SYNTHESIS REPORT

FOR PUBLICATION

Packaging robot fur biscuits

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Abstract

A substantial part of the packaging activities m the biscuit industry is manually operated. 'Quality' and 'Hygiene' are principal aspects m this industry and for this reason packaging automation was very welcome. Unfortunately, automation was not feasible, since biscuits are very fragile and, secondly, are submitted to significant variation.
This project was initiated to develop *a* packaging robot for ii-agile biscuits, m combination with a Visual Surface Recognition System (VSRS). With the VSRS the robot would be able to 'observe' the biscuits. Based upon predetermined quality characteristics the robot should be able to resolve which biscuits are in compliance with established quality standards. Next, the robot should package the good biscuits, removing the bad ones m the process. In addition, an Expert System / Quality Data Base, suitable for restoring, analyzing and retrieving the VSRS-data needed to be created. Also, an interactive operating system allowing an easy communication with the robot system had to be conceived.

Technical description

Objectives

This project was set up to develop a packaging robot for biscuits for two reasons:
The first reason was, that the finished product would be more consistent, would have a higher quality. Secondly, packaging would take place under more hygienic circumstances.

More specifically, the following *objectives were* identified

A *'pick-and-place'-robot, SNC-F4,* had to be adjusted to make it suitable for handling fragile, complex-shaped, differing biscuits. This robot was the improved version of his predecessor, the SNC-F3. In particular, the *grasping* tool needed ample analysis and design. The SNC-F4 has four axes, which can be programmed independently. The positioning accuracy required was about 1 mm. Also, dedicated periphery equipment was designed and manufactured.

Furthermore, specific *internal transport* trays needed to be designed in order to make it possible to position and to handle so tailed 'cakes'. Caisses are thin paper cups seining as a packaging for a stack of biscuits. Caisses have a negligible weight and for this reason empty caisses are virtually impossible to transport in a controlled (i.e. positioned) way. This issue was of particular importance, because market demand for this kind of environment-friendly packaging was growing rapidly.

A *Visual Surface Recognition System* (VSRS) had to be developed. This was the critical and most essential part of the research programme. Based upon identified quality characteristic (such as shape, colour (shine), kinds of damage) the robot had to determine which biscuits were in compliance with established quality standards. The robot should only package the good biscuits; the biscuits that did not meet the quality standards should be skipped.

Surface recognition on-line requires a very sophisticated hardware equipment and software-programme which are capable of executing high-speed calculations per line, since about 2,000 pixels need to be processed within 1 ma. Furthermore, the system should be able to process up to 256 grey tints.
The required capacity of the system was determined on .50,000 biscuits per hour.

Au important issue to be resolved was the optical system, especially with respect to the influence of the lighting source under the belts. This solution was suitable for contour recognition, that only required the recognition of the two-dimensional shape.
For colour recognition, however, it was absolutely necessary to light the biscuits form above. One of the most important parameters for colour recognition is the difference in contrast between colours.

An Expert System/ Quality Data Base, suitable for restoring, analyzing and retrieving the VSRS-data had also to be designed. The data should be restored into the computer memory. Actual biscuits had to be compared with the acceptable product variations. Output should be utilised not only for controlling the robot itself, but also for adjusting other process parameters where and *when* indicated (e.g. the oven temperature).

Finally an interactive computer communication programme had to be developed. The number of production changeover to other types of biscuits are rather frequent. Hence, a user-friendly interactive computer programme was essential to obtain maximum profit with this system. In particular, relatively low-educated operators should be able to communicate effortlessly with the system. The idea was to develop a graphic communication system, with which the operator could 'program' the system.

Economic and Industrial Benefits

Nowadays, the two most important competitive edges in food industries (such as the biscuits-industry) are 'Outstanding Quality' and 'Maximum Hygiene'. In combination with a Visual Surface Recognition System a robot could seine both aspects.

A substantial part of the packaging activities in the biscuit industry is manually operated. Straightfonvard mechanisation was only an appropriate solution when only one type of biscuit was produced in a significant volume, because this type of equipment was designed to a dedicated kind of biscuit and therefore was highly inflexible and the shape of the biscuit differed only within small margins. Moreover, the product is fragile. For these reasons, within the biscuit industry no packaging operations had been automated.

Another aspect is that biscuit packaging requires concentration, since a part of the job is on-line quality inspection.
In addition to these facts, the working conditions are bad because the operation is monotonous and this incontestably had a negative influence on operator's performance. Obviously, a robot doesn't suffer from monotony, so over the day a consistent performance, both in a quantitative and qualitative regard, can be achieved through automation.
Furthermore, the VSRS has to seine as an unbiased quality inspection, i.e. independent of subjective perceptions of human beings. Hence, another important benefit of the new equipment is an improved process control.

Pick-and-place-robot

Since the start of the project in 1995 a completely new robot-steering has been installed at the Merba plant, which makes colourpicture-calculation possible. To make this possible several actions were undertaken.

To make the robot work a learning program on PC was installed. This way colourhistograms could be calculated under production circumstances. The calculated data were then gathered on the EPROM and installed m the robot.

After this the production instructions with colourrecognition were placed in the PC and send to the robot.

After the above mentioned testa were done. The tests revealed a number of problems that were recognized as a problem during manual packaging. Indeed, the robot operated with a clear 'true/false'-distinction.

* Small differences in size and shape between individual biscuits brought along high rejection rates. Consequently, variation of several raw materials (fat, dough) needed to be controlled more tightly. For this reason Merba decided to purchase a texture measure device. This purchase proved to be a good investment, because differences due to variations in raw mater-ids were insignificant since.

* Also, some existing process equipment gave too much variation. The parameters on the dough depositor (height, width and length of the biscuits) were manually controlled "role of thumb". The setting of parameters therefore varied by the individual m charge. By installing sophisticated process control equipment and a fixed predetermined setting procedure, this problem was solved-

* One of the major unexpected problems was that crumbs, decoration and fat from biscuits rapidly caused severe contamination of the vacuum system. This problem was tackled by the following measures:

- One single vacuum system for all four robots was installed. This functioned not satisfactory due to contamination of the vacuum tubes. The solution was to replace this system by four independent vacuum tubes.
- A cyclone separator ('particle catcher') was installed.
- The diameters of the gripper tubes were enlarged.
- The vacuum tube was redirected (to the ceiling) in order to reduce the number of coils. Moreover, the vacuum tube proved to be replaced more easily.
- It showed to be necessary to *control the* level of vacuum accurately, dependent on the type of biscuit to be packaged. Hence, a frequency control device was installed (one for each individual compressor).

Furthermore anew cooling system was installed to prevend changes in humidity and temperature. The present cooling prior to packaging gave too much variation, causing inconsistent hardness and stability of products. This variation caused problems with gripping the products. High outside temperatures caused warmer fat. This fat was then sucked out by the grippers which resulted in contemination of the grippers.
After studuing to find out wether a more sophisticated cooling system was useful to solve this problem, it was decided to install a new cooling system. Since the cooling system has been installed no problems concerning temperature changes had occurred.

Since this method proved to be working, development of specific internal transport trays was no longer necessary.
The SNC-F4 has now been installed at the plant of Merba and is working according to the given accuracy.

Visual Surface Recognition System

Prior to this project a feasibility study was performed. In brief, it was concluded that visual recognition of surfaces would be a promising method

A high speed trilear colour camera became available on the market and could be used to the purpose of this project. However, an interface board between the camera and the VME-bus-system had to be developer Also, a vision system for processing colour images in real time had to be developed. The system would recognise products of different size, shape and colour and communicate their position and orientation to the robot.

The following components would need advanced research and consecutive development.

vision hardware

a) Colour on-line camera interface

An interface board between the high speed trilinear colour SCM camera and the vision system had to be developed. The main features of that board would be the transformation of the RGB-input signal into an appropriate colour space followed by a data reduction. The latter was necessary for achieving fast processing of colour images.

b) Dedicated hardware

The identification of products by their location, shape and colour required considerable computation. Therefore, dedicated hardware based on special processors (e.g. signal processors) had to be developed.

c) Further hardware

Besides the boards described above, adjustments on further hardware components that alreadywere being used had to take place m order to extend them to colour vision. The so obtained multiprocessor system would enable a real time colour image processing.

Vision so ftware

a) Image analysis algorithms

Based on the hardware described above, efficient algorithms had to be developed in order to identify products according to their main features, i-e.: location, orientation, size, shape, colour, etc. For most applications a recognition rate of at least 1000 products/min. was required. This was in line with the objective (b) of the research programme (50.000 biscuits per hour).

b) Data base of products

For each application a data base of products had to be preliminary created during the learning phase of the vision system. An identification programme for the appropriate features characterising a product had to be discovered. Methods for extracting the appropriate features characterising a product had still to be found. A programme to carry out this task and support the operator had to be developed,

Consequently, the robot should only pick up those products whose features comply with the quality requirements. The biscuits that not met the quality standards should not be packaged and should be destroyed.

Parallel to the development of the VSRS research took place to find out what kind of light was necessary for this system. One of the questions was wether changes m light (sun) influenced the VSRS.
To maintain a constant level of light light from above and through the transporting belt was necessary. The second light is necessary to make sure there are no false shadows.

During the project the following components were designed and set up: a camera interface, a colour recognition camera, an processingboard, an imageprocessing board, a CPU-board and a correlation-board.

The VSRS has been installed at the Merba plant and is working according to plan. The system is capable of recognizing the different shapes and colourd of the biscuits. The robot only packages the good biscuits, that are m compliance with the given parameters.

Expert System

The expert system can be seen as composed of two main parts:

1) a system for managing product data related to the vision.
2) a system for managing production data.

A packaging Sine was setup by specifying its components (robots, tools, conveyer belts, ..). The parameters characterizing each component were then introduced into the system. In the same way parameters related to each product (area, length, width, height, ..) and to each tray (position and dimensions of the tray, location and angles of the cavities) were entered into the system.

Now, when the packaging line is running, the system supervises the production and statistical data like production run time and production rate. Eventual errors and detected and related messages are communicated to the operator immediately via a display through a monitor. Error analysis is carried out using a connected PC to the packaging line.

The robot controller system is basedon dedicated hardware components using the transputer technology. High performances of hardware and software are combined to achieve a fast amputation of the trajectories. The gripping tool within the working range per robot is about 1600x 500 mm^2.

Because the gripping tool (that works on pneumatics) had to be designed to pick up more biscuits in one travel, a capacity up to ZOO products per minute had to be very well possible. Consequently, a system of four robots (each robot equipped with a gripping tool) was necessary to meet the required capacity.

The robot also had to be able to handle a mix of products, i.e. biscuits of different sizes and shapes. When handling products of different sixes and shapes, the robot had to utilize efficient collecting strategies in order to optimise its performance. It had to be able to programme different strategies depending on the application at hand.

The most important parameter to adjust however was the oven. Adjusting of the other process parameters appeared to be not feasible. The oven now in use at the Merba plant is not capable of changing its heat in reaction to signals of the expert system.

On the other hand research has shown that after the installation of a new oven the system is capable of working according to the methods wanted for by Merba. R is expected, that in future the plant will work completely according to the noted objectives.

As alternative for the above mentioned system a new system for learning products direct during production has been developed. Now the system analyses the data of the biscuits on the conveyorbelt. On a screen next to the conveyorbelt a diagram gives accurate information about the quality of the biscuits and the rejectionrate. Because this information is constantly updated changes m quality and rejection-rates can be observed in a very short amount of time. This makes quick adjustments of the other process parameters possible.

Development of an interactive computer communication programme

The number of production changeovers to other types of biscuits in a biscuitplant are rather frequent. Hence, a user-friendly interactive computer programme was essential to obtain maximum profit with this system, In particular, relatively low-educated operators had to be able to communicate effortlessly with the system. The idea was to develop a graphic communication system, with which the operator could ‘program’ the system.

The expert system can be seen as composed of two main parts:

1) a system for managing product data related to the vision.
2) a system for managing production data. Included m production data are:

- components of the packaging line (robots, took, periphery)
- items to handle (products, trays, cups, ..)
- actions to carry out: production programmes.

Depending on the application a packaging line had first to be set up by specifying its components (robots, tools, conveyer belts, ..). The parameters characterising each component had then to be introduced rnto the system. In the same way parameters related to each product (area, length, width, height, ..) and to each tray (position and dimensions of the tray, location and angles of the cavities) should be entered into the system.

The changing of grippers and the programming of the system within the limit of 20 minutes by low-educated operators has been accomplished.

Role of the participants

The four following proposers (SME's and all confectioneries) worked together on the proposed project in a consortium and contributed to research and development tasks.

Banketbakkerij Merba, a medium-sized bakery based at Sliedrecht, the Netherlands, would bring in its expertise on biscuit production, packaging and logistics The complete system would be tested at the Merba facilities.

Ravensbergen, a medium sized confectionary m the Netherlands, would bring in its expertise and would test their products at the pilot plant at Sliedrecht.

Stieffenhofer, a confectionery m Germany, would also bring in its expertise and know-how and would be able to test their products.

Carlos M.S. Gonsalves, a small confectionary m Portugal, would bring m its expertise and different biscuits to test.

After the components and system tests had been completed successfully, the prototype would be installed on the pilot plant of the prime proposer (Merba). Next, the packaging robot would be tried out for several kinds of biscuit from the assortments of all four proposers.

The cooperation of four potential endusers of the packaging robot would be very interesting to the European Community. In this way it would be possible to do parallel research on one subject-packaging robot by several competing firms form different member-states.

The proposed research was primarily carried out by Schubert (Germany). Gerhard Schubert GmbH, a manufacturing company of flexible production automation equipment, based in Crailsheim, Germany, had expertise on designing, engineering and manufacturing robot systems for packaging applications, including hardware and software for robot control and vision systems. Schubert would partially develop hardware and software for the vision system and for managing data such as a biscuit data bases.
Schubert already manufactured the SNC-F3 'pick-and-place'-robot and had a lot of know-how on robot systems/applications.
For this project Schubert would be responsible for the integration of all components and subsystems and could be considered as the prime R&D performer.

Major R&D performer:

- Lachmann & Rink GmbH
  Lachmann & Rink developed hardware and software controlling the robot axis and its periphery.
  Furthermore L&R would develop:
  a. an expert system for managing data related to biscuits, trays, tooling, etc. for communicating with the robot line
  b. an operating system for storage and retrieval of operating data (production time, line rate, ..).

Detailed description of tasks

The project was split up in the following five phases.

During PHASE ONE together with all participants a concise project definition was made. A Steering Group and several Project Groups were, including project management and communication structure. Time schedule, deadlines, major milestones and responsibilities were fixed more in detail. This phase took one month.

PHASE TWO lead to a complete set of technical drawings (parts as well as assembly) and to specifications of the several elements. This Phase was split up into five R&D-tasks:
- VSRS (without colour)
- VSRS (with colour)
- ROBOT Design and development
- Periphery (conveyor belts, etc.)
- Gripper

The THIRD PHASE included the System Integration. Preparations - like specification and construction of test equipment, setting up test procedures - were done during phase 2 already.
The test would take place m the laboratory set-up of Schubert. All the components in the process line would be tested.

Soon after the building of the pilotline, we found out that testing in the Schubertplant was of no use.

- The products were sometimes colder, which meant that the breakage of a product could not be defined.
- However, creamproducts were warmer, which meant that through sticking of the cream on the nozzles it was impossible to test.
- Sprinkled products seemed easier to pack (due to manual package + transportation). However, under real circumstances it gave totally different results 011 the line.
- Products were placed on the belt with molds, so the products were offered to the robot in position with respect to each other, which did not reflect the actual situation.

Only a small number of products could be offered to the robot. Bigger amounts were not workable for the employees.

Due to offering biscuits in lower numbers at various temperatures with respect to reality, it was impossible to test the:
- rate of contamination
- accuracy at high speed
- accuracy at extensive productiontime
- differences between the products over a longer period can not be overseen.

To carry out the tests m this way was not sufficient. It was decided to move the pilotline to Merba B.V. in Sliedrecht.

Many problems were m no way comparable to the problems that Schubert encountered in other areas. The contamination problems were huge. Also Merba made extensive adjustments in the way of working, the machinery and belt-exchange (so the products were not offered against each other).

The variances between the products were much bigger than expected. Because of this the inspection of raw materials, doughs etc. were extended and carried out through different techniques, in order to produce a product as constant as possible.
To carry out this work as optimal as possible, an analyses had been bought. This gave Merba the opportunity to visualise things, which were not diagnosed before.

Because we let the tests take place under the real production circumstances, it gave us more understanding in the problems and the differences between for instance packing of chocolate or cookies.

Because of this change of approach the problems with which we were confronted became more clear and could be solved one by one.

During PHASE FOUR it was intended to built up the integrated system at Merba by Schubert's engineers and test it under practical conditions. Employee education was included. Technical employees of Schubert would give in-house training sessions for the maintenance personnel of Merba.
Since the system was moved to Merba sooner this phase was included m the phase three.

PHASE FIVE was mainly testing of the system.

During this phase a Iot of problems became visible, which were solved.

Problems

The biggest problem that occurred was the contamination of the total vacuumsystem caused by grease. Because the existing vacuumsystem was not sufficient, it was rebuild to a system which had shorter tubes and less curves.
For this operation a big gangway above the ceiling (above the line) was assembled. Afterwards the pumps and cyclonefilters were placed on the gangway. Now each robot has his own pump and filter. These pumps are provided with frequency regulators, so that each product receives the right pumpspeed from the programme. This preventa unnecessary contamination of the system.
Ash as the gripper the system stayed reasonably clean. However, with some products the gripper got so much contaminated that is was impossible to have a productionrun of seventeen hours.
We also noted that higher outside temperatures effected the contaminationgrade of the vacuumsystem negatively.

The productionline caused problems because of the contamination of the seam. The seam of the belt appeared on the camera as a product. Because of this the product was rejected. Beneath the productionbelt there was contamination that could not be cleaned without removing the belt. This gave stripes on the monitor. The problem was related to the black and white camera. The installation of the colourcamera solved this problem.

Contrary to the expectations cleaning of the vacuümheads with only hot water was not sufficient. Moulding appeared. An installation had to be placed on the cleaning-trolly to supply cleaning means and disinfectant. Afterwards there is drying with hot air.

Project Management

Basically, each specialised SME was responsible for executing his own part in the project. However, many interactions between the participants took place, so this complicated project required intensive co-ordination between the sever-d necessary disciplines and partners. For this reason the project was organised as follows:

1. A Steering Committee was setup consisting of the managing directors of the participating SME's (or their representatives). The *Steering Committee* had the overall responsibility of this project would meet on a regular basis. The start of each next Phase would be subjected to a formal **'GO/NO** GO'-decision of the Steering Committee.

   Chairman of this Steering Committee was Mr. W.T.W. Boerman, Managing Director Merba.

2. Each participating SME would setup a Project Group. One representative of the Project Group would act as Project Co-ordinator. All Project Co-ordinators would meet twice a month (Project Meeting), or more often as required- A copy of the Minutes of Meetings would be sent to the members of the Steering Committee.

3. A Project Manager would be appointed by Merba. This Project Manager would act as a 'linking pin' between the Steering Committee and the several Project Groups, as well as between the interacting Project Groups. The Project Manager would report to the Steering Committee and would be present both at all Steering Group Meetings and at all Project Meetings.

The steering committee provided the report for the Commission.
AU written deliverables to the Commission were in English.

These deliverables consisted of:
- brief progress reports every six months
- mid-term report
- final report
- exploitation report
- non-confidential summary and synthesis report accompanying the final report.

Furthermore the committee would be m charge of the tests and demonstrations in the pilot plant and would report on the progress of the system. When needed they would redefine the workprogramrne.

During *the* project it became clear that the communication between the partners mainly took place between Merba and Schubert. During the project also Ravensbergen and Merba had contact frequently. There was also some contact between Stieffenhoffer and Merba. Because of problems with the language and the distance the contacts between Goncalves and Merba were limited to some faxes and the two meetings that took place.

Because we had chosen for a flexible production-line, this did not differentiate a lot from the intention. The assortment of Merba was a reasonable reflection of the variety of products of the above mentioned partners.

For the communication between Merba and Schubert, besides some visits we used the fax and telephone frequently. This prevented a lot of kilometers with by car.

As projectcoordinator I can conclude that all meetings and conversations took place in a pleasant way and that all the appointments were strictly fulfilled.

It seemed to be that not only in this area, but also in for instance sales, the partners were talking to each other for a possible cooperation. This had not occurred without this project.

Exploitation

After the manufacturing and matching of the different elements Schubert developed the prototype robot. Technical employees from Schubert were stationed with Merba and gave r"-house training sessions for the maintenance and engineering personnel of Merba Sliedrecht and furthermore they develop the robot sufficiently for the industrial environment.

All participant bakeries had a direct interest in this advanced technology, because it gave them a distinct lead in packaging technology. Merba (the prime proposer) purchase the system since its feasibility was demonstrated.

Lachman & Rink developed specific equipment for the robot and took advantage of the required research that was needed for such innovative *technology.* They cooperated and exchanged their experiences during the manufacturing of this complex system.

The commercial exploitation of the packaging robot system is undertaken by Schubert who anyhow benefits from the development of VSRS-technology, since it accentuates its competence to produce innovative, high-tech packaging systems, thus enforcing its commercial position.

Dissemination

The consortium takes a positive view of dissemarinating the results of the project through European scientific and trade journals. Besides, visitors are welcome to see the system in action, now it has been installed.

Development of this system has given Europe a lead in Visual Surface Recognition technology and as far as the community-wide interest is concerned, this project will certainly contribute to improve translational cooperation, because SME's from different Member States participated.

Final conclusion

All in all it has been possible to develop and implement a new packaging system for biscuits, that lives up to all the the following standards:

* Products that vary in size are packed in packaging materials which have a fixed size.
* A production of 17-hours non-stop without problems and without having to clean the machinery has been accomplished.
* Change-overs in a short time by less-educated employees takes place.
* Products cart be judged by size, perfectness, colour of the product and decoration in a short time. The computer is informed about the correct products and location of the products.
* The above takes place under good hygienic circumstances and is easy to clean.

The project has succeeded almost completely in the objectives mentioned in the project proposal. On those places where realisation of the objectives was not possible solid alternatives have been found.

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