Public Final Report of EUTIST-IMV

Activity COOKIES

(quality COntrOl of baKing status of ovEn products)

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Abstract
The Cookies Project was aimed to design, prototype, test and validate an automatic feedback control system for an industrial band oven used to bake biscuits. The main target was to achieve a sensible improvement of the product quality and a consistent scraps reduction. These results have been gained by means of a real-time feedback controller obtained by coupling a Visual Inspection System with a Fuzzy Logic Supervisor.

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1. Synopsis

Biscuits or rusks are usually industrially baked using continuous band ovens. A band oven is composed by several independent cooking stations. The product travels through these stations carried by a continuous conveyer belt. For each station it is possible to set the burner temperature in order to heat appropriately the air flow used to cook the biscuits.

The oven settings are normally handled by an oven manager, an expert technician with several years of experience. The subjectivity introduced by an human operator causes several inconveniences. For example, each oven manager has a different sensibility and bases the decisions on his own experience. As a consequence, the same product could be baked differently during the same day. Moreover, the baking process is very sensitive to environmental factors such as air temperature, pressure, and humidity. If any of these factors changes, the oven manager has to modify the oven settings in order to keep constant the product quality. Unfortunately, oven surveillance is not continuous, so that any drift in the environmental conditions can cause significant product losses. Finally, due to the employees turn-over and the enlarged spectrum of baked products, ovens are often controlled by insufficiently experienced managers. The sum of all these factors has caused, in the recent years, at the Colussi plant an increase in the number of sub-standard biscuits. A significant fraction of the rejected biscuits and about a quarter of the customer complaints are due to incorrect oven regulations.

The Cookies project solves all these problems by adopting machine vision to automate the baking process. A Visual Acquisition System monitors the biscuits color and, on the basis of this information, a real-time autonomous oven control system automatically adjusts the burner temperature. The baking process can therefore be much more closely controlled and wastes can be reduced. The following benefits can be obtained:

- Reduction of product waste
- Reduction of complaints
- Reduction of energy waste
- Improvement in product consistency
- Continuous measurement of quality and statistical assessment of cooking and production data.

An experimental system has been installed at the Colussi factory in Petrignano di Assisi (Italy). A visual acquisition system based on a color digital camera inspects the biscuits. The acquired data are then analysed to evaluate the biscuits baking condition. These results are transferred to a supervisory computer which automatically manages the baking process by controlling the oven burners.

The collected results have demonstrated a good stability and robustness of the system also during the experimental phase. The accuracy, sensibility and stability of the Visual Acquisition System are consistent. The supervisory oven controller has demonstrated to be able to keep constant the baking color and to recover the system from incorrect cooking conditions.

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2. Executive Summary

2.1. The Problem

Baking industries normally use *band* ovens. A band oven is made of several modular independent cooking stations. The product travels through these stations carried by a steel band conveyer. For each station it is possible to set the burner temperature to appropriately warm up the air flux used to cook the biscuits.

The whole baking process is very sensible to several environmental factors such us air temperature, pressure, humidity, wind speed and wind direction.

The control of the baking process usually relies on the experience of the human operator. The corrective actions (including changes of burner set-points, changes of the conveyer speed, etc…) are manually performed by technicians who visually check the product cooking status and, consequently, take the appropriate decisions. If the temperature of the oven units is not properly set, the product quality could degenerate due to overcooking or undercooking so that, in many cases, it could be necessary to discard entire lots of product. Unfortunately, inappropriate tunings are very common because human inspection, in spite of the high expertise of the oven managers, is subjective, inconsistent, non-continuous and does not allow timely feedback actions.

As a consequence, the relevance of developing an automatic system for the inspection and the control of the baking process is evident. Indeed, it is important to have global information on the production (biscuits count, statistical analysis, etc) as well as specific measurements on the baked biscuits (color, area, length, perimeter, shape factor) and to continuously process the collected data in order to tune the burners, to alarm the oven managers when a wrong baking process is found, to suggest the best control actions and, in some extreme cases, to activate a rejection mechanism. The system has also to detect and collect a large amount of data concerning the biscuits (color, shape, size, dimension) and the environmental conditions (temperature, humidity, air pressure, wind direction and wind speed) because the baking process is cumulatively affected by these factors.

2.2. The Solution

The solution adopted to control the baking process is based on an accurate measure of the cookies baking color. This information is used to automatically set the oven temperature by means of a real-time control system. In the current implementation the cookies baking is controlled by acting exclusively on the last burner of the oven because it suffices to consistently improve both the biscuits quality and the efficiency of the baking process.

The control system is essentially made of two units:

- A **Visual Inspection System**, based on a high performance color line-scanning camera placed at the oven outlet, which collects data concerning the biscuits baking condition. The cookies are illuminated with a special light source capable of producing a very stable and evenly distributed light. These components and some special optics and electronics are all enclosed into a single cabin. The resolution of the camera across the 1000mm wide conveyer is 1mm per pixel and along the conveyer 0.5mm per pixel. The final version is going to have a pixel resolution of 0.5 x 0.5mm, being more suitable for dimension control. The measuring software can produce a lot of information concerning the cookies color (whole cookie and middle part of the cookie), dimension, shape, surface roughness, color profile across the conveyer, etc. The visual inspection could be also directly connected to a mechanical rejection system.

- A **Fuzzy Logic Controller** that selects the most appropriate burner temperature depending on the baking status provided by the **Visual Inspection System** and on the current working conditions. Owing to the plant characteristics, an adaptive control scheme is used. It is governed by a supervisor, which selects the most appropriate control strategy depending on the current working conditions. The control system can also acquire information concerning the environmental conditions that deeply influence the baking process by means of a meteorological unit: temperature, humidity, pressure, wind direction, etc. are continuously monitored. All relevant data are stored into formatted log files to allow a post process analysis. The saved data makes it possible to have a better insight about the baking dynamics and the controller behavior. This knowledge can be usefully used to improve the performances of the overall control system. An easy-to-use interface has been implemented. By means of such interface it possible to easily tune the control algorithm, to manage saved tunings, to manually act on the oven by disabling the automatic controller, etc. The oven controller is able to detect several malfunctioning conditions and to set up proper alarms for the oven manager.

2.3. Benefits

An experimental system has been installed at the Colussi factory in Petrignano di Assisi (Italy). The collected results have demonstrated the good stability and robustness of the system. The accuracy, sensibility and stability of the Visual Acquisition System are appreciable. The supervisory oven controller has demonstrated to be able to correctly manage the baking process and to recover the system from incorrect cooking conditions.

The following immediate benefits have been verified:

- Reduction of product waste due to a continuous oven surveillance
- Reduction of energy waste due to smoother and faster burner control
- Improvement of the product consistency
- Continuous measurement of quality and statistical assessment of the baking and the production data.
- Easy adaptation of the oven control to different products
- Shorter startup time (less rejections at the beginning of each lot)

Further, long time benefits are expected:

- Reduction of complaints due to the better product consistency
- Faster setup of the oven temperature profiles for new products
- Faster training of new oven managers

Due to the sensible improvements on productivity, quality assurance and savings, the application of the automatic quality control system permits producing high quality baked products which meet, at best, the market requirements.

3. Full Technical Text

3.1. State of the Art

From a physical point of view, the biscuit baking process consists of a thermal treatment that causes a large reduction in the product density in association with the development of an open porous structure, a large reduction of the moisture level and several changes in the surface coloration: the pale color of the raw product changes into the typical light brown color of the finished product (the color varies enormously according to the recipe and the type of the product). The color appears to be a fundamental factor for the acceptability of the baked product by the consumer.

The biscuit color is the result of complex biochemical reactions of Maillard type (initiated when the surface temperature of the product exceeds 100 °C) between sugars and amino acids. There are many parameters that influence the biscuit color: the recipe, the size, the dough weight and, above all, the baking process.

Baking industries usually use *traveling* or *band* ovens. A band oven is made of several modular independent cooking stations. The product travels through these stations carried by a steel band conveyer. For each station it is possible to set the burner temperature to appropriately warm up the air flux used to cook the biscuits. Moreover, several mechanical valves are used to correctly drive the air flux inside the cooking chambers and to regulate the air exchange with the external environment. The hot gases convex naturally from the baking chamber up to the flues pipes but it is common to have fan assistance. The whole baking process is very sensible to several environmental factors such us air temperature, pressure, humidity, wind speed and direction.

The parameters that can be controlled in an oven during the baking are:

- the **baking temperatures** (set points)
- the **ratio** of heat directed to the **top** and the **bottom** of the band
- the **humidity**
- the **baking time**

If the temperature of each zone is not properly set, the product quality could degenerate due to over or undercooking. As a result, entire lots of product could be discarded. The corrective actions (including changes of burner set-points, changes of the conveyer speed, etc…) are manually performed by technicians who visually check the product cooking status and, consequently, take the appropriate decision. The control of the baking process usually relies on the experience of the human operator. This approach presents several problems. Indeed, human inspection, in spite of the high expertise of the oven managers, is subjective, inconsistent, non-continuous and does not allow timely feedback actions. Under normal conditions, operators may take 15 – 20 minutes to detect a wrong baking and perform the consequent correction. The result is an expensive loss of production.

COOKIES (*quality COntrOl of baKIng status of ovEn productS*) is a 20 month TAKE-UP activity within EUTIST-IMV (European Take-up of essential Information Society Technologies - Integrated Machine Vision), a group of Trial actions, supported by the European Commission, aimed to demonstrate the business benefits that can be obtained by applying an advanced machine vision technology into industrial processes.

The Project was aimed to design, prototype, test and validate a visual inspection and a feedback control system for an industrial oven used to bake biscuits, in order to achieve a sensible improvement of the product quality.

The following benefits can be obtained:

- **Reduction of food scraps**, thanks to a more precise temperature supervision and real-time feedback

- **Improvement of the product quality stability,** thanks to a non-subjective inspection
- **Reduction of manpower** needed for the oven regulation and the quality control
- **Reduction of energy waste**, due to a better and faster burner control
- **Continue quality measurement** and statistical treatment of the process data
- **Fast recovery** from wrong baking situations

The project is based on the experience and collaboration between industry and university. It exploited and improved the outcomes of the earlier project "Use Vision" in a new field, "The process of biscuit baking", by adapting and engineering its results to the baked product manufacturers requirements.

The project partners are:

Colussi Perugia S.p.A (Italy): is the project End-user and also covers the role of technical coordinator. It is one of the main Italian manufacturers of biscuits and baked products. It has nine production lines for cookies, petit, rusks and crackers and has a production capacity of 50.000 tons/year. Colussi is certified on the basis of ISO 9001 and is "Total Quality" oriented.

DIPARTIMENTO DI INGEGNERIA DELL'INFORMAZIONE (DII) - University of Parma (Italy): technological provider of the feedback control system design. The DII-UniParma offers competencies in Information Technologies, including Computer Engineering and Control Systems. The DII-UniParma mission is to perform both University-level researches and to transfer the acquired knowledges into the teaching activity.

ATE - Applied Technical Engineering Oy (Finland): technological provider of the visual inspection system. It is a Finnish company designing and manufacturing fully integrated color vision systems for industrial applications. ATE has a solid knowledge in making high performance measuring equipment for extremely complex color machine vision applications. The company has experience in both designing vision systems and adapting them to different applications.

3.2. Approach

The baking process in an industrial band oven can be appropriately controlled if an accurate measure of the cookies baking color is available. Such important information can be used to select the most appropriate oven temperature. More precisely the proposed controller acts on the temperature set-point of the last oven unit, which most influences the final baking color.

The basic idea is to implement a real-time oven feedback system obtained by coupling a Visual Inspection System with a Fuzzy Logic controller

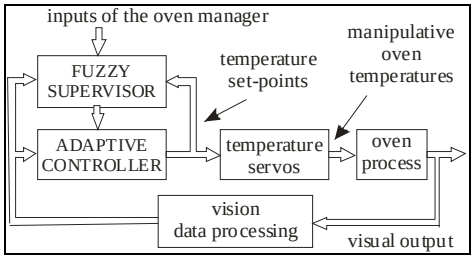


Figure 1. The control scheme for the continuous band oven

An experimental system has been installed and tested on the 'Misura' line at the Colussi factory in Petrignano di Assisi. It is a rotary molding line with an indirectly fired band-oven made of seven baking stations. The oven is 80 m long, 1 m wide and is equipped with seven independently controlled burners. It is used to bake several types of biscuits, which differ for size, shape, recipe and color. The line production capacity can be up to 1.400 kg per hour.

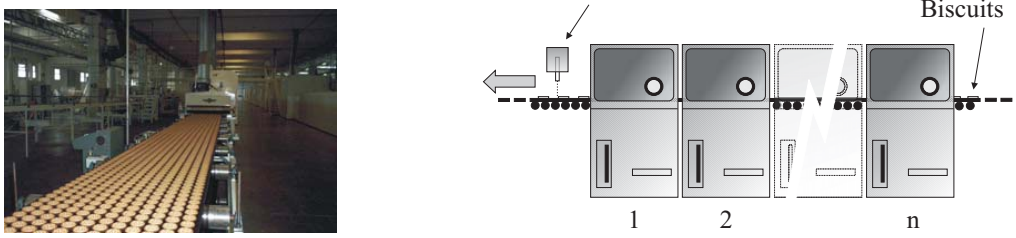


Figure 2. The Colussi band oven and a schematic representation of a continuous band oven composed by n elements

The main element of the Visual Inspection System is a high performance color line-scanning camera. The cookies are illuminated with a special light source able to produce a very stable and evenly distributed light.

Figure 3. The Visual Inspection System

The resolution of the camera across the 1000mm wide conveyer is 1mm per pixel and along the conveyer 0.5mm per pixel. The final release of the Visual Acquisition System is going to have a pixel resolution of 0.5 x 0.5mm, being more suitable for dimension control.

The measuring software can generate a lot of fundamental data concerning the baking process. The surface color of each cookie can be measured but the system is also able to detect the color of the sole middle part of the cookie. The system can also acquire the cookies dimensions, shape, surface roughness, color profile across the conveyer, etc. The Visual Inspection System can be directly connected to a mechanical rejection system to discard cookies which do not satisfy the specified requirements. All the measured cookies data are sent to the oven Control System using a serial line.

Figure 4. Cookies samples

The Control System is implemented using a standard Personal Computer. Depending on the cookies status the controller selects the most appropriate temperature set-point for the last oven burner.

Owing to the plant characteristics, an adaptive control scheme is used. It is governed by a supervisor, which selects the most appropriate control strategy depending on the current working conditions. The overall architecture of the supervisory mechanism is based on a *Takagi-Sugeno* fuzzy approach.

Two more serial lines are used to communicate with the burner controller and the meteorological unit. The first line is mainly used to send the burner set-point and to acquire the current burner temperature. The second line is used to acquire the environmental conditions deeply influencing the baking process (temperature, humidity, pressure, wind direction, etc.).

All relevant data are stored into formatted log files to allow a post-process analysis. The saved data makes it possible to have a better insight of the baking dynamics and of the controller behavior. This knowledge can be usefully used to improve the performances of the overall control system.

An easy-to-use user interface has been implemented. By means of such interface it possible to easily tune the control algorithm, to manage the saved tunings, to manually act on the oven by disabling the automatic controller, etc. The oven controller is able to detect several malfunctioning conditions and to set up proper alarms for the oven manager.

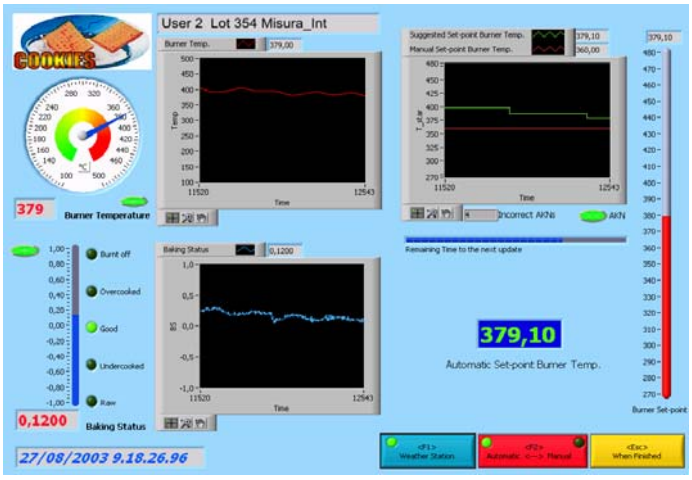


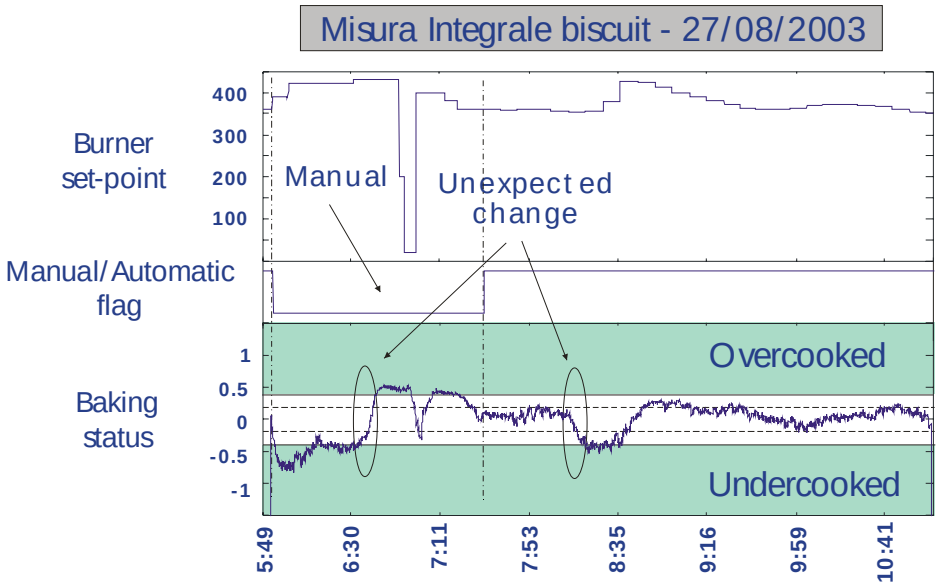
Figure 5. The Control Software

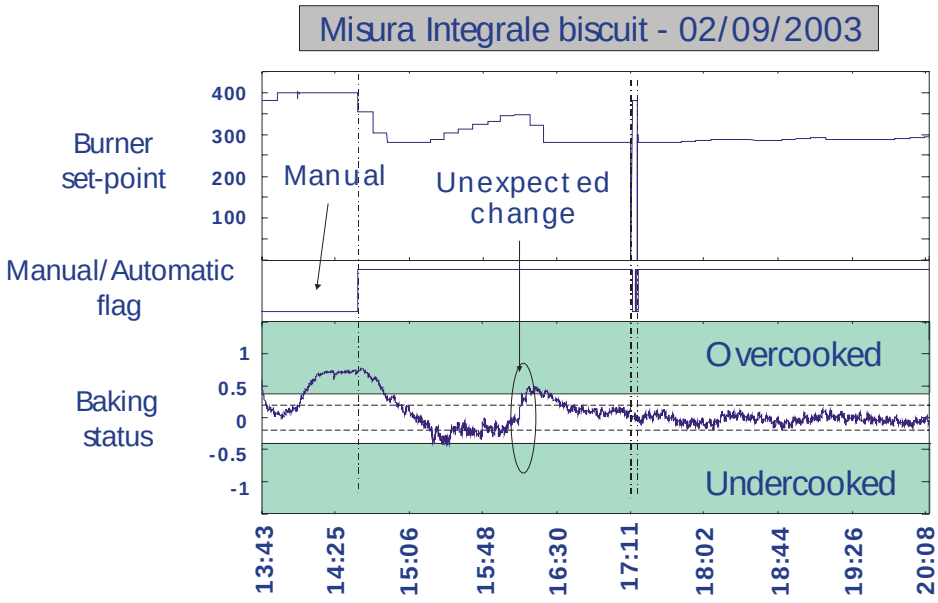
The performances of the Visual Inspection System were measured during the validation phase. The output of the Visual Inspection System is an integer number in the interval [0, 1000]. It will be indicated in the following as "Baking Color". Human eyes can distinguish a color difference when the Baking Color gap is larger than, at least, 3-5 units (this range is valid when the Baking Color is close to 610). The performances of the Visual Inspection System can be summarized as follows:

- The color stability was measured considering a long time period (8h). The color fluctuations were measured using a white piece of Teflon placed under the Visual Inspection System. The measured color stability is less than 0.5 units (standard deviation less than 0.08% of measured values).
- The same cookie was acquired 100 times placing it in the same position of the conveyer. Repetition accuracy of the measured cookie is ±0.25 units when the average Baking Color is close 620.
- Measured color changes less than 0.5 units if the same biscuit is placed in different positions of the oven conveyer (1m wide conveyer - average Baking Color close to 610)
- The equipment is able to detect a change in the baking color corresponding to a 5°C change of the burner temperature.
- The equipment is ready to measure a correct Baking Color after a 20 minute warm up.
- The software is able to acquire at least 250 cookies per second.
- The software is able to acquire the 100% of the cookies on the conveyor.

Also the performances of the Automatic Control System were verified during the project validation phase. Each type of biscuit has a different optimum Baking Color: some biscuits are intrinsically very dark while others are very light. In order to use the data of the Visual Acquisition System to control the oven, the Baking Color has been normalized into a number named Baking Status (*BS*). The Baking Status normally spans in the range [-1, 1] (even if higher or lower values can be detected for overcooked or undercooked biscuits) and does not depend on the biscuit type. Biscuits are considered perfectly baked if their Baking Status *BS* is located inside the interval [-0.2,0.2] (in this case human eyes cannot distinguish the differences between the baking degrees). When *BS* is within the intervals [-0.4,0.2) and (0.2,0.4] the differences are more evident, but the biscuits are still considered acceptable. Outside these ranges the biscuits are discarded.

The following figures report the results of two different baking sessions. They are obtained from the system log-files and show the burner set-point temperatures, the automatic/manual flag and the biscuits baking status.





As it is shown in the figures, the product line is always started manually by the oven-manager. The figures also demonstrate that the automatic control system, differently from the human supervision, makes it possible to obtain an almost constant baking color and to reduce the amount of scraps. With the current set-up and under normal operating conditions, the system is able to correct a wrong baking situation in no more than 16 – 20 minutes, while operators may take up to 15 – 20 minutes to detect a wrong baking situation causing a total recovery time normally equal to 30-35 minutes.

It has been verified that the control software, in automatic mode, can keep the baking color within the ranges:

- [-0.2,0.2] for the 80% of the time (optimum baking)
- [-0.4,0.2) and (0.2,0.4] for the 99% of the time (acceptable baking)
- outside such intervals for the 1% of the time (non acceptable baking)

Experimental results have clearly shown that the large distance between the oven outlet and the Visual Acquisition System introduces additional delays in the feedback control system which worsen its performances. An appropriate optimization of the system architecture will sensibly improve the control efficiency.

The controller task is further complicated by a non adequate number of sensors. With the current set up, the control system can only acquire the burner temperature of the last oven unit and the baking conditions of the biscuits but it does not know the status of all the other oven units. For this reason it cannot compensate in advance any variation of the biscuit baking status until such variation is detected by the Visual Acquisition System.

Finally, the baking process could be remarkably improved, with quite limited costs, by acting not only on the last burner set-point but also controlling the other oven zones (at least the second-last burner set-point). Besides, the thermal transients could be easily speeded up by acting on the fan coils used to extract, by force, the hot air from the oven.

3.3. Results, Achievements and Benefits

Only 15 days of real trials have been performed due to the project delay. For this reason the project results can not be considered a final achievement. A longer test period is required. To this purpose, the prototype of the visual and control system will be tested at least until the end of December 2003. During that time more data will be acquired and analyzed.

The Colussi factory produces several bakery products, such as biscuits, rusks and crackers. During the Cookies project activities only the control of the biscuits baking process was investigated. Due to the specific technology used for rusks and crackers it is not possible to estimate, at the moment, the possible benefits deriving from the use of the control algorithm with this types of products.

System validation was carried out following the project specifications. Particularly, a comparison between the quality control response of expert technicians and the response of the automatic system was performed.

In the following sections, the benefits effectively verified by Colussi during the trial period are briefly described.

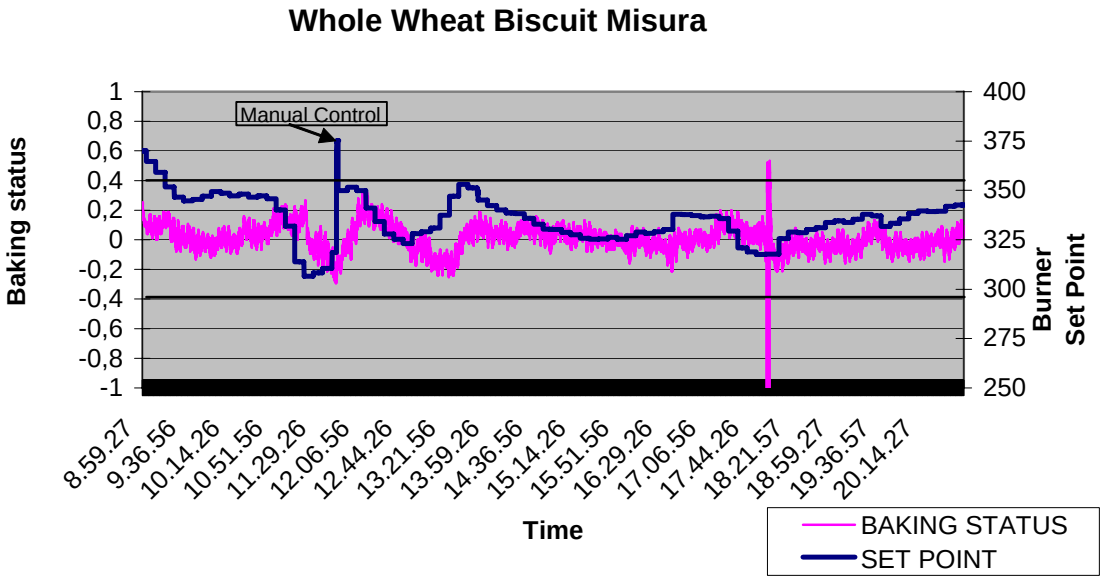
3.3.1. Reduction of scraps and consequent economical benefits

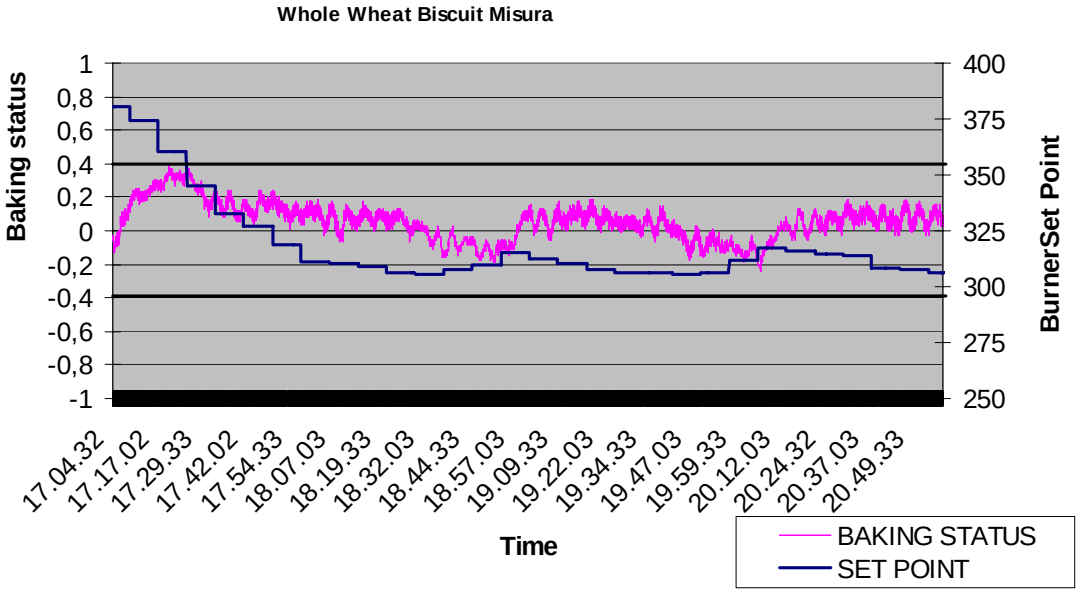
During the trials it was possible to evidence that the automatic control of the baking process performed by the Cookies System guarantees a very stable baking status. According to the algorithm tunings, biscuit are not discarded if their baking status ranges between -0.4 and +0.4. During the experimental phase this happened for the 99% of the time **so that the amount of scraps due to baking problems was close to zero**.

This result is obtained due to the following properties of the autonomous control system:

- Continuous oven surveillance which guarantees a short reaction time from the visual check to the feedback action
- Shorter start-up time (less rejections during the line start-up)
- Fast adaptation of the control system to new products (less losses during the tuning)
- Same control approach for different products (the controller behavior does not depend on the type of biscuit)

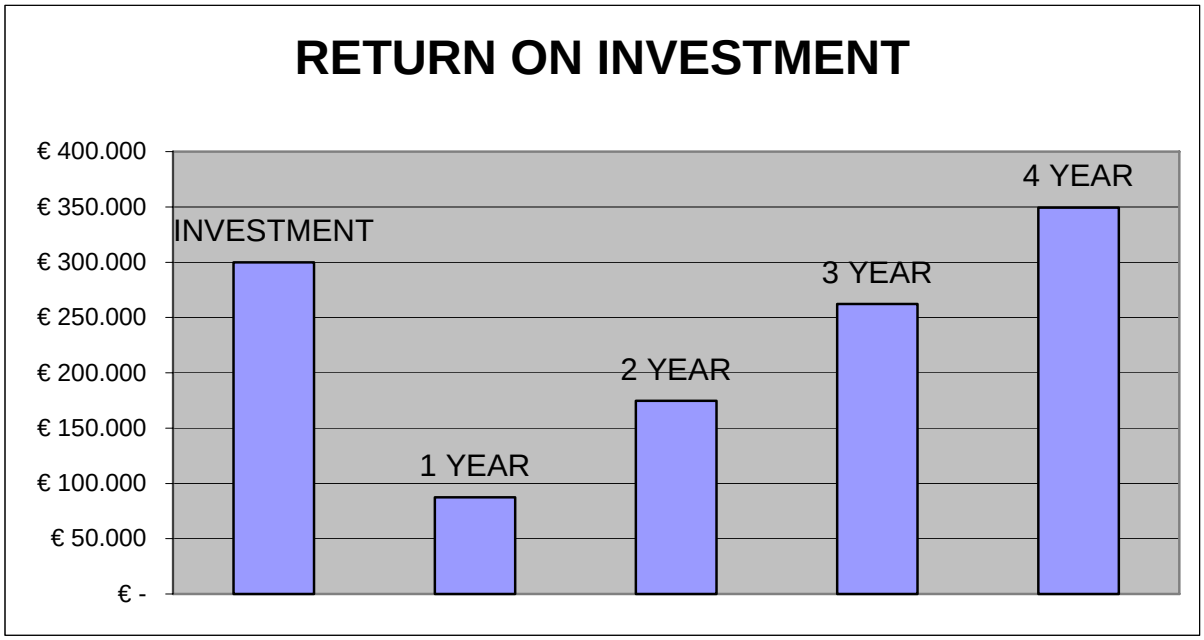
The following graphics report two typical results concerning several hours of biscuits production. In the graphics both the baking status and the burner set point diagrams are shown.





About 25% of total quantity of goods rejected by Colussi are due to wrong plant regulations, a third of them is specifically due to wrong temperature regulations. With the implementation of the Cookies System it is realistic to assert that it will be possible to save about the 8,7% of the total losses. Only the amount of scraps due to lines start-up (0,4%) cannot be eliminated.

The following graphic reports an estimation of the return on investment calculated for six production lines. In less than four years it should be possible to recover the cost of the Vision and Control System.



3.3.2. Reduction of complaints and better return on image

The control system permits keeping the baking status within the range [-0.2, 0.2] for the 80% of the time. This range corresponds to perfectly baked cookies: it is possible to assert that the vision and control system makes it possible to guarantee a very constant product quality. As a result, the amount of complaints due to baking causes should decrease in the future. At the same time, owing to the quality steadiness, the product should be more appreciated by the consumers.

The evaluation of this kind of benefits requires a long time (not shorter than one year, since the products shelf-life is about 11 months) so that it will be estimated in the future.

3.3.3. Improvements of quality assurance

The continuous measurements and the statistical treatment of production data will allow to improve the quality assurance activities.

The system will be a precious instrument since it will permit to analyze data and to ensure a real politic of positive product release. Indeed, for each product it is possible to have objective data which permit to verify the product quality. It is a strong instrument to be used when clients contact the factory for complaints.

Some data can be utilized for the line predictive maintenance. For example, the burner time response could suggest the necessity of maintenance assistance.

3.3.4. Oven manager training time reduction

During the 15 days tests a change in the oven managers behavior has been noticed. Particularly, they have immediately become confident with the system. They understand its potentialities and consult its suggestions before making any manual change. The control program is also a valid instrument to shorten the new employees training period.

Normally, an oven manager needs several years of job experience and attends specific courses where his color discrimination capability is compared with definite standard color. With the Cookies System also operators with non sufficient experience could manage the baking process.

3.3.5. Reduction of energy consumption

Thanks to the enhanced productivity and the smoother and faster burner control the energy consumption should be reduced. About 18 months of system tests should be necessary to estimate the return on investment due to the reduction of energy consumption.

3.4. Dissemination:

The dissemination activities performed during the project have been particularly consistent and have concerned several channels:

- Fairs expositions
- Conferences presentations
- Technical paper publications
- Newspapers articles
- Magazine articles
- Radio news
- Multimedia CD-ROMs developments
- Flyer design
- Poster design
- Web pages realization

The dissemination activity has been particularly effective since both the UniParma and ATE units have been contacted by industrial manufactures potentially interested to the system.
In the following a summary of the main dissemination actions is reported.

External events:

- *SIAL fair* (Paris, 20-24 October '02)
  a poster of the project was presented
- *Alimentaria Lisboa '03* fair (Lisbon, 6-10 April '03)
  a poster of the project was presented
- *Automaatio 03* fair (Helsinki, 9-11 September '03)
  a demonstration of the COOKIES system was held in the EUTIST-IMV cluster stand
- *ECC03* (European Control Conference, Cambridge, UK September 2003)
  a technical paper titled "Vision-based feedback control of an industrial band oven" was presented. The presentation was appreciated by the audience and the proposed system aroused interest.
- *IST 2003 exhibition* (Milano, Italy, October 2003)
  The project will be presented at the EUTIST-IMV cluster stand
- *47° Convegno Nazionale ANIPLA* (Brescia, Italy, November 2003)
  A technical paper titled "Controllo mediante visione artificiale del processo di cottura di un forno industriale" will be presented. The audience will be composed by industry and university exponents.

Dissemination material:

- *Web pages*
  Project web pages have been activated with descriptive synopses on the partners web sites.
  Links:
  - www.colussigroup.it
  - www.ce.unipr.it/automatica

    - www.spt.fi/eutist
- *Poster* (Sept 02)
  A poster of the project has been designed in order to be exposed in international fairs. The poster synthetically describes the objectives, the benefits, and the partners of the COOKIES project.
  It is really very attractive and invites the reader to investigate its content.
- *Video clip* (Dec 02)
  A project presentation was done with an interview to A. Piazzi in Barcelona. It was recorded on a CD-ROM
- *Success story* (Mar 03)
  An article describing the project and the advantages deriving from the use of a vision assisted control has been written and published on the EUTIST Web site.
- *Web pages* on the Finnish portal for the food sector (Mar 03)
  An article about the COOKIES project was published
  Link:
    - www.finfood.fi
- *Radio* (Mar 03)
  A description of the project was presented in the local morning news in Satakunta (26.03.03)
- *CD-ROM* (September 03)
  The multimedia CD-ROM describes the objectives, the befits, and the partners of the COOKIES project. Videos and figures clarify the project targets. A preliminary copy of it has been distributed at the *Automaatio 03* fair in Helsinki.
- *Flyer* (September 03)
  It is a two-pages document aimed to diffuse the results of the Cookies Project.
- *Web pages* on the Italian portal ITA FOOD, the Web portal for the companies of the food industry
  http://www.ita-food.it/ - info@ita-food.it
  An article describing the project has been published in the Italian website.

Publications:

- *Magazine article* (May 2002)
  An articol about COOKIES was published on Biscuit World Magazine.
  In the article the background of the project and its objectives are accurately described. The expected benefits are pointed out. The article has been used to disseminate the project between suppliers, clients and Universities.
- *Technical paper* titled “Vision-based feedback control of an industrial band oven” (C. Guarino Lo Bianco, M. Romano and A. Piazzi, ECC03 , Cambridge, UK, September 2003)
  The paper describes with details the visual real-time feedback controller designed by the University of Parma.
- *Articles in local magazines*, (Mar 03)
  The presentation of the COOKIES project was submitted to local newspapers and magazines in Finland: Satakunnan Kansa (26.03.2003), Porin Sanomat (26.03.2003), Huvudstadsbladet (26.03.2003), Satakunnan työ (27.3.2003),
  Uusi Aika (27.3.2003), and Tekniikka ja Talous (10.04.2003)
- *Magazine article* (Mar 03)

An article about the COOKIES project was published in the European Integrated Machine Vision Magazine

- *Technical paper* titled "Controllo mediante visione artificiale del processo di cottura di un forno industriale" (C. Guarino Lo Bianco, M. Romano, A. Piazzi e E. Pinazzi, accepted for 47° Convegno Nazionale ANIPLA , Brescia, Italy, November 2003)
  The paper describes with details the real-time feedback controller designed by the University of Parma. Experimental results are reported.
- *Magazine article* (April '03)
  An article about the COOKIES project was published in RASSEGNA ALIMENTARE – a two-monthly or four-monthly multilingual magazine concerning the Italian technology for Food and Beverage. Good visibility: the magazine is distributed to several thousands of companies and professionals of the food industry.
- *Magazine article* (April 03)
  An article about the COOKIES project was published in INDUSTRIE ALIMENTARI – A monthly magazine on food industry technological, scientific, economical and legislative issues. Good visibility - magazine distributed to several thousands of companies and professionals of the food industry
- *Magazine article* (May 03)
  An article about the COOKIES project was published in TECNOLOGIE ALIMENTARI – An 8 monthly magazine with the sponsorship and collaboration of AITA (Association for Food Technologies)
  Good visibility - enquiry received from a manager of FERRERO (a multinational food company).
- *Magazine article* (September 03)
  An article about the COOKIES project was published in ITALIAN FOOD TECHNOLOGY – A 6-monthly magazine on Italian technology related to all branches of the food industries (in English). Good Communication for English speaking audience.
- *Magazine article* (September 03)
  An article about the COOKIES project titled "IMV technology improves biscuit production" was published in Food&Beverages.

3.5. Conclusions

The project was a technical success. It has proved that a machine vision based equipment coupled with a digital controller makes it possible to implement a robust autonomous system for the automatic biscuits baking. This confirms the effectiveness of Visual Inspection Systems for industrial applications where the most relevant characteristic of the produced items concerns their shape and color. It has also proved how an automatic vision system can help human operators in the supervision of industrial processes and can improve the product quality by eliminating the subjectivity which is an intrinsic characteristic of the human inspection.

Experimental results clearly demonstrate that the developed automatic control system, differently from the human supervision, makes it possible to obtain an almost constant baking color and to reduce the amount of scraps. With the current set-up and under normal operating conditions, the system is able to correct a wrong baking situation in no more than 16-20 minutes.

The Visual Inspection System permits an accurate measure of the cookies baking color. The measure sensitivity, accuracy and stability obtained are much better then those achievable with human eyes. The system can measure at least 250 cookies per second and its visual range fully covers the conveyer band.

The Control System, based on an Adaptive Fuzzy Logic Supervisor, probed to be reliable and able to guarantee a high quality production.

During the project development all the participants have acquired a significant know-how about the problems and the solutions concerning the industrial biscuit baking process.

In particular ATE succeeded in implementing a reliable real-time vision algorithm able to compute the baking status of the biscuits. ATE acquired the capability to perform different evaluations on the analyzed products concerning the cookies color (whole cookie and middle part of the cookie), dimension, shape, surface roughness, color profile across the conveyer, etc. The developed Visual Inspection System can also be used to drive a mechanical rejection system in order to reject cookies that are not within specified parameters.

The UniParma unit has acquired a depth knowledge of the baking process used to optimally control the oven burner. More precisely, it has acquired a good insight on the dynamics of the cooking process and identified the external factors most influencing the process itself. Several strategies have been developed in order to find the most performing control actions to recover from a wrong baking and to offer a constant quality product.

All the partners (Colussi, Ate and UniParma) have acquired a good system knowledge during the integration phase. Analyzing the results, several lessons have been learnt. First of all, it is clear that a wide number of sensors is required to better control the plant. Moreover, the recovery time is deeply influenced the position of the Visual Inspection System which is, at the moment, quite far from the oven outlet. This time can be easily reduced, with an appropriate optimization of the system architecture, to 12-15 minutes.

In the current implementation only the last burner temperature is regulated by the automatic system. Simulative and online analysis clearly show that, owing to the baking process dynamics, it is not possible to further reduce the recovery time acting only on the last burner set-point.

The economic analysis has evidenced that the Vision and Control System guarantees substantial business benefits. They concern immediate economical benefits deriving from the reduction of the product scraps and delayed benefits deriving from the product quality improvement.

Due to the evidenced business benefits, plans for the project exploitation have been tentatively devised. First – we make it clear – exploitation is strictly linked to the know-how acquired working on the project. A know-how list can be summarized as follows:

1) real-time vision algorithm to compute the baking status of the biscuits (developed by ATE);
2) fuzzy logic algorithm to control the oven burners (developed by UniParma);
3) systems integration knowledge (shared by all the project partners).

Two exploitation strategies are viable: the technology partners (ATE and UniParma) can independently commercialize their know-how; the end-user Colussi can maintain and develop his prototypal automatic oven with the collaboration of UniParma and ATE. These strategies, non mutually exclusive, have been preliminarily probed. Contacts made by ATE and UniParma have evidenced the potential of the devised algorithms. In particular the fuzzy logic software, still using the visual feedback, could be adapted to address other baking problems such as, for example, the thickness control of baked products.

In the short term maintaining and further improving the prototypal automatic oven at the Colussi factory appears to be the most viable exploitation approach. In the long term, the possible start of a spin-off company focused on real-time visual feedback for the bakery industry can be foreseen.

3.6. Contact details

Colussi Perugia S.p.A (Italy): is the End-user of the project and also covers the role of technical coordinator. It is one of the main Italian manufacturers of biscuits and baked products. It has nine production lines for cookies, petit, rusks and crackers and has a production capacity of 50.000 tons/year. Colussi is certified on the basis of ISO 9001 and is "Total Quality" oriented.

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DIPARTIMENTO DI INGEGNERIA DELL'INFORMAZIONE(DII) - University of Parma (Italy): technological provider of the feedback control system design. The DII-UniParma offers competencies in Information Technologies, including Computer Engineering and Control Systems. The DII-UniParma mission is to perform both University-level researches and to transfer the acquired knowledges into the teaching activity.

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ATE - Applied Technical Engineering Oy (Finland): technological provider of the Visual Inspection System. It is a Finnish company designing and manufacturing fully integrated color vision systems for industrial applications. ATE has a solid knowledge in making high performance measuring equipment for extremely complex color machine vision applications. The company has experience in both designing vision systems and adapting them to different applications.

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The projects web-site is http://www.spt.it/eutist

Start date of the COOKIES Project: 1 January 2002
End date of the COOKIES Project: 30 August 2003
Duration of the project: 20 months
Overall cost of the project: € 298,080
Financial contribution from the European Community: € 227,015