On-line machine vision system for fast fruit colour sorting using low-cost architecture

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ABSTRACT

The work presented in this paper is part of a system developed for fruit sorting. The machine vision unit is part of a distributed control system in which several machine vision modules can be integrated with a control module and a user interface unit. The control module takes care of the distributed control of the conveyor belt, weight units and fruit output units. The user interface is a front end to the user who can watch and control any part of the distributed system. The machine vision units are connected through a LAN to the user interface and through a CAN bus to the control unit in order to send and receive real time information during the on-line sorting process. Information that does not need real time communications are sent trough the LAN under an ethernet protocol.

The machine vision unit is a self-contained module based on a Pentium-II processor with an image acquisition card, with no user interface. All the image processing is done under the Pentium-II processor. Each machine vision module can process two lines at the time. The system allows fruit size and colour sorting at 20 fruits/second using the aforementioned hardware. The segmentation process is performed using the information the user specifies through the user interface which allows to define complex colour classes and colour classification rules interactively. Real time performance at rates specified before are achieved using a colour camera in asynchronous reset mode and programming techniques avoiding hard computational processes. Size calculation accuracy depends on the camera set-up. Typical camera set-ups in the fruit sorting system developed can provide 1 mm error approximately using one camera per two lines.

Keywords: Fruit inspection, Colour grading, Colour segmentation, Real Time, Low Cost Architectures.

1. INTRODUCTION

Fruit and vegetables market is getting highly selective, requiring their suppliers to distribute the goods according to high standards of quality and presentation. In the last years, a number of fruit sorting and grading systems have appeared to fulfil the needs of the fruit processing industry. From the first mechanical weight and size sorters, evolution has been steady. Present sorting systems tend to include the development of an electronic weight system and a vision-based sorting and grading unit with the possibility of measuring size or length. All these units are linked together and mastered by a central unit with a friendly user interface that enables reprogramming of classification parameters, reconfiguration of the outputs and the semi-automatic maintenance of a database and statistics for the production lots.

Some commercially available systems are approaching this objective, but prices are becoming almost prohibitive for small and medium companies which try to maintain its competitive. Most of the systems we can find in the market are based on special architectures, for instance, DSP-based processors boards, hardware implementation of special purpose algorithm, VME architectures, etc.

This is the case of many Spanish fruit packing companies which are usually small and agriculture products are price-sensitive and suffer from a hard competitive market like the European Union market. Moreover, while in other countries there are impressive facilities to classify and pack a single fruit (i.e. apples in the north of Italy), the requirements of Spanish producers tend to low-cost, scalable, robust systems that offer the ability to process different fruits in short but intensive seasons.

The work we are presenting in this paper is the result of a project funded by an agricultural machinery company, with the participation of an electronics designer and manufacturer company, the Digital Signal Processing Group at the University of

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Valencia and the Computer Vision Group at the University Jaume I in Spain. Previous work done by the same team[2] was directed to integrate existing control and weight systems, but they were limited by the capabilities of that system. Even with the aim of reducing costs, special purpose image acquisition and processing cards were designed and developed[1], but due to the low number of items to be produced, commercial cards with similar capabilities are available and very affordable.

Thus, the idea was to build a new system integrating in a flexible way all parts (mechanics, control, weight and vision) of a fruit sorter. From the very beginning there was the criterion that the system should be conceived as an open platform ready to evolve and incorporate, without major changes, new requirements from the customers or simply an upgrade of any of its modules to avoid the obsolescence of its design or components.

The knowledge in the computer vision field has made a significant progress in the last years and hardware improves very fast providing powerful electronics and low cost architectures due to its standardisation and use for many purposes. Therefore, the main idea of the project was to develop a system using standard hardware when possible, which is the basis of a low cost architecture, trying to meet the requirements of the system, mainly in speed and accuracy of the measurements.

The result to this work has been a system that is able to control up to 10 lanes, classifying the fruit according to its weight, size and colour and distributing the fruits in different outputs at a maximum speed of 20 fruits per second approximately. The speed limitation of the system, in the case of the vision module, is imposed by the constraints of the standard image capture devices used.

2. SYSTEM OVERVIEW

As it has been pointed out in the previous section, the complete system is a flexible modular system consisting of (Figure 1):

1) a central control unit.
2) a user interface and storage unit.
3) a set of weight modules.
4) a set of vision modules.
5) a set of output control units.

The central control manages all the information about devices and sensors. It manages the encoder and generate synchronisation signals to the weight, vision and output modules. It also controls the speed of the conveyor belt and gather the information all the other modules send during the fruit sorting process, like weight measurements, colour and size estimations, error messages, configuration messages, etc.

The control unit is linked with all other modules through a CAN (Control Area Network) bus which allows real time communication for control purposes. The CAN bus using a CAN protocol is able to manage short message under real time requirements. All real time information is send across this bus, like synchronisation signals, classification results, control orders to sensors and devices, etc. CAN interfaces for PC-based and embedded systems have been developed in the project by the electronics company.

The control unit is also connected via LAN (Local Area Network) to the user interface module and the vision modules. All messages which do not have to meet real time requirements are send through the LAN under an ethernet protocol. For instance, classification results to be processed as statistics by the user interface, configuration and definition of classification parameters, configuration of the outputs, images to be shown in the user interface, etc. LAN messages are processed when no CAN messages has to be treated and when the real time requirements in the on-line classification allow the system modules to process these messages.

The user interface is a front-end unit based on a PC computer with a graphical user interface. The user interface is connected to the system only through LAN and allows the user to work in the interface treating statistics, programming the classification parameters or defining colour image processing rules while the system is on-line or any other module is working. The graphical user interface is mainly based on direct manipulation style under a window manager system. In particular, it allows the user to define colour maps and colour rules to configure the vision modules to measure the fruits colour and to classify them into different colour classes.

The weight modules consist of a control card which can manage several electronic weight cells. The control card is interfaced to the other parts of the system through the CAN bus. Each electronic weight cell is in charge of a lane of the fruit transport system, providing weight measurements of each single fruit in about one gram accuracy.

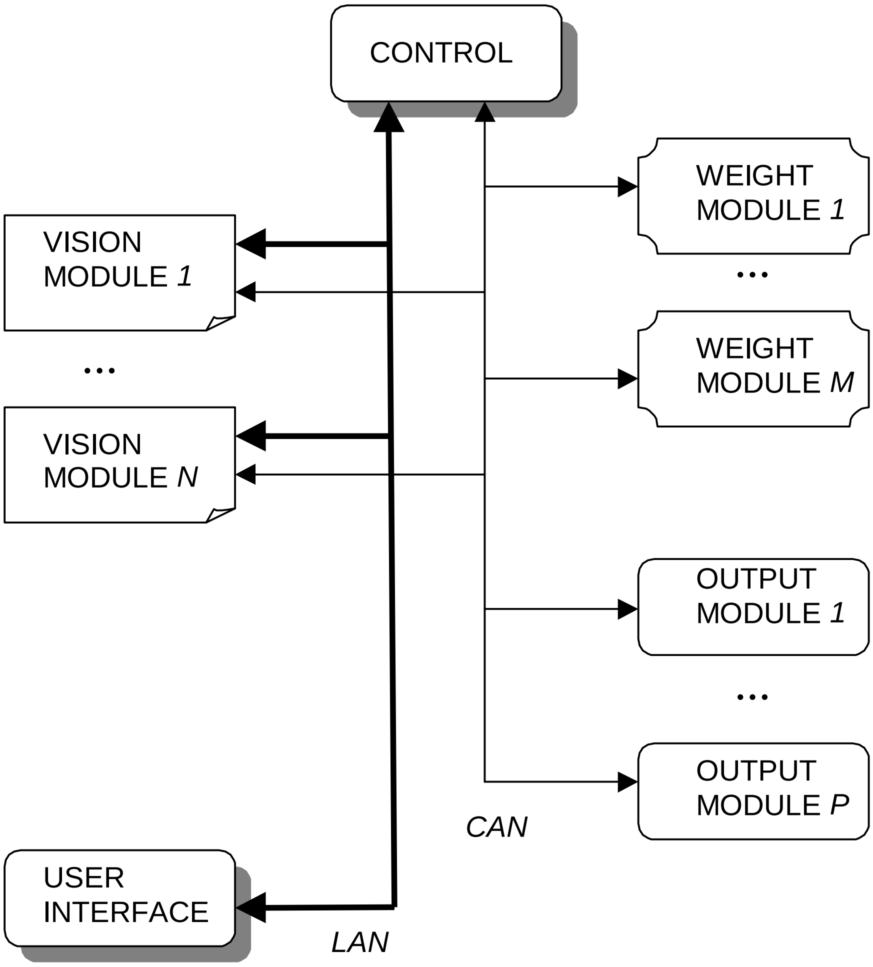

Figure 1. System overview.

An output control unit is also composed by a control card interfacing the CAN bus that manage several gates that are activated when a fruit is classified and assigned to a certain output. All control messages, like opening and closing gates, are received from the central control unit through the CAN bus.

3. MACHINE VISION MODULE

3.1. General description.

Each machine vision module is in charge of inspecting visually the fruits and estimate their size and classify the fruits according to their colour properties. Each vision module is able to inspect two lanes at the same time and it is an embedded system based on a PC architecture without user interface and controlled through the CAN and LAN by the central control unit and the user interface module.

The vision module (Figure 2) is composed by a PC-based motherboard with a Pentium II 300 Mhz processor and 32Mb of RAM. An image acquisition card is plugged into the mother board through a PCI bus. This is configured as an embedded system with no display and input devices, running the software previously stored in a flash memory card. The application software of the vision module runs under DOS operating system, using a DOS extender to work in protected mode.

The image acquisition card is a commercially available card that digitises the video signal and transfers the image directly into the RAM of the host processor through the PCI bus. The image acquisition card can also generate reset signals to the camera. The colour camera is also a commercial camera with RGB output and asynchronous reset facility. The camera is also provided with a progressive scan method to avoid image blurring due to high speed movement of objects and generates a non interlaced RGB video signal.

The synchronisation signal comes from the control unit through the CAN bus. In the on-line state, when a synchronisation signal arrives, a reset signal is generated via software from the image acquisition card and an image is acquired. Thus, image capture is always synchronised with the transport line, assuring that every fruit is analysed at the same position and all fruits are inspected.

The process (Figure 3) inside the vision module starts when the module is switched on. At this point, the network (LAN and CAN) is tested and the system waits until connection with the user interface is established. After the user interface response, if there is stored a configuration of the system it is charged into the system and the system goes into a standby state. The standby state puts the system in a waiting state until an order from the user interface or the control unit is received to do some action.

Possible actions in the standby state are configure the system from the data sent by the user interface or store the colour programme that the user has defined and sent to the vision module. If an on-line state order is received and the vision system is configured and has stored a colour programme, the vision module begins to process the images acquired and synchronised with the CAN signals and the fruit size and colour are estimated. Processing results are send through the CAN bus to the control unit. While the vision system is in on-line state, the system is also listening to the network and can receive messages from the user interface and control unit. In case the user interface sends an off-line order, the system goes to standby state and stops processing fruit images.

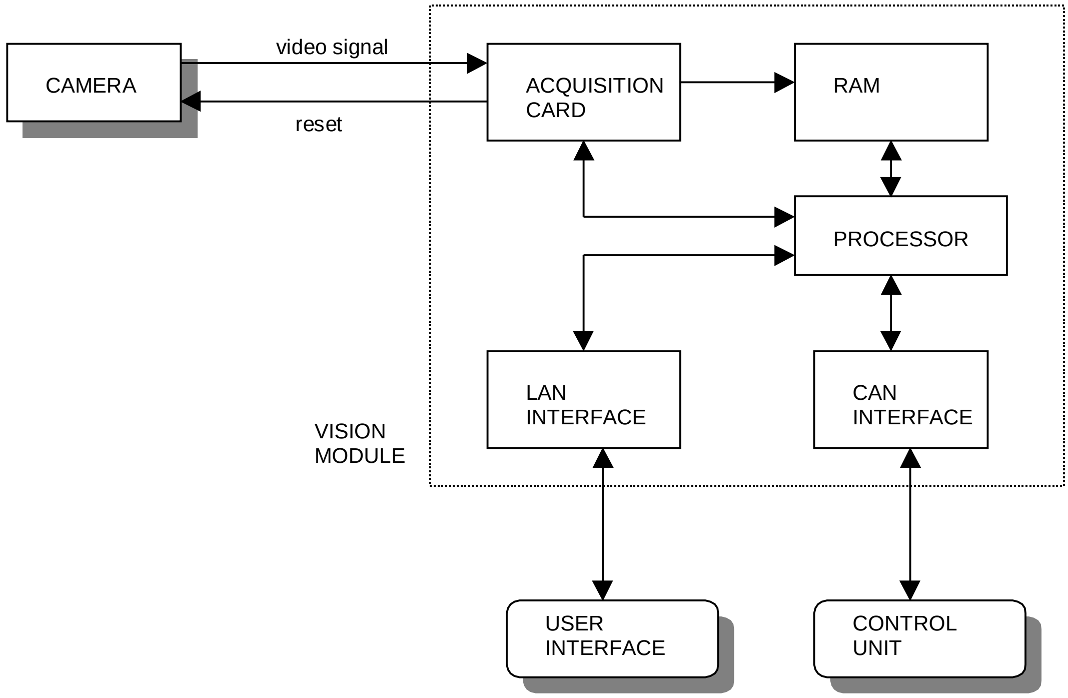

Figure 2. Vision module parts.

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1. LAN and CAN Test.
2. If there is a configuration stored then load configuration.
3. Standby state: listen to the network and wait for orders from the user interface.
4. Switch order received

    Case On Line then go to step 5: On Line state.

    Case New Configuration then set up configuration received.

    Case New Colour Programme then set up colour programme received
5. If NOT Configured or NOT Colour Programme present then go to step 3: Standby state.
6. Capture and process image.
7. Listen to the Network.
8. If Stand by order received then go to step 3: Stand by
9. Go to step 5.

Figure 3. Process and states in the machine vision modules.

The network management is done in two different software levels. The low level is formed by the interrupt handlers of the CAN and LAN interfaces. These interrupts handlers mange two FIFOS, one for the messages received and one for the messages to be sent. In the case of the CAN interface, the messages received have assigned a priority and they are put in the FIFO according to its priority. For instance, the synchronisation signal messages are the messages with the highest priority.

The LAN interrupt handler has got implemented a shifting window protocol in order to avoid network errors. The handler is in charge of joining the corresponding ethernet packets to form a message of the set of messages in the protocol defined for the communication with the user interface. The CAN message are all formed by single packets and are also part of a set of messages in the protocol defined to communicate with the central control unit.

The high level software of the network management are in charge of peeking the messages from FIFOs and process them at high level. On the other hand, when a message has to be sent, the high level software is in charge of putting the message to the output FIFO and calling periodically to the sending routines to extract the messages from the output FIFOs and send them using the low level software.

3.2. Image analysis process.

When the system enters in on-line state, fruits are analysed and visual parameters are extracted to classify them by colour and size. Fruits on the line are singulated as the conveyor is formed by rollers that separate and rotate the fruit. When a new roller enters the illumination chamber, a synch signal from the control unit through the CAN bus warns the vision module to send a trigger signal to the camera and an acquisition request for the frame-grabber. The captured image contains two lines with four fruits per lane (Figure 4). Then, data processing begins for the eight pieces in the image. The final measurement for each fruit is obtained by combining the results of the four views analysed when the fruit comes out of the chamber. Roller rotation assures that the majority of the surface of the fruits is being considered. Using the synch signal assures that every fruit is always processed the same times and synchronised with the weight measures and outputs.

The basis for the fruit classification is to determine some measures about the colour labels defined by the user and use these measures to decide the corresponding colour class according to the rules also defined by the user. In the human visual system, the sensation of colour arises from the response of three types of colour sensitive light receptors in the retina of the eye. Therefore, colours can be represented by mixing an appropriate set of three primary colours[3]. As the primary colours are not unique, we have chosen the RGB representation, mainly because the camera provides images in this representation, although data is further processed and transformed in an adequate format to simplify its interpretation.

Image analysis begins with colour segmentation by means of a RGB LUT (Look Up Table). The colour LUT for image segmentation is built previously to the image processing step when the user interface sends to the vision module the colour map the user has defined. The user defines a number of colour labels and the regions in the colour space assigned to each colour label through a direct manipulation based user interface (Figure 5). The user defines the regions in the colour space using a 2D chromatic representation that allows the definition of regions in the RGB space through the equivalent spherical coordinates.

Although the illumination is controlled, changes on the illumination level at different points of the fruit surface arise from the geometry of the light reaching the imaging device[4]. One of the objectives in the segmentation step is to avoid the problems caused by highlights on the fruit surface. We can either take into account pixels identified as highlights, or trying to avoid them. To use the information provided by highlights points we would have to use some colour representation regardless of the illuminant. We adopted a scheme based on characterising the highlights based on Gershon's approach[5] using the dichromatic reflection model[7].

Therefore, a colour representation independent from the illumination is more adequate to define colour maps. This representation also helps to the user the definition of colours taking into account the highlights and mate colours present in the fruit surfaces. The situation of mate colours and highlights can be interpreted through the spherical representation of the RGB space[6].

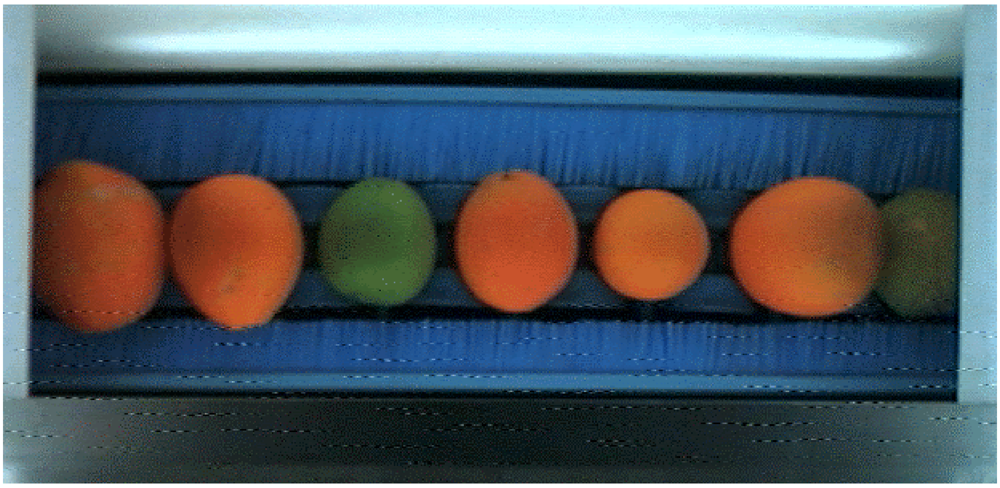

Figure 4. Typical view of fruits on a transport line taken by the image acquisition system.

3.3. Size and colour classification

After images are segmented by the colour LUT, a projection based-technique is used to identify and separate possible touching fruits for individual processing of each fruit. After fruits are singulated and situated in the image, the rectangle in the image that inscribes the fruit is calculated. From this rectangle, the different types of size measurements are made (transversal, longitudinal, average, maximum, minimum, etc.) and their values in pixels are converted to millimetres using the calibration parameters.

The ratios of each colour label defined by the user are also calculated once each fruit has been singulated. The information for each fruit is stored and, after processing up to four views for every fruit, a decision about its class is derived and queued to be sent to the control unit via CAN interface.

For every colour, the ratios of colour labels defined by the user are calculated from the segmented and singulated fruits. This ratios are used as input for the classification rules defined by the user that consist of setting for each colour label the range in which the ratio of this colour label is present in the fruit surface for every colour class. A fruit is assigned to the class that satisfy all the ranges imposed to the ratios for each colour label.

3.4 User interface

A graphical user interface with an icon-direct manipulation-based style (Figure 5) allows to handle all the options of the system such as the initial set up of the system (focus, lighting and camera placement), change criteria of selection (number of classes and colour class classification rules), colour map and colour labels definition, colour calibration, size calibration

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and camera calibration. The simplicity and usability of the interface allows the system to be flexible and easy to use to non technical operators.

The parts of the user interface concerning the vision module are:

- Colour map editor (Figure 5). It allows to define the colour labels and the areas assigned in the colour space to each colour label.
- Colour class editor. To define the colour classes rules setting up the range of the ratios for each colour class.
- Colour calibration. In order to make that that colour measurements of all vision modules in the system are the same for the same objects in the same conditions, the cameras of each vision modules are calibrated and a set of colour parameters to correct the colour measures of each camera are calculated. These parameters correspond to a linear model of the colour camera measurements.
- Camera and size calibration. To calculate the ratio between pixels in the image and millimetres the calibration uses a calibration grid and a calibration object to calculate this relation.

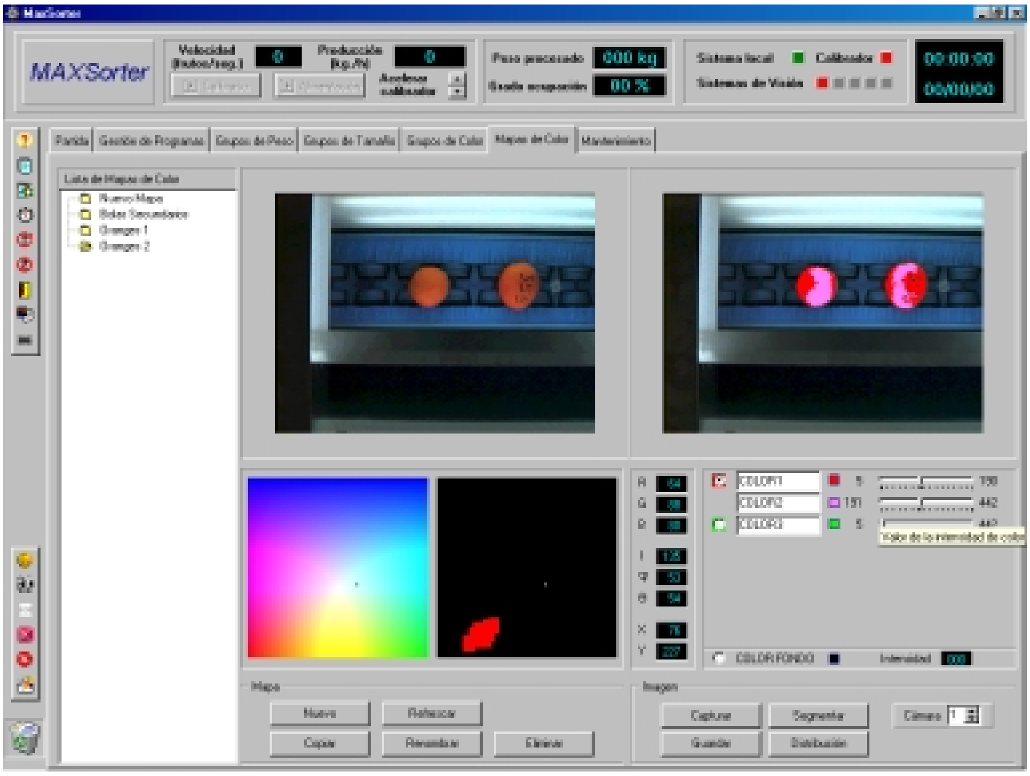

Figure 5. Colour map editor of the graphical user interface.

4. PERFORMANCE OF THE SYSTEM

The maximum number of colour classes is at present fixed to eight, which covers the most types of fruits and vegetables of the market in Spain. The system performance has been compared with human criteria and no significant disagreement has been found between human and machine decisions in colour classification. Noteworthy is the case of fruits that can be assigned to two different classes: human decisions often vary, nevertheless the machine vision rarely changes its grading in different trials.

Concerning the computation time required for the standard classification, and using a PC-based motherboard with a Pentium II at 300 MHz with 32 Mbytes of RAM, the system can process up to 20 fruits/second and line, inspecting two lines at the time. Image processing speed is limited to the image acquisition card and camera used, due to video signal

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standard specifications and image digitiser cards from analogue signals. To increase image processing rate non standard colour cameras or digital camera with high frame rate should be used, but hardware costs would grow considerably, moreover, present mechanical specifications of rolling chains and transport lines are not designed to support higher speeds.

The machine vision module has been tested with satisfactory results and previous versions of the system[2] have been working in several facilities in Spain grading tomatoes, apples, pears, oranges, peaches, etc., for long periods of time with satisfactory results.

Size calculation accuracy depends on the camera set-up. Typical camera set-ups (focal length of the lens of the camera and distance from the camera to the transport lines) in the fruit sorting system developed can provide 1 mm error approximately using one camera per two lines.

5. CONCLUSIONS AND FUTURE TRENDS

We have presented a fruit grading machine vision system for colour and size classification which is being commercialised. by a company in Spain. The vision system is part of a modular fruit grading system that integrates mechanics, control unit, user interface, weight cells and output control units, all linked with a real time CAN based network and a LAN for non real time communications. The system can process up to 20 fruits per second and sort them according to its weight, size and colour.

The vision module uses a low cost architecture. The architecture consists of a PC-based embedded system with a commercial image acquisition card and a colour camera which makes the cost of the system really competitive with respect to previous existing systems in the market.

The modularity of the approach makes the system easy to be upgraded in the future, although at present it covers most Spanish fruit-market requirements of the medium-sized and sensitive-to-price fruit packing plants.

Given that processing speed achieved is considered enough for the existing mechanics of the transport lines and present packing houses facilities, future work is directed to add other fruit inspection capabilities, like detection of damages or other features on the fruit surface. That will be possible with the present system taking into account that PC-based hardware is developing fast and increasing their computational power considerably at low costs. Therefore, with the same type or architecture it is possible to add more capabilities to the vision module using the present approach maintaining the rate of fruits per second processed due to the limitations of the image acquisition hardware.

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