Teleoperation: A Review

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1 Introduction

1.1 Definition

A teleoperation system consists of at least one master and one slave [1]. The master is controlled by human using operator and the communication between master and slave needs to be established so that the slave can be controlled remotely by the master.

[1],[2] have pointed out that teleoperation can extend human expertise to remote or inaccessible sites and scale the power. This improves efficiency and reduce the requirement for manpower. Additionally, teleoperation has many applications in a wide range of areas. such as handling hazardous materials [3], telesurgery and telemedicine [4], underwater vehicles [5], mobile robots [6].

In general, teleoperation control techniques could be divided into three trends. The first one is direct control where teleoperators rely on visual feedback provide control input using traditional input devices (e.g. joysticks or steering wheels). The second one is supervisory control where the teleoperator and the operated robot shares duty and control of the whole system. The last one is multi-modal mode, also known as multi-sensory mode, collects and synthesises more than one sensor data and provides a multi-modal view of the world to the teleoperator [7].

1.2 History

In 1940s, Goertz first built a master/slave mechanically controlled teleoperator and introduced a later version using electrical force reflecting position servomechanism in 1954 [8]. Then, communication delay between master and slave significantly affected the performance of teleoperator, and some control theories, such as Lyapunov-based analysis and internal virtual model [2], was developed to address this issue until early 1990s [9]. From then on, with the development of technology, Internet has been used as a means of communication. As a consequence, new problems emerged, such as information loss [10], randomly varying delay [11]. In the 21st century, advancements in the fields of robotics, sensor systems, artificial intelligence (AI), and computer vision, mobile robot teleoperation technologies are integrated to modern civilisation [12].

1.3 Challenges and solutions

The main challenge of teleoperation is latency, which will lead to closed-loop instability. There are unavoidable delays between master and slave. It takes time to transmit information from one node to the other. Therefore, many control techniques aiming to minimise the negative effect of delays emerged. For example, predictive feedback [13] is exploited to predict the evolution of the state variable for the period of the delay, so that the slave side could change in advance accordingly. In addition, passivity-based control was proposed to cope with time delay issues [14].

In terms of control systems, it is challenging to accurately model the complex master/slave system with disturbances [15]. To cope with this problem, adaptive control was used. [16] summarised four categories of adaptive controllers, which are 1) adaptive controllers for operator and environment model estimation, 2) adaptive controllers for disturbance rejection, 3) adaptive controllers for communication delay compensation, and 4) multiple function adaptive controllers respectively.

Furthermore, with the increasing computing power, more advanced methods were developed. [17] has reviewed wave variables method which is used to satisfy the transparency requirements of teleoperation systems. Additionally, Neural Network (NN) based techniques and fuzzy logic-based control mechanisms could help to estimate the system dynamics' uncertainties. Su *et al* in [18] have proposed that a model-free based deep convolutional neural network (DCNN) structure provides superior accuracy for predicting the noised dynamics force and enable its feasibility for bilateral teleoperation. Additionally, Chen *et al* in [19] have provided a radial basis function (RBF) neural network based adaptive robust control design for nonlinear bilateral teleoperation manipulators to cope with the main issues including the communication time delay, various nonlinearities, and uncertainties. Furthermore, Luo *et al* in [20] have proposed a hybrid shared control approach so that a force feedback is provided, driving the human partners to update their control intention with predictability.

1.4 Significance

Increasing range of applications of teleoperation nowadays makes it more significant in our daily life. Telesurgery is one of the state-of-the-art techniques. This means surgeons can examine patients in real-time from remote positions via electronic communication. They do not need to be physically present in the operating theatre, which is known as telepresence or telemedicine [21]. In this paper, 5G-enabled Tactile Internet (TI) are used to ensure ultra-low latency, ultra-high reliability, security and privacy. Also, a case study is provided, which is about the worlds first successful telestenting heart surgery (telesurgery). This proves the effectiveness and efficiency of 5G-enabled TI. If the telesurgery technique could be widely developed and applied clinically, the shortage of surgeons would be overcome. High-quality surgical treatment can be accessible in less-developed areas.

Additionally, teleoperated robots could replace human in the hazardous environment. For instance, the authors in [22] proposed an admittance controller based teleoperation system aiming to replace human in the deposited iron lump removal task in the steel mill. This paper suggests a practical solution for various contact-rich teleoperated tasks in the hazardous industrial workspace, so the method could be extended to other similar situations, such as fire-fighting and maintaining and repairing nuclear power plants. If this teleoperation technique is well developed, human workers could avoid facing risky environment and safely perform the tasks needed. In addition, marginal cost incurred by risky working environment can be reduced.

2 Research plan

The duration of this UROP project is tentatively set to be 3 months, starting from 26/06/2023 (Monday) to 22/09/2023 (Friday) in full-time. The following describes briefly the weekly plan.

- Week 1:

  Hardware purchase and preparation (e.g. Robotic arm, Raspberry Pi etc)

- Week 2:

  Assemble the experimental platform to test basic teleoperation functions of the robotic arm, that is, controlling the servo motors of the robotic arm via Raspberry Pi.

- Week 3:

  Derive the dynamic model of robotic arm

- Week 4–5:

  Develop the software platform: teleopertion algorithms to implement machine to machine communication

- Week 6–7:

  Develop control algorithms: trajectory planning, aiming to move the robotic arm to desired position quickly and accurately.

- Week 8–9:

  Deal with issues such as latency and information loss in the Internet-based wireless communication system.

- Week 10:

  Evaluate the effectiveness of the control and teleoperation algorithms on the experimental platform.

- Week 11:

  Conclude all the work. Write a report or paper if possible.

3 Open problems

As mentioned in [15], older control techniques should be adapted to discrete time frames since modern computer and network rely on digital systems. Also, Moniruzzaman *et al* in [7] argued that in the predictive feedback technique, prediction is limited to only first-order state or direction prediction, which means new methods should be able to perform higher order state prediction. What is more, adaptive controller is based on linearised model using linear systems techniques. However, the real teleoperation systems are highly nonlinear and coupled. Therefore, more research needs to focus on nonlinear models. Moreover, Shahbazi *et al* in [1] proposed that existing research focus mainly on Single Master/Single Slave (SM/SS) model. For more complicated and demanding tasks, Multi Master/Multi Slave (MM/MS) model might be more beneficial. Finally, [23] mentioned that future works should focus on human-in-the-loop design, meaning that the role of human in controlling the robot is minimised. Therefore, the autonomy level of the teleoperation system could increase.

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