2021 6th International Electrical Engineering Conference (IEEC 2021)
April, 2021 at NEDUET, Karachi, Pakistan

Anchored Haptic Tele-operation with optimized latency

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Abstract:
In this paper, we present a case study to investigate the network delays and system jitters a user may face while using virtual reality & haptic tele-operation in a developing country. The key contributions of this paper include a longitudinal design to achieve network efficiency, its main focus on continually optimizing the effectiveness of optimized latency and analyze the results of time delay reduction in order to achieve the stabilized connection for a smoother and better virtual reality experience. We hope that our experience from this study together with the free materials and data available for download will be beneficial to other practitioners working with virtual reality and haptic teleportation around the world.

Keywords:. Haptic, Network, Latency, Time delay, tele-operation, feedback, UDP, tele-presence

I. INTRODUCTION

The world is in the continuous process of evolution mainly due to the development of new technologies which are being improved day by day. One of the examples includes VR (virtual reality) which is being improved gradually by blending with new technologies. Besides, there is another huge potential concept of using haptic feedback in daily life which can portray the sense of touch through machine data. Using such a technology would bring revolution in human lives. The problem in utilizing it on a global scope is that it comes with network issues like data loss, jitters, latency, etc. We have to use several techniques especially where the network is established to ensure that a good haptic device data is transmitted on time and has a smooth operation throughout [1].

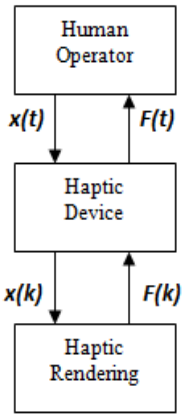

Fig 1. The difference between the real time and discrete time data

II. PROJECT SETUP AND NETWORK

In the proposed project, we have two haptic devices constituting a system with the feedback from one device to other one. We have separate PCs connected in local area network and control haptic rendering through these computers e.g., due to the simplicity of the network, the server silent methodology yields promising results and the loop of data between both of the haptic devices, i.e., server haptic device and the client haptic device have minimum time delay, low latency issues and also have great connection stability.

But when the same system is shifted to the wide network. This also applies when it shifts over a long-distance network. This is the point where we start to face problem with the transparency of the network and where we have latency issues and time delay as well.

Fig 2. The picture of the setup connected over LAN

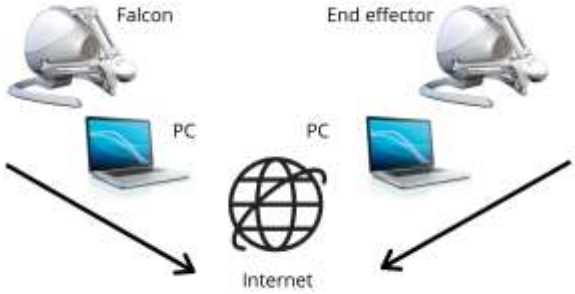

Fig 3. Setup of a haptic device communicating via an internet network

III. NETWORK AND INTERNET

A. Internet Protocol

In networking, there are certain set of rules that are used when the data packet from the haptic device is sent. The internal protocol is attached with every packet, which is sent through networking. When the data reaches the destination, it is treated with different protocol.

B. UDP (User-Datagram Protocol)

When the data reaches its destination, it is treated with transport protocol. It is like zip, address or postal code along a mail. There are two transfer protocols. Those are UDP (user datagram protocol) and TCP (transmission control protocol). The TCP dedicates the way for the data and establishes a connection itself. TCP transfers complete data with no losses in packet and also, they are in order when we receive them. But it can cause delay and thus not suitable for real time applications. Where UDP does not establish any connection before sending the data packets, the connection is less reliable due to the loss of data. The data transmission is fast, but it may be unordered. The UDP network transport protocol is preferred when it is used in the real time applications.

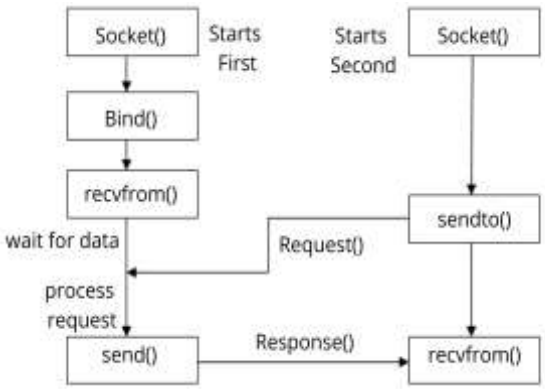

Fig 4. UDP socket model

C. Virtual Private Networks

A virtual private network, or VPN, is an encrypted connection over the Internet from a device to a network. The encrypted connection helps to ensure that sensitive data is safely transmitted.[2] It prevents unauthorized people from any involvement on the traffic and allows the user to conduct work remotely. [2] In any virtual private network, we can purchase a dedicated IP. This is due to the reason that in any network, there are security walls and the ports are not allowed to open and receive data due to the security of that network. Using a VPN, the port does not understand the data, it does not have the key and it will pass the data thought that network. This technique is very useful when we transmit data over a long-distance connection or in intercontinental distances.

IV. TECHNIQUES FOR EFFICIENT NETWORK

A. Optimized Latency

Latency basically refers to a combination of data loss (packet loss) and the time delay involved in the trans-receiving of a signal. The latency is a hurdle that has caused severe problems in the tele-operation through decades, similar to the case of haptic tele-operation. When a command is executed due to latency, its effects could not be fully observed. The sensor (Haptic device) translates a command and it is delayed due to the latency or the data present in the command is lost due to the latency would not actuate the end effector properly and it would not be a successful tele-operation. Most of the problems faced in the tele-operation were due to latency. The latency of the whole system was optimized using packetizing of data and using a small packed buffer of size 2048Byte and six memory allocations.

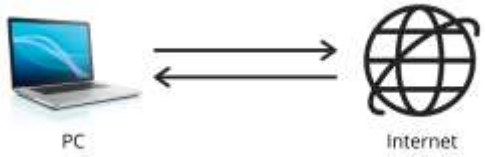

Fig 5. The request time from the computer and the data sending time can be expressed in Eq.(1)

$$T = T1 + T2 . \quad (1)$$

There are methods by which we can reduce latency. Some are defined below.

The HTTP/2 devices are used for latency reduction by reducing the round trips coming from the server back to

the receiver and vice versa. In haptic, employment of HTTP/2 will be helpful for reducing the latency, which will be beneficial for the haptic devices to work efficiently. Reducing the numbers of external HTTP requests will help in reducing the latency. When you reference something from a different website rather than using your own knowledge, this creates a link between you and the reference point, which increases the latency of your program (or your website) according to what the Latency of the website you are using at that point. If we reduce the number of HTTP requests, the efficiency and responding rate of a haptic device will increase. Using the prefetching method does not affect the latency, but it reduces the latency which increases the website's performance and this happens when the latency intensive process is running behind the background of the website on browsing the website. This method of reducing latency is a good way to work better using a haptic device and it doesn't show much of a delay during the working of the device. Caching process specifically allows you to cache certain resources and functions of a program to operate which helps in reducing the latency of the website and reduces the round trips. This method is helpful for reducing the latency rate, which is better for a haptic device to operate more easily with less interaction occurring due to less latency.

The basic difference HTTP1 and HTTP2 is that In HTTP1 the data is transmitted in plain text format whereas the HTTP2 transmits and receives the data in binary number format enabling the use of maximum network resources, it enables full request response and multiplex it, it efficiently compresses the header fields of the protocols and support the prioritization of request and server push, it also use the transport layer of the Internet protocol and as whole it reduces the latency quite drastically.

Fig 6. Demonstrating the difference of latency between http1 and http2 [3]

In order to optimize latency, there are further more techniques available that could also perform good but they come having their side effects. Some of them are as below [4]:

DNS Prefetching
Caching
Pre-connect

B. Time delay reduction

To perform successful tele-operation, the most prominent hurdle is the time delay. To minimize it, there are various techniques, some were applicable on the cost of data loss such as using SSH tunneling, but on the cost of data loss and the security of the data was compromised. There were many techniques which were not applicable to this scenario. At first, the thing is to calculate the time delay on the networks used for tele-operation i.e. LAN, WAN, etc. The delay calculated is found to be in milliseconds on an average. The minimum delay was on LAN and the maximum delay was found when tele-operating between continents using VPN. The technique used to minimize the time delay was using UDP socket that transmits the data in packets in minimum time. The other requirement was using a buffer size of 2048Bytes that helped to transmit the data at a faster pace minimizing the time delay and preventing data loss at a certain level.

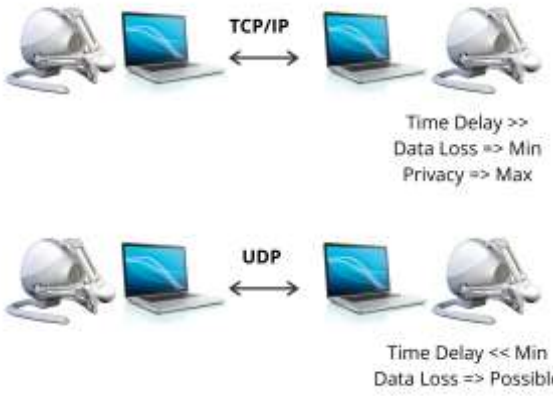

Fig 7. Tele operation using different type of network protocol

C. Stabilized Tele-operation

The haptic tele-operation enables you to manipulate and amplify human strength by transmitting the human senses and command over the network thereby controlling those using smart electronic or mechanically intelligent devices. The problem lies in

the fact that it senses quite small signals and also transmits them. Due to this problem, the end effector executes them and starts oscillating creating useless, unintentional vibrations. The solution to the problem was using a constant to control the amplitude of sensing signals from haptic device and executing them with a multiplying factor. The constant used was similar to the spring constant Kp. Different values of it were used and a successful combination was deployed, which stopped the unwanted oscillations and jittering of devices over a network.

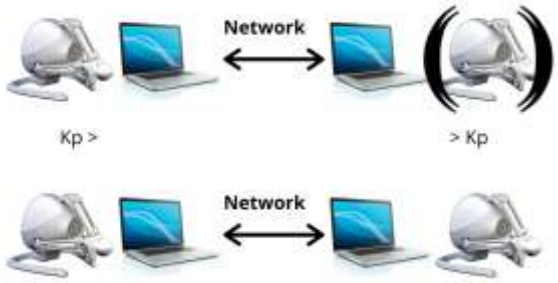

Fig 8. Relative difference between Kp of both. Kp of end effector more than Kp of falcon.

D. Reliable Connection

The problem arises while tele-operating, is the loss of connection. It keeps breaking on being idle or operating. That's quite unreliable as it could break down due to various reasons including over-population of packets, jitters, network delays, etc. It needs to be reliable and robust. Various techniques were used, but all have different consequences that could result in data loss, higher latency or complicity. The problem was addressed and solved by using a smallest possible buffer that is adequate to carry the information needed to send and receive data by the devices. The program involved a buffer of size 2048Bytes [5] having three allocations for sending data and three allocations to receive it. It is enough to send and receive the three-dimensional data and it provides a rigid ground for a robust connection. [6] The connection was tested again and again and it is found that it does not break while being idle or operating continuously until the data or command is given (that is more than the prescribed limit of the falcon (haptic device) or the end-effector and the connection is not terminated by the user himself).

Choosing the right number of allocations in the buffer and setting an adequate size for it is so crucial. It would enable us to develop a reliable connection. The problem with choosing a bigger size for buffer would fill the remaining allocations with unwanted data as UDP socket are being used that would make the devices misbehave exceeding their physical limits hence, breaking the connection. And choosing small buffer size with less than 3 allocations would result in the data loss. Hence, the buffer size of 2048 Bytes with maximum 3 allocations is preferred which resulted in the most reliable connection giving maximum durability and was found most robust.

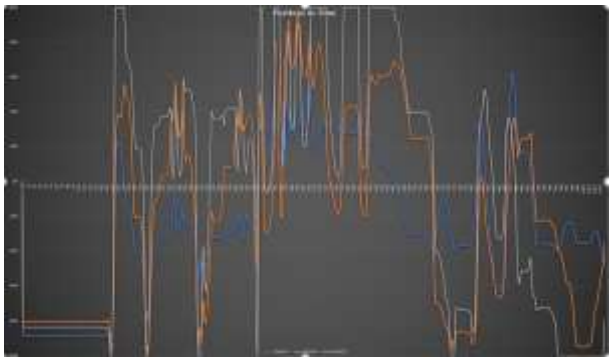

Fig 9. The graph between the time and the (x,y,z) values of the haptic devices

V. CONCLUSION

The proposed idea is about tele-operation haptic devices and having complete control on the manipulation and feedback over local and wide area network. The idea is itself innovative in a sense that it is equipped with optimized latency, minimum time delay and an adequate amount of control over the strength of the signals. The haptic device would be used to help the world. It would revolutionize the medical as well as astronomical world. We are working on the haptic tele-operation based medical equipment that would be able to make surgeries on inter-continental level and we want to deploy it to the inter-planetary level.

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