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Robust Haptic Shared Control for Train Tele-driving Operation

Zaid Cahya Dinul Haq[1,2,*], Chouki Sentouh[1], Jean-Christophe Popieul[1], Estiko Rijanto[2]

[1]*LAMIH UMR CNRS 8021, Valenciennes, France*
[2]*OREI BRIN, Jakarta, Indonesie*
* *zaid002@brin.go.id, zaidcahyadinul.haq@uphf.fr*

Recent studies in intelligent transportation systems have focused on enhancing autonomy while minimising human involvement in operational tasks [1]. This change is aimed at increasing efficiency, reducing costs, and reducing human errors [2]. However, achieving maximum levels of automation, particularly in train operations, poses notable challenges due to various unpredictable variables that must be managed, such as malfunctions occurring in the train system or the infrastructure. On the other hand, even with significant technological progress, the ability to forecast faults is not yet fully reliable [3]. These limitations introduce considerable risks when considering fully autonomous train systems, as they impact the train movement dynamically [4]. Consequently, there is a growing recognition of the need for a solution that effectively integrates automation with human intervention, propelling remote driving as a viable solution [5].

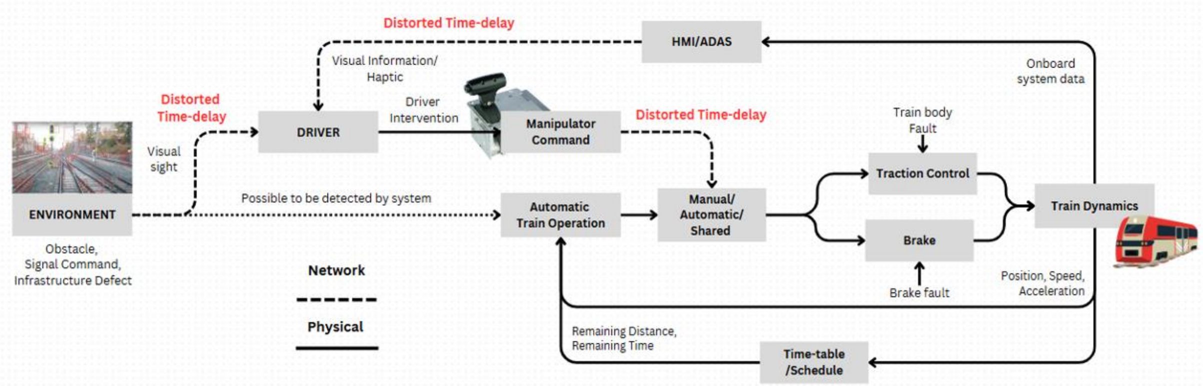


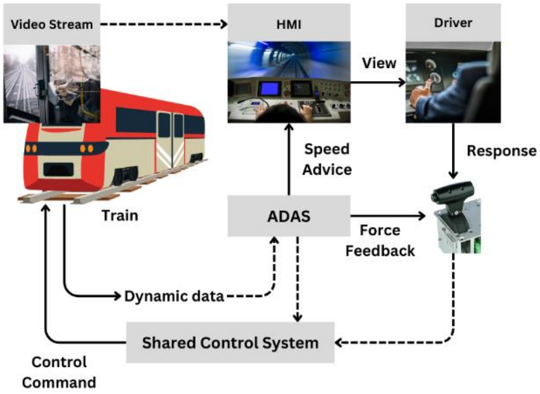
Fig. 1 Architecture of shared remote control

Research on the possibility and crucial point of remote train driving has been conducted by Gadmer et al. [6]. The main challenge is closely related to human factors, which are situational awareness (SA) and the shared task with the train control system when its authority is transferred. Tele-driving in train operation reduces all the usual senses and feelings of driving, so most of the current train drivers will have difficulty controlling the train remotely. Most of the information obtained by the driver is known to be visual information, either as video streaming or numerical data shown in the Advanced Driver Advisory System (ADAS). These limited pieces of information are also received later than the actual situation, even with the current advancement in networking technology still giving some uncertain delay when transmitting or receiving data. So, the control signal to operate the train is also delayed by the same amount of time. The appearance of the time-delay system in this operation can be challenging as the train operation demands reliability and safety.

Table 1 Current available network technology

Category	Technology	Latency during Teleoperation (ms)	User Data Rate (Mbps)	Maximum Capacity
Cellular	5G	11-13	4-8	1-10 Gbps
	4G (LTE)	100	3-8	100 Mbps-1 Gbps
	Satellite {[]8[]}	2000	around 10^4	10 Mbps (UL), 1 Gbps (DL)
Non-cellular	LAN/WLAN/WiFi	50	500	11/54/600/1000 Mbps
	Bluetooth	34-200	2	1.5-2 Mbps
	Zigbee	200	0.250	250 kbps

Reduced feeling of driving also becomes one of the challenging issues for the remote train operator. Implementing a full-scale dynamic simulator to simulate driving feeling is uneconomical as it requires unnecessary resources. The haptic device is one solution that was acceptable to drivers [7]. The haptic response is obtained by giving the joystick a force that can assist or counter the driver's hand force. Its control force was influenced by the difference between the actual train manipulator and the position of the remote manipulator. The haptic controller should be designed to be able to give some response even when the driver's intention differs from the Automatic Train Operation (ATO) command.



The force of haptic feedback Fh given to the driver a function related to the ATO command pATO and the current position of the joystick pj and also influenced by the desired position of the human driver pd represented in Equation 1. An essential advantage of incorporating haptic force feedback into tele-operation is its capability to boost operator performance, it should give some force to track the joystick position similar to the real actuating command in the controlled train, but giving an appropriate force when the human want to interact with the ATO. Studies show that haptic feedback markedly increases task success rates and decreases the mental effort required from operators during teleoperation. This is especially critical in railway teleoperation, where operators must handle complex scenarios involving moving trains and potential obstacles.

$$F_h(t) = f(p_{ATO}, p_j, p_d)$$

The aim of this research is to find a fail-safe solution in complement to fully automatic train operation, which aims to make the train fully unattended by adopting a teleoperation strategy. There are many challenges that must be solved before it can be fully implemented, such as uncertainty about the network delay and the absence of driving feel. The design of a haptic remote manipulator, as well as a shared authority transfer algorithm, is one of the main approaches to improving the safety and reliability of remote train driving.

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