Vision-based Network System for Industrial Applications

Taweepol Suesut, Arjin Numsomran, and Vittaya Tipsuwanporn

***Abstract*—**This paper presents the communication network for machine vision system to implement to control systems and logistics applications in industrial environment. The real-time distributed over the network is very important for communication among vision node, image processing and control as well as the distributed I/O node. A robust implementation both with respect to camera packaging and data transmission has been accounted. This network consists of a gigabit Ethernet network and a switch with integrated fire-wall is used to distribute the data and provide connection to the imaging control station and IEC-61131 conform signal integration comprising the Modbus TCP protocol. The real-time and delay time properties each part on the network were considered and worked out in this paper.

***Keywords*—**Distributed Real-Time Automation, Machine Vision and Ethernet.

I. Introduction

An image processing has been researched and developed since 1920s[1]. It can be applied to several areas such as medicine, biology, satellite, commercial documents, archaeological data, forensic data, industrial processing and so on. Consequently, the development of computer and communication technology brings about machine vision and image processing is able to work in more real-time system. There are many researchers that applied machine vision for control and logistics applications. G.S Virk. [2] applied distributed image processing in quality control of industrial fabrics as the vision inspection machine. Del Fabbro[3] presented work for a framework for distributed computation of large image and deals neither with the industrial nor real-time aspects. Further, machine vision was applied to control applications such as Ivan's research group [4] used machine vision for measuring the angle of the ball and beam model as a feed back control. Nazrul's research group [5] applied vision system for feed forward control in tunnel freezer process by using USB camera interface [4][5] and other researchers [6][7][8] that use communication interface between camera and computer via IEEE 1394a. The recent applications cannot support a hundred meters communication. In this paper, the network system is designed supporting the large industrial plant in harsh industrial environments that requires many issues to be considered such as steel plant therefore, the Ethernet TCP/IP is selected for the control and logistics applications by using vision system.

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II. Delay Time in Loop

Real-time property is concerned to the response time in communication system. The delay time in loop has to be considered without avoidable. The control application in this network is fit in to the Network Control System [9], which the delay time in control loop is affected directly to the stability and performance of control system. According to Fig. 1, it is illustrated the vision feedback control model. The delay overall the system can be classified into 3 parts.

- *Waiting time delay*. The waiting time delay is the delay, of which a source (the main controller or the remote system) has to wait for queuing and network availability before actually sending a frame or a packet out.

- *Frame time delay.* The frame time delay is the delay during the moment that the source is placing a frame or a packet on the network.

- *Propagation delay*. The propagation delay is the delay for a frame or a packet traveling through a physical media. The propagation delay depends on the speed of signal transmission and the distance between the source and destination.

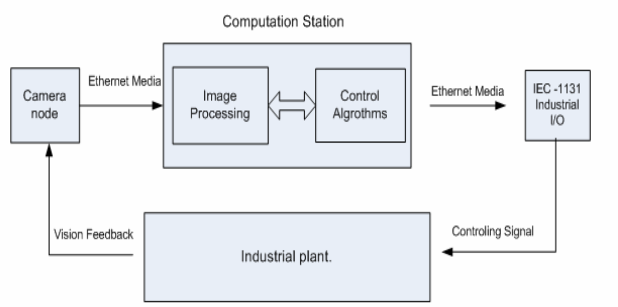

Fig. 1 Visual feedback control system

All of delay times on the designed system can be divided as the delay time in Ethernet Network, the delay time in capturing object of camera node, delay time in imaging and controlling process as well as the commanding signal between distributed I/O to an actuator. The delay time solution will be presented in next topic.

III. Distributed Real-Time based on Ethernet

Historically, Ethernet [10] has been perceived as an unsuitable medium for real-time data distribution. The fear was that the fundamental access algorithm, CSMA/CD, and the popular transport protocol, TCP/IP, could not provide sufficiently consistent latency for deterministic applications. There are compelling reasons to utilize the Internet Protocol (IP) for real-time systems. IP is quickly becoming the lingua franca of the information age, reaching into every area of modern life. Designs using IP networking will be able to take advantage of this connectivity, for instance by monitoring and debugging systems remotely, collecting usage statistics, and even notifying service personnel of impending failures. However, many real-time application engineers are concerned by the fact that most IP systems currently utilize non-deterministic software and hardware. For instance, the most compelling implementations today use the Ethernet physical layer. Of course, IP can run over many media, and is in fact already becoming available on fast deterministic architectures such as FireWire (IEEE 1394). However, most hardware and software currently available for IP uses Ethernet hardware and Ethernet was not designed for fixed timing. Similarly, most networking software utilizes a transport protocol such as TCP. Like Ethernet, TCP was never designed for real-time operation. Instead, it provides reliable delivery-retrying dropped packets regardless of the delay incurred.

A. Ethernet Access Algorithms

Most IP LANs use one of the flavors of the 802.3 Ethernet networking standard. Inexpensive, reliable hardware implementations, such as 10BaseT, are ubiquitous in offices and laboratories. Ethernet provides fast, efficient transport at either 10 or 100 Mbits per second. In real-time systems, Ethernet's utility is challenged because, in a busy environment, it does not provide a fixed time for nodes to access the network when multiple nodes try to access the network at the same time.

Ethernet media access is subject to delay when the network is in use and when two nodes attempt access at the same time. Real-time application developers claim this is the flaw that prevents them from using Ethernet for data communications, despite its ubiquity and attractive pricing. A closer look at these delays, however, dispels these concerns. For example, Ethernet is fast enough that the time a node must wait for the wire to be free causes only a small, bounded delay.

B. Gigabit Ethernet

Since its inception at Xerox Corporation in the early 1970s, Ethernet has been the dominant networking protocol. Of all current networking protocols, Ethernet has, by far, the highest number of installed ports and provides the greatest cost performance relative to Token Ring, Fiber Distributed Data Interface (FDDI), and ATM. For desktop connectivity, Fast Ethernet, which increased Ethernet speed from 10 to 100 megabits per second (Mbps), provided a simple, cost-effective option for backbone and server connectivity. Gigabit Ethernet builds on top of the Ethernet protocol, but increases speed tenfold over Fast Ethernet to 1000 Mbps, or 1 gigabit per second. This protocol, which was standardized in June 1998, promises to be a dominant player in high-speed local area network backbones and server connectivity. The gigabit network provides sufficient bandwidth and avoids access collisions for this application.

IV. Machine Vision Network

This network consists of a gigabit Ethernet network and a switch with integrated fire-wall is used to distribute the data and provide connection to the imaging control station and IEC-61131 reconcile signal integration comprising the Modbus TCP protocol as shown in Fig. 2.

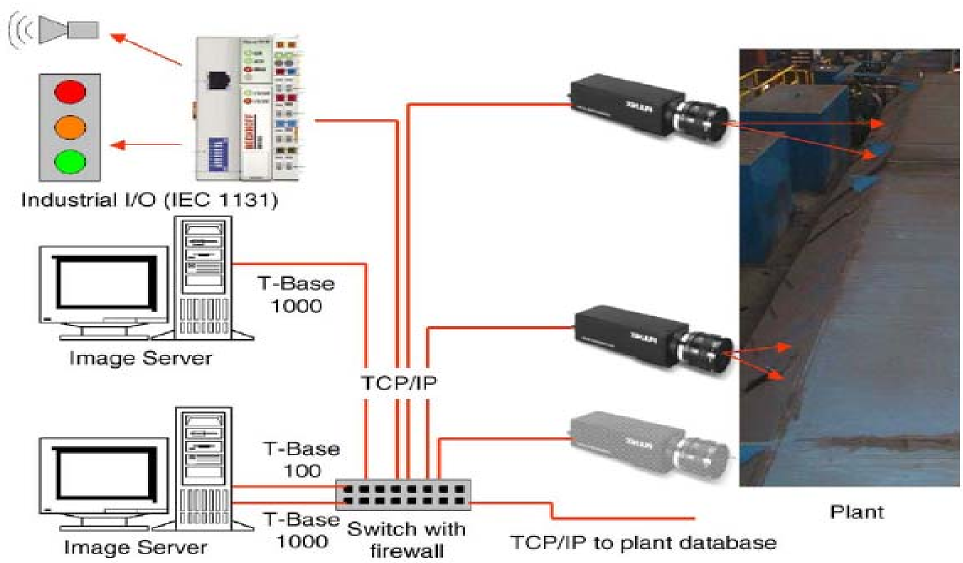

Fig. 2 Machine vision network

The image processing algorithms use statistical estimates of confidence to ensure robust operation under extreme conditions. Feedback-control requires a sampling rate approximately 10 times higher that the bandwidth of the system which is to be controlled PID Controllers [11]. The system demonstrates the acquisition and processing of 500 frames per second in real time, this is commensurate with 50 Hz bandwidth presently possible for hydraulic systems. This opens the door to real-time feedback control using digital image processing.

The successful application of machine vision in harsh industrial environments requires many issues to be considered:

- robust image acquisition, which can withstand the harsh environmental conditions associated with industrial production plant;
- mechanisms for the transmission of the images which are not susceptible to the electro-magnetic disturbances which are associated with large electrical drives;
- theoretically well founded image processing algorithms, which enable the integration of a priori knowledge. In particular the question of confidence interval in the measurement data should be addressed;
- access to and the generation of input/output signals to control machines and plant (IEC-61131)

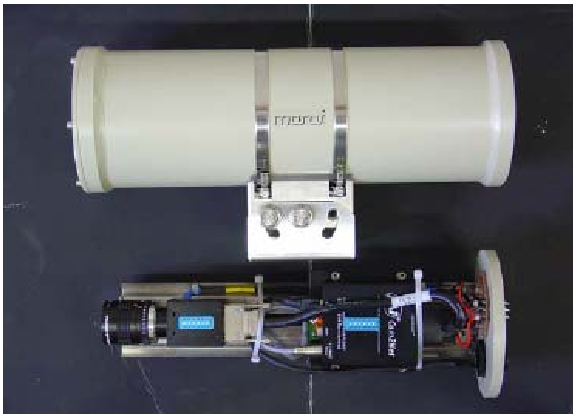

Fig. 3 Camera housing

The images which need to be acquired have an unusual aspect ratio of approximately 10:1. This has lead to the selection of a CMOS camera (JAI CV-A33), with which the speed of acquisition can be increased by reducing the number of rows, which are acquired. The camera has 640x480 pixels and can acquire 117 full frames per second. In this application a region of interest with 640x64 pixels is used, theoretically this enables the camera to acquire over 850 such frames per second. However, a frame rate of 500 per second has been chosen; this corresponds to 10 times the bandwidth of the servo-hydraulic system, which is selected to be a case study, more was not considered necessary. The CMOS camera has a camera-link interface, which was considered unsuitable for the transmission of data over longer distances in an industrial environment.

Consequently, a camera-link to gigabit ether-net converter was selected, this enables the use of standard Ethernet cabling (1000-Base-TX, SSTP double shielded twisted pair RJ45) over distances of 100 m at 1 gigabit/s. Optical fibers can be used and are recommended (1000-Base-SX) for longer distances. The use of Ethernet for the transmission of images, leads to a consistent communications concept based on standard components: switches, routers, etc. as shown in Fig. 2. The system includes a gigabit switch with the camera housing, containing the camera, camera-link to gigabit Ethernet converter and power supply adapter. This provides a IP-67 protected image acquisition system, requiring a single 24 V power supply and an Ethernet connection. Integrated firewall, all components associated with the image processing system are behind the fire-wall. Whereas, the external ports are used to provide connectivity to the plant database and for remote servicing. This concept enables the simultaneous routing of image data from multiple cameras to multiple computers for processing.

A. Ethernet Distributed I/O

The IEC 61131 compatible that based on Modbus/TCP industrial I/Os are implemented using an ether-net bus-coupler with a T-Base 100 interface. The computer responsible for the communication to the I/Os has two Ethernet connections: a T-Base 100 for IO data and a T-Base 1000 for image data. This together with the speed of the bus provides sufficient bandwidth and avoids access clashes, ensuring a real-time response. Ethernet CAT-5 connections are required.

V. Distributed Vision for Logistics Application

In this paper, the vision network system can be applied for logistics application and quality control on a large scale industrial plant appropriately [12]. But the requirement is different from control applications such as communicating with many nodes, fault tolerant feature as the dynamics plug and play or dynamics reconfiguration when a new node added or removed to the network. In this article, the easy solution to employ in the Ethernet is use of a middleware. There are many middleware available by several venders. However the most suitable middleware to support this work is the RTPS model (Real-Time Publish Subscriber) that standardized by OMG (Object Management Group's) Successively, Network Data Delivery Service (NDDS) is RTPS middleware developed by Real-Time Innovation (RTI)[10] and widely used for mission critical applications. It has interesting features such as complex network data flow, dynamic reconfiguration, many to many communication, scalability configurable QoS and supports multi platforms and operating system (Windows, Linux, Solaris etc.,). In Ethernet networks, the transport layer has protocol TCP/IP and UDP/IP. Ethernet networks are considered to be statistically Real-time networks. TCP/IP protocol is asynchronous connection oriented and reliable protocol. Indeed, TCP/IP is not designed for Real-Time applications because it is not deterministic. UDP/IP is asynchronous user Datagram protocol, which is faster than TCP/IP but reliability is not assured while no handshaking mechanism is implemented. In practically, the performance of middleware can be showed that UDP/IP could perform well for a wide range of Real-Time applications in industrial environment. Additional services in the UDP/IP based middleware can assure reliability for mission critical systems [10]. In this part, the employment of Real-time Publish- Subscribe (RTPS) middleware for real-time distributed industrial system (RT-DIVS)[13] is discussed. This research is aimed to find how suitable RTPS for RT-DIVS for quality assurance and logistics applications. The aim of this part in the research is to test vision network system by using NDDS middleware capabilities in transporting images with different sizes. The objective is to measure image transmission time between two computers without clocks synchronization as recommended by several middleware vendors. According to Fig. 4 is illustrated the measuring diagram, firstly the signal generator employs triggering signal (10 Hz and 50 Hz) input of Ethernet distributed I/O which connected to the computer (Vision server) and then the image is transmitted from one computer (Vision node) (to another and bounced back to its source. A timestamp is attached to the image and the round trip time is calculated when the image is back.

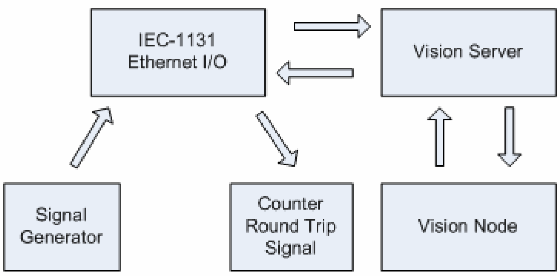

Fig. 4 RTT measurement diagram

The experiment result is obtained by transmitting data 6942 packets with speed 10 packets per second for the data size 3KB, 6KB and 18KB as shown in Fig. 5, Fig. 6 and Fig. 7 respectively.

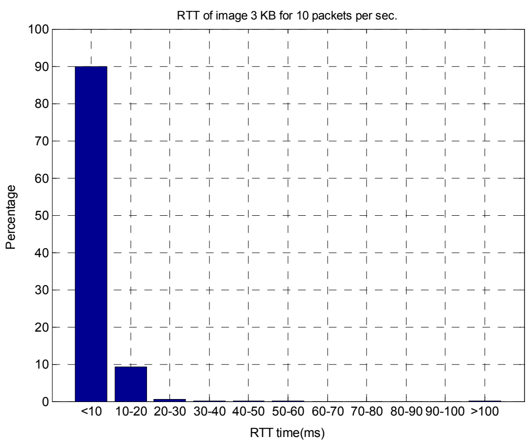

Fig. 5 RTT of image 3KB

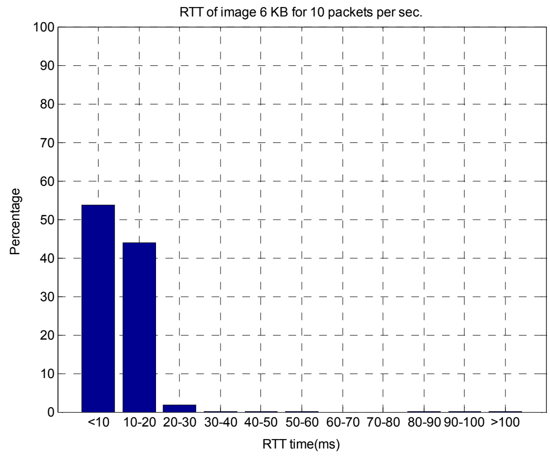

Fig. 6 RTT of image 6 KB

Fig. 7 by increasing the data packets size to 18 KB, the middleware is higher RTT because of data packets for sending and receiving in the Vision node and Vision Server. The average round trip time of data packet 18 KB with 50 packets per second achieved between Vision node and Vision Server is around 40 ms is sufficient for logistics and quality control applications in industrial.

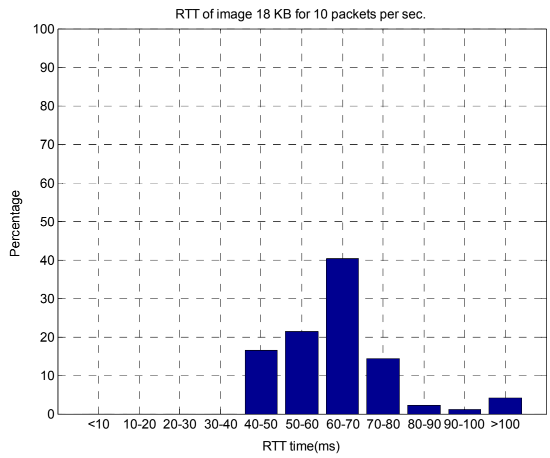

Fig. 7 RTT of image 18 KB

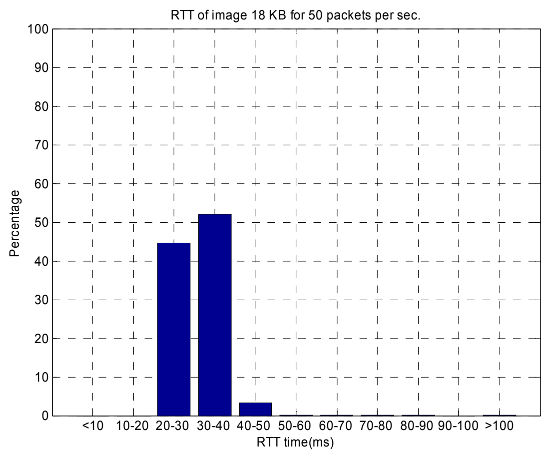

Fig. 8 RTT of image 18 KB for 50 packets per sec

VI. Conclusion

A robust system for image acquisition, suitable for use under harsh industrial conditions (IP-67 protection) has been demonstrated. The gigabit Ethernet based transport of image data has proved stable and robust in an industrial environment. It brings many advantages with it such as standard switches, bridges, etc., can be used to route the data to the required processing node. Furthermore, the machine vision network supports a bi-directional communication with the camera enabling the configuration of the camera under working conditions. The communications concept supports multiple cameras and multiple processing nodes. The implementation of RTPS in NDDS middleware on designed network is suitable for soft and firm timelines requirements quality assurance and logistics management applications. Therefore, the network in this paper is able to implement to a distributed real-time vision system for control applications as well as quality control and logistics.

Acknowledgment

Most of the original work on testing and analyzing performance of network by using RTPS middleware was performed by Basem AL-Madani.

References

[1] Deryn Graham and Anthony Barrett, "Knowledge-Based Image Processing System", Springer London 1997.

[2] G.S. Virk, P.W.Wood and I.D. Durkacz, "Distributed image processing for the quality control of industrial fabrics", IEE Computer and Control Engineering Journal, November 1990.

[3] S.J.D. Fabbro, "Developing a Distributed Image Processing and Management Framework", Dissertation, University of Adelaide, 2000.

[4] Petrovic, I. Brezak, M. Cuped,R. "Machine Vision based Control of the ball and beam" , 7th International Workshop on Advanced Motion Control, 2002.

[5] Nazrul I. Shaikn, Vittal Prabhu "Vision system for model based control of cryogenic tunnel freezer", Computer in industry 56, Elsevier 2005.

[6] Do Hyoung Kim, Do-Yoon Kim, Hyum Seok Hong and Myung Jin Chung "An Image-Based Control Scheme for an Active Stereo Vision System", IEEE International Conference on Intelligent Robots and Systems, 2004.

[7] Gupta, G.S. Messom, C.H. Demidenko,S. "Vision assisted measurement for optimization of robot motion and position control functions", Instrumentation and Measurement technology Conferrence,2004.

[8] Han, S.H. See, W.H. Lee, M.H. Hanshimoto,H " Image-Based visual servoing control of a SCARA type dual-arm robot", IEEE international Symposium on Industrial Electronics ISIE 2000.

[9] Yodyium Tipsuwan, Mo-Yuen Chow "Control methodologies in networked control systems" , Control Engineering Pratice 11, Pergamon 2003.

[10] http://www.rti.com

[11] K.J.Astrom, T.Hgglund, " PID Controller:Theory ,Design and Tuning", Instrument Society of America, 1995.

[12] Michael Weiss "A Vision-Based Object Tracking Framework for Logistics ans Quality Control in Industrial Environments", Dissertation, University of Leoben, Austria 2000.

[13] Basem AL-Madani "System Design Framework for Real-Time Distributed Industrial Vision System", Dissertation, University of Leoben, Austria 2004.