their mixtures of different materials they are interested in. They were interviewed about the requirements the machine should fulfil. They provided as much information as possible about the behaviour and features of the materials to be inspected, and attended all the meetings where their information was useful.
- SPECIM, CSL and ROBOTIKER worked very closely in the vision module. The vision module is constituted by the hyper-spectral camera, the lighting and the software algorithm to classify the elements. The camera services were required to build the illumination module, and the results verified by the algorithm have to be taken into account when designing certain aspects such as the shines, the intensity or the uniformity of light and to verify how homogenous the light over the field of view is. They both exchanged information continuously to reach the objective.
- HEVAC was concentrated on the design and development of the elements of the machine, this is, the feeding module, transportation (profiles and conveyor belt), mechanical supports for fixing the vision module elements, and the separation pneumatic system. The goodness in the manufacturing of the elements was also a key to guarantee a correct flow of the particles over the belt and proper extraction of the particles to be removed.
- ACLIMA, in charge of the exploitation and dissemination issues, evaluated the exploitable results of the project. Also developed the website of the project.

The results achieved at the end of the project are satisfactory. It has to be remarked the good results of the classification algorithm, which is capable of separating perfectly several metals in a mixture. Special attention has to be paid to the possibility of classifying aluminium and stainless steel, which at this moment is not achieved in market machines. The problem with these elements is that they are not possible to be separated in the visible range, and therefore, other wavelengths were to be used. This is a major output of the project that enabled a PhD, a patent and many articles.

2. WORKPACKAGE PROGRESS OF THE PROJECT

A survey of the work carried out during this first year follows:

WP1: Preliminary tests & Design of the WEEE separation system

Objectives:

- To test with different scrap fractions in order to evaluate available equipment (multi-spectral camera, illumination, separation).
- To define the prototype requirements (market and technical), provided by the users, and the subsequently definition of specifications of each component, in order to obtain the required performance for the prototype.
- To define the preliminary global design of the prototype.

Achievements:

The end users IGE Henemmann and INDUMETAL have provided 10 different mixtures of material. These have been studied from different points of view. On the one hand, it has been studied from the image processing point of view. The nature of the material, colour, size, shines, is essential for the vision module development. The tests were separately carried out for:

- Illumination module: the goodness of the lighting is essential for the success of the image processing. As good the quality of the image is, the better the processing will be. The gleams provoked by the elements have to be identified, and therefore, the illumination module must remove these shines to provide a uniform light.
- Camera and framegrabber: it is also important to select the proper camera according to the desire resolution in wavelengths, the resolution in size of the particles to identify, the speed of acquisition, the required sensibility of the sensor, etc.
- Algorithm for elements classification: the key point of this project is the algorithm development to separate elements that cannot be distinguished in visible range. This is the case of aluminium and stainless steel. They both present the same colour so with a standard colour camera; it is not possible to separate them. This is the reason why the hyper- and multi- spectral technology was the key point of the system, that would allow to see further. However, it is not easy since special processing is needed, first for the image formation coming from the wavelengths information, and then, it is necessary to establish which the wavelengths that better discriminate the metals are. Moreover, once the range is identified the classifier algorithm has to be defined and developed.
- Feeding, transportation and separation module: these mechanical elements have to be correctly designed according to the requirements of the system. In general overview, the material will be spread in a thin layer over the conveyor belt, which will be inspected under the vision module, and then, the identified particles will be removed by the extraction system. The range of sizes of the particles, the weight, and the thickness are to be taken into account for the final system. The different extraction possibilities have been studied, such as blowing pumps, vacuum pumps, mechanical methods, as well as the blowing air capacity, and other key issues.

In this workpackage, the market requirements of the end users were also gathered, this is, the production expected for the system, (thus, the planned speed), the possibilities in the market. An important trade show was visited by IGE to check which were the separation systems used in the market for similar systems.

Once these tests were accomplished and the conclusions gathered together, the global design of the system was drafted. This global solution also contains the algorithm to control the whole system itself, this is, the synchronization of the different elements by means of hardware and software flags and signals, the motors, the transportation belt, the information that the user would like to see into the user interface, the errors management, etc.

The detailed information about this workpackage is in D1 entitled Report with tests results, prototype concept, and validation test plan.

WP2: Detailed design

Objectives:

The main objectives are:

- To design in detail the different modules which form the overall prototype.
- To design the modules, their functionality and internal relationships, inputs and outputs.
- To define the hardware and software development platforms to be used in the project.

Achievements:

Along this workpackage, the principles and methods of the overall machine and the single components have been designed according to the requirements stated in the deliverable D1: "Report with tests results, prototype concept, and validation test plan". The design results have been thoroughly described in the deliverable D2 "Design of prototype".

This workpackage is subdivided into three tasks connected with the different single components: multi-spectral vision system, feeding and extraction systems, and control module.

- Multi- and hyper-spectral system design

In this task design of hardware (acquisition, storage, illumination) and software (sorting algorithms, calibration) for multi- and hyper-spectral system has been carried out. The different cameras types proposed by Specim were tested and their acquired information processed. The best choice in speed, quality and services has been finally chosen. Partners (SPECIM and CSL) have participated in this module.

- Feeding and extracting system design

The goal of this task is to design the mechanical structure and functional characteristics of the transport, conditioning and extracting modules. Also the mechanical tools for vision system have to be designed. ROBOTIKER and HEVAC have continuously been in contact to coordinate this task. The colour, length and width of the conveyor belt are important. Another key issue is the manufacturing of the electric box that must contain all the power elements, input /output signals, transformers, protection, emergency and security elements.

- Control system design

Concerning this task, on the one hand, the design of software architecture, platforms (software & hardware), system options, graphical user interface, and communications module of the prototype has been carried out. Besides, the design of the real-time control framework for multi-spectral, feeding and extraction subsystems. Robotiker has been in charge of this task.

The detailed information about this workpackage is in D2 entitled "Prototype design".

WP3: Development of the prototype

Objectives:

- To develop (programming, manufacturing, assembling) of each module of the prototype, according to the design of WP2. At the end of this WP single modules will be available to be tested and ready to be integrated.
- To develop the spectral system development (task 3.1)
- To develop the feeding and extracting system (task 3.2)
- To develop the control system (task 3.3)

Achievements:

The work has comprised the development of the following elements:

- **Mechanical module**: The mechanical module is constituted by different elements: the conveyor belt, the feeder, the mechanical fixing elements for the camera and lighting. HEVAC is in charge of these modules. Complementary and necessary to this, there is an electric box that contains all the electrical elements and power supplies necessary to make the whole run properly. We will include the electric box explanation also in this section. Inside the electric box the pneumatic elements to activate the blowing pumps are inserted. A description of the main features of the mechanical elements is detailed in D7 – Results of final tests of prototype.

  The electric box and mechanical elements arrived at the beginning of July; the integration of the elements into the electric box was done during September 2008. The actions were:

  - PLC modules were connected
  - Camera power was inserted and connected
  - Encoder counting module for PCI-6601 (linked to the PC) was inserted and connected
  - Pneumatic tubes were connected from the electric box to the blowing elements at the end of the conveyor belt
  - Electrical connections were checked and some problems were solved:
    - The encoder connection from the conveyor wheel to the PLC
    - The trigger pulse was adapted to the camera
    - The feeder automatic control board was configured and connected

As output of these actions, the electric box was ready and its connections towards the rest of the elements were verified. The mechanical elements can be activated properly.

Some images of the separate mechanical elements are shown next:

Fig. 2.1. Feeder

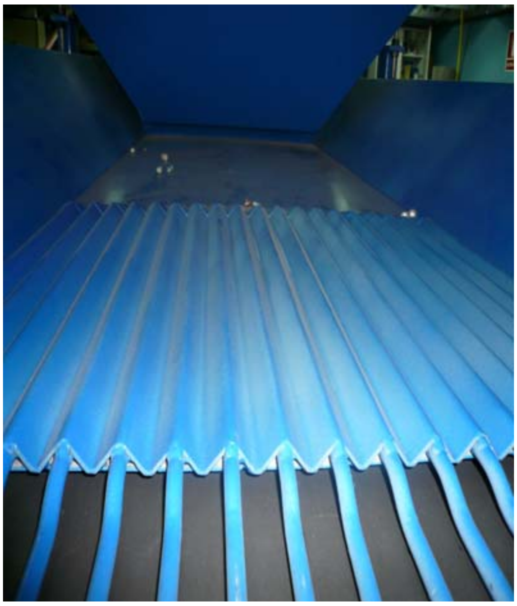


Fig. 2.2. Feeder channels

Fig. 2.3. Conveyor belt

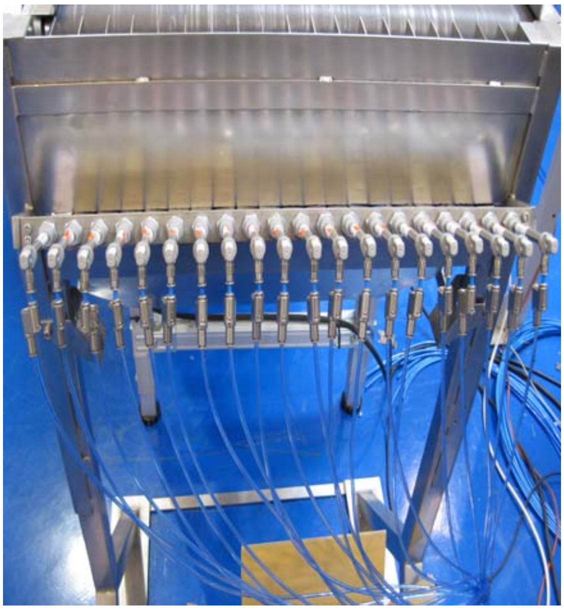


Fig. 2.4. Blowing module

Fig. 2.5. Blowing system from lateral

Fig. 2.6. Detail of pneumatic cylinders

Fig. 2.7. Electric box

- **Blowing module**: The blowing module is constituted of 40 blowing pumps distributed in two separate lines at different heights. The initial aim is to separate the input mixture in 3 different materials. The 40 blowing pumps are activated by means of 40 electro valves placed inside the electric box. These ones are activated by means of the digital output modules of the PLC.

  The blowing module has to be controlled automatically, as well. It is done by means of the digital output modules of the PLC. This is, when the PLC program, in a continuous working mode, decides that the pump 35 has to be opened, the program activates the digital output named as 35, and therefore, it will be opened immediately. In the same way, the PC can communicate with the PLC and activate the output 35 directly from the PC by delivering the proper data to the PLC. This is the first stage of the test, since the working efficiency of single blowing pumps has to be verified before making them work together. To do that, the following interface was developed:

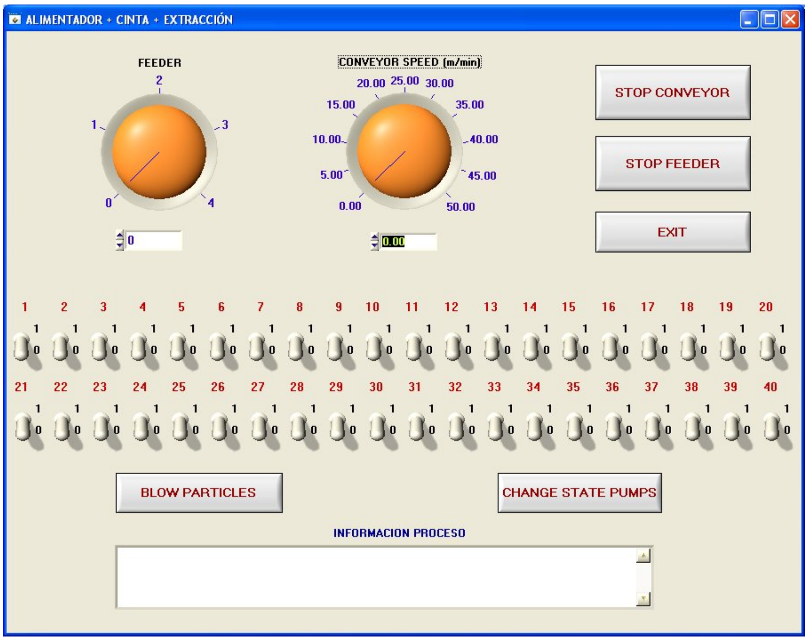


Fig. 2.8. User interface for testing the blowing system, the feeder and conveyor belt.

With this useful interface and a sequence of tests, several problems were detected in the separation system. HEVAC, in charge of the blowing module came to Robotiker facilities to verify the results of the tests. Then the blowing system was decided to be modified. It was delivered to HEVAC again where it was modified and sent back to Robotiker in November 2008. The solution was that the blowing pumps were replaced by pneumatic cylinders. The new separation system was tested.

Further details about the testing process, problems encountered and solutions can be found in D7 – Results of final tests of prototype.

- **Vision module**: The vision module is constituted of several elements: the camera with the fore objective, the frame grabber, the lighting module and the software that manages the acquisition of the data and then processes it in order to extract valuable information.

- Camera and frame grabber: The final camera of the system is PHF Fast 10. In the meeting that the consortium held in Barcelona in June 2007, it was decided to use this instead of the previous one, HS V10E, because of the possibility of reaching a higher frame rate with the Fast10. The block diagram of the camera and its related elements for the connection with the PC is shown next:

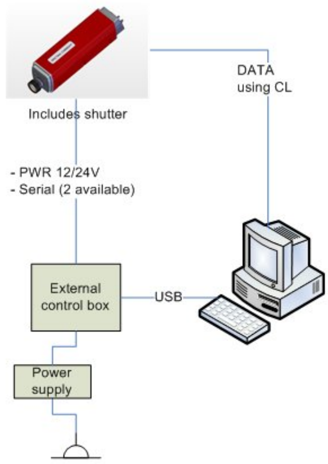
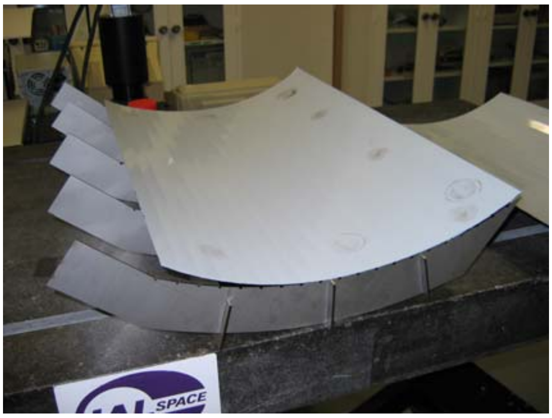


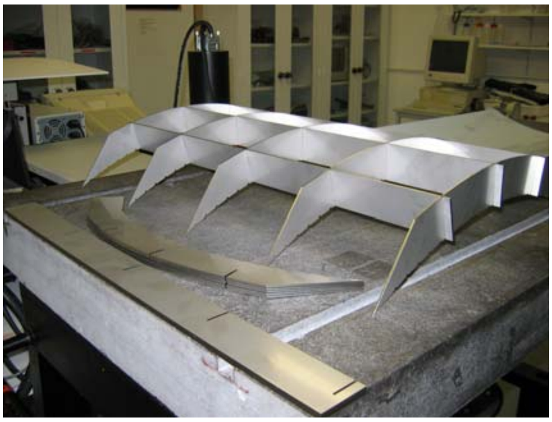
Fig. 2.9. Block diagram for the camera and frame grabber

The chosen frame grabber is the one from National Instruments (NI) PCIe-1429. By means of this frame grabber, it is possible to communicate Camera Link cameras from the PC and to receive the acquired data. It is fast and presents the possibility of having DLLs that allows to manage the camera and to integrate the code in a standard programming environment.

- Lighting module: The lighting module, developed by CSL, was received and fixed to the mechanical structure of the machine. This allowed to test at a real working distance of 760 mm between the camera and the samples that had been previously calculated to obtain the field of view and required resolution.

  The lighting module is composed of different oriented flat mirrors simulating an hyperbolical surface and two different kinds of illumination: halogens and LEDs. Next, several images of the process of manufacturing the lighting module is shown:





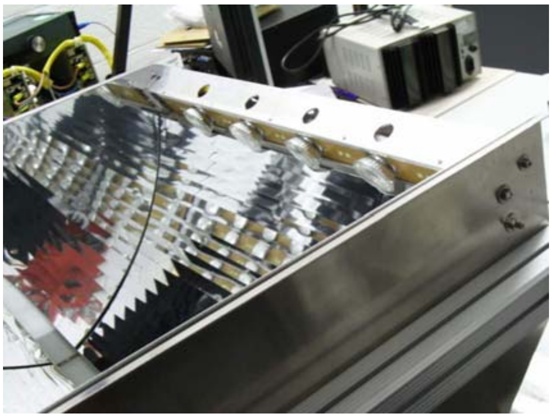
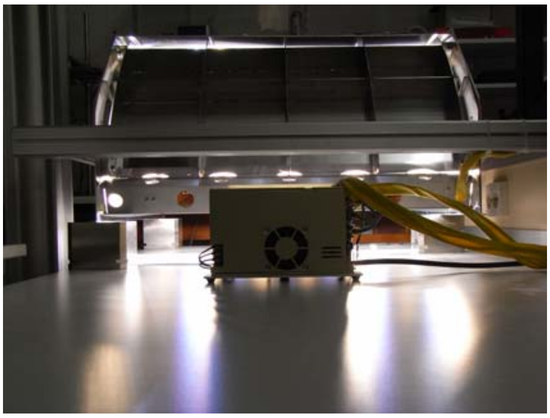



Fig. 2.10. Process of the manufacturing of the lighting module and final element.

Once the lighting module was installed, two kinds of measurements were made, intensity and wavelengths tests; this is, spectral profile, spatial profile and passline variation in order to verify how good the vision module was. The detail of the results is provided in D7 – Results of final tests of prototype.

- **Control module**: the control module is constituted of two elements, this is, the PLC and the PC. Exhaustive code development is mandatory to manage all the elements properly. The development environments are detailed in D7.

- PC: The PC is one of the two control elements. It is a double core PC with high services. It has allocated several PCI boards by means of which to control the following elements:
    - PCI – 6601 to receive the counting pulses of the encoder
    - PCIe- 1429, the frame grabber that manages the camera and receives data
    - PCI board for Controller Link communication between PC and PLC.

- PLC: The PLC is the second control element mainly in charge of managing different elements by means of the different analogical and digital modules. The feeder vibrating frequency and the conveyor speed are controlled by means of a 0-10 V analogical module. The blowing elements are managed by means of 3 digital outputs modules. The list of the PLC elements is shown next:
- CJ1G-CPU42H: CPU
- CJ1W-PA205R: Power supply
- CJ1W-CLK21-V1: Controller Link module, communication with PC
- CJ1W-CT021: Counter module, for synchronization of system with PC
- CJ1W-ID211 CHN: Digital Input module
- CJ1W-OC211 CHN: Digital Output module, expulsion valves management

- CJ1W-DA021 NL: Analogue Output module, feeder and conveyor motors control
- 3G8F7-CLK21-EV1: PCI board in PC for communication with PLC

- **Classification algorithm**:

Taking into account the preliminary tests results, see D6, it was possible to discriminate with high success rate among different materials. The worst case was aluminium and stainless steel, which is especially difficult since it cannot be distinguished in visible range by more conventional methods (RGB bands). So, a good processing algorithm, based on the generation of statistical models for every material and the background had to be designed. In that moment, it was not possible to obtain data from samples with the final lighting module and camera. Now it is the moment with final vision elements.

An industrial spectral algorithm was created to meet the requirements of the system: speed, robustness, easiness for its tuning for new materials and accuracy. Complex methodologies are not suitable to meet these requirements, since hyper spectral images have to deal with a great amount of data and in this case, we have to assure a fast response, near real time. Therefore, a re-design of the previous algorithms was done based on:

- The use of hyper spectral data only when really necessary (classification and model)
- The segmentation and separation of the particles using only single pixel information

The general scheme of the processing algorithm is shown next:

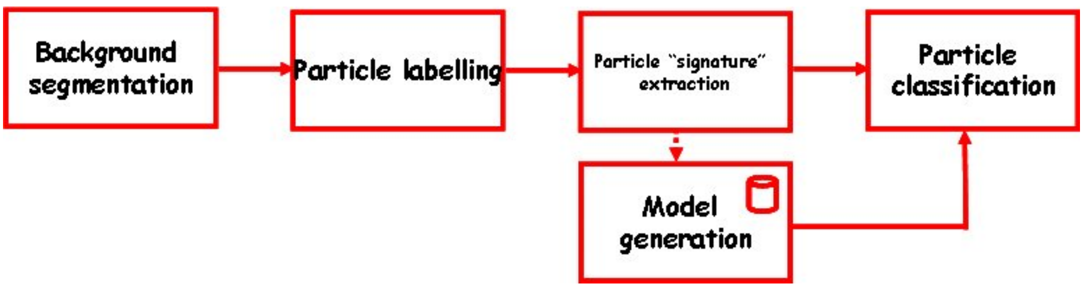


Fig. 2.11. Processing algorithm scheme

In the deliverable D7 – Results of final tests of prototype, the complete description of every box in the previous scheme is detailed with samples.

In the following image, once the statistical models have been generated, the classified particles (aluminium and stainless steel) are shown.

A specific statistical model is created for every material, the main descriptive parameters are saved automatically by the program, and can be uploaded at the beginning of the processing stage in order to calculate the Euclidean distance of every particle to every model. The minimum found distance will indicate the model (the material) that particle belongs to. In the following image, once the statistical models have been generated, the classified particles (aluminium and stainless steel) are shown.

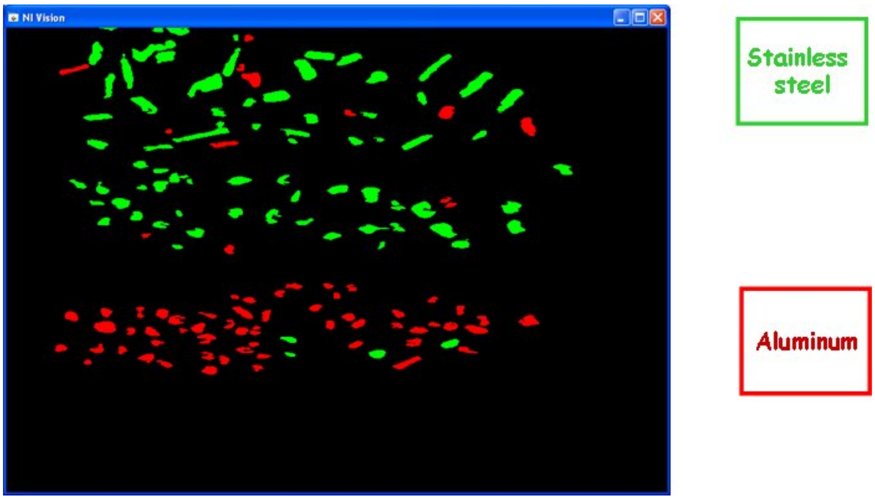


Fig. 2.12. Image with classified particles of aluminium and stainless steel

Many tests were carried out with the processing algorithm, and the following conclusions are extracted:

- More than 90% accuracy is achieved when sorting stainless steel and aluminium (most difficult case).
- The processing speed is really high: 0.28 seconds/meter. (1024x600 pixels image). It is valuable for a real time inspection in a manufacturing line.
- The processing speed is limited by the needed exposure time produced by the weakness of the intensity of the light.

WP4: Integration and tests

Objectives:

- To test every module separately (task 4.1)
- To integrate all the modules in the whole prototype (task 4.2)
- To tests the integrated system (communication and co-ordination among the different modules) in order to achieve the working prototype (task 4.3)

The end-users supervise the integration.

Achievements:

Every single module, slightly described in previous section was tested separately. The methodology for the testing, detected problems and proposed solution has been thoroughly detailed in D7 – Results of final tests of prototype. It is recommended to check that deliverable to have precise information.

Once the single modules are ready, the integration of the whole prototype started. Every module had to be connected and properly managed by the control element, this is, the PLC or PC. For that, every required piece of software has been developed, which is very time consuming and not easy. Moreover it is necessary that the developed code is robust enough as to work perfectly in every condition, prepared for possible errors in communication or working events.

The integration of the elements has been divided into two big groups:

- the PC and PLC communication (crucial for the control of the mechanical and electrical elements)
- the grab and process parallel action, that integrates the data acquired by the camera, the image processing algorithm, the identification of the particles to be removed and the delivery of the proper information to the PLC to remove those particles.

The integration of all the elements has been done by Robotiker. Some images of the integrated prototype can be shown next:

Fig. 2.13. Integrated vision module: power supply, light and camera

Fig. 2.14. Integrated prototype

- **PC and PLC communication**:

This first action is really crucial, since both controlling modules must communicate perfectly and transfer the data between them for the proper working of the prototype. Once every development environment was installed, the hardware configuration of the modules of the

PLC was done. The main problem encountered was that it was not possible the communication between them by the Controller Link module. It was due to the bad configuration of the PCI driver, and that the Controller Link board provided by OMRON had a bug for dual core PCs, our case. Corrective software was provided by OMRON and it was solved.

From this point on, several control software was developed:

- Conveyor speed control (by DA021)
- Feeder speed control (by DA021)
- Counter value read (PLC and PC)
- Counters value synchronization (PC and PLC)
- Output of every frame (particles to be removed) were sent to the PLC queue for removal
- Threads to guarantee no lines were lost

At the same time, the PLC contains a program developed by CSL. This program has distributed the memory addresses of the PLC, and contains the low level instructions as to interpret the data coming to the PC (and written in specified memory addresses). A high level description of this program could be done as follows.

A queue of data is delivered from the PC to the PLC; in this queue, for every particle identified to be removed, 3 values are given sequentially:

- the number of the pump to be opened (from 1 to 40)
- the pulse number in which that pump has to be opened
- the pulse number in which that pump has to be closed

The queue is ordered from lower to higher opening pulses values. So, the PLC is in charge of verifying that the counter pulse to remove the particle is equal to a given value, and if so, it has to open the specified pump, and then close it in the second specified counter pulse. This operation is done continuously in short cycles, which is the big advantage of using PLC.

All these programmes were tested separately and later integrated under a user interface.

- **Grab and process**

The final interface that integrates all the mentioned separated programs is the following one:

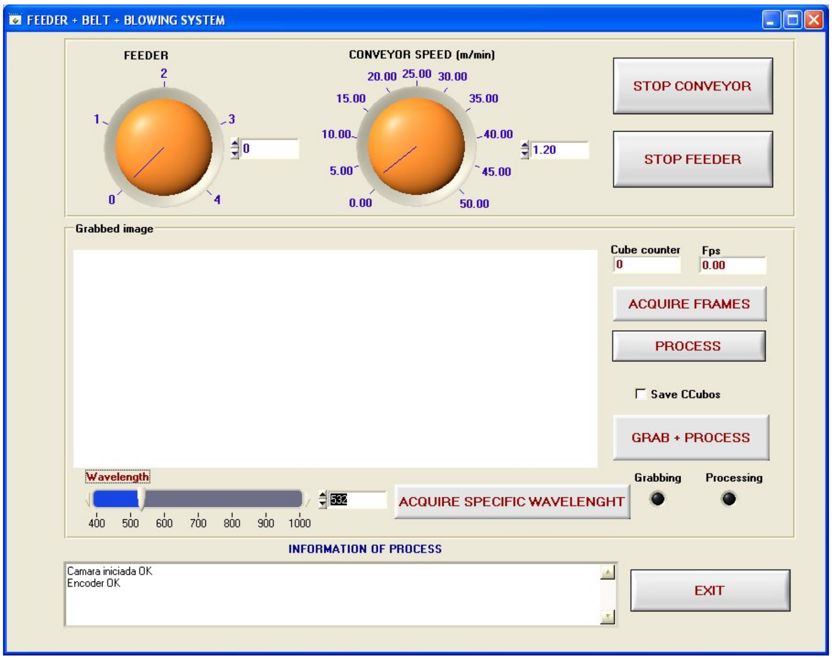


Fig. 2.15. Final user interface for integrated control

In this interface we can appreciate several areas and command buttons:

- Rotary wheels for feeder and conveyor belt speed: the vibrating frequency of the feeder and the speed of the belt can be modified.
- Stop conveyor: the movement of the conveyor belt is stopped.
- Stop feeder: the movement of the feeder is stopped.
- Acquire frames: the acquisition of frames exclusively is possible
- Process: It accesses to the processing specific user interface whose algorithms are possible to be applied to the more recent set of lines (the last spectral cube).
- Grab + process: the integrated process is carried out; it grabs every spectral cube, this cube is processed according to the classification algorithm exposed in previous section and the detected particles and its related information is delivered to the PLC.
- Acquire specific wavelength: the specific selected spectral band is grabbed and displayed. It was used for focusing, alignment and adjustments.
- Exit: The user quits the application
- Information of process: this text box provides information about the process itself. It communicates whether the camera has been correctly opened and configured, the speed of grabbing and processing, information about the number of particles detected and that have to be removed from the belt, and this kind of useful information valuable for the follow-up of the process in order to verify it has occurred in the correct way.

In this way and with this interface the whole and integrated performance of the prototype has been tested and evaluated.

- **Problems encountered and solutions**

During the integration and test process, several problems were encountered and were solved properly. It has to be stated that it was not easy at all to complete the whole process, some of the main difficulties were:

- the proper configuration of the PLC
- the robustness of the processing algorithm regarding the different situations,
- the format of the data to be transferred to the PLC; it has to maintain the specific number of bytes, structure, checksum, headers and terminators. This implies a very careful programming for the generation of the messages towards the PLC.

Apart from that there was a problem not possible to be solved under the scope of the project due to the lack of time: it was not possible to grab in a synchronized way with the trigger. Trigger pulses arrive faster than needed integration time (24 ms) so, if the trigger pulses are followed, a black image is grabbed.

There are some solutions for this limitation:

- to develop a hardware module that generates one trigger pulse every group of them
- to buy the adaptor board for the frame grabber NI-1429 to skip some encoder (trigger) pulses before grabbing.

Anyway, the best solution is to improve the lighting conditions by more powerful halogens in order to provide a higher intensity of the lighting. It is true that also the sensibility of the CMOS sensor of the camera could be improved, but this is a more complicated solution and it is linked to the market circumstances, so not so easy to be implemented. The objective is to reach integration times of 1-2 ms to speed up the grabbing process.

WP5: Final system evaluation

Objectives:

The objective of this work package is:

- To obtain a final evaluation of the performance and functionality of the prototype machine.

Achievements:

For this final system evaluation, the prototype was planned to be installed in Indumetal facilities. The considerable delay in the manufacture of the single modules in the project, that took more than planned, made it impossible to move the prototype to the industrial shopfloor. The proper integration and tests of the prototype were prioritised in order to extract conclusions about the design and manufacture process, as well as the classification algorithm in real time working way, which was key issue in the project. The supervision of the end users was done in Robotiker facilites. In fact, there was no real problem in that, since Indumetal is 10 km far from Robotiker, so this let the users to come as often as they wanted. During this testing period, they provided with more samples of aluminium and stainless steel, they were also involved in the arrangement of the mechanical elements, the pneumatic elements and the general working of the prototype. Even if physically it was not working in its facilities, Indumetal team considers that this stage has been fully covered by the work achieved in Robotiker.

As output of final system evaluation, several conclusions were extracted:

- Hyper spectral camera PHF Fast10 has been demonstrated as proper hardware to acquire information from 400 to 1000 nm over metals with enough quality as to be later processed.
- The image processing algorithm has been fully achieved and it has been possible to separate different kinds of metals: brass, copper, aluminium, stainless steel, etc. It is important to remark that the classification of aluminium and stainless steel is specially difficult since they are not distinguishable in visible range, but it was needed to use other spectral wavelengths.
- Even in the worst case, this is, aluminium and stainless steel, it was possible to classify correctly the 90% of the mixture.
- The processing algorithm is robust enough as to train any kind of material, to generate its statistical model and to tests easily with new mixtures to be separated. In fact, this processing algorithm is part of the PhD carried out by one member of the Robotiker team, patent protected at this moment. Besides, this processing algorithm is fast enough for production speed. It takes 0.28 seconds in a image of 1024 x 600, which corresponds approximately to one meter inspection.
- The full control software has been specifically developed.
- Light intensity is not good enough as to grab synchronized with the trigger pulses at a integration time of about 2 ms. Now the integration time is needed to be higher and that would be solved with the improvement of the lighting system.
- The blowing module is possible to work at 0.2 seconds / action, this is, it is capable of blowing 5 particles in a second with the same blowing pump.
- The developments and results obtained under the scope of the project have been considered very positive by the consortium. It has been specially interesting for the end users the possibility of separating aluminium and stainless steel since now there are not any other methods in the market that allow doing this.

From the point of view of Robotiker, coordinator, integrator and developer of the image processing algorithm, this project has also provided added value since it has allowed partially the obtaining of a PhD and the consolidation of its capabilities in the hyper spectral processing.

WP6: Exploitation and dissemination

Objectives:

The objectives of this workpackage are to ensure that the results of the project are properly protected and exploited by the SME partners and to define the best way to disseminate the results during the project live and beyond. HEVAC will be responsible of this workpackage, to exploit the following three lines:

- Exploitation Plan.
- IPR issues.
- Dissemination Plan

Achievements:

The first actions in dissemination and exploitation matters were carried out during the first year, while the main key actions for second year were planned. There is a specific deliverable produced in the second year that comprises all the actions that took place.

The project website is available at the end of year 2007, where the objectives of the project are shown as well as the developments, main achievements and other useful information. This is an important dissemination tool that is totally finished now and has been leaded by ACLIMA.

The IPR issues have already been treated in some of the held meetings this year. The conclusions of the IPR of the machine were dealt with in the final meeting held in December 2008, and are gathered in the corresponding minutes.

The exploitation and dissemination actions have been encouraged during the second year of the project. At this stage of the project, the main exploitable output is the classification algorithm of aluminium and stainless steel (not separable in visible range) by using other wavelengths of the spectrum. It will be carefully managed to increase the benefits. At this moment, there is nothing similar in the market.

WP7: Management and coordination

The referred actions are detailed in next section.

3. CONSORTIUM MANAGEMENT

The Project Official Start Date was the 2nd of October 2006, and the project duration is 24 months (i.e., up to September 30th, 2008).

This report concerns the first reporting period of the project. There are some management aspects that have to be mentioned.

After the first 4 months of the project, the consortium appreciated the small participation of Proeko in the project. It did attend neither the kick-off meeting nor the WP1 meeting in CSL. The coordinator asked their interest in the project and they answered that due to reorganization of the company, they were no longer interested in the project. The co-ordinator consulted with the administrative assistant, and he indicated the legal steps to validate this amendment of the contract, though he agrees that it did not imply any important disruption in the project plan. The implied member (Proeko) and the co-ordinator of the project (Robotiker) filled the related documentation, the permissions and official sheets.

The rest of the partners remained with their initially assigned responsibilities and no big problem has arisen till the moment. Everybody is aware of its role and the work to be carried out. Anyway, the communication is fluent in the consortium and there is constant information about the state, questions and comments usually by mail exchange.

During the project, the following Project Meetings have been organised to properly coordinate the Project activities:

DATE	LOCATION	DESCRIPTION	ATTENDANTS
October 3rd-4th, 2006	Robotiker, Bilbao, Spain	*Kick-off meeting* A project overview is provided as long as the workplan, and review of the role of every partner.	ROBOTIKER, INDUMETAL, CSL, ACLIMA, HEVAC, IGE, SPECIM
January 16th-17th, 2007	CSL Liège, Belgium	*Technical meeting* The purpose of the meeting is to review the results of the preliminary tests of the developers, and to show the proposed global solution.	ROBOTIKER, INDUMETAL, CSL, ACLIMA, HEVAC, IGE, SPECIM
June 28th-29th, 2007	Hevac Barcelona, Spain	*Technical and management meeting.* The main issue was to specify the last elements in the design of the system in order to start the development. Managerial issues were	ROBOTIKER, INDUMETAL, CSL, ACLIMA, HEVAC, IGE, SPECIM

		also dealt with facing up first reporting period.	
September, 6th, 2007	Specim Oulu, Finland	*Technical meeting.* Camera responsible and illumination responsible partners fixed this meeting to establish common criteria for the design of the illumination system and further integration of the vision module.	CSL, SPECIM
January, 24th – 25th, 2008	Robotiker, Bilbao, Spain	*Midterm Meeting* A project overview is provided in the midterm meeting. The state of every work package is reviewed, and the technical problems to be solved are discussed. The management issues are explained in order to present the Cost Statements of first period.	ROBOTIKER, INDUMETAL, CSL, ACLIMA, HEVAC, IGE, SPECIM
October, 2nd, 2008	Robotiker, Bilbao, Spain	*Technical meeting* Two people from HEVAC came to Robotiker to verify the results of the tests of the blowing system. Technical problems about mechanical modules were discussed.	ROBOTIKER HEVAC
December, 16th, 2008	Robotiker, Bilbao, Spain	*Technical and management meeting.* The overview about the technical development of every module and the integrated prototype is given by the related partners. Managerial issues were also dealt with facing up second reporting period and end of the project.	ROBOTIKER, INDUMETAL, CSL, ACLIMA, HEVAC, IGE, SPECIM

For these meetings, the co-ordinator has circulated the relevant agenda in advance, has driven and moderated the relevant meeting discussions, and has completed and circulated the relevant meeting minutes. For the meetings to be done the co-ordinator will inform all the partners on time.

Referring the incidences and deviations, project was delay three months, from end of October 2008 to first of January 2009:

First deviation from the plan was in T4.2 Integration of components. As it was explained this task suffered a delay. This delay was due to the fact that the preliminary tests took more than planned, mainly the tests related to the classification algorithm development. This algorithm was difficult to achieve. It was difficult to identify first which was the range in wavelengths more appropriate for the discrimination, and secondly the classification method to apply in such a difficult problem.

Other reason of this delay in the project was that the manufacture of the separate modules took more than planned, mainly the manufacture of the mechanical modules. Specially, the blowing module presented some problems to be designed and built properly. Later, in the exhaustive tests carried out by Robotiker, it was shown that it was not efficient enough regarding the requirements established in WP1, so further modifications had to be done, and a second round of tests. This delayed the integration of all the elements in the whole prototype. This implied that part of the work planned to be done in the WP5 was carried out under the framework of WP4. Anyway, the objectives of the project have been fulfilled, the conclusions have been exposed previously (and more detailed in D7) and future actions are gathered in last meeting minutes.

As coordinator, Robotiker has undertaken the following actions:

- Strategic management functions: decisions about key personnel, negotiations and communications with the Commission, elaboration of Consortium Agreement, exploitation issues, decisions with co-operation with related projects, training aspects…
- Technical management functions: detailed planning of technical work and deliverables, detailed monitoring of technical progress, decisions about technical methods and equipment to be used, preparation of technical progress reports, preparation and review of technical publications…
- Administrative support functions:
    - For project management meetings: organisation of meetings, agenda preparation and logistics arrangement, preparation and delivery of minutes…
    - For technical reports: following of technical developments of the partners, reminder of due dates, preparation of global documents and the concerning deliverables…
    - For cost statements: notification and reminder to partners of due date, revision of form C, preparation of overview of budget situation, delivery to the commission, reception and revision of accepted cost over the declared ones, possible appeal to them and distribution of related amounts between the partners of the consortium…

4. OTHER ISSUES

SORMEN project is a co-operative project. This section will describe the overall contributions of the SMEs, of RTD performers, and of other enterprises and end users. In particular, the extent to which the work of RTD performers has provided benefits to the SMEs and the balance of work/resources between the RTD performers and all other contractors.

The SORMEN Consortium is a well-balanced group. It was stated so in the proposal and it has been verified on work. It is constituted by 2 end users, 2 RTD performers and 3 other SMEs. Everyone has its perfectly defined and complementary role.

The two end users, Indumetal and IGE, provide the different material to be tested and express their preferences for separation and the conditions of the future machine to be installed in their facilities.

The RTD performers, CSL and Robotiker, are complementary. On the one hand, CSL has carried out the tests for the choice of the illumination of the metals. As it is a material that provokes shines, it has to guarantee the uniformity of light over the material and the quality of the image. Moreover, CSL owns spectrometers to measure the light emitted by every metal, therefore, the preliminary tests consisted also in computing this emission quantification into the range selection for discrimination. With this preliminary information, Robotiker carried on with the software algorithm to discriminate the elements. A quite complex advanced algorithm, Support Vector Machine based, has been defined and developed. From now on, improvements will be done over this algorithm to save time and achieve higher accuracy.

The 3 other SME play also an important role. SPECIM is the international prestigious manufacturer of multi- and hyper- spectral cameras. Its excellent technology has been specially calibrated and improved for SORMEN application, lighting system and physical nature of the material to inspect.

HEVAC, which is a specialist in manufacturing machines for recycling activities, provides its knowledge to this application. This company will lead the future exploitation of the system in the market.

Finally, Aclima can lead the dissemination of the results of SORMEN projects at a high scope, since it takes part in multiple events, congresses and conferences, and has access to lots of communication media.

This well-balanced and committed consortium guarantees the success of SORMEN project.

ANNEX 1 – PLAN FOR USING AND DISSEMINATING THE KNOWLEDGE

The dissemination activities for SORMEN project have been carried out to show the general aspects of the project. At the following table presents the events that have taken place during the two years of the project. In more detailed all these actions are explained in D10 “Final plan for using and dissemination the knowledge”

The table also gathers the type and size of the audience, the countries addressed and the responsible partner.

DATE	TYPE	AUDIENCE	COUNTRY ADDRESED	PARTNER RESPONSIBLE/INVOLVED
June 07	“WATCH IT!”	Industrial enterprises	Spain	Indumetal Recycling
September 07	Congress	Logistic Enterprises	Spain	Robotiker
November 07	Press Release Reflexion Site	Stakeholders	Belgium	CSL
December 07	Poster	Stakeholders	Spain/Finland/ Germany/Belgium	Aclima
January 08	Brochure	Stakeholders	Spain/Finland/ Germany/Belgium	Aclima
January 08	Project Website	Stakeholders General Public	Wider world	Aclima
March 08	Publication ‘Proyectos en Curso’	Stakeholders	Spain	Aclima
June 08	Press Release Robotiker webpage	Stakeholders	Spain	Robotiker