Remote control on Internet,long distance experiment of remote practice works, measurements and results

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Philippe Le Parc[3], Nasreddine Berrached[4]

Abstract – *The aim of our work is to control remotely mechanical systems which have nowadays local controls. With the development of the e-technologies, improvement of the network in term of time and band-width, the remote control will be common and will be made using networks without true quality of service, even unpredictable like Internet. In a first part of this paper, we are presenting some existing applications we have used. In a second part, we are describing generic software architecture to realize such remote control and a methodology to take into account the unpredictable nature of the communication media. In the third part we present experimental results of long distance remote control.*

***Keywords**: Remote Control, Internet, Methodology, Reliability, Networks.*

I. Introduction

The development of the technologies of communication and the standardization of the exchanges of data were very important at the end of the 20th century. It was a period of growing usage of these both technologies and of their industrial applications.

Since 1970s, the development of the Internet is certainly one of the major changes. The Internet network is now accessible from nearly every point of the Earth, using various technologies from telephone lines to satellite transmission systems, becoming faster and faster, cheaper and cheaper, day after day, with the developing of new technologies and the increase in number of Internet links.

The problem to solve is to act remotely. The none issue is how to use the new technology of communication for the remote control of machines as safely as possible.

Today the technology is sufficient to be able to control a production process from any point of the world using usual tools like a laptop and a telephone line.

The Fig 1 represents a system for remote action from the expression of the will of the remote user on the left to the local system which acts on the right. It appears that the complete system needs energy everywhere. But the quantity of power consumed to transmit the "will" is smaller compared to the power consumption at the right end. The sub-system of transmission is sensitive to the overflows of data but also to the breakdowns of power supply at each node.

Although the reliability of the equipments increases, the complexity increases too, then the probability of a failure of the transmission can not be considered equal to zero.

The problem that will still remain is the confidence user can have in the Internet in terms of Quality of Services (QoS). One solution to ensure the QoS is to use redundancy for the power supply everywhere and to use redundancy of the paths followed by the data. Right now, no quality is guaranteed and in the future, quality could be guaranteed but it will be expensive. Without this QoS, it becomes really hazardous to perform remote control of industrial processes.

Nevertheless, in some fields, using Internet technologies to control production lines or mechanical systems is possible, for example in the following fields:

- Tele-maintenance [1]: with Internet technologies, it is now possible to make remote diagnostics, to solve and repair problems, to prepare maintenance phases etc...
- Tele-expertise: some specific operations on mechanical systems can only be made by expert. In a close future, it will become possible for experts to operate from their office a machine located somewhere in the world, just using classic web technologies.
- Tele-teaching: a lot of universities are using machines to teach the basics of mechanical engineering. The profitability of these machines is of course really poor because they are only used a few weeks a year. Why not developing common centers, where students may have access to real machines without being close to them?. One of the problems of e-learning is to make practical experiments. Why not using Internet

technologies to let distant students to manipulate real systems?

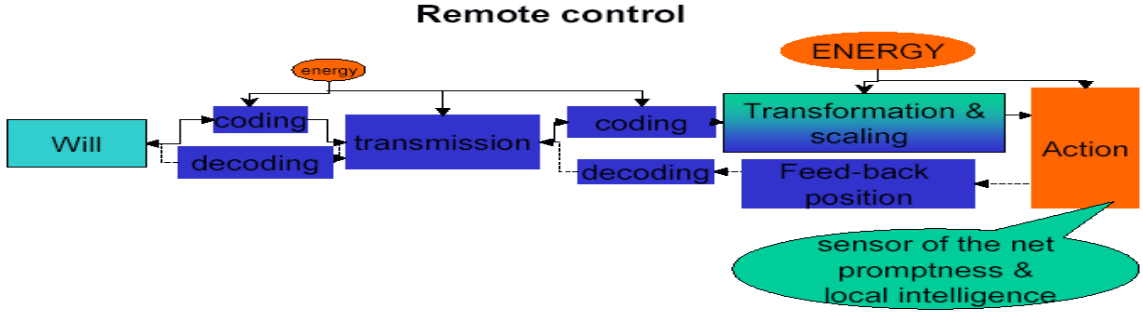

Fig. 1. Remote control

In the Nineties, several projects of control of mechanical systems using Internet as network of communication appeared with varied objectives the Mercury project [7] to prove feasibility, the Australian télérobot [6]-[16]-[14] for the interaction with the user, Puma Paint [10], mobile robotics KhepOnTheWeb [13] , augmented reality [15], etc….none of them was the occasion to develop a generic software architecture fascinating of account the unforeseeable nature of the network.

The use of Internet will reduce the costs of these activities. The increase of Internet abilities in term of speed and bandwidth in the future. Let us also think that the quality of the remote control and the comfort of the user will also increase (?). The problem for the industry is to find an economical compromise between the cost of the local control and a local maintenance or the cost of a remote control and a remote maintenance, assuming potential failures of the transmissions. When developing such applications, we have to think that these activities rely all the time on an unpredictable network and that we have to build them taking into account this parameter. We have used two concepts, the first is to check the quality of the communication during the remote control on the side of the action, the second is to switch to a safe state under the control of a local intelligence, when the delays of transmission exceed the time of reaction of a worker present in the factory.

II. Applications

Different applications have been developed using concepts explained in this paper Fig. 2. Several of them, the Ericc robot, the small milling machine, the Mentor robot, the motorized cameras, and a modem were used.

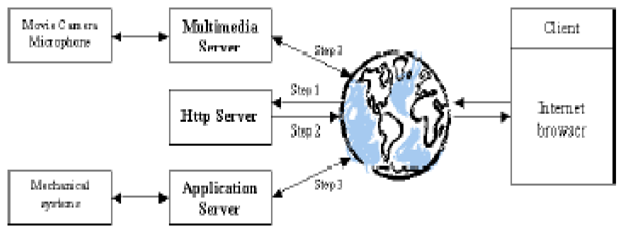

Fig. 2. General Architecture

II.1. Ericc Robot and the milling machine

This first application [9] concerns the control of a robot arm with 5 degrees of freedom Fig. 3. This robot may grasp some small objets with its pliers and move them to other places. A first camera (Sony EVI-D31) is placed in front of the robot. As it is motorized, it can make movements (left, right, up, down) and also has zoom facilities. It enables the distant user to adjust the images to its works. A second camera is placed on the top of the robot to give another point of view of the scene. It is a fixed focus and zoom camera, but it provides an embedded web-server to spread video. An audio module is also available.

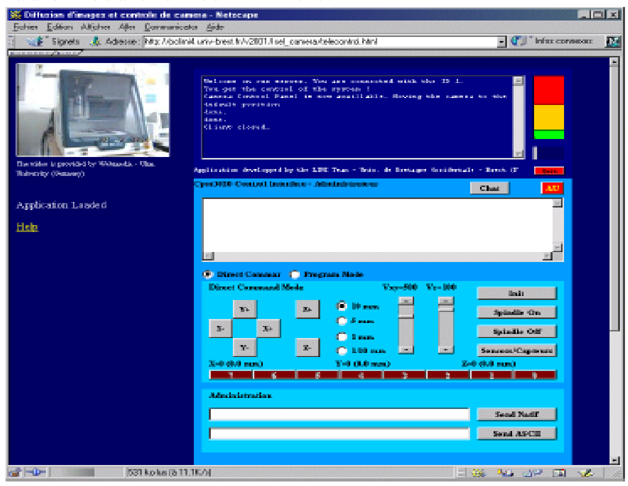

Fig. 3. The user interface of the milling machine

This robot is used for teaching by professor from our institution and also by colleagues from other universities in France or abroad. The same development has been made for a small milling machine for rapid prototyping and we plan to use it for teaching as well Fig. 4. These two applications show the interest of such a work in the educational context and its feasibility. Comments from users help us to improve the whole system.

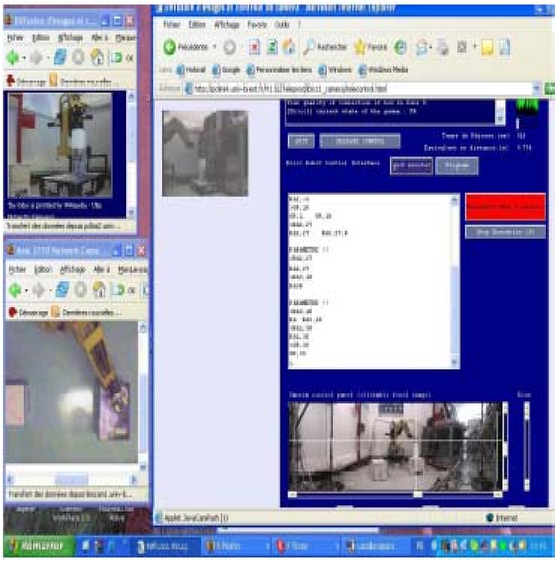

Fig. 4. Snapshot of the user screen

II.2. Mentor Robot

This application [17] concerns the control of an other robot arm with 5 degrees of freedom (Laresi

II.3. Motorized web-cameras

Another experiment [5] has been settled up to control a pan, tilt and zoom camera using the VISCA protocol and has been implemented in a aquarium close to Brest (France) to look at penguins. 4/5 images per second are produced with a size of 192x144 pixels. In this context, the interest of this work is not to protect the camera and its environment in case of network failures (damages are physically not possible), but to check that the kernel of our software is bug-free. This environment is also used to study network connections: as soon as a client is connected to the server, the ping/pong mechanism is launched and information it collects are stored. A second camera is installed in the lab.

II.4. Modem

We develloped also an application which make it possible to make the control of a modem through the network, this application is used to send AT command which will be used to control a phone in Oran (Algeria) from Brest France Fig. 6.

Laboratory USTMB in Oran, Algeria) using augmented reality Fig. 5. This application allow an operator to plan and control the robot movement using visual and sensory feedback information, the interaction between the operator and the virtual world through the I/O data provide an immersion sensation and an update of the virtual environment by the real (position) sensory feedbacks.

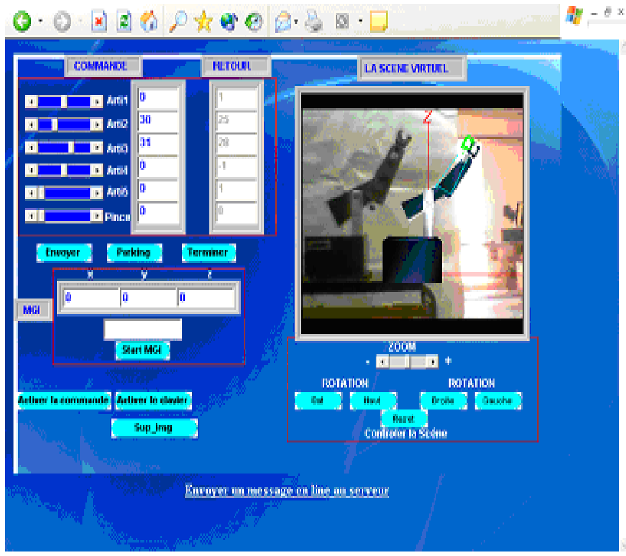

Fig. 5. The user interface of the Mentor robot

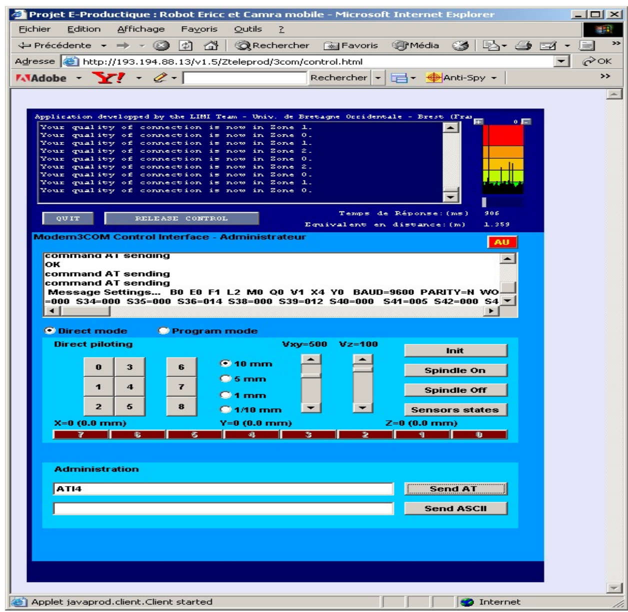

Fig. 6. The user interface of the Modem Fax

II.5. Network quality

The Internet network is working using the "best effort" strategy, which means that any user may send information and that there are no priorities between them. This strategy implies that characteristics for a connection between a user (or client) and a server is depending on, of course, some physical constraints (mainly type of the network, distance, number of nodes) and also depending on the overall use of the Internet. It is then really difficult to propose a model for the Internet network and in many cases, Internet has to be considered as a black box, which takes inputs and may deliver outputs after some time.

II.6. Managing network unreliability

In the context of remote control, the choice of TCP to send orders is obvious to be sure that orders are transmitted as well as to have a rather stable transmission delay. A way to measure it is to use a Ping/Pong method: one side of the system send a request (ping) and the other has to answer it immediately (pong). This method is easy to implement, does not disturb the general working of the system (client/server/network) and gives information, which may be exploited in two different ways:

1. Statistical way: when the pong is coming back, the measure made corresponds to the previous state of the connection. This information, associated with previous ones, gives to the server and the client a general idea of the quality of the connection which may have an impact on the remote control and the way a user will be confident in the system: for example, he will not try any critical operation if its connection looks bad.
2. Dynamical way: when one side of the system is sending a ping (or pong), watchdogs may be setup to monitor the waiting time. If it overruns some predefined limits, some autonomous decisions may be taken to prevent any damage on the whole system.

transition condition (Boolean expression depending on input or interval values) that may exist between the different states. Moreover, the "D1: emergency stop", is a specialized sub-area that may be reached from any other sub-area. The Gemma tool may be seen as a generic Statechart [3].
We have used a methodological tool, Gemma-Q [11], that may be used to specify how to take into account network distortion in a remote control application. The Ping/Pong measures the whole round trip time from one java-thread to another java-thread and back including the network, the two operating systems and treatments by the application level of the language java

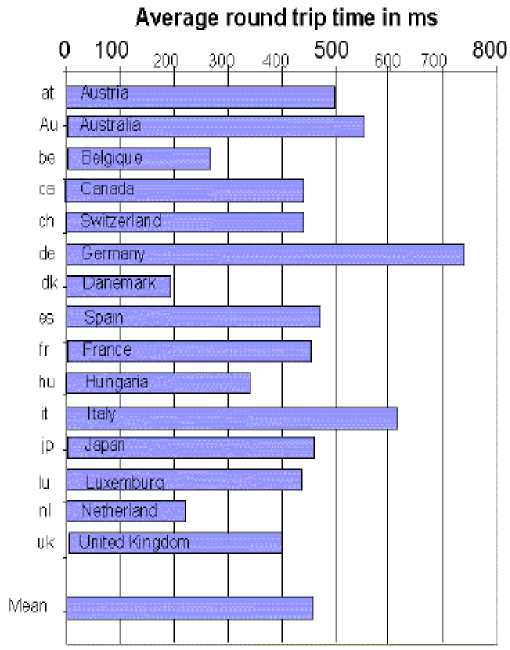

Fig. 7. RTT versus country

So this ping pong cannot be replaced by an ICMP ping. The Ping/Pong method acts as a sensor, which gives information about the network quality. Basically, one can decide that the connection is correct when the delay observed is lower than a limit and incorrect in the other cases. This implies two different states for the system under control and transitions between them.
More generally, mechanical systems may have different states. A specification tool called Gemma 2 has been defined to model these different states. It is composed of three main areas (?): Initialisation, Working and Defect. Each area is itself composed of sub-areas, which corresponds to sub-cases. For example, the Working area is composed of 6 subareas like "F1: normal production", "F2: start procedure" or "F6: operating test". When an engineer has to specify the way a mechanical system is working, he will describe, in each interesting sub-area, what the system will do and also the

at both sides. The small frame used for the ping pong is time-stamped, and could bring emergency commands.
Each sub-area of the Gemma is splitted in sub-sub-areas, connected by specific transitions, depending on the network quality. Six different quality levels have been defined; the border between qualities may vary from one application to another one depending on its constraints.
A Gemma-Q has to be defined for each device driver (Tool Interface) to control, and has to be implemented on the device, if it has resources to manage the implementation or on a computer connected to it with a safe link (like a serial link). User who will create his own application will also have to define and implement

a Gemma-Q, which may or not overlap the device's one.

II.7. SOFTWARE ARCHITECTURE

A software architecture [12] has also been defined to make remote control of industrial mechanical systems possible. It is based on a set of independent modules running in parallel. On the left side of Fig 8, the server side is represented. It is basically composed of three main processes: Groom which is in charge of the initial connection, DeviceManager which manages the different devices that can be controlled and ConnectionManager which manages the different connected clients according to the ControlAlgorithm module. This one is choosed by the designer of the system depending on the application: master/slave, priority, timeout... ToolInterface are specialized modules that control specific tool.

The right side of the Fig 8 represents the client side. Processes are loaded in a web navigator using Java Applet technology. RemoteClientManager acts as a router between the ToolGui processes and the NISender and NIReceiver one. A ToolGui corresponds to a graphical user interface to control a specific tool: user may send orders and receive information through them. One ToolGui is associated to one ToolInterface and to one real mechanical system. NIprocesses are used to communicate with the server side.

When a client wants to take control of the system, he will first download applets that will try to establish a communication with the Groom using TCP/IP protocol based on socket. If connection is accepted, Groom will inform the ClientManager and the DeviceManager. A set of processes LocalClientManager and again NI processes will be started to take in charge this new client. If he gets the control of the system (depending on the ControlAlgorithm), then he will be able to send commands to the system. In parallel, and processes are launched to observe dynamically the network.

This architecture has been designed as a kernel of services that will take in charge the connection, the management of users and tools, the supervision of the network. Around it, independent modules have been defined to manage a specific tool and can be added to the whole system using some "plug and play" mechanism. In the same way, the ControlAlgorithm can be chosen in a set of components.

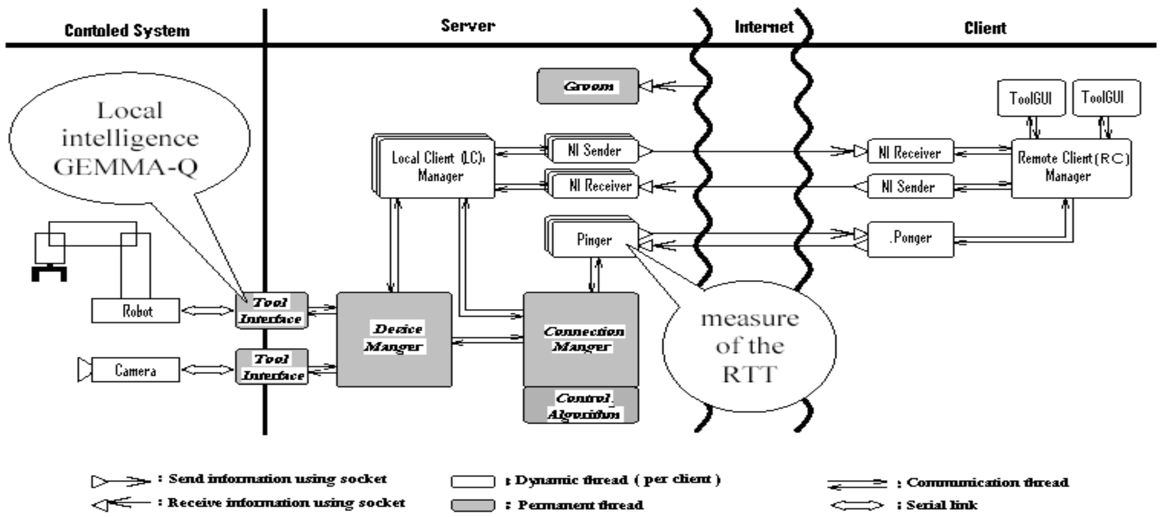

Fig. 8. Software Architecture

III. Experiment results

After 18 months of uses, statistics show that this motorized webcam has been controlled by 18000 people, coming from all over the World, using modem line, xDSL solutions or Local Area Network. The mean round time trip (time needed for a packet make a Ping/Pong) is respectively around 800ms, 200ms and 150ms. It really shows that controlling such a system is possible with the nowaday Internet technologies and infrastructures.

Since 2001 we have stored the data of more than 14 000 connections of more than one minute. The last three years the performances of Internet have been increased dramatically.

We collect the values of each RTT of each connection in html files on our server, so we can access from every where to the data. We transfer the data on a MySql data base manager and we have written some typical requests to analyse the quality of the connections.The Fig. 7 generated early in 2003 shows mean values of RTT versus the country of the remote controller [15].

Although our RTT cannot be compared with ICMP pings, the results of measures performed during the CAIDA are similar in term of RTT times.

Other figures show some records performed during remote practice works.

The data about a remote control of the milling machine from Oran are displayed on the Fig. 9. The RTT are mostly close to the mean value of about 300 ms, but there are many exceptional values. The second diagram presents the frequencies of the RTT. The presence of several peaks separated by the same distance of about 55 ms seems to be an effect of the computer used for the server, a Pentium II 450 MHz, and of the operating system windows 98. It corresponds to the refreshment period of the OS. The third diagram shows the cumulated frequencies, 95% of the RTT are better than 500 ms, but 1% are worst than 3000 ms. For an industrial application we have to choose a criterion of reliability. The safe remote control is usable only with slow processes. With a perfect network and fixed delay of transmission, this diagram should be a simple step at the fixed delay. About a remote control of the Web-Cam Similimi from Guadeloupe Fig. 10 we can see that the behaviour during the night on the side of the server is better. But if the network was perfect we could suppose that the shape of the diagram should be a step at the CAIDA project are similar in terms of RTT time value of 160 ms. We don't know the path used by the data, the length of this path is probably over 8,000 km. So the operational speed of the data is 2*8,000 / 0.16 = 100,000 km/s, the half of the light speed in optic fibbers!

The third fig 11 shows the RTT of one experiment made during the day, and the reduced performance of the transmission.

During the experiments between Brest and Oran we used the ICMP commands ping and traceroute to compare.

Example of ping:

Statistic Ping for 193.52.16.98:

Paquets: sent = 20, receive = 14, lost = 6 (lost 30%),

Approximate duration of the loops in milliseconds:

Minimum = 444ms, Maximum = 732ms, Average = 583ms

It means that 30% of the paquets were considered as lost because they were over the allowed limit of 1000 ms. Our values were similar, during the experiment the mean value of our RTT was 566.20 ms, the maximum 6500 ms, the minimum 156 ms and the median 391 ms. But our system gives more information, and is useful for the remote control.

Example of traceroute:

Determination of the route towards pclimi4.univ-brest.fr [193.52.16.100] with a maximum of 30 jumps .

1 107ms 131 ms 82.101.184.129

2 114 ms 107 ms 119 ms 81.22.57.1

3 124 ms 287 ms 119 ms 10.100.100.5

4 339 ms 347 ms * So3-2-1-0-grtmaddrr2.red.telefonica-wholesales.net [213.140.50.17]

5 282 ms 393 ms 419 ms GE6-0-0-0-grtadrr1.red.telefonica-wholesale.net [213 140.37.129]

6 318 ms 345 ms 323 ms So6-0-0-0-grtpaix1.red.telefonica-wholesale.net [213.140.36.134]

7 317 ms 299 ms 335 ms renater.sfinx.tm.fr [194.68.120.102]

8 339 ms 359 ms 503 ms nri-a-pos1-0-0.cssi.renater.fr [193.51.179.3]

9 318 ms * 364 ms rouen-pos2-0.cssi.renater.fr [193.51.179.22]

10 353 ms 383 ms 719 ms caen-pos2-0.cssi.renater.fr [193.51.180.21]

11 509 * * rennes-pos1-0.cssi.renater.fr [193.51.180.18]

12 362 ms 251 ms * megalis-rennes.cssi.fr [181.51.181.125]

13 326 ms 335 ms * 193.101.145.5

14 603 ms 623 ms 514 ms 193.101.145.26

15 1035 ms 875 ms 851 ms 193.48.78.198

16 853 ms 743 ms 695 ms 193.50.69.250

17 * * * Délai d'attente de la demande dépassé

18 331 ms 347 ms 442 ms pclimi4.univ-brest.fr [193.52.16.100]

Given route.

The path determined by the tracert command from Oran to Brest shows that the data travel from Oran through Alger, Paris, Rouen, Rennes, and then Brest. The great-circle distance between Oran and Brest is about 1400 km, the data don't travel along the shorter way but a way over 2000 km. The operational speed of the data reach 2000*2/0.6 = 6,667 km/s the 30th of the light velocity in optics fibbers. We can expect that this operational speed will increase in the next years, if this increasing is upper than 3 times, we will be under the limit of 200 ms considered as the maximum acceptable delay for teleoperation with force feed-back.

We can also note that between time where we made the experiments and the end of the year 2006, times of ping ICMP decreased in a considerable way. What gives a considerable idea of the futures improvement of Internet Networks.

Exemple of ping 2006:

Statistics Ping for 193.52.16.98:

Paquets : sent = 87, receive = 86, lost = 1 (lost 1%),

Approximate duration of the loops in milliseconds: Minimum = 58ms, Maximum = 120ms, Average = 69ms

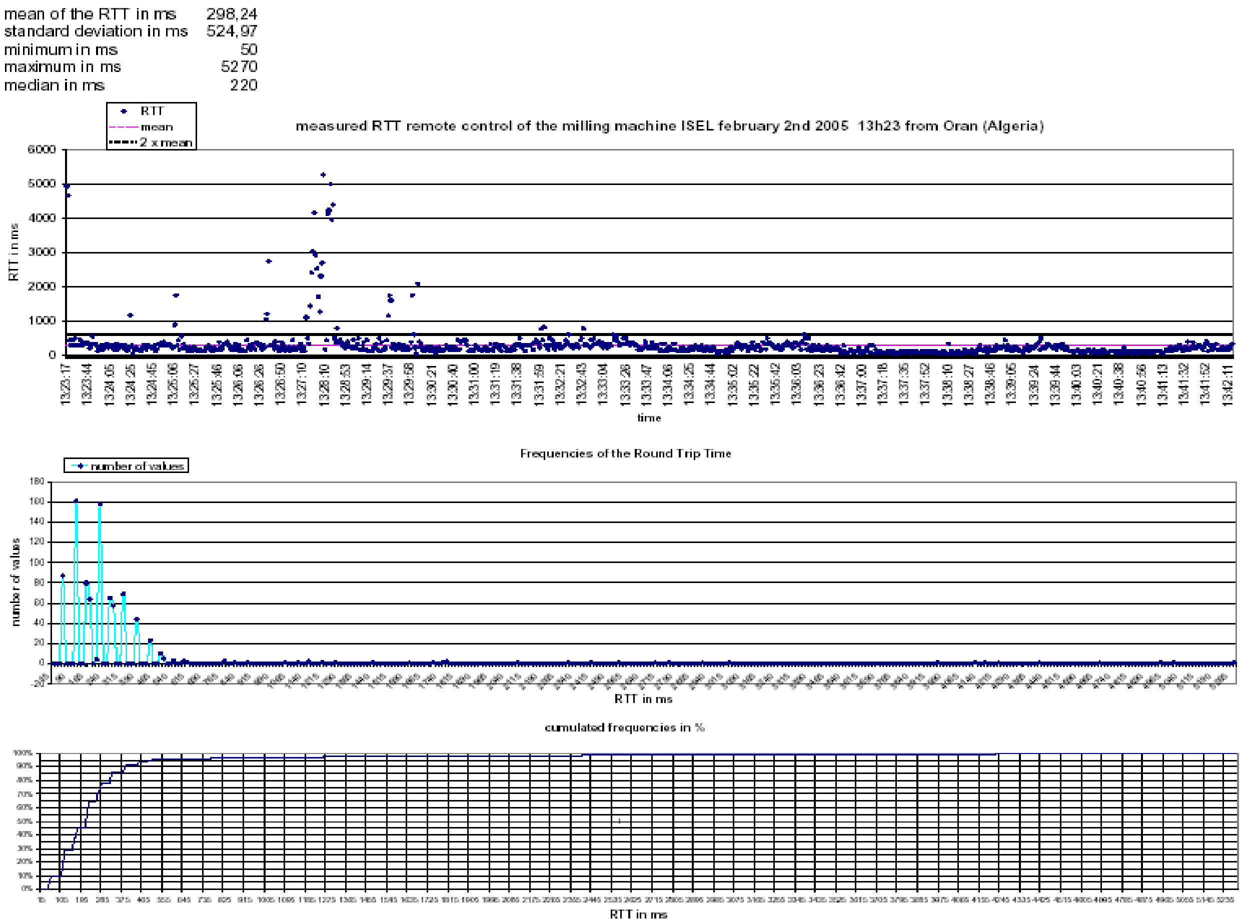

Fig. 9. Trace of the remote control of the milling machine from Oran

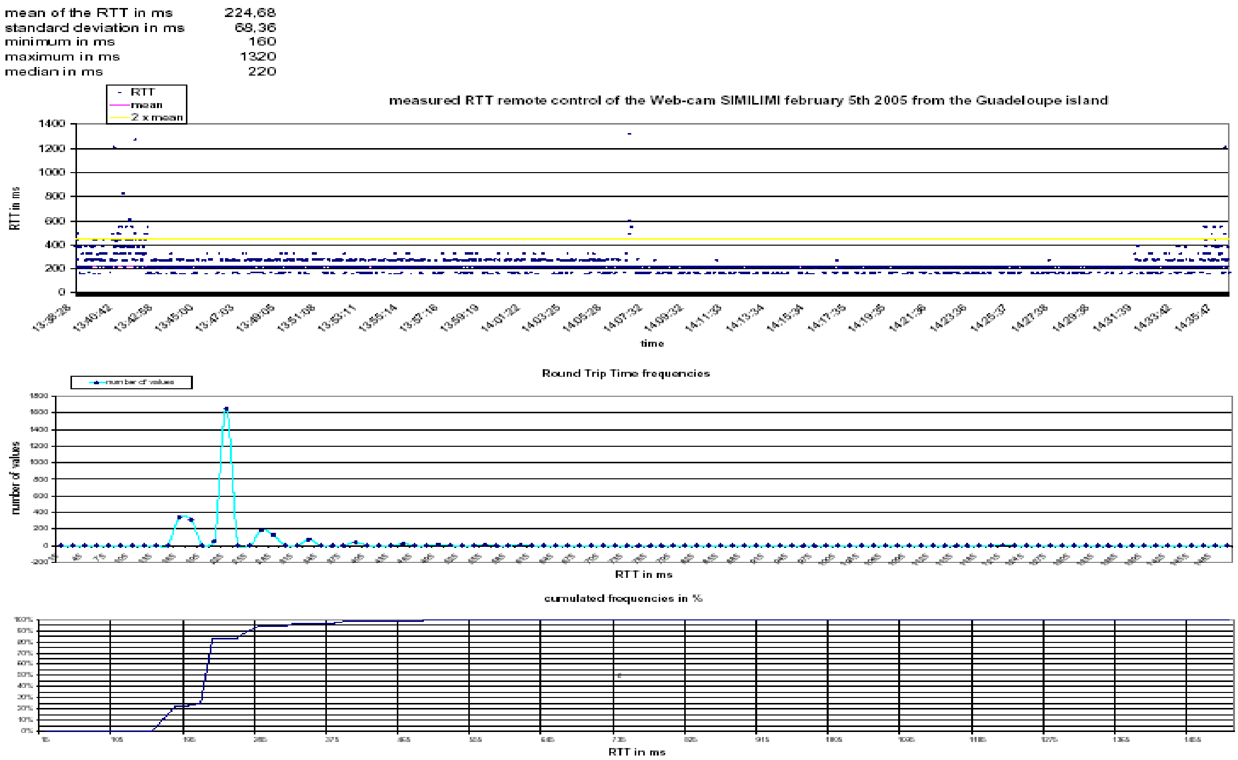

Fig. 10. Trace of the remote control of the Web-Cam Similimi from Guadeloupe

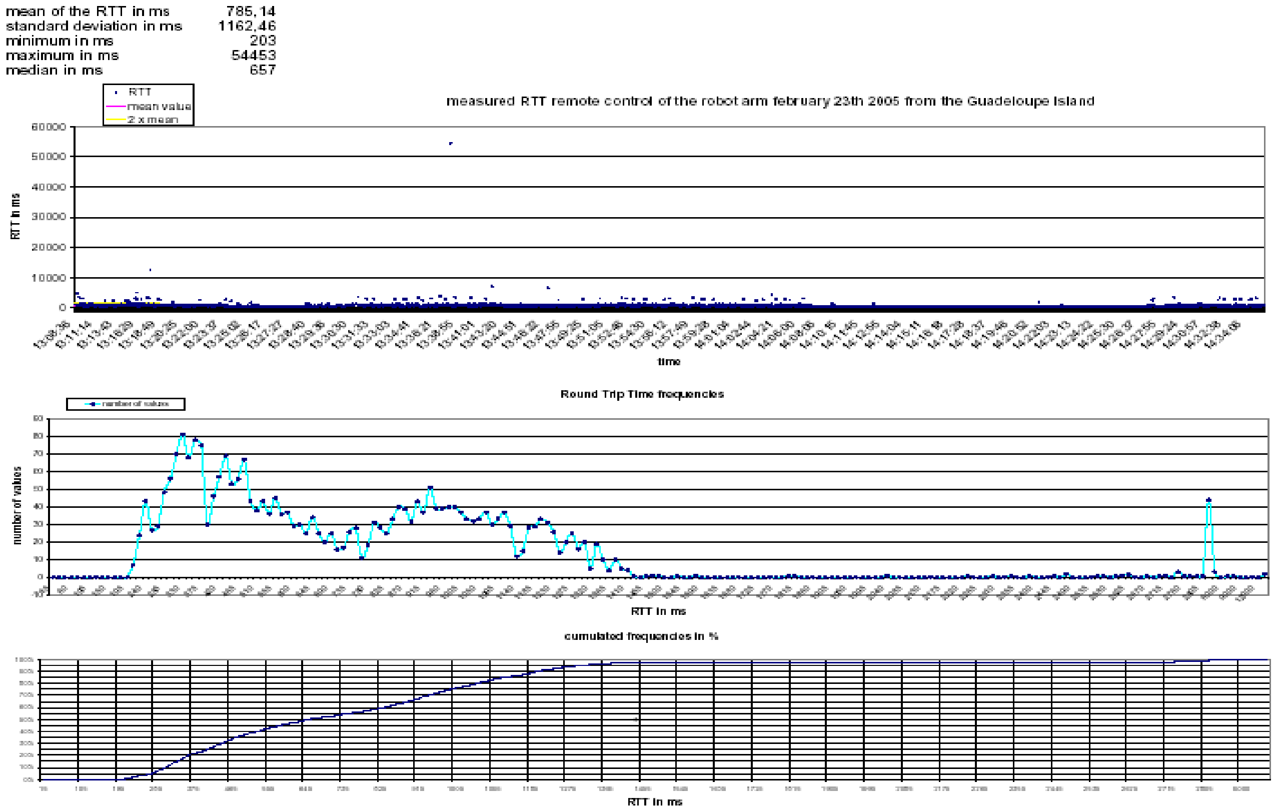

Fig. 11. Trace of the remote control of the arm Erric from Guadeloupe

IV. Conclusion

The remote control of mechanical system over an unpredictable network such as Internet is feasible and will be developed in the close future for tele-teaching, tele-maintenance, tele-expertise or tele-production. A good system may rely on a kernel of services to communicate, to manage people and tools, to study the network and to adapt itself to the quality of the connection.

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Authors' information

Lahouari Kaddour-El Boudadi was born on 07.02.1967 in Oran Algeria. He received the Eng. Degree in Electronics from the University of Sciences and Technology of Oran (USTO, Algeria) in 1990, and the Magister degree from the University of Sciences and Technology of Oran (USTO, Algeria) in 1995; his thesis title was " Commande dynamique d'un robot à 6 d.d.L". Since 2000 he is working as a teacher with the departement of electronics. His interest is in man-machine interface, telerobotics.

Philppe Le Parc was born in 1968 in Lorient (France). He pased his PhD in 1994, on the modelling and validation of sequential functional Charts using synchronous languges. He is currently Professor at the University of Brest, working both on remote controls of mechanical systems on the Web and on industrial manufacturing problems.

Nasr-Eddine Berrached was born in 1954 in Tlemcen, Algeria. He received the Eng. Degree in Electronics from the University of Sciences and Technology of Oran (USTO, Algeria) in 1978, and the Dr. Eng. Degree from the University of Sciences and Technology of Lille (USTL, France) in 1982. He also received the Dr. of Eng. Degree in Computer Science from the Tokyo Institute of Technology (TIT, Japan) in 1992, and the Dr. "d'Etat" degree in Electronics from USTO in 1994. He joined USTO in 1982, where he is professor at the Department of Electronics. From 1986 he was leading the Laboratory of Robotics, and from 2000 he is leading the Research Laboratory in Intelligent Systems of the same university. His interests include man-machine interfaces, telerobotics, machine vision, pattern recognition, and inverse problems.