Multimedia Applications in Industrial Networks: Integration of Image Processing in Profibus

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***Abstract*—This paper analyzes the transmission of images through Profibus for applications concerned with the processing of images integrated in control systems, by means of a detailed study of two real cases with different bandwidth requirements. We analyze the special features of an artificial vision system making use of Profibus as a transport system, the scheduling of the traffic in order to guarantee the delivery of the images and the control traffic before their deadlines, the protocol used, and the compression techniques usable in this kind of system, which enable us to reduce the necessary bandwidth for the applications without degrading the operation of the image processing application. We prove that this integration is currently viable in applications with medium-sized bandwidth requirements, above 17 Mb/s, and coexisting with control traffic, while current control techniques prevent its use in systems with greater bandwidth requirements, in particular in the application with 53 Mb/s requirements.**

***Index Terms*—Factory automation, machine vision, real-time systems, scheduling.**

I. INTRODUCTION

MULTIMEDIA systems are rapidly acquiring a more relevant role in several domains, and industrial networks, in their different hierarchical levels, are no exception [1]–[7]. In this area there are two main types of application, visual monitoring and image processing [6], [8]. Although both applications share certain similarities, they differ in several key aspects, which makes it necessary to analyze them separately (see Table I).

The integration of these applications through industrial networks provides important advantages with regard to wiring reduction, CIM integration, reduction of the number of processing nodes, cost reduction, etc. Nevertheless, special care must be taken in order to assure that the introduction of multimedia traffic does not affect the normal functioning of the network. Another aspect to be considered is the range of applications where the transmission system is possible, given the available bandwidth limitations, which will require a careful selection of the compression techniques to be used (see Fig. 1).

The processing of images transported through fieldbus was initially analyzed theoretically by Cavalieri [9] using a robot for the inspection of fruit. Shin [10] and Tovar [11] use video transmission as an example of the validity of the strategies they propose for the scheduling of the transmission in real time communication systems over the standard SP-50 and P-NET, respectively. In the field of robotics, the use of image processing is becoming more and more common [12]–[16]. In electrical companies [17] remote monitoring of the installations is used in order to reduce the necessary labor for their control. In their analysis of the evolution of fieldbus, when it comes to distinguishing local area networks from industrial networks, Dietrich and Sauter [4] point out that the only difference today is the need for industrial networks to meet real time traffic requirements, so that neither the bandwidth nor the size of the packet will limit the introduction of multimedia applications over these networks. As for networks with Timed Token Medium Access Control, Kee-Yin [19] analyzes the scheduling of video sequence transmission over these networks. This study focuses on the scheduling schemes of video transmission that enable the improvement of MPEG video transmission. Concerning Profibus, Tovar [5] analyzes the scheduling algorithms for the transmission of multimedia contents with or without quality of service (QoS), integrating TCP/IP over the Profibus stack. The authors analyzed the capability of MAP 3.0 to transport multimedia information [20]; performance analyses revealed a high degree of inefficiency due to the overhead introduced by the large number of MAP layers. They have also studied the use of Profibus for the transmission of images with control purposes in several test, analyzing various aspects of this integration [6], [7] and [26].

The aim of the present paper is to demonstrate the viability of the implementation of a system for the transmission of images for control purposes through an industrial Profibus network. For that purpose an analysis has been carried out on automated systems for the classification and quality control of fruit, which operate in real time and, being leading systems on the market, are able to process 15 000 and 3000 kg/h, respectively. In this system control and multimedia information clearly coexist, guaranteeing the temporal requirements of both types of traffic, as long as a suitable traffic scheduling has been previously carried out. The repercussions for the use of different compression codecs have also been analyzed in detail, and a qualitative and quantitative analysis of them has been carried out, which enables us to select whichever codec depending on the bandwidth consumed and the quality needs for image processing.

The remainder of this paper is organized as follows. In Section II, the elements that make up artificial vision are briefly introduced so that we can understand the advantages of this integration, its field of application, and some of the options chosen in the implementation of the system. In Section III the architecture of the system is defined, specifying the traffic model used,

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TABLE I
CHARACTERISTICS OF THE APPLICATIONS

	Monitoring	Image Processing
Resolution (XY pixels)	Standard analog Video	Very variable (f on application)
Number of images by second	24 o 30	Very variable and not necessarily periodical
Compression	Spatial and temporal redundancy	Spatial redundancy
Tolerance loss of images	Yes	No
Tolerance delays of images	Yes	No

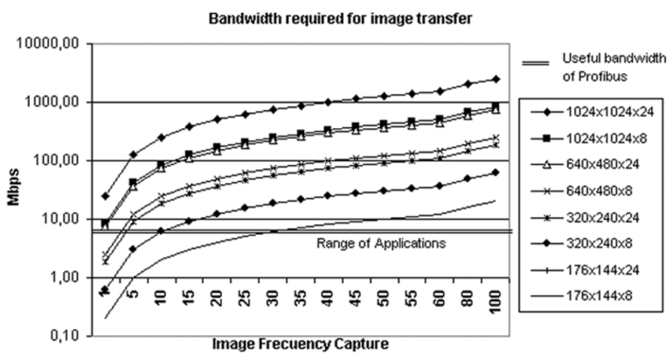


Fig. 1. Bandwitdh required for image transfer.

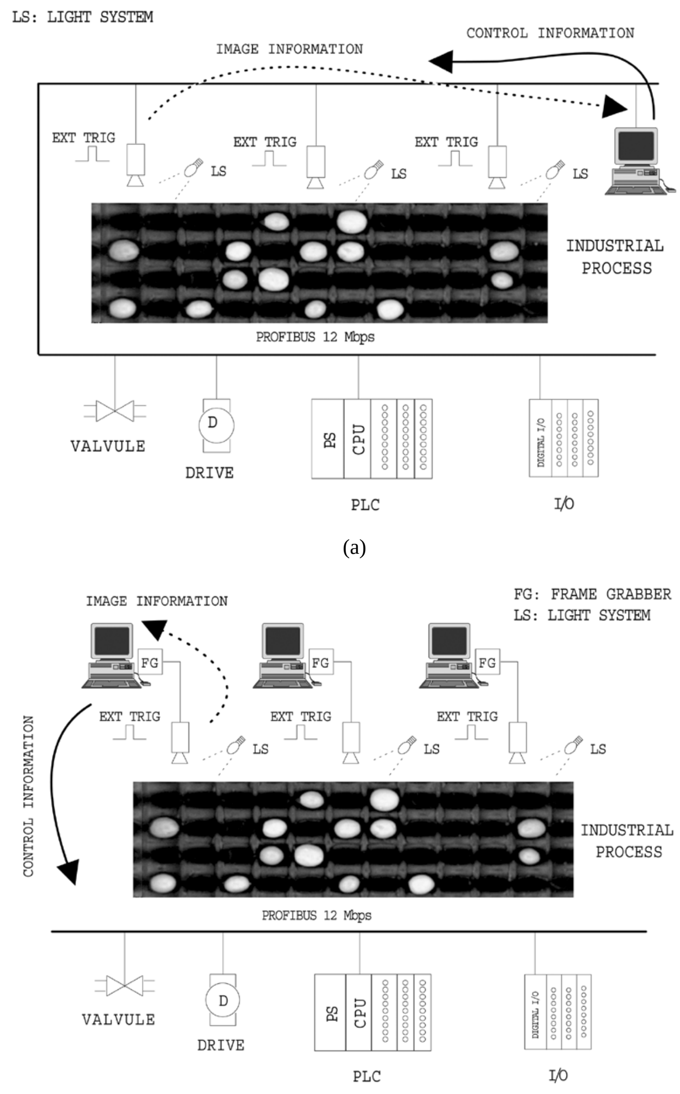


Fig. 2. (a) Typical industrial artificial vision system. (b) Image transfer over industrial network.

the layer architecture and the scheduling, the compression, as well as the protocol defined. In Section IV the scenario and the measurements obtained are presented, and the conclusions drawn are presented in Section V.

II. Artificial Vision Through Industrial Networks

In a typical industrial artificial vision system we can find the elements seen in Fig. 2(a). The system proposed replaces the connection of the cameras by means of the frame grabbers with the processing nodes using a direct connection from the camera to the Profibus network, the latter being in charge of carrying out transport of images [Fig. 2(b)]. The motivation and most important field of application of the model presented is when various vision control cameras are used in an industrial process locally connected to their processing nodes by means of the normal interfaces in the vision systems (Camera Link, EIA-644, IEEE 1394, etc.) and where the global load which represents the processing of these images is achievable with a single processing node. This depends on the resolution of images, the capture frequency, the complexity of the vision algorithms, etc., but given the important increases in the functions of general purpose processors, the medium-/low-type applications to be found in this category are constantly increasing. In these cases Profibus provides us with the capacity to transmit images to the processing node, in this way integrating within the same architecture artificial vision and the control of external actuators, and furthermore providing an important economic saving in processing nodes and frame grabbers.

Other alternatives to the classic systems of artificial vision provide intelligent cameras with connection to communication networks characterized by local processing of the information. For example, the Newton 9000 camera [33] incorporates an embedded MMX processor and Ethernet connection. Cognex [31] and DVT sensors [34] make cameras available with digital signal processors (DSPs) or Motorola Power PC processors (for example, the DVT 6000 model of the Cognex In-Sight 1010) and Ethernet connection. These cameras also make a determined number of input/output signals available. Siemens [32] with the models VS 110 and VS 710 provides equipment for simple artificial vision systems with an 80486 processor and Profibus connection.

All these devices provide a wide range of medium- and low-type capacities and network connection, but they are expensive for systems with medium- and low-type loads. Also, in the majority of cases, the control signals are not integrated in the rest of the control systems, but use programming libraries specific to the different processor, which makes the changing of acquisition sensors difficult, and does not give the flexibility provided by the programming of the vision algorithms in industrial computers. However, there is also the possibility of using libraries that are independent of the device (Intel, Microsoft) and the programming of specific routines [18]. These systems also require and high number of processing nodes, since they are included in the camera and are more limited with respect to the applications that can be developed.

Although the use of distributed intelligent devices is an interesting option (given the evolution of micro computing and communications networks, it can be expected that in two or three years the capacity will be available for the transmission of a large flow of high resolution control images for processing by a single high-capacity node. Being general purpose, these computers will always be more competitively priced than those with specialised processors or distributed processors), the system proposed in this paper is based on centralized processing with image transmission by means of standard networks. One such solution is offered by PPTVision [35], but with the inconvenience of using a proprietary network, which limits its flexibility when choosing capture devices.

A. Synchronization of the Capture of the Image

One of the most important aspects in artificial vision systems, and which has a special relevance for our system, is the signal that commands the camera to capture an image. Vision systems enable us to command the capture by means of a software trigger, or, more often, by means of an external synchronism signal (EXT_TRIGG, Fig. 2) [30].

The use of the fieldbus for the transmission of this signal, though this bus may be able to guarantee the delivery, might generate capture with the subject partially or completely out of shot, since it is not possible to maintain a constant and recognized delay of these signals, due to the fact that, among other aspects related to the traffic's periodicity, the generation process of this signal is asynchronous with the possession of the token (Fig. 3).

III. System Architecture

Firstly, we are going to describe the traffic model used in the system with the values defined in the real scenario and with the layer model designed over Profibus; later, we describe the rules used by the scheduler that operates above the FDL/MAC and which guarantees the traffic's temporal requirements, and the architectural level employed. Finally we analyze the properties that the compression process must have in image processing applications, the implemented communications protocol is briefly described, and a new profile definition abridgment is introduced.

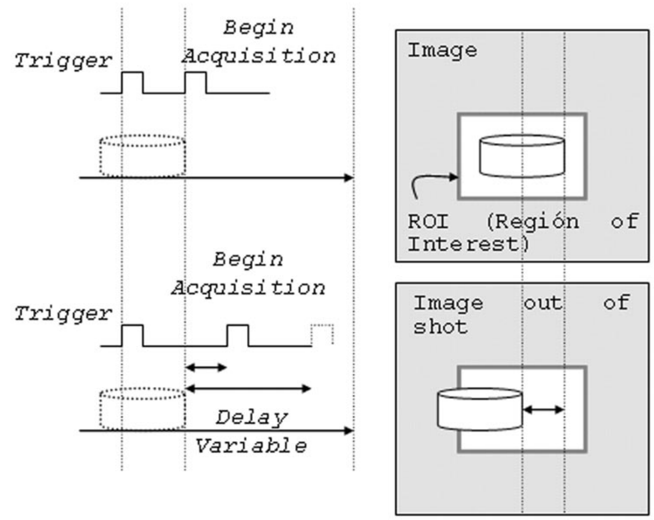


Fig. 3. Image adquisition process.

A. Traffic Model

In the system proposed, only low-priority "services" are used, since most of the cards on the market do not implement high priority services. Moreover, the analyses carried out in order to guarantee the transmission of the high priority traffic are not applicable to image transmission, since their transmission, even when compressed, usually needs more than one packet.

We use a network containing N master stations. There are two types of station (control and image), which generate and consume three types of traffic.

- *Real-time control synchronous traffic (input/output control)*
  - There are $m < N$ stations emitting synchronous messages. Each one of these stations j emits a set of n synchronous messages $S_1, S_2, \ldots, S_n$, which give us a set of synchronous messages of the station $jM^{(j} = \{S_1^{(j}, S_2^{(j}, \ldots, S_n^{(j}\}$. These messages have a constant inter-arrival time. We will call $P_i^{(j}$ the periodic message period $S_i^{(j}$ of station j, this period determining also its deadline.
  - The length of each message $S_i^{(j}$ of the station j is $C_i^{(j}$, which is the maximum amount of time necessary to transmit the message. It is assumed in this paper that the synchronous information always fits a Profibus packet (0.3 ms).
  - Each $\mathrm{S_i^{(j}}$ is characterized by $\mathrm{S_i^{(j}} = (\mathrm{P_i^{(j}}, \mathrm{C_i^{(j}})$
- *Real-time control asynchronous traffic*. The stations that transmit asynchronous traffic also have the capacity to introduce nonperiodic traffic into the system. However, in this paper asynchronous traffic has been characterized as periodic traffic with a determined constant inter-arrival time.
- *Image traffic (image output, control input)*
  - There are p stations $(p + m = N)$ that transmit images. Each one of these stations emits a single

TABLE II
CONTROL INFORMATION OF THE APPLICATIONS

N	P	$M^{(j}$	Application	$S^{(j}_1$	Bandwidth for control traffic
5	1	$M^{(j}=\{S^{(j}_1\}$, j=2,3,4,5	Classification	$S^{(j}_1$=(33.3ms,0.3ms)	57,6 Kbps
			Quality	$S^{(j}_1$=(47.6ms,0.3ms)	40,3 Kbps

flow of images $I^{(h}$. The image sequence of each station has a constant inter-arrival time named $T^{(h}$.

- The deadline of sequence $I^{(h}$ is $T^{(h}$.
- The length of each sequence $I^{(h}$ is $L^{(h}$.

The control data for the scenarios used in Section III are those shown in Table II.

B. Scheduler Algorithm

The analysis of the temporal behavior of token-passing networks, and the special features introduced by Profibus, have been widely described and analyzed in [21]–[25].

Since in the proposed system only low-priority services are used, it is necessary to implement a scheduling system that enables us to guarantee the delivery of periodic control traffic and of images before their deadline. The only possibility of guaranteeing the deadlines in these conditions is by introducing mechanisms that limit the transmission capability of the stations [5] according to the periodic traffic that each one of them must carry. On this assumption we need a new value for T_{TRT} in order to guarantee the best usage of the network and both image sequence and periodic traffic deadlines. In this case a T_{TRT} has been selected [26]:

$$T_{TRT} \geq \sum_{j=1}^{m}\sum_{i=1}^{n} C_i^{(j} + \sum_{j=1}^{p} V^{(j} + \max_{j=1\ldots p}\{V^{(j}\} + \Theta N \quad (1)$$

in order to guarantee that the space assigned to each one of the stations in each rotation of the token is respected, $V^{(j}$ being the time window assigned to station j so that it can transmit part of its $L^{(j}$ in each possession of the token, and being Θ the latency introduced by the token passing between the stations.

However, in order to be able to guarantee the deadlines, the condition must be fulfilled that the time consumed by all the stations should be

$$\sum_{j=1}^{m}\sum_{i=1}^{n} C_i^{(j} + \sum_{j=1}^{p} V_j \leq P_{\text{MIN}}. \quad (2)$$

C. Levels

In order to meet the temporal requirements of the traffic it is necessary to limit the load that the stations can send through the network each time they get the token. For that purpose it is necessary to add a scheduler over the FDL/MAC Profibus layer. This scheduling must be carried out offline and in a global way (It has been demonstrated that it is not possible to reach an optimally local synchronous bandwidth allocation scheme [27], and so in order to implement a hard real-time system it is necessary to know beforehand the characteristics of the traffic that must move along the network, [28]).

For that purpose, stations will be assigned a time slot which should be large enough to be able to transmit its periodic traffic whenever it receives the token, while respecting the deadline restriction (2). Therefore, on this level the size of the emission buffer accepted by the scheduler will be determined, limiting for that purpose the number of active transmission SAPs, and not allowing the upper layers (packing or control application, depending on the type of station) to send more packets until some space is released in the buffer.

In the scenarios used in Section III, an architecture with levels that can be seen in Fig. 4 has been used, where we can also see other times that must be considered between the capture of the image and the control actions derived from its processing (3). A Siemens Profibus DP 5613 card has been used with the libraries for development in C++ Profibus FDL. As for the PC which emulates the camera and the processing and control PC a Pentium III 800 Mhz has been used with the operating system Windows 2000. Over these systems two processes are executed: the Profilink process, charged with communicating with the card and doing the scheduling and packing of the data, and the ProfiVision process, charged with the capture/compression in the transmitter, and the decompression/processing in the receiver. Both have been programmed using Microsoft Visual C++ 6.0 using shared memory and event synchronization. Both have been executed in the experiments as the only CPU client process and with real time priority. This will introduce minimum operating system latency over the rest of the times (3). We are currently working on the possibility of using Real-Time Extensions for Windows or Linux Real-Time.

D. Image Compression in Process Control

The compression of images for processing in control applications must take into account three essential properties.

- *Compression rate:* In the case of Profibus, and depending on the network's configuration, the usable bandwidth is between 40%–70% of the 12 Mb/s [29]. Moreover, part of this bandwidth will be reserved for control traffic. Therefore, it is evidently necessary to use compression techniques that enable us to use high compression rates so as to be able to reduce the bandwidth required by image traffic.
- *Quality:* Compression techniques without loss obtain very poor compression rates. Therefore, it is necessary to use compression techniques with loss and to control the difference between the original image and the compressed one, typically,

$$\text{MSE}(Y) = \frac{1}{N_x N_y}\sum_{x=1}^{N_x}\sum_{y=1}^{N_y}(Y(x,y) - Y'(x,y))^2$$

$$\text{PSNR}(Y) = 10^{*}\log_{10}\left(\frac{255^2}{\text{MSE}(Y)}\right).$$

However, this value can be representative, and it is in fact fairly often used as a video codec quality evaluation parameter, but may be inadequate for a control process.

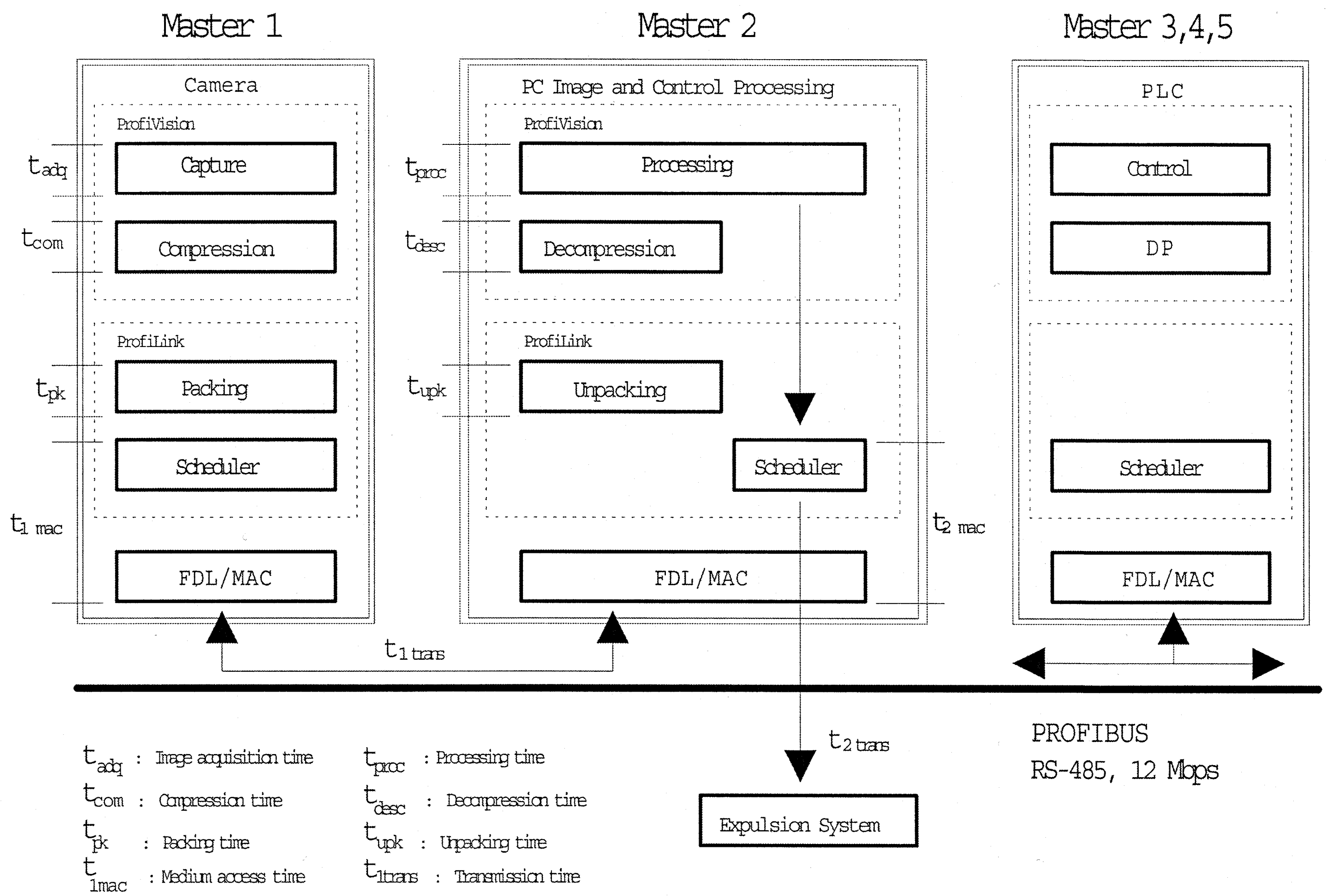


Fig. 4. Architecture levels.

Therefore it is necessary to carry out an empiric evaluation of the ratio compression rate/ quality reachable with the selected codec.

- *Latency introduced by the compression/decompression processes:* Available time is limited by a deadline that can be very demanding. Therefore, the selected codec will have to use up little time in doing its task, as well as seeking a suitable compromise between compression rate and quality.

Another important aspect to be taken into account in all these parameters is the uniformity of the values obtained. Since it is an image processing system for quality control, it has been proved that these parameters present very uniform values removing possible problems.

E. Protocol

The Profibus data link level provides the necessary SDA and SDN services for the transmission of images analyzed in this paper. SDA packets are used to carry out operations whose reliability has to be guaranteed, while SDN packets are utilized for image information transmission (in Table III the coding of information by means of up to 6 bytes in the data area of the SDA packet and the coding used in the SDN packets can be observed). The protocol defined for the establishment and release of connections, as well as the image transfer protocol, is described in Fig. 5 [6].

F. Profile

The proposed system could serve as a basis for the future definition of a new application profile which would integrate image capture systems in Profibus networks. The new profile should cover two types of applications in such a way that the majority of possible cases are covered.

1) *Remote Monitoring (Type 1):* The capture device operates asynchronously with the process distributed through the network and operating uninterruptedly from the start until the stop message are received. During this time it sends images through the network toward the control system according to the values programmed and with the maximum rate respecting always the information control deadlines.
2) *Remote Control (Type 2):* The capture device operates in such a way that is synchronised with the process by means of an external trigger for the capture of each image. These must be sent through the network within a pre-established time limit (deadline) toward the control system where they will be dealt with by the control devices.

The parameter to be considered in both cases are image size and compression rate. For the Type 1 there must also be considered

TABLE III
DATA FIELD OF THE SDN/SDA PACKETS

SDA	1	2	2	1	← n° bytes utilized
	code				
	0	X	Y	4bits / 4 bits compression/color	negotiation
	1	n° bytes	-	-	End of image
	2	-		-	End of the communication

SDN	1	1	1	1	1			1
	n° packet LSB	n° packet MSB	byte 0	byte 1	byte 2	...	...	byte 237

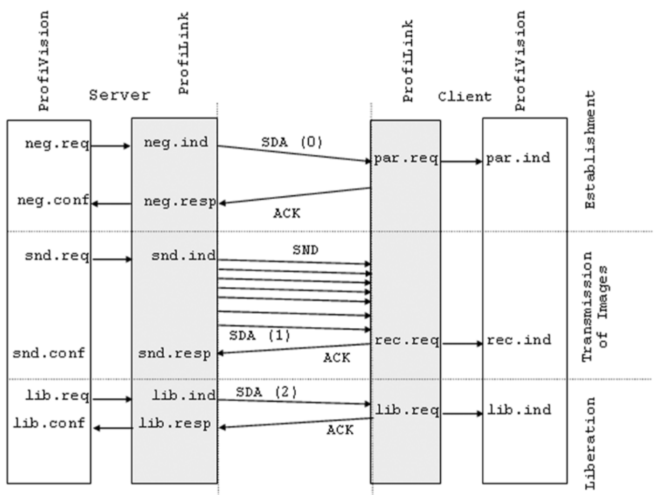


Fig. 5. Image transfer protocol.

the interval between keyframes, and the number of frames per second, and for the Type 2 the maximum image arrival rate and the deadline of each image.

IV. Scenario and Measurements

The applications that make up the scenario selected to analyze this architecture are: an application for fault detection of table olives and their classification into three categories (quality), and another application for the classification of olives by color (classification). In both we propose the substitution of the current architecture by one totally based on Profibus (see Fig. 4).

The quality application uses a 624 $\times$ 490 camera to analyze a matrix of 12 $\times$ 4 cells (one olive per cell), so the region of interest (ROI) to be transmitted and analyzed is of 600 $\times$ 176 pixels [Fig. 6(a)]. This application captures images by means of an external synchronism, reaching a maximum capture rate of 21 images per second, which means the acquisition of an image every 47.6 ms. This requires a bandwidth of 154.1 Mb/s, taking into account 3 bytes per pixel (RGB). Considering only the region of interest, the necessary bandwidth is 53.22 Mb/s. The aim of the classification application is to separate green olives from black ones, operating with 624 $\times$ 140 images, and 600 $\times$ 40 pixel ROIs [Fig. 6(b)], triggering the capture by means of external synchronism at a maximum rate of 30 images per second, i.e., one capture every 33.3 ms. This requires 63 Mb/s for the images, or 17.28 Mb/s for the ROI. The data of both applications can be found in Table IV.

Obviously, these transmission rates are unattainable for current fieldbuses, which makes the need to compress/decompress the images inevitable.

In order to analyze the maximum compression rate admissible by these applications, the following process has been followed:

- obtaining the results of the applications with disk-recorded sequences of images;
- obtaining an AVI, DIB-type (i.e., uncompressed) file of these sequences;
- applying various compression codecs to the AVI file;
- generating the original sequences starting from the compressed AVIs, so these sequences will include the degradation generated by the compression;
- obtaining the results of the applications with the new sequences.

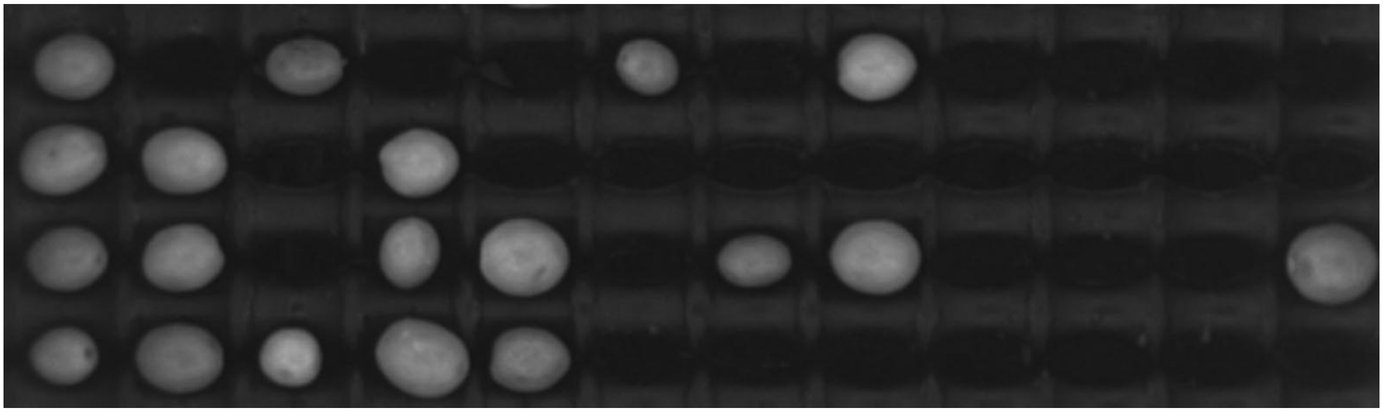
A. Classification Application

The tests carried out on the sequences of the classification application have provided us with the results found in Table V. As can be seen from this, JPEG 2000 codecs are those providing the best compression rate, without degrading the operation of the image processing application, although they require a longer compression and decompression time than with LEAD's JPEG. For the selection of the most suitable codec, the following rule will be used (see Fig. 4) in order to analyze the fulfillment of the process deadline:

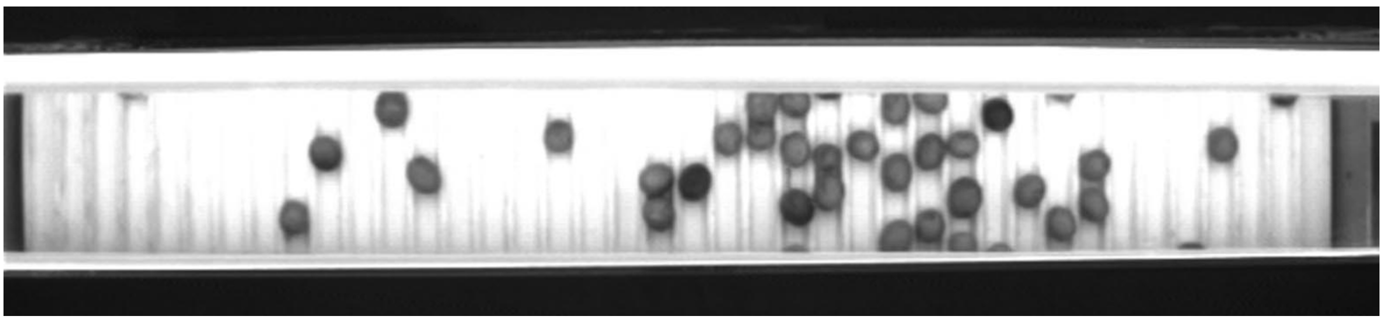
$$t_{\mathrm{adq}} + t_{\mathrm{comp}} + t_{\mathrm{pk}} + t_{1mac} + t_{1\mathrm{trans}} + t_{\mathrm{desc}} + t_{\mathrm{proc}} + t_{2\mathrm{mac}} + t_{2\mathrm{trans}} \leq \mathrm{deadline}. \quad (3)$$

That is to say, the addition of all the times involved between the capture of the image and the transmission of the expulsion packet must be lower than the arrival rate of the images. In the proposed scenario, three PLCs emit control information ($C^{(3,4,5} = 240$, $P^{(3,4,5} = 33.3$ or 47.6), which gives us a scenario with five master stations.

The LEAD codec, even using JPEG, has the advantage of obtaining very low compression/decompression times, but it obtains an excessively large packet size (>17 300, see Table VI) in order to be able to work with a success rate near 100%, which in turn leads to achieving the worst global delivery time and prevents it from meeting the required deadline. As for



(a)



(b)

Fig. 6. (a) Example of quality application. (b) Example of classification application.

TABLE IV
CHARACTERISTICS OF THE CONTROL APPLICATIONS

Application	QUALITY					
	Size X	Size Y	Frequency	Deadline	Channels	Bandwidth (Mbps)
I. Size	624	490	21	47,6 msec	12	154.10
ROI	600	176	21			53.22
Application	CLASSIFICATION					
	Size X	Size Y	Frequency	Deadline	Channels	Bandwidth (Mbps)
I. Size	624	140	30	33,3 msec	40	62.90
ROI	600	40	30			17.28

JPEG 2000 codecs, in spite of their consuming longer time in the compression/decompression of the image, this difference is compensated by a much smaller image size, which requires some five times fewer packets to be able to transmit the image. Choosing M-C20 and reserving image transmission windows for 14 packets (800 Kb/s), applying (1) we determine the T_{TRT} to be used in all stations

$$T_{TRT} \geq (4+14+14) \times 300\ \mu\text{s} + 5 \times 9\ \mu\text{s} = 9.645\text{ ms}$$

(the transmission time of a complete packet is 300 μs) and, thus, condition (2) is also met.

B. Quality Application

Applying the same analysis to this application, the M-C100 codec provides the lowest classification error, 3%, with the lowest frame size, 18 700 bytes, which requires 78.5 packets for its transmission (3.14 Mb/s, see Table VI).

These results prevent the use of the model proposed in this application, due to the high compression and decompression times and the large number of bytes to be transmitted in order to maintain an acceptable success percentage, despite meeting the deadline restriction (2) $(4+79) \times 300\ \mu\,\text{s} = 24,9 < 47,6$ ms given the rest of the times to be considered.

V. CONCLUSIONS

The use of Profibus industrial networks for the transmission of images in applications for image processing with medium image resolution and transmission frequency requirements, such as the classification application (17 Mb/s), is feasible by using the suitable codecs (800 kb/s, reduction 22:1). The selection of these codecs must be empirical, since obtaining PSNR(Y,U,V) values above a certain value does not guarantee the correct operation of the vision processes, the most significant example of this being that the success percentage of L10 (47.30, 42.29, 45.93) is lower than that obtained with I T100K(32.77, 40.14, 43.62). In this process in particular, and for JPEG 2000 codecs, PSNR(U,V)>(39,40) values seem to be

TABLE V
RESULTS OBTAINED FOR EACH CODEC IN THE CLASSIFICATION APPLICATION

	PSNR(Y)	PSNR(U)	PSNR(V)	Size frame	t_{com}	t_{desc}	Percentage successes
Liv C1 C5	38.56	36.53	39.92	6555.64	11.82	0.85	89%
L 10	47.30	42.29	45.93	17310.20	2.11	1.16	99%
L 30	44.16	39.86	44.01	11180.50	1.90	0.95	96%
L 40	43.12	39.33	43.63	9930.05	1.87	0.94	96%
L 50	42.09	37.66	41.98	8703.45	1.67	0.79	88%
I T50K	28.90	38.89	42.11	1545.23	6.60	4.72	95%
I T60K	29.13	38.97	42.16	1607.61	6.60	4.72	96%
I T70K	30.24	39.28	42.50	1908.45	6.60	4.72	97%
I T80K	30.80	39.45	42.76	2063.20	6.60	4.72	98%
I T90K	31.44	39.66	43.07	2278.68	6.60	4.72	99%
I T100K	32.77	40.14	43.62	2870.16	6.60	4.72	100%
I T150K	35.75	40.71	44.50	4314.91	6.60	4.72	100%
M-C5	31.91	36.14	40.20	3076.70	5.02	2.75	75%
M-C10	37.43	37.76	41.26	1014.73	5.57	3.01	89%
M-C15	39.96	39.55	42.61	2250.02	5.56	3.15	96%
M-C20	41.36	40.48	43.83	3263.23	5.77	3.24	100%
Dx-C50	42.6536	37.85	42.41	9177.04	2.91	2.03	78%

L: Lead MJPEG 1.0.0.11(http://www.leadtools.com) Parameter: Quality
I : Image Power JPEG2000 Codec (http://www.imagepower.com) Parameter: Target Kilobytes per second
M: Morgan Multimedia MJPEG 2000 v1.28 (http://www.morgan-multimedia.com) Parameter: Quality
Dx: DivX codec v3.11 (http://www.divxmovies.com/codec)
Times taken with a Pentium III 1.6 Ghz

TABLE VI
ANALYSIS OF THE DEADLINE IN THE CODES SELECTED IN THE TWO APPLICATIONS

		t_{adq}	t_{comp}	t_{pk}	$t_{1\ mac}$	N° pack	$t_{1\ trans}$	t_{desc}	t_{proc}	$t_{2\ mac}$	$t_{2\ trans}$	T_{total}
Classification	L10	ε	2.11	0.50	0.945[1]	72.73	21.82	1.16	8.00	0.945[2]	0.300	≤35.78
	I T100K	ε	6.60	0.50	0.945	12.05	3.61	4.72	8.00	0.945	0.300	≤25.62
	M-C20	ε	5.77	0.50	0.945	13.71	4.11	3.24	8.00	0.945	0.300	≤23.81

[1,2] In the worst case, access time to the medium will be the addition to the transmission of 3 complete information packets (3 PLC) and 4 rotations of the token (in no case is it necessary to wait for the transmission of an image to take place, since station 1 is the one transmitting images, and station 2 emits the control command after finishing the processing of the received image, and before capturing the following one).

		t_{adq}	t_{comp}	t_{pk}	$t_{1\ mac}$	N° pack	$t_{1\ trans}$	t_{desc}	t_{proc}	$t_{2\ mac}$	$t_{2\ trans}$	T_{total}
Quality	M-C100	ε	17.03	0.50	0.945	78.5	23.55	9.70	13.00	0.945	0.300	≤65.97

enough, although the value of PSNR(Y) is slightly below 35 dB. The video codecs have given the worst results, despite using each image as a different key frame; it is therefore obvious that they are not generally applicable to image processing systems.

As for applications with high-resolution and image frequency requirements, like the quality application (53 Mb/s), in which the image processing algorithm may be less tolerant concerning the compression rate admissible for control processing (3.14 Mb/s, reduction 17:1)—it is not currently possible to use codecs that enable their use without carrying out important modifications in the machine, such as delaying the situation of the ejecting system in order to tolerate larger deadlines, or reducing the operation speed. This may make the system more expensive or less productive, despite the existence of enough available bandwidth, and the meeting of the deadline restriction due to the times used up in the higher levels of the application.

We are now working on the achievement of quality measurements for compressed images that are more suitable for vision processes, so that the characteristics influencing the image processing algorithms are given more importance, such as the degradations of high frequency components that the edges of objects of interest usually have, or the defects within them, and which are not adequately reflected in PSNR values.

We are working on the development of: an autonomous hardware sensor for connection with Profibus; an algorithm enabling the performance of the scheduling implemented in this paper online. This algorithm will be usable in both control and monitoring applications, where the network will be able to adapt on line to periodic and image traffic requirements existing at any moment.

REFERENCES

[1] J. R. Pimentel, "Industrial multimedia systems," *IEEE Ind. Electron. Newslett.*, vol. 45, pp. 7–9, June 1998.

[2] C. Wu and J. D. Irwin, "Multimedia and multimedia communication: a tutorial," *IEEE Trans. Ind. Electron.*, vol. 45, pp. 4–14, Feb. 1998.

[3] C. Wu, J. D. Irwin, and F. Foster, "Enabling multimedia applications for factory automation," *IEEE Trans. Ind. Electron.*, vol. 48, pp. 913–919, Oct. 2001.

[4] D. Dietrich and T. Sauter, "Evolution potentials for fieldbus systems," in *Proc. 2000 IEEE Int. Workshop Factory Communications Systems*, 2000, pp. 343–351.

[5] E. Tovar, F. Vasques, F. Pacheco, and L. Ferreira, "Industrial multimedia over factory-floor networks," presented at the 10th IFAC Symp. Information Control Problems in Manufacturing (INCOM), Vienna, Austria, 2001.

[6] J. Silvestre and V. Sempere, "Machine vision in Profibus networks," in *Proc. 8th IEEE Int. Conf. Emerging Technologies and Factory Automation (ETFA'01)*, vol. 1, Sant Juan Les Pins-Antibes, France, Oct. 2001, pp. 367–375.

[7] V. Sempere and J. Silvestre, "Image transport in Profibus networks," in *Proc. IFAC Int. Conf. Fieldbus Systems and Their Applications FeT'01*, Nancy, France, Nov. 2001, pp. 24–31.

[8] V. Sempere, J. Silvestre, and A. Cano, "Evaluación del transporte de imagen en procesos de visión sobre una red industrial Profibus," in *Proc. III Jornadas Ingeniería Telemática (JITEL'01)*, Barcelona, Spain, 2001, pp. 453–460.

[9] S. Cavalieri, A. Di Stefano, and O. Mirabella, "Impact of fieldbus on communication in robotic systems," *IEEE Trans. Robot. Automat.*, vol. 13, pp. 30–48, Feb. 1997.

[10] K. G.Kang G. Shin and C.-C.Chih-Che Chou, "Design and evaluation of real-time communication for fieldbus-based manufacturing systems," *IEEE Trans. Robot. Automat.*, vol. 12, pp. 357–367, June 1996.

[11] E. Tovar, F. Vasques, and A. Burns, "Adding local priority-based dispatching mechanisms to P-NET networks: a fixed priotity apprroach," presented at the 11th Euromicro Conf. Real-Time Systems (RTS'99), York, U.K., June 9–11, 1999.

[12] G. Collins, "Sophisticated image processing controls assembly robot," *Ind. Robot, Int. J.*, vol. 27, no. 6, pp. 445–448, 2000.

[13] G. Burgess, "Implementacion of a robotic depalletizing cell," *Ind. Robot, Int. J.*, vol. 28, no. 3, pp. 199–201, 2001.

[14] R.-L. Sun, X. Wang, and H.-Y. Chang, "A mobile robot for pressurizer inspection," *Ind. Robot, Int. J.*, vol. 27, no. 3, pp. 217–222, 2000.

[15] P. Wilke and T. Bräun, "Flexible wireless communication network for mobile robot agents," *Ind. Robot, Int. J.*, vol. 28, no. 3, pp. 220–232, 2001.

[16] F. Basile, P. Chiachio, and N. Mazzocca, "A suboptimal multimedia remote supervisory control of a robotic cell," *Ind. Robot, Int. J.*, vol. 28, no. 2, pp. 136–142, 2001.

[17] J. A. Clavijo *et al.*, "Real-time video for distributed control systems," *Control Eng. Practice*, vol. 9, pp. 459–466, 2001.

[18] J. Cano, J. C. Perez, J. M. Valiente, R. Panetworks, and J. Arlandis, "Textile inspection with a parallel computer cluster," presented at the 5th Int. Conf. Quality Control by Artificial Vision (QCAV-2001), Le Creusot, France, May 2001.

[19] J. K. Y. Ng, "MPEG transmission schemes for a timed token médium access control network," *SIGCOMM Comput. Commun. Rev.*, vol. 29, no. 1, pp. 66–80, Jan. 1999.

[20] V. Sempere, J. Mataix, and E. Tordera, "Video transmission on industrial process over MAP network using MMS," in *Proc. 7th IEEE Int. Conf. Emerging Technologies and Factory Automation (ETFA'99)*, vol. 1, Barcelona, Spain, 1999, pp. 423–433.

[21] G. Agrawal, B. Chen, and W. Zhao, "Guaranteeing synchronous message deadlines with the timed token medium access control protocol," in *Proc. 12th IEEE Int. Conf. Distributed Computing Systems*, June 1992, pp. 468–475.

[22] E. Tovar and F. Vasques, "Real-time fieldbus communcations using Profibus networks," *IEEE Trans. Ind. Electron.*, vol. 46, pp. 1241–1251, Dec. 1999.

[23] ——, "Guaranteeing real-time message deadlines in Profibus networks," in *Proc. 10th Euromicro Workshop Real-Time Systems*, Berlin, Germany, June 17–19, 1998, pp. 79–86.

[24] ——, "Analysis of the worst-case real token rotation time in Profibus networks," in *Proc. 3rd Int. Conf. Fieldbus Systems and their Applications (FET'99)*, Magdeburg, Germany, Sept. 20–21, 1999.

[25] "Setting target rotation time in Profibus based real time distributed applications," in *Proc. 15th IFAC Workshop Distributed Computer Control Systems (DCCS'98)*, Como, Italy, Sept. 9–11, 1998, pp. 1–6.

[26] J. Silvestre, V. Sempere, and M. A. Belda, "Optimization of the capacity of Profibus for the transmission of images and control traffic," in *Proc. 2002 IEEE Int. Workshop Factory Communications Systems*, Västeras, Sweden, Aug. 2002, pp. 133–140.

[27] C. Han, K. G. Shin, and C. Hou, "Synchronous bandwidth allocation for real-time communications with the timed token MAC protocol," *IEEE Trans. Comput.*, vol. 50, pp. 414–431, May 2001.

[28] C. Chou and K. G. Shin, "Statistical real-time channels on multiaccess bus networks," *IEEE Trans. Parallel Distrib. Syst.*, vol. 8, pp. 769–779, Aug. 1997.

[29] Profibus Interface Center. Profibus technical information II. [Online] Available: http://www.sea.aut.siemens.com

[30] CiberOptics. Hamma sensors, high speed, real time machine vision. Imagenation Vision, Beaverton, OR. [Online] Available: http://www.imagenation.com/white_papers.html

[31] Cognex. (2002, Summer) In sight machine vision sensors. [Online] Available: http://www.cognex.com/pdf/insight/In-Sight-brochure.pdf

[32] Siemens.. [Online] Available: http://www.ad.siemens.de/machine-vision/html_76/produkte/produkte/vs710.htm

[33] Newton Research Labs.. [Online] Available: http://www.newtonlabs.com/area_systems.htm

[34] DVTSensors.. [Online] Available: http://www.dvtsensors.com

[35] PPT Vision.. [Online] Available: http://www.pptvision.com

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