INTERNET-BASED TELEOPERATION: A CASE STUDY
Toward Delay Approximation and Speed Limit Module

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Abstract: This paper presents the internet-based remote control of mobile robot. To face unpredictable Internet delays and possible connection rupture, a direct teleoperation architecture with "Speed Limit Module" (SLM) and "Delay Approximator" (DA) is proposed. This direct control architecture guarantees the path error of the robot motion is restricted within the path error tolerance of the application. Experimental results show the effectiveness and applicability of this direct internet control architecture in the real internet environment.

1 INTRODUCTION

Internet is not only an information highway, but also a mean to remotely control mechanical systems, such as robotic devices. But Internet doesn't provide a guaranteed Quality of Service (QoS); it entitles a number of limitation and difficulties, such as bandwidth constraint, transmission delays, packet lost, connection rupture etc. The situation above influence the performance of Internet based telerobotics systems, which is a new field in the recent decade.

The Mercury project (Goldberg et al., 1994) is one of the earliest telerobotics implementation over the internet, then coming with the Telerobot in Australia (Taylor and Dalton, 1997), the painting PumaPaint Robot (Stein, 1998), and Khepera robot (Saucy and Mondada, 2000) etc. During the past ten years, lots of such systems have been introduced by different researchers all over the world.

Most of these researches use a supervisory control scheme which enables operator to issue high level commands. As the internet time delay is unpredictable, the design of direct control scheme which enables user to control the motion of robot continuously may not be easy. Such control schemes have been proposed, but are not adequate to alleviate the influence of Internet time delay.

This paper presents direct teleoperation architecture of a continuous robot motion control which meets path error tolerance under the unpredictable Internet time delay. Here, the path error is guaranteed only if the path error at every turning/stop point is restricted within a path error tolerance which depends on application itself.

Two kinds of control strategy are introduced in the Section 2, followed by the detail of "Speed Limit Module" (SLM) with the quality level idea of GEMMA-Q (Ogor, 2001) and how it works together with the "Delay Approximator" (DA) to meet the application requirements. During the Section 3, the software implementation is presented with an application over Miabot (two-wheeled robot widely used in soccer competition organized by FIRA).

2 TELEOPERATION ARCHITECTURE

2.1 Generic Architecture

The teleoperation over Internet lies on a generic teleoperation architecture (Figure 1), through which commands are exchanged between remote system and operator (user). The user, through his Internet navigator, addresses a request to a Web Server (step 1) and downloads an application, such as a Java applet (step 2), on his own workstation. A connection is then established towards the Application Server in charge of robots and client management (step 3). In the same time, another connection with Multimedia Server is also established in the form of exchanging media signals. The user is now able to control the remote robot upon request.

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The generic architecture is the same in most applications. The key problem is to alleviate the influence of Internet time delay and towards a continuous control within the path error requirement.

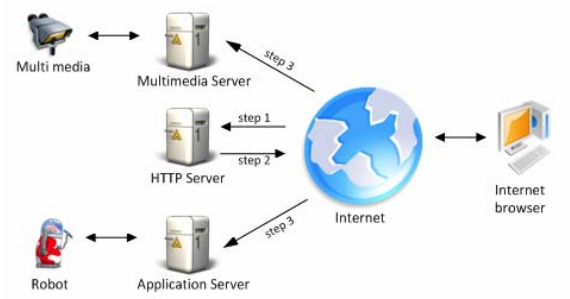

Figure 1: Generic architecture.

2.2 Control Strategies

2.2.1 "Move and Wait" Strategy

The " Move and Wait" strategy (Sheridan, 1992), which is typical for space robots with long distance communication has been applied first. In the Miabot case, five commands: "move forward" (MF), "move backward" (MB), "turn left" (TL), "turn right" (TR) and "stop" (ST) have been defined. These commands are enough to perform any complex task, but the user has to send lots of commands and change the move or turn parameters from time to time to meet the requirement.

2.2.2 "Speed Control" Strategy

To reduce user's workload and towards a fluent process during the complex task, a "Speed control" strategy, similar to real driving, is introduced. "No-stop move forward" (NSMF), "no-stop move backward" (NSMB), "turn left" (TL), "turn right" (TR) and "stop" (ST) commands are defined in this strategy. When the robot executes a turning command, it stops running first, perform the entire turning next, and then runs in previous speed again. The user may choose different running speed as well as turning degree.

The user's operation reduce is significant. The robot is running with speed v during the whole task even though there is a turning/stop point. When the user sends a turning/stop command to robot, the command reaches the robot with a discrete time delay Δt due to Internet time delay. The robot may run an extra distance Δd before it performs the turning/stop.

$$\Delta d = v \times \Delta t$$

Where

v indicates the current speed of the robot, Δt is the current Internet time delay between sending the command from the user and executing the command by robot.

As Internet doesn't provide a guaranteed Quality of Service (QoS), the time delay is unpredictable. Figure 2 is an execution result of the task A $\rightarrow$ E with "Speed control" strategy. The path error is accumulative, and path deviation is significant which may result in the failure of the task.

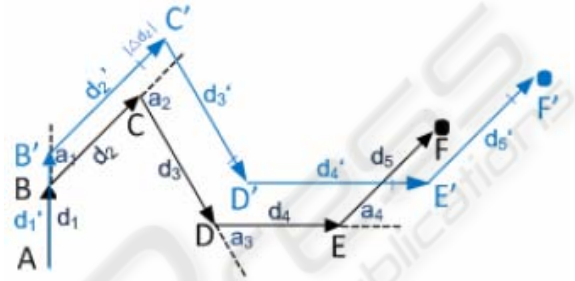

Figure 2: A path result with "Speed Control".

2.3 Speed Limit Module and Delay Approximator

2.3.1 Speed Limit Module (SLM)

The GEMMA-Q (Ogar, 2001) methodology derived from GEMMA (ADEPA, 1981) has been proposed. The basic idea is to define the quality of communication as a discrete value. Following the value, the automated system has to follow different rules to ensure the security (path error). According to the type of quality, these rules might be different. If the user has a slightly deteriorated communication quality, the user might keep the control and the automated system has to work in deteriorated mode.

The GEMMA-Q has been used in the application over robot arm and prototype machine (Le Parc et al., 2001). In this paper, which aims to control a simple robot, use only the quality level idea of GEMMA-Q to design SLM. n communication quality levels are introduced which corresponds Internet time delay zone (Time D.). Each time delay zone has its own sub path error tolerance $\Delta\varepsilon_j$ (Sub T.) and Max Speed v_j as shown in the Table 1.

Table 1: Quality levels in SLM.

Qual.	Time D.	Sub T.	Max Speed
Q_0	$0 \sim t_0$	$\Delta\delta_0$	$v_0 = \Delta\delta_0 / t_0$
Q_1	$t_0 \sim t_1$	$\Delta\delta_1$	$v_1 = \Delta\delta_1 /(t_1 - t_0)$
Q_2	$t_1 \sim t_2$	$\Delta\delta_2$	$v_2 = \Delta\delta_2 /(t_2 - t_1)$
Q_3	$t_2 \sim t_3$	$\Delta\delta_3$	$v_3 = \Delta\delta_3 /(t_3 - t_2)$
...	...	...	...
Q_{n-1}	$t_{n-1} \sim t_n$	$\Delta\delta_{n-1}$	$v_{n-1} = \Delta\delta_{n-1} /(t_n - t_{n-1})$
Q_n	$\geq t_n$	0	$v_n = 0$

When the quality level changes, the Application Server evaluates the Current Robot Speed (CRS) and the Max Speed of this quality level (MSoT). If CRS $\leq$ MSoT, no command is sent to robot; else the Application Server sends MSoT command to robot (change CRS to MSoT).

MSoT is calculated by the time delay zone and sub tolerance which are defined by user according to application. In order to meet the path error tolerance δ at the turning/stop point, the following constraints are used when designing SLM:

$$\begin{cases} \sum_{j=0}^{n} \Delta\delta_j \leq \delta \\ v_{j+1} \leq v_j \quad j \in (0,1,\cdots n-1) \end{cases}$$

The above constraint guarantees the path error at the turning/stop point is restricted within δ in any Internet time delay situation. Q_0 is the best quality level, its Max Speed v_0 is the fastest running speed of the robot. Q_n is the disconnection situation, and the robot stops running immediately $(v_n = 0)$. The proof of how the constraint works are shown below.

There are two kinds of situation when the robot runs under the speed limit rules.

1. Stable network delay

It means the robot is running in the same time delay quality level Q_i between two continuous actual Internet time delay (from the real clock time of receiving previous actual Internet time delay to the real clock time of receiving next actual Internet time delay). Then

$$\begin{aligned} \Delta d &= v_i \times t_i \\ &\leq v_0 \times t_0 + v_1 \times (t_1 - t_0) + \cdots + v_i (t_i - t_{i-1}) \\ &= \Delta\delta_0 + \Delta\delta_1 + \cdots + \Delta\delta_i \\ &= \sum_{j=0}^{i} \Delta\delta_j \\ &\leq \delta \end{aligned}$$

2. Unstable network delay

The robot is running in the different time delay quality levels between two continuous actual Internet time delays. The worst case is from Q_0 to Q_n:

$$\begin{aligned} \Delta d &= \Delta\delta_0 + \Delta\delta_1 + \cdots + \Delta\delta_n \\ &= \sum_{j=0}^{n} \Delta\delta_j \\ &\leq \delta \end{aligned}$$

The path error Δd is within the restriction of path error tolerance δ in both situations. Then the path error at every turning/stop point in the task is guaranteed and the successfully continuous control of the robot is achieved.

With the constraints, the different quality levels with its respective time delay zone value, sub tolerance and max speed are defined according to different application. e.g.: the normal quality level of Internet time delay is Q_j in the application, its sub tolerance $\Delta\delta_j$ should take a larger percentage of δ. It means the robot is preferred to have larger sub tolerance in the normal quality level; in the same time, speed limit rules guarantees $\Delta d \leq \delta$ in any situation.

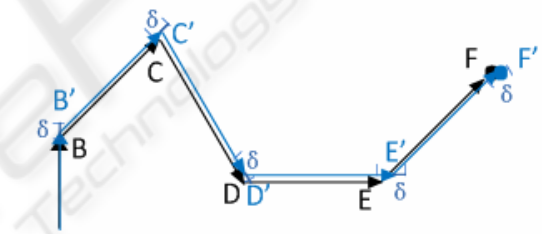

Figure 3: A path result using “Speed Control” with SLM.

In Figure 3, the path deviation at every turning/stop point is restricted within δ. Then a successful task is achieved using “Speed control” with SLM. The above describes the detail SLM with the quality level idea, next part emphasize on how the gets the quality level information of current time delay from DA.

2.3.2 Delay Approximator (DA) Principals

In the generic architecture, Pinger-Ponger is the mechanism to provide the Internet time delay information to DA. The next actual Internet time delay Δt_n is calculated as follows:

$$\Delta t_n = T_n - T_p$$

Where

T_p is the real clock time of receiving previous actual Internet time delay from Pinger-Ponger; T_n is the real clock time when Pinger-Ponger sends the next Internet time delay to DA.With above feature,

the current (up-to-now) time delay Δt_c from T_p is formed as:

$$\begin{cases} \Delta t_c = t_j & j = 0 \\ \Delta t_c = t_j - t_{j-1} & j \in (1,2,\cdots n) \end{cases}$$

t_j is the time delay zone in SLM. Δt_c is the watchdog and j is the automatic counter initialized with 0. Δt_c is only activated when there is quality level change, and this quality level change is used as current time delay change information.

Pinger-Ponger only provides the Internet time delay when it gets one. The Internet time delay is unpredictable, so there is no idea when Pinger-Ponger gets new information.

There is no idea about the future, but the current situation is supervised by DA as following principals:

1. DA receives information from Pinger-Ponger.

Pinger-Ponger informs DA of receiving the next actual Internet time delay, and then DA forwards the quality level of calculated Δt_n to SLM. Meanwhile the previous parameters are set to be the current ones: the value of T_p is set to T_n , the quality level of previous actual Internet time is changed to the quality level of Δt_n, reset the watchdog (Δt_c).

2. No information from Pinger-Ponger and Δt_c is activated to a quality level change.

Δt_p is the previous actual Internet time delay. There are two kinds of situations:

- $\Delta t_c \le \Delta t_p$

  The quality level of current time delay is no worse than that of previous actual time delay; there is no action and DA keeps supervising.

- $\Delta t_c > \Delta t_p$

  The quality level of current time delay situation is worse than that of previous actual Internet time delay. When Δt_c is activated, it indicates a change of quality level and "DA" forwards the new quality level to SLM. DA keeps supervising.

DA keeps supervising the Internet delay situation all the time. It provides the real Internet time delay or current time delay to SLM.

3 EXPERIMENT

The remote control system server has been built in UBO, France. Some users (mainly from France, Sweden, and China) are invited to test the feasibility of effectiveness of the system. The average Internet time delay varies a lot between European users and Asian users. It's not easy to find a uniform SLM for all the users, but certain SLM works fine for some users. The test is still on-going currently. The average Internet time delay of the user is able to observe during the test, so next step consideration is to build SLM for respective user group (distinguished by average Internet time delay. e.g.: Asia, Europe, etc.) and the system can choose different SLM automatically due to the user group.

4 CONCLUSION

In this paper, the SLM and DA based architecture is proposed to face the unpredictable Internet delay in Internet-based robot control. This approach guarantees the path error of the continuous robot motion. Here, the path error is guaranteed only if the path error at every turning/stop point is within a path error tolerance δ which depends on application itself.

In this architecture, the current time delay is supervised by DA; and SLM applies different speed limit rules according to the current time delay situation. Then the robot is always running in a proper speed which meets the path error restriction. Finally, a continuous control of the internet-based robot is achieved successfully.

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