SIXTH FRAMEWORK PROGRAMME
HORIZONTAL RESEARCH ACTIVITIES INVOLVING SMES
COLLECTIVE RESEARCH

CO-OPERATIVE RESEARCH PROJECT

Project no. **COOP-CT-2004-50774**7

Project acronym: **MEPOS**

Project title: **Optical Measurement of Position and Size of Wood Panels for Intelligent Automation of Sanding Machines'**

Publishable Final Activity Report

Period covered: from August 23rd 2004 to August 22nd 2006   Date of preparation: Oct.4th 2006

Start date of project: 23 August 2004   Duration: 24 months

Project coordinator name: Prof.Nicola paone

Project coordinator organisation name Università Politecnica delle Marche

Publishable final activity report

1. Project execution

The project tackles problems for **automation of wood-sanding machine,** in 24 months through the development of a **robotic agency** based on 3 interacting agents:

a) an **optical sensing system** to detect **wood panel shape** and **position**
b) an **intelligent control system**
c) driving an **improved array of pneumatic actuators**.

In order to control the sanding process and to optimise panel surface finish it is necessary that **panel dimensions**, **shape** and **position** are **measured on line**, while the panel is moving on the transport belt and entering the machine and that **actuators are controlled in force** in order to apply the required **force distribution on the panel surface**, so that each part of the panel is machined at the desired pressure level.

This Co-Operative research project is designed on the **needs of a cluster of complementary SMEs**, which operate in different business areas.

1. VIET SpA – Manufacturer of wood-working machines (IT)
2. Sibois–Supplier for furniture industry, expertise in wood-working machinery (F)
3. MEL Mikroelectronic GmbH-Manufacturer of optical sensors (D)

RTD performers

1. Università Politecnica delle Marche-UNIVPM–Research and development on structured illumination systems and advanced sensing for mechanichs–Project COORDINATOR (IT)
2. Politecnico di Milano–Research and development on intelligent control systems fuzzy logic and on image acquisition and processing (IT)
3. Advanced Computer Vision GmbH–Research and development of image processing (AT)

OTHER ENTERPRISES

1. COSMOB Consorzio del Mobile–Service centre for supporting furniture industry (IT)
2. Fluid Automation Systems s.a.-FAS–Manufacturer of pneumatic valves and actuators for automation (CH)

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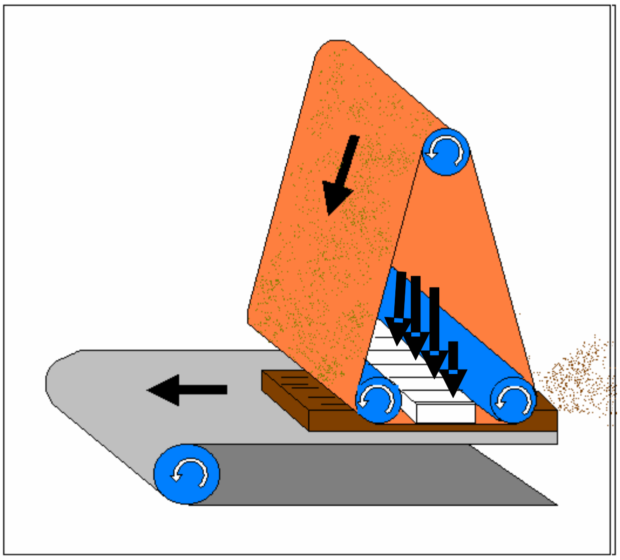
The project has achieved the automation of wood-sanding machines through the development of a **robotic agency**; the agency is based on three interacting agents:

a) an **optical sensing system** to detect **wood panel shape** and **position** which feeds information to
b) an **intelligent control system** which is in charge of
c) driving an **improved array of pneumatic actuators**.

In particular, sanding machines are used for the surface finishing and/or thickness sizing of natural wood panels, veneered panels, or panels lacquered with either polyurethane or polyester. These machines operate on a translating panel by sanding paper pressed on the panel either by a rubber drum or by a set of parallel linear actuators (see fig. 1). Pneumatic actuators are commonly in use; an array of several tens of pneumatic actuators across the sanding belt allows to apply a force only on the panel.

In order to control the sanding process and to optimise panel surface finish it is necessary that **panel dimensions**, **panel shape** and **panel position** are **measured on line**, while the panel is moving on the transport belt and entering the machine and that **actuators are controlled** in order to apply the required **force distribution on the panel surface**, so that each part of the panel is machined at the desired pressure level, so to optimize the sanding process.



Schematic of a sanding machine for wood panels: an array of actuators presses the sanding-belt on the moving wood panel.

Today sanding machines have a relatively low level of automation and this technological delay is common to most of the wood working industry; this is on one side due to the need to keep as low as possible the costs and on the other side to the complexity and variety of natural materials such as wood, which have physical characteristics which make it difficult to model the processes and therefore limit the performance of classical automation

The **project objectives** have been to introduce an intelligent automation strategy and advanced optical sensing to control and optimize the sanding process. In particular the project has developed **three independent agents**, **interacting** with each other so to realize an automatic sanding process:

a) a **measurement system based on imaging acquisition and processing under off-axis structured illumination**, so that real time information on the **panel position** and **size/shape** can be measured by triangulation and made available to the control system which supervises machine operation;
b) a **two-pressure pneumatic actuator** be able **to vary and optimize** the **pressure applied on the moving wood panels during the sanding process,** based on information on panel shape and dimension, available from the optical measurement system which inspects each panel entering the machine;
c) an **intelligent control strategy** based on **fuzzy logic** in order to use **information on panel position** and **size/shape to control the actuator valves that press the sanding belt on the wood panel**.

The **technical specifications for the position and size measurement system** were:

1. detect and measure panel position on the transport belt while panel is travelling at a speed up to 15 m/min (typically 10 m/min);
2. panel lateral position should be detected with an uncertainty lower than 3 mm;
3. image processing frame rate >50Hz;
4. observe and measure panel thickness with an uncertainty lower than 0.5 mm over a vertical range ± 3 mm;

5. maximum size of the panels to be measured (1300 mm width, 2200 mm length, 160 mm thickness);
6. the system should operate in presence of dust which is normally produced during sanding;
7. the system should operate under normal light conditions of a factory environment on panels of any colour and surface finish;
8. the system should allow the manual loading of the panels on the transport belt at random position and random rate of arrival.

Innovation with respect to the state of art of optical scanners is mainly in the following points:

1. measurement range in z is much smaller than lateral field of view;
2. real time operation at 50 Hz frame rate is required;
3. no averaging is allowed because panels are moving, therefore uncertainty is an issue;
4. overall available volume for sensor is limited by machine geometry, this implies the use of folded optical paths, which make optical design complex and geometrical stability critical;
5. operation of very different surfaces is required (different colour, different roughness, different texture);
6. operation in a dusty environment is required.

The **technical specifications** for the **two-pressure pneumatic actuator** were:

1. to press the sanding paper with at least **2** distinct **values of pressure** (normal / low), so to create a variable pressure profile across the panel width;
2. to have a valve response time lower than 5 ms so to respond to the input and allow operation on moving panels up to a speed of 15 m/min;
3. to drive the array of pneumatic valves by microprocessor, so to be fully integrated in the digital agency of the machine.

Innovation with respect to the state of art of actuators in sanding machines is mainly in the following points:

1. no sanding machine exists with variable pressure at the actuators;
2. fast response time is required, thus making critical the design of air seals and valves.

The **technical specifications** for the **intelligent control system** were:

1. to exploit data from both the optical sensing system (panel position and size) and from the process system (panel speed, sand paper type and velocity etc.);
2. to emulate the control strategy adopted by human operators through a fuzzy logic approach used to represent knowledge and to encode control strategies.

Innovation with respect to the state of art of controllers in sanding machines is mainly in the following points:

1. no structured knowledge about the sanding process already exists, therefore tuning of the controller is critical;
2. real time operation is needed therefore networking and timing must be developed.

Work performed in the project

The following technical Work-packages were active during year 2.

- WP1- Optical sensor for panel position and shape (completed by month 15)
- WP2- Development of improved pneumatic actuator (completed by month 13)
- WP3 – Development of intelligent control (completed by month 15)
- WP4 – Development of machine architecture (completed by month 15)
- WP5 – Integration of all elements (completed by month 18)
- WP6 - Testing of the automatic sanding machine (completed by month 24)

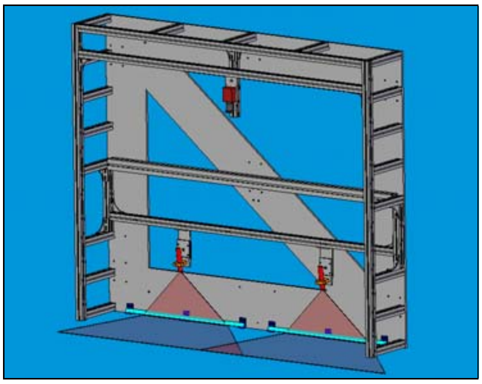
WP1- Optical sensor for panel position and shape

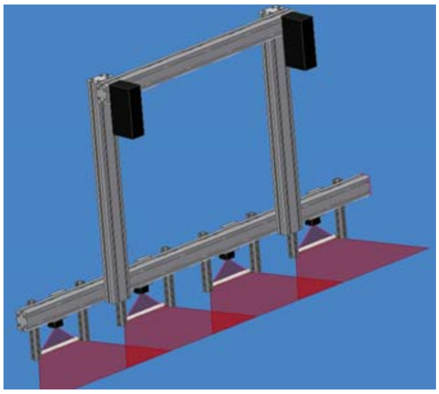
During year 1 of the project the partners designed and realized 4 different versions of large size triangulation sensors; each version embodies very particular characteristics and fit within a volume which is defined by the geometry of the sanding machine. This implies that the triangulation sensors have to be designed with a folded optical path, making use of mirrors to deflect the laser sheet. This makes particularly complex the overall layout, because of long optical paths; measurement uncertainty related to geometrical stability is therefore a delicate problem to be solved. Therefore, the first three months of year 2 were devoted to optimize each sensor based on metrological performance evaluation. Some important modifications and improvements were made on all sensors, in particular for the structured illumination, which strongly affects signal-to-noise ratio and sensor uncertainty. The final testing of the sensor installed on the machine performed in WP6 has provided a large amount of information which will allow to select the best technical solutions, for a possible future industrialization. The 4 final versions of the optical sensor are:

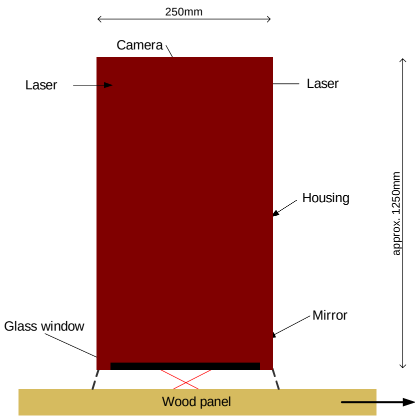
1) UNIVPM has designed and realized a prototype optical sensor for WP1 composed by:
    a. 2 inclined high power (50 mW) laser diode line projectors with prismatic optics to realize one single light sheet with uniform intensity profile
    b. 1 single CMOS high resolution camera 1280x1024 pixels 8 bit
    c. one PC based frame grabber for the vision system;
    d. area of interest image acquisition and processing, with sub-pixel interpolation.
2) POLIMI has selected and developed a prototype optical sensor for WP1 composed by:
    a. 1 parallel set of green light projectors with an array of high brilliance green LEDs with a metal screen used to project a green light shadow;
    b. 1 single high resolution CCD camera 1380x1040 pixels 12 bit, mounted slanted for better sub-pixel accuracy;
    c. one frame grabber on PC with high speed camera-link bus;
    d. algorithms for line detection, sub-pixel interpolation and line fit.
3) ACV has studied and developed a different optical lay-out for the sensor for WP1, with particular reference to:
    a. 2 medium power inclined power laser diode line projectors to produce 2 parallel light sheets with uniform intensity profile, thus realizing a shadow tolerant illumination system with possible redundant read-out;
    b. 1 single CMOS high resolution camera 1280x1024 pixels 8 bit;
    c. one conventional PC frame grabber for the vision system;
    d. area of interest image acquisition and processing, with sub-pixel interpolation.
4) MEL has selected and realized a prototype optical sensor for WP1 composed by:
    a. 4 inclined low power laser diode line projectors with diffractive optics to realize one single light sheet;
    b. 2 parallel CCD cameras with standard resolution 566x732 pixels, 8 bit, with synchronous image acquisition;
    c. one industrial PC for image acquisition and processing based on an ultra compact rugged PC P266/300 MHz, which hosts controllers for scanners, microdrives, it has no moving parts, several industrial interfaces, digital input-output.
    d. algorithms for line detection programmed on-board the ASICS.

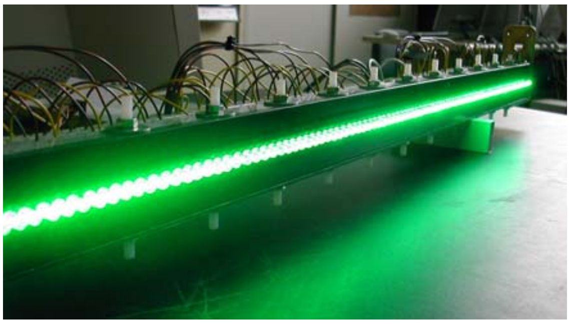
All RTD partners have dealt with the question of sensor calibration, which for a large size sensor is a critical issue. In particular UNIVPM has realized two calibration procedures, which are able to determine the sensor output versus the input distance and to estimate uncertainty, according to the ISO-Guide to the Expression of Uncertainty in Measurements; the first procedure makes use of a calibration bench where a flat reference surface can be displaced below the sensor at known positions, the second makes use of a specially designed calibration tool, made of a series of steps of given dimensions which can be inserted on the transport belt for calibration verification on the sanding machine.

UNIVPM has also analysed the problems of thermal drift, by experiments and by finite element modelling. A thermal effect correction procedure has been successfully implemented.
Within WP1, and partly in WP5, UNIVPM and VIET have also concentrated on the problem of dust removal, by performing an experimental fluid-dynamic analysis of the dust evacuation hood by laser Doppler anemometry which has given evidence for some modifications to the shape of the hood which could enhance performance.









The four types of sensors realised

WP2- Development of improved pneumatic actuator
During year 1 FAS realized a pneumatic actuator which contains 60 pistons in parallel; this was delivered at month 1 of year 2. Its technical characteristics are described in the Periodic Activity Report of year 1. In the first part of year 2 the completed prototype, delivered by FAS to VIET during week 39/05, has been assembled and tested. It works according to the technical specifications agreed between FAS and VIET. VIET spent a long time testing the pneumatic bloc unit. During life tests, the pneumatic performances were satisfying. The valves and the bloc performed in a reproducible way and the system proved to be very sensitive. A few valves did not perform appropriately during the endurance tests. These were replaced by FAS. During these tests, Viet found that electronic noise interfered with the communication between the master unit and the bus system.
FAS spend additional electronic development time in order to improve the communication card. Therefore a subcontractor was mandated to manufacture the communication card. Finally, the error rate in the communication was improved from 1 incorrect over 1’000 ordered to less than 1 per 100’000.

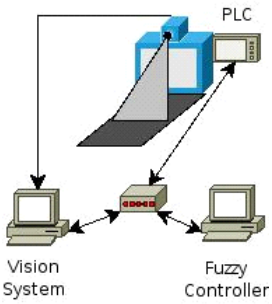
UNIVPM within has developed an instrumented panel which is aimed to observe the applied forces during sanding; this is a tool to characterize performance of the pneumatic actuators. This panel has been used during machine testing in WP6 and results have been fully positive.

The two-pressure actuators on the bench.

WP3 – Development of intelligent control

In the first 3 months of year 2 POLIMI has produced the final version of the Intelligent Control System (ICS), which was delivered to VIET at month 15 and integrated into the prototype within WP5. The specifications for the Intelligent Control System (ICS) were defined by POLIMI together with the other partners. Knowledge to be embedded in the ICS was in part acquired from experts of the machine, available at VIET, and encoded in a conceptual model. The fuzzy rules implementing each of the modules of the architecture have been defined and implemented from the knowledge acquired. Rules can be modified by the user of the ICS. Parameters, variables and input data to be taken into account in the implementation of the ICS have been identified, together with their relationship with the desired shape of sanding paper that should be obtained by imposing the correct pressure to the pistons.

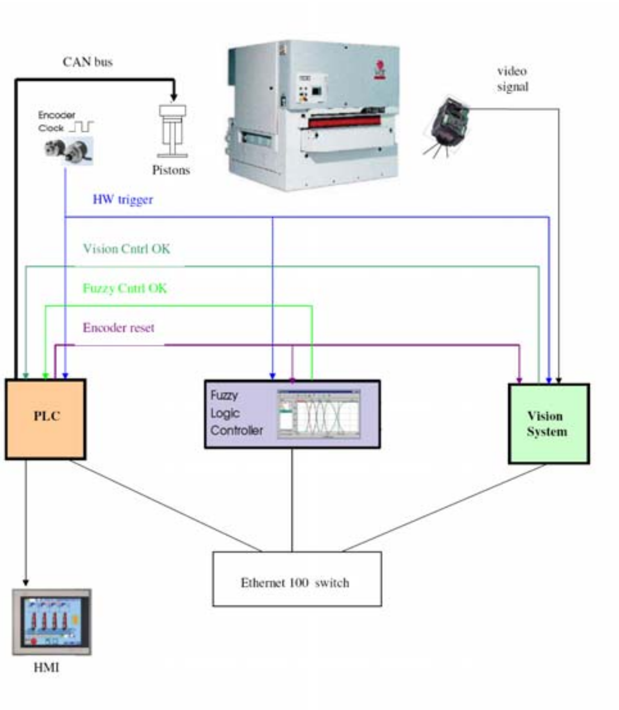
The ICS is interfaced to the other modules of the machine architecture via TCP/IP and an Ethernet link. It is client of the vision server and server for the PLC client.

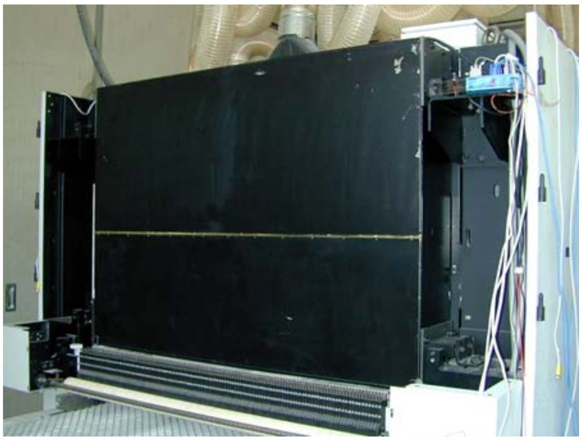


The scheme of the control agency of the sanding machine

WP4 – Development of machine architecture

By the end of month 15, in the first part of year 2 the machine architecture designed to host the optical sensor, the two-pressure pneumatic actuator and the fuzzy controller was delivered. The classic architecture of the sanding machine of VIET has been modified so to host the new agents. Both mechanical and electric/electronic modifications had to be implemented. An improved software interface with the new necessary functions has been implemented, making use of the machine PLC, which will communicate on an Ethernet link.





The system architecture of the MEPOS machine and a picture of the machine

WP5 – Integration of all elements

Integration has been the crucial issue in this project; due to the delays in WP1, WP3 and WP4, it was decided to extend by one month the duration of WP5 and to maximize man-power efforts aimed to integrate the optical sensor, the pneumatic actuator and the ICS in the new machine architecture. These efforts have made it possible to complete successfully WP5 by month 18, therefore meeting the deadline which was set at end of year 1.

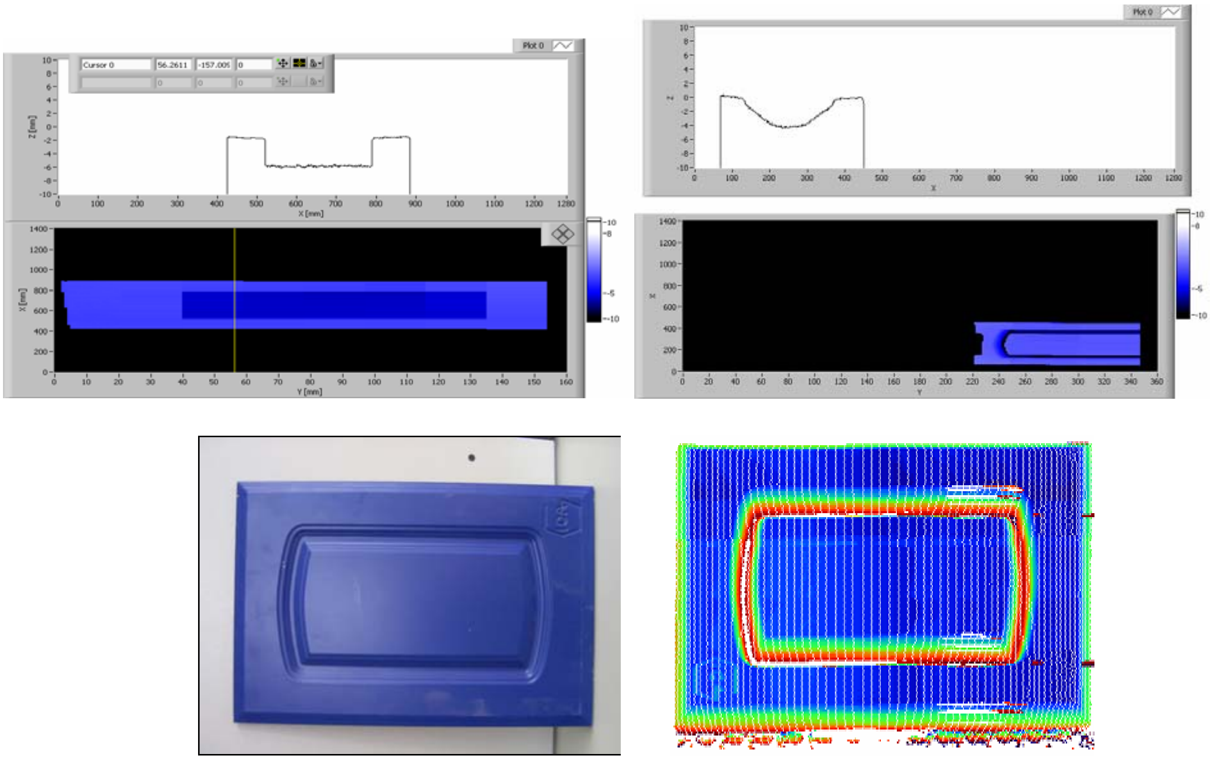
Therefore WP5 has produced a prototype machine which hosts a PC based network of independent agents, namely a vision system, realized in 4 different versions, a pneumatic actuator with two pressure levels and the intelligent control system, all interacting together and with the machine PLC. The prototype machine has an external aspect which practically coincides with conventional sanding machines and it hosts all innovative elements inside. The control panel allows the selection of the mode of operation, namely the MEPOS mode, which exploits the newly developed elements, or the classic mode, which does not make any use of the sensor output, of the two pressure actuator and of the ICS. Therefore this machine was ready for final testing in WP6 with only one month delay with respect to initial planning. The machine was fully operational according to specifications.

WP6 - Testing of the automatic sanding machine

The objectives of WP6 were the testing of performance achieved by the sanding-machine equipped with optical sensing unit, two-pressure actuator and intelligent control. Tests should have aimed to a comparative validation of quality and flexibility of the innovative sanding process, with respect to a conventional mode of operation.

To this purpose VIET, SIBOIS and COSMOB have defined the procedure for testing, according to the experience in panel testing. State of art shows that finishing is evaluated by visual observation of the light scattering over the sanded panel and by observing the surface aesthetics and the dust distribution on the panel surface at the exit of the sanding machine. To this purpose SIBOIS and VIET have selected a set of panels which were considered as test cases; they were different in colour and surface finish and size, so to test the system in various typical working conditions. Being available different optical sensors, part of these tests have been made with each of the sensors.

All tests performed on panels have been successful. The automated sanding machine was able to operate correctly also on very thin layer of paint and on complex surfaces.
SIBOIS has also brought to the attention of the partners a special potential application of sanding machines in a different sector, in particular the sanding and surface finish of large format electronic boards made in composite polymers; tests to validate the capacity of the sensors to measure surface flatness by the optical sensor have been successfully carried out, therefore highlighting a potential transfer of this technological solution to a specific nice of the electronic industry.
UNIVPM and VIET have developed an instrumented panel which has a matrix of load cells on board, together with a multichannel digital acquisition system, which has been used to measure actual forces applied by the actuator on the panel during a real sanding process. These observations allow to better know the sanding process.
Finally, UNIVPM and VIET have dealt with the problem of dust evacuation. VIET has built an evacuation hood with transparent windows and UNIVPM has measured by laser Doppler anemometry the air velocity distribution in laboratory conditions; these results highlight possible area for improvement of performance.



Panel shape measured on line: different examples

Panel type	Before sanding	After sanding (visual inspection allows to estimate quality of surface finish)	Outcome
			The whole panel is uniformly sanded. The entrance and exit timing of the actuators are good, there are not present side effect.

Typical results achieved in sanding.

Project public website.
For more information: https://mm.univpm.it/mepos/
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Impact of the project on its industry or research sector

Two industrial sectors are directly affected from the results of MEPOS project. They are:

1. wood-working machinery
2. optical sensor manufacturing.

The first, wood-working machinery, may exploit directly the results achieved and mainly the automatic sanding machine. One relevant result has been the transfer of know-how and technologies about optical systems and intelligent control to an industrial sector which does not make a large use of high-technologies. VIET and SIBOIS as representatives of machinery producers, and FAS as producer of pneumatic devices may take advantage from these results. Their mutual cooperation is also an indirect result of this project, with potential future follow-ups.

The second industrial sector, optical sensor manufacturers, represented by MEL, has been exposed to a number of new ideas and technical solutions to be adopted in sensor design, that will highly probably be implemented in the future production of large size optical scanners. Its interaction with the wood-working industry has also opened opportunities for new market areas, that now MEL is exploring together with VIET.

2. Dissemination and use

Section 1 - Exploitable knowledge and its Use

At the end of MEPOS project, 4 main exploitable results have been achieved.
The first and most important result is:

1. a fully automated sanding machine, which embodies one of the developed optical scanners, plus a two-pressure pneumatic actuator and one intelligent control system.

The last 3 exploitable items can be considered as single sub-systems of the machine, but may find application also as stand-alone devices:

2. a set of 4 prototypes of optical sensor (optical scanners for shape and position of panels which move on a line)
3. a two-pressure pneumatic actuator
4. an intelligent control system

At the end of the project, the partners are bound to each other according to the rules set out in the Consortium Agreement – amendement n.1 and in the general rules of the co-Operative research funding scheme.

It is expected that mostly VIET and MEL, with a secondary role of SIBOIS, will be able to exploit such results from an industrial point of view.

Timing plans for exploitation are short/medium term. Therefore dissemination of knowledge during the project has been limited, with the aim not to compromise later exploitation.

In particular the plans for each individual result today are the following:

a) <u>Automated sanding machine</u>.
   - VIET is the main actor in use of results, because the automated sanding machine contains many innovative elements, all potentially industrially exploitable in a short period. The sanding system, composed by double pressure pad, fuzzy controller, vision system, has been tested with very good result and VIET is confident of future industrialization and application on series sanding machines. SIBOIS is interested in having available highly automated sanding machines to be proposed to the furniture industry as elements of a panel process line. Therefore the industrial plans of VIET are to continue for one year the testing of the machine and then to propose it to the market and the following steps for improvement and industrialization are forecast:
     - *Dimension of vision system* The optical scanning system has to be reduced in dimension to be fitted in standard sanding machine. The best thing would be if it could be interchangeable with the actual microswitches bar. In this way VIET can choose the type of equipment to fit up in the machine with no other part changes. In the MEPOS prototype machine the electrical board has been fitted in the back side to leave free space on the front side for the vision system, but VIET would prefer not to adopt this solution. The MEPOS project has shown that the LED array illumination developed by POLIMI can be the solution for reduced size.
     - *Installation and calibration of vision system* The sensor for series application has to be calibrated very simply and quickly to reduce the cost of skilled labour. It is very important that the calibration can be carried out also by the after sales service engineers. The best solution provided by MEPOS project is using the calibrated panel according to the procedure developed by UNIVPM. UNIVPM has proposed a step panel. A dedicated software has to be implemented to carry out the calibration with no mechanical adjustments and no human intervention. ACV provides a solution using a devoted

software for calibration, in order to obtain a very simple procedure. The calibration procedure can be performed inside the sanding machine and consists of image acquisition and analysis performed using a flat surface as calibration sample. The surface must be set at three relevant vertical positions, namely +3.0 mm, 0.0 mm and -3.0 mm. The automatic conveyor belt vertical adjustment makes this operation easy, so that the complete calibration procedure can be executed in a some minutes.

- *Temperature calibration of vision system* The various vision system tested have been influenced by daily temperature variation. VIET feels necessary to implement the automatic correction of temperature induced bias, therefore to develop a temperature compensation routine.
- *Case design to avoid long-term dust problems* The industrialized the vision system should be sealed from the external dust, which after months of operation would inhevitably enter the cavity. Therefore it has to be implemented the solution demonstrated by MEL. VIET plans to improve it with a closed frame to be pressurized.
- *Electronic system* Electronic system has be improved in some aspects:
    - use of a single computer unit for all machine functions
    - unified human machine interface for all functions
    - use of industrial communication network and software
- *Cost of the system*
    - The complete sanding system will be accepted by the market only if its price is adequate. The industrialization project has to reduce the cost of component materials but VIET thinks above all that will be important to reduce the time of assembly and set up.

b) Subsystems.

1. The 2 pressure pneumatic actuator is certainly of immediate interest and can be applied on certain machines made by VIET also without the use of the optical sensor and of the fuzzy controller; FAS, which produces the pneumatic actuator is already able to manufacture it and to sell it to VIET, under commercial conditions that are dealt separately between the two parties. FAS will be able to provide to the market the innovative pneumatic actuator. Amongst the motivations having driven FAS to engage in this European project Craft (MEPOS), there is the desire to open up to new partners in many other fields (electronic, sensors, software, pneumatics) to acquire and exchange experience in partnerships simultaneously with European companies and high technology institutes. FAS has a very strong track record of penetrating industrial domains such as medical equipment, fluid power, textile, water management, ink jet and physical instruments. FAS is motivated to expanding its competences in sanding machines, which may also be a large opening to automation industries thanks to the interfacing of its pneumatic products to intelligent control systems. The automation market has a lot of potential opportunities. For all these reasons time to market for this sub-system is immediate.
2. The intelligent control system (ICS) is certainly of immediate interest, and could be embodied in sanding machines at different levels of automation; an appropriate tuning of the fuzzy rules has in any case to be done for each type of sanding machine. POLIMI has provided the source code so that VIET can implement the software according to its needs, depending on the actual processor, operating system and communication network that will be implemented on the machines. Further to this, the engineering of the ICS to be put on a machine for the marked will require a more extensive tuning phase. This possibly expensive tuning activity should be still

done by VIET to have it working on the market on any machine. Therefore time to market is medium term (probably one to two years).

3. The <u>optical sensor</u> appears the most challenging result which has been achieved; its exploitation will take two distinct directions, one in the hand of VIET the other in the hands of MEL.
    - In order to implement it on its machines, VIET needs to count on the availability of an industrial actor on the market which could produce and maintain it at an acceptable cost (possibly this is MEL); depending on these issues, VIET will decide on its application on the sanding machines of new generation.
    - MEL is interested to exploit some of the results obtained on the optical scanner. Indeed MEL has to evaluate the potential for entering in the market with large size optical sensors, such as the MEPOS one. With the contribution of UNIVPM, VIET, COSMOB and SIBOIS, MEL has already identified some nices where such sensors may have a market, not only within sanding machines, but as stand alone quality control systems. The scanner could also be used for counting and positioning of work pieces. The most important possible application areas which were identified during MEPOS:
        - wood based-panel industries (COSMOB is today coordinating a Collective Research project on the manufacturing of panels [project DIPP], where these issues will be brought to the attention of the partnership);
        - electronic boards (SIBOIS has provided a number of samples which were used successfully for testing);
        - ceramic tile industries (UNIVPM has many contacts with ceramic tile industry and has participated to a number of european projects in this sector).
    - In any case, MEL has an interest to implement specific technical aspects developed in the project by the RTD partners. These are in particular:
        - the use of CMOS sensors operated over Region-of Interest (as developed by ACV and UNIVPM)
        - the use of surface coated low cost mirrors derived from coated glass for windows (as it has been demonstrated by UNIVPM)
        - the use of PC based system architectures (as it was done by ACV, POLIMI and UNIVPM)
        - the use of multiple laser lines (as it was done by ACV)
        - the use of LED arrays and shadowing screens (as it was done by POLIMI)
        - the implementation of calibration procedures (as those developed by UNIVPM with the stepped reference plate).
        - Algorithms developed for image processing will also be considered for exploitation by MEL (as those developed by ACV, UNIVPM and POLIMI).
    - Depending on application, MEL plans to partly implement such technical solutions in the new generation of MEL sensors, even for different application areas. A combination of two of the MEPOS-project developed scanner is a probable effective solution and could increase the market volume. An example could be a combination of the LED array developed by POLIMI as light source and the two camera system developed by MEL.
    - As regards to time to market, MEL declares that it will take probably one year to convert these results and develop a commercial scanner which is

ready for the market, given the need for a good cooperation with a possible customer.

- A market analysis could show the exact demands and requirements of possible customers. MEL is interested to understand from the market if there exist a demand for stand-alone quality control stations, fact that would increase the number of potential installations.

Overview table

Exploitable Knowledge (description)	**Exploitable product(s) or measure(s)**	**Sector(s)** of application	Timetable for commercial use	Patents or other IPR protection	**Owner** & Other Partner(s) involved
Autoamted sanding with two-level pressure control based on panel shape	*Automated sanding machine*	*Furniture Industry*	***n/a***	*n/a*	*VIET UNIVPM POLIMI FAS ACV SIBOIS MEL*
Optical laser canner by ACV	*PC based 3D surface measurement system real-time with double laser light sheets and single hi-resolution CMOS camera*	*1.Industrial inspection 2. Process automation*	*2007-2008*	*None*	***ACV, VIET, MEL, SIBOIS***
Optical laser scanner by UNIVPM	*PC based 3D surface measurement system real-time with single laser light sheet, double laser projectors and single hi-resolution CMOS camera*	*1.Industrial inspection 2. Process automation*	*2007-2008*	*None*	***UNIVPM, VIET, MEL, SIBOIS***
Optical laser scanner by MEL	*3D surface measurement system real-time with single laser light sheet, quadruple laser projectors and double standard CCD cameras*	*1.Industrial inspection 2. Process automation*	*2007-2008*	*None*	***MEL, VIET, SIBOIS***
Optical laser scanner by POLIMI	*PC based 3D surface measurement*	*1.Industrial inspection 2. Process automation*	*2007-2008*	*None*	***POLIMI, VIET, MEL, SIBOIS***

Exploitable Knowledge (description)	**Exploitable product(s) or measure(s)**	**Sector(s)** of application	Timetable for commercial use	Patents or other IPR protection	**Owner** & Other Partner(s) involved
	system real time with LED bar illuminator, shadowing screen and single hi-resolution CCD camera				
Two pressure pneumatic solenoid valves in conjunction with fast electronic command.	*Pneumatic solenoid valves, Pneumatic blocs with large amount of cylinders*	*1. sanding machine industry 2. automation industry*	*2006*	*None*	***FAS, VIET***
Intelligent control of sanding pressure	*Intelligent Control software for sanding machine*	*1. sanding machine industry 2. automation industry*	***2007-2008***	*n/a*	*VIET POLIMI*

Automated sanding machine

- Functionality:
  Sanding machine with two-level automatic control of sanding pressure
- Purpose:
  Efficient sanding of panels, especially at panel edges and on complex shape panels
- Innovations:
  Automatic control of sanding pressure based on shape of incoming panel and knowledge of sanding parameters
- Partner(s) involved in the exploitation, role and activities
  VIET: after a careful market analysis, it will industrialize this machine, or parts of it, and later it will start production and commercialization to the market. Also SIBOIS, as a consequence, will indirectly exploit this result, being a large dealer of wood-working machinery;
- How the result might be exploited: it will be direct exploitation by VIET;
  - technical and economic market considerations – VIET and SIBOIS, who have a deep knowledge of sanding machine market, declare that the complete sanding system will be accepted by the market only if its price is adequate. The industrialization project has to reduce the cost of component materials but VIET thinks above all that will be important to reduce the time of assembly and set up.
  - possible obstacles identified which might prove to be barriers to commercialization are:
    - the cost
- Further additional development work has to consider the following areas where improvements would be necessary:

- Dimension of vision system: to be reduced as much as possible;
- Installation and calibration of vision system: to be simplified and automated;
- Temperature calibration of vision system; develop a correction procedure for temperature drift;
- Case design to avoid long-term dust problems; implement a closed enclosure for the sensor;
- Electronic system: single PC, industrial communication network, unified man-machine interface for all functions

Optical laser measurement system by ACV

- Functionality:
  Real-time measurement of a moving object surface
- Purpose:
  Surface measurement for actuator control
  Innovations:
  System compactness (small volume), simultaneous use of two laser sheets for increased robustness and improved surface reconstruction, adaptation of system properties depending on the surface velocity, interpolation of laser line positions to compensate horizontal shifts caused by irregular surfaces.
- Partner(s) involved in the exploitation, role and activities
  ACV, MEL: analysis of market potential, search of alternative applications, development of a prototype

Optical laser measurement system by UNIVPM

- Functionality:
  Real-time measurement of a moving object surface
- Purpose:
  Surface measurement for actuator control
- Innovations:
  PC based system, realization of a high intensity single light sheet by two parallel laser projectors, use of first surface economic mirrors, use of hi-resolution CMOS camera with ROI processing
- Partner(s) involved in the exploitation, role and activities
  UNIVPM, MEL: analysis of market potential, search of alternative applications, development of a prototype

Optical laser measurement system by POLIMI

- Functionality:
  Real-time measurement of a moving object surface
- Purpose:
  Surface measurement for actuator control
- Innovations:
  PC based system, realization of a structured illumination by LED array and shadowing screen, use of hi-resolution CCD camera
- Partner(s) involved in the exploitation, role and activities
  POLIMI, MEL: analysis of market potential, search of alternative applications, development of a prototype

Optical laser measurement system by MEL

- Functionality:
  Real-time measurement of a moving object surface
- Purpose:
  Surface measurement for actuator control
- Innovations:
  PC based system, realization of a high intensity single light sheet by four parallel laser projectors, use of two parallel CCD cameras
- Partner(s) involved in the exploitation, role and activities
  MEL: analysis of market potential, search of alternative applications, development of a prototype

Comparative comments on the 4 optical sensors developed.

Optical sensor developed by:	Complexity of illumination architecture	Complexity of image acquisition architecture	Cost	Main advantage
ACV	Complex (*2 laser light sheets with 2 laser projectors*)	Simple (*1 hi-res CMOS + PC*)	Illumination=High Imaging=Medium Processing=Medium	Best system to detect panel edges (both forward facing and backward facing steps)
UNIVPM	Medium (*1 laser light sheet with 2 laser projectors*)	Simple (*1 hi-res CMOS + PC*)	Illumination=Medium Imaging=Medium Processing=Medium	Good compromise between cost/complexity and performance
POLIMI	Simple (*1 LED array with shadowing screen*)	Medium *(1 hi-res CCD +PC*)	Illumination=Medium Imaging=High Processing=Medium	Most compact illumination system thanks to LED array
MEL	Medium (*1 laser light sheet with 4 laser projectors*)	Medium (*2 low-res* CCDs + ASICS+PC)	Illumination=Medium Imaging=Low Processing=Medium	Fastest image processing

The following comments apply to the exploitation of all the 4 types of optical scanners that have been developed in MEPOS project.

- How the result might be exploited: the knowledge has been shared with the industrial partners, amongst which MEL is an optoelectronic company which may direcly exploit it or part of it.
  - technical and economic market considerations – from a commercial and technical point of view, the optical scanner can be also considered as a stand alone system; this opens the possibility to use it as a quality control system, on any type of line where large format panels move and need to be counted, and their shape measured real time.
  - any obstacles identified which might prove to be barriers to commercialization

        - the industrial actor on the market of optoelectronic has to closely cooperate with an industrial end-user in order to develop cost-effective solutions necessary to maximize the return of investment
- Further additional research and development work, including need for further collaboration and who they may be;
    - the sensor developed is fully operating complying to specifications
    - further development work is needed only for industrialization
    - collaboration with an optoelectrnic sensor manufacturer has high potential to bring it to the market.

Two pressure pneumatic solenoid valves in conjunction with fast electronic command.

- Functionality: pneumatic actuator composed by a parallel set of 60 two-pressure pneumatic cylinders operated by fast solenoid valves;
- Partner(s) involved in the exploitation, role and activities: the system has been developed by FAS, that has the possibility to manufacture it in series and to commercialize it upon demand from the market. VIET has shown a strong interest based on the positive results achieved with this result, therefore it will potentially be the first partner and customer of FAS for this particular device.
- How the result might be exploited: the result is an industrial product of immediate availability to the market. It will exploited directly by FAS, as manufacturer and indirectly by VIET, as industrial customer, upon commercial conditions that will be agreed by them; also SIBOIS, as a consequence, will indirectly exploit this result, being a large dealer of wood-working machinery;
    - technical and economic market considerations: this pneumatic actuator is needed in high performance sanding machines, mostly used for finishing purposes; being these the most expensive machines, this pneumatic actuator can be accepted by the market at short time.
    - No major obstacles are identified which might prove to be barriers to commercialization
- Further additional research and development work, including need for further collaboration and who they may be: VIET and FAS will continue industrial developments

Intelligent control of sanding pressure

- What the exploitable result is: it is a software program implementing a set of fuzzy rules to control a multi-pressure pneumatic actuator, based on input about its type, shape, position on the transport belt and on sanding parameters;
- Partner(s) involved in the exploitation, role and activities
- How the result might be exploited: this software can be exploited directly by VIET which can implement it on its machines; support from POLIMI may be required for industrialization, especially for specific tuning of the fuzzy rules to specific application cases.
    - any technical and economic market considerations – the engineering of the ICS to be put on a machine for the market will require an extensive tuning phase, to adapt it to a specific application. This possibly expensive tuning activity should be done by VIET to have it working on the market on any machine.
- Further additional development work, including need for further collaboration; this is again related to tuning of the controller. Cooperation between VIET and POLIMI may be necessary.

Section 2 – Dissemination of knowledge

For what concerns Dissemination of Knowledge, the partners have limited it mostly to generic information on the project and on its main elements. Technical details have been kept reserved, with the aim not to compromise possible exploitation. This was agreed upon request of the industrial partners.

UNIVPM and COSMOB have concentrated in disseminating general knowledge about automation in the wood furniture sector,. This has been done at seminars organized by COSMOB, and given to Italian furniture industries. No detailed technical knowledge has been disseminated in these occasions. UNIVPM has held meetings on this topic with COSMOB; the purpose of these meetings was to consider results for dissemination, being COSMOB an industrial association specific for the wood-furniture industry.

COSMOB has also organised a press release and a communication on local television, within a presentation of several research projects in the furniture industry sector.

UNIVPM and ACV have set-up web-sites on the project, which again have a general character.

For the optical sensor, part of the scientific relevant aspects have been presented by ACV in a scientific meeting. UNIVPM is also writing a paper on the specific topic of calibration of these large size sensors, which has a scientific interest; the paper is not published yet.

No dissemination of knowledge on the pneumatic actuator is planned by FAS

Finally UNIVPM and POLIMI are disseminating knowledge to students; some students of the faculty of engineering are making part of their final projects on subjects related to MEPOS, in close cooperation with VIET. One PhD student is also directly involved in MEPOS and two post-doc as well.

Overview table

Planned /actual Dates	Type	Type of audience	Countries addressed	Size of audience	Partner responsible /involved
May 2005	*Press release on a series of research projects related to wood industry (national and local press and local TV)*	*General public*	**Italy**		*COSMOB*
May 2005	*Conference on research activities in the furniture industry*	*Furniture industry*	**Italy**	*50*	*COSMOB + UNIVPM*
17-2-2005	*Presentation of the MEPOS project within a seminar for italian furniture SMEs*	*Industry funiture*	**Italy**	*50*	*COSMOB + UNIVPM*
Since Septemb er2004	*Project web-site* *Idea of multiagent sanding machine published on Web-site of MEPOS project*	*General public*	**All**	*n/a*	*UNIVPM + all partners*
Since 2005	*Partner web site http://www.acv.ac.at/PROJEKT_Mepos.html*	*General Public*	**All**	*n/a*	*ACV*
April	*Conference Paper on*	*Research public*	**All**	*n/a*	*ACV*

Planned /actual Dates	Type	Type of audience	Countries addressed	Size of audience	Partner responsible /involved
2005	*Optical sensor development at IS&T/SPIE International Symposium on Electronic Imaging*				
Jan. 2006	*Conference*	*Research*	**n/a**	*2000*	*ACV*

Paper presented.

H. Ramoser, L. Cambrini, H. Rötzer: Real-time 3D wood panel surface measurement using laser triangulation and low-cost hardware, Machine Vision Applications in Industrial Inspection XIV, Proceedings of SPIE, Vol. 6070, 2006.

Section 3 - Publishable results

MEPOS project, has produced 4 main exploitable results.
The first and most complex result is:

1. a fully automated sanding machine, which embodies one of the developed optical scanners for measuring position and shape of incoming panels, plus a two-pressure pneumatic actuator and one intelligent control system to control sanding pressure.

Then 3 other exploitable results, which are sub-systems of the machine, have been achieved. They may also find application as stand-alone devices and are:

2. a set of 4 prototypes of optical sensor (real time optical scanners for shape and position of panels which move on a line)
3. a two-pressure pneumatic actuator
4. an intelligent control system

Each result is described below in a publishable format.

1. **Automated sanding machine.**
   This machine has been realised by VIET, with the support of the MEPOS partners.
   In order to control the sanding process and to optimise panel surface finish it is necessary that **panel dimensions**, **panel shape** and **panel position** are **measured on line**, while the panel is moving on the transport belt and entering the machine and that **actuators are controlled** in order to apply the required **force distribution on the panel surface**, so that each part of the panel is machined at the desired pressure level, so to optimize the sanding process. The developed automatic sanding machine achieves this result.
   It is composed of 3 main units which are integrated over a standard machine:
   a. an optical scanner to detect panel shape and position
   b. a two-pressure pneumatic actuator to change sanding pressure
   c. an intelligent control system based on fuzzy logic to control sanding pressure based on input from the optical scanner and on knowledge about sanding parameters and panel type.

This machine has been realised as a working prototype and it has been tested successfully on a number of different panels.

Its main advantages are:

a. automatic operation
b. good performance when sanding the borders of the panels, even with complex 3D shapes
c. good performance when sanding on thin layer of paint, especially at the borders where a very delicate action is necessary

This machine is therefore particularly useful for finishing processes.
It is now at the stage of an industrial demonstrator.
For more information contact VIET SpA, viet@viet.it or Ettore Vichi at ettore@viet.it .

2. Optical scanners for panel shape and position

MEPOS project has realized four different prototypes of optical scanners for real-time measurement of 3D shape and position of panels moving on a transport line.
Scanner specifications are:
The **technical specifications for the position and size optical scanner** are:

1. detect and measure panel position on the transport belt while panel is travelling at a speed up to 15 m/min (typically 10 m/min);
2. panel lateral position detected with an uncertainty lower than 3 mm;
3. image processing frame rate >50Hz;
4. uncertainty on measured panel thickness lower than 0.5 mm over a vertical range ± 3 mm;
5. maximum size of the panels to be measured (1300 mm width, 2200 mm length, 160 mm thickness);
6. the system operates in presence of dust which is normally produced during sanding;
7. the system operate under normal light conditions of a factory environment on panels of any colour and surface finish;
8. the system allow loading of the panels on the transport belt at random position and random rate of arrival.

Hereafter each system is presented.

1) UNIVPM has designed and realized a prototype optical sensor composed by:
   a. 2 inclined high power (50 mW) laser diode line projectors with prismatic optics to realize one single light sheet with uniform intensity profile;
   b. two separate first surface mirrors low-cost;
   c. 1 single CMOS high resolution camera 1280x1024 pixels 8 bit;
   d. one PC based frame grabber for the vision system with Fire-Wire IEEE 1394 connection;
   e. area of interest image acquisition and processing, with sub-pixel interpolation.

   For more information contact Unievrsità Politecnica delle Marche, prof. Nicola Paone, n.paone@univpm.it .
2) POLIMI has developed a prototype optical sensor composed by:
   a. 1 parallel set of green light projectors with an array of high brilliance green LEDs with a metal screen used to project a green light shadow;
   b. 1 single high resolution CCD camera 1380x1040 pixels 12 bit, mounted slanted for better sub-pixel accuracy;
   c. one frame grabber on PC with high speed Camera-Link® bus;
   d. algorithms for line detection, sub-pixel interpolation and line fit.

   For more information contact Politecnico di Milano, prof. Vincenzo Caglioti, caglioti@elet.polimi.it .
3) ACV has realised a sensor which has:

a. 2 different parallel light sheets with opposite inclination realized by 2 medium power inclined power laser diode line projectors with uniform intensity profile, thus realizing a shadow tolerant illumination system with possible redundant read-out;
b. 1 single CMOS high resolution camera 1280x1024 pixels 8 bit;
c. one conventional PC frame grabber for the vision system;
d. area of interest image acquisition and processing, with sub-pixel interpolation.

For more information contact Advanced Computer Vision, dr. Herbert Ramoser
herbert.ramoser@acv.ac.at

4) MEL has realized a prototype optical sensor composed by:
    a. 4 inclined low power laser diode line projectors with diffractive optics to realize one single light sheet;
    b. 2 parallel CCD cameras with standard resolution 566x732 pixels, 8 bit, with synchronous image acquisition;
    c. one industrial PC for image acquisition and processing based on an ultra compact rugged PC P266/300 MHz, which hosts controllers for scanners, microdrives, it has no moving parts, several industrial interfaces, digital input-output.
    d. algorithms for line detection programmed on-board the ASICS.

For more information contact MEL Elektronik GmbH, Dr. H.J.Langer,
h.langer@melsensor.de

All the above mentioned 4 sensors are developed at demonstrator stage.

3. Two-pressure pneumatic actuator

Fluid Automation Systems sas has developed a two-pressure pneumatic actuator for sanding machines.

The **technical specifications** for the **two-pressure pneumatic actuator** are:
1. to press the sanding paper with **2** distinct **values of pressure** (normal / low), so to create a variable pressure profile across the panel width;
2. to have a valve response time lower than 5 ms so to respond to the input and allow operation on moving panels up to a speed of 15 m/min;
3. to drive the array of pneumatic valves by microprocessor, so to be fully integrated in the digital agency of the machine.

The system developed has the following characteristics:
Below is a brief summary of the results achieved:
1. Solenoid valve design has the follwing performance and it is suitable for application :
- Life tests of more than 100 million cycles.
- The pull-in voltage at 1.7 & 2.5 bar : < 17 V (nominal values 21.6-24V), which ensures a working safety margin for the product.
- Solenoid valves have an operating range, without leaking, of between 0 and >10bar. Which is another safety margin.
- The pneumatic response of solenoid valves is a time of (at 1.7 & 2.5 bar) : < 7 ms; which ensures a satisfactory response time for the complete actuator system.

2. Cylinder – block has been realised and has the following performances:
- Piston opening : minimum switching voltage 1.7 bar < 17V; minimum switching voltage 2.5 bar < 16V at 50°C (worst case scenario)
- Behaviour of the cylinder – blocks are fully within the specifications for the complete temperature range.
- Tests pointed out that an initial slight lubrication is necessary to prevent stick/slip effect of cylinders.
- The cylinder response times for final applications are suitable regarding the full system (sanding response time) which requires around 20 ms for a full displacement.

The two-pressure pneumatic actuator is developed at the stage of an industrialised product.

For more information contact Fluid Automation Systemes, dr. Georges Magne, georges.magne@fas.ch .

4. **Intelligent control system**.

The **technical specifications** for the **intelligent control system** are:

1. to exploit data from both the optical sensing system (panel position and size) and from the process system (panel speed, sand paper type and velocity etc.);
2. to emulate the control strategy adopted by human operators through a fuzzy logic approach used to represent knowledge and to encode control strategies.

In particular it has been realised a digital controller which implements fuzzy rules to control the sanding process. The final ICS is composed of 8 fuzzy logic controllers, organized in a hierarchical architecture, operating on the following parameters:

- *asporto*: the kind of operation to be executed (provided by the operator); presently this corresponds to the quantity of material to be removed.
- *oggetto-p*: the amount of panel surface under the presently considered piston; this comes from a pre-elaboration of the data output from the optical sensor.
- *abrasione*: the abrasion coefficient, provided by the operator and depending on the kind of sanding paper, how much it has been used so far, the speed of the sanding paper, the speed of the panel on the feeding carpet
- *durezza*: how hard is the material to be treated, as given by the operator
- *qualità*: the eventual feedback about the quality of the work done so far, provided by the quality control system after the machine; the corresponding part of the controller has been implemented, although such a quality control machinery is not available on-line in the present implementation of the machine, and this part of the ICS has not been integrated with the others.

It is realized by using a freely available C++ library (Free Fuzzy Logic Library – http://ffll.sourceforge.net/fcl.htm) which implements the primitives for the management of fuzzy control systems represented in FCL (Fuzzy Control Language) defined in the IEC61131-7 document.

For more information contact Politecnico di Milano, prof. Andrea Bonarini, bonarini@elet.polimi.it .