ECE 590/CS 595 Human Robot Interaction
Teleoperation on L4 Autonomous Cars - Project Report

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Abstract
Remote operation has been advocated in recent years as a bridge to autonomous mobility by providing human assistance remotely when an automated driving system identifies an unclear circumstance and requests feedback from a remote operator. The remote operation of road vehicles has also been proposed to enable drivers to operate vehicles from safer and more comfortable locations. While commercial remote operation solutions are available, the research community is continually testing and analyzing the feasibility of introducing remote operation of road vehicles on public roadways. These tests range from technological to social factors such as acceptability and usability, which have an impact on human performance. This project is a compilation and analysis of the User interface and challenges of works on the remote operation of road vehicles. We begin by outlining the underlying architecture of remote operating systems and categorizing their modes of operation based on the degree of human involvement. We discuss the technological, regulatory, and economic challenges associated with the implementation of remote operating systems. Finally, we would like to add on few suggestions improve the challenges faced by RO's.

Introduction
Teleoperation is to control the entire system of autonomous vehicles remotely. This means that a human operator, often located at a distance, has direct control over all aspects of the system, such as driving a vehicle. The operator's inputs are transmitted to the system, and the system's outputs or feedback may be relayed back to the operator. There are three modes of operation.

- Remote driving where the system is fully under remote control.
- Remote assistance receives event driven remote assistance from the operator, while still being responsible for the driving task.
- Remote Monitoring is remote monitoring of the driving task.

Below given Fig1, are the companies that are actively working on different modes of operation.

	Company	Remote Driving	Remote Assistance	Remote Monitoring
Remote Operation Support	Designated Driver [9]	✓	✓	✓
	Ottopia [10]	✓	✓	✓
	Fernride [11]	✓		
	Phantom Auto [12]	✓	✓	✓
	Voysys [13]	✓	✓	✓
	Imperium Drive [14]	✓	✓	✓
Network Providers	T-Systems [15]	✓		
	Telefonica [16]	✓		
	Ericsson [17]	✓		
Vehicle and Service Providers	Nissan [18]		✓	
	Cruise [19]		✓	✓
	Aptiv/Motional [20, 21]	✓	✓	
	Waymo [22]		✓	✓
	Uber [23]		✓	✓
	Zoox [24]		✓	✓
	Drive.ai [25]	✓	✓	
	Vay [26]	✓		
	Einride [27]	✓		

Fig:1 Companies actively working on different modes of remote operation.

- Designated Driver is a company established in Portland, Oregon. It offers RORV-as-a-Service for cars with and without DA capabilities, if the vehicle is capable of driving by wire.
- Ottopia is a software firm that offers RORV-as-a-Service mobility. It is now in the round funding stage (a startup that has progressed beyond the seed stage and is attempting to establish product-market fit prior to escalation), and it is collaborating with car manufacturers and OEMs such as BMW and Hyundai, as well as firms that provide transportation services (e.g., robotaxis).
- Fernride is a spin-off company from the Teleoperations Research Lab at the Technical University of Munich. It provides logistics enterprises with intelligent mobility as a service by offering RORV systems in remote driving mode.
- PhantomAuto offers three key services to logistics companies: remote forklift operation, remote support for self-driving automobiles, and remote driving education. It specifically provides a framework for controlling forklifts, yard trucks, and other robots in remote driving and remote assistance modes.
- Voysys develops visual technologies that enable remote operation of machinery, including automobiles.It gives mobility providers and fleet managers a platform for monitoring and driving self-driving cars in real time, even in poor network conditions.
- ImperiumDrive provides a remote operating platform that allows service providers and fleet managers to conduct remote driving activities.
- Nissan, has the Seamless Autonomous Mobility (SAM) system, developed with NASA, to use remote human support to help autonomous vehicles make decisions in unpredictable situations which they expect to include obstacles on the road.
- Valeo demonstrated in 2019, Drive4U Remote, their remote operation system expected to take over in unprecedented situations such as weather events or a health problem.
- Zoox offers TeleGuidance where the remote ‘human-in-the-loop’ is able to offer guidance to the vehicle without taking control.

Categories of Teleoperation Challenges:

Below are the categories of challenges faced and a brief overview of different authors who made interesting arguments made on each complication.

- Latency Issues for remote operators:

- Latency Threshold: Any delay in signals beyond 50 milliseconds negatively impacts the Remote Operator's ability to quickly understand and respond to critical situations.[1]
- This has caused industry discussion over whether remote management or teleoperated driving is really a viable option since any latency will have a negative safety impact on the operator's ability to develop time-critical SA.
- Real-time Requirement: For remote driving to work, Autonomous Vehicles must send data in real-time to the control center to ensure immediate decision making. Few case studies like scania and designated driver argued that latency is not an issue for RO on 4G networks. [2]

- Network Coverage Challenges: However, issues such as tunnels, overhead trees, and limited 4G coverage in rural areas pose obstacles to maintaining seamless communication between the vehicle and the control center.
- 5G Solution: Building better situational awareness for the remote operators ,reducing the latency upto 10ms.

➢ Embodiment Issues for remote operators:

- Lack of Physical Sensation:Remote operators lack the physical sensations of vehicle movement and steering feedback, crucial for manual control in challenging conditions, leading to potential situational awareness gaps.
- Detached Perception and Risk:The absence of embodiment may result in remote operators feeling 'deaf' to the driving experience, potentially treating it like a game, thus eventually reducing their awareness of real-life consequences and risk.[1]
- Empathy Deficiency:Remote operators, even when not directly driving, may struggle to establish the empathy and rapport crucial for passenger comfort, contrasting with on-board safety drivers.[1]
- Speed Perception Challenges:It also impacts speed perception, making it difficult for remote operators to accurately judge their driving speed. Training methods incorporating spatial audio, multiple viewpoints, and enhanced video feeds are suggested for improvement.[3] [4]

➢ Workload Issue for remote operators

- Cognitive Overload Risk:The remote operators raises concerns about cognitive overload, as each piece of information adds processing demands (i.e.) the burden of absorbing the information and deciding how to act.[4]
- Balancing Workload:At the same time, low workload situations may lead to decreased vigilance, highlighting the need for a balanced workload to prevent operational issues.
- Interaction of Workload with SA:Understanding how workload interacts with Situational Awareness (SA) is vital for ensuring operator safety and performance.
- Impact of Allocation Strategies:Operator allocation strategies, including handling or prioritising new requests during ongoing tasks, significantly influence workload and potential errors.[6]
- Variability in Autonomy Levels:Different autonomy levels, such as long-distance trucking versus local delivery, impose varying workload demands on operators.
- Effective Team Allocation:Companies, like Waymo, use separate support teams to manage workload and prevent errors, emphasizing job specialization and effective team allocation.[7]
- Stress and Training Needs:Remote operation work is stressful and specialized, necessitating urgent training and regulation for operators to ensure safe performance.[8]
- Technological Solutions for Workload Reduction:Exploring technologies like Virtual Reality (VR) and Head Mounted Displays (HMD) can make interfaces more intuitive, reducing workload and improving operator Situational Awareness (SA).[9]

➢ Remote Interaction with humans (Passengers, pedestrians):

- Passenger Confusion Resolution: ROs tackle challenges in clarifying AV actions to passengers, preventing confusion or unintended consequences.
- Driver Communication in Mixed Traffic: RO intervention may be necessary in mixed traffic scenarios where human drivers rely on non-verbal cues, such as gestures, creating potential ambiguity.
- AV-Pedestrian Communication Channels: Establishing communication channels between ROs and pedestrians, especially in situations involving unconventional traffic rules or law enforcement directives.
- Diverse Environmental Interactions: ROs engage with various environmental entities, including guards, misdirected deliveries, and roadblocks, emphasizing the need for effective human communication in diverse scenarios.
- Alternative Communication Methods: Implementing alternative communication methods when conventional approaches fall short, ensuring ROs can effectively communicate with passengers and external parties in unexpected situations.

Analysis of Disengaged Data- Real-Time Analysis:

- Among the 2676 manufacturers in united states, there were 364 different reasons of disengagements, the top among them were Map discrepancy led to undesirable motion plan, test driver soft stop, Issue with software component, due to perception issue the safety trigger is issued, the operator disengaged the system to correct the trajectory, undesirable motion planning resulted in incorrect vehicle position on roadway.[12]

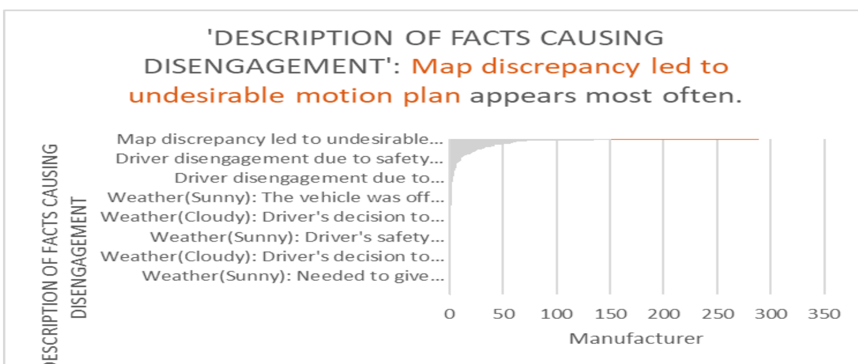

Fig:2 Anallysis on Disengaments of AV's of DMV of California

- Later, We grouped the similar reasons from column "Description for disengagements" then scaled the total number of disengagement in each company. Although these disengagements mostly involved test drive as shown in the below figure, Waymo has the greatest number of disengagements other than apple which is still under testing.

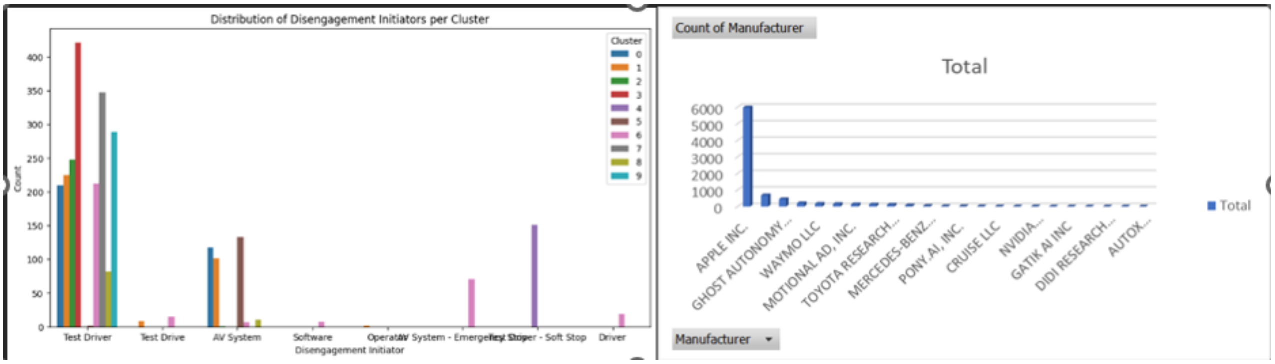

Fig:3 Analysis of Total number of disengagements on different roads (right figure) Total No. of disengagements with each company

Discussion on some of the challenges and Optimal solutions:

According to the above-mentioned challenges and real-time analysis, there are few points that we wanted to focus on:

- Latency Issues:

Having 5G technologies would mitigate the latency but during bad conditions or while going under the tunnels this might not be the case. In the above real-time analysis the most focused area of description of disengagement was undesirable motion planning, which resulted in incorrect position or trajectory of the vehicle. One of the reasons for this problem might be the latency and lack of proper controls remotely.

To mitigate this we might think of a model called the Successive Reference-Pose Tracking (SRPT) differs from traditional vehicle teleoperation methods. Having this model with predicting future might not affect the performance, since the controls and steering are done real-time. [10]

- SRPT involves the use of a predictive model, often implemented through Nonlinear Model Predictive Control (NMPC). This model predicts the future behavior of the vehicle based on the sequence of reference poses provided by the control station. Instead of directly transmitting steering and speed commands to the vehicle, the control station sends a sequence of successive reference 2D-poses (points on the map) that the vehicle should follow. The teleoperated vehicle continuously sends feedback to the control station, providing real-time information about its current state and position.
- The control station operator, knowing the entire reference trajectory and accounting for downlink (from control station to vehicle) and uplink (from vehicle to control station) delays, transmits the reference pose for the end of the prediction horizon.
- By sending the reference pose for the end of the prediction horizon, the control station compensates for the communication delays, allowing the vehicle to anticipate its next set of actions.
- The NMPC (Nonlinear Model Predictive Control) block on the vehicle side uses this received reference pose, along with the continuous feedback, to generate optimized steering and acceleration inputs.
- The control algorithm adapts to the changing conditions, and the vehicle follows the reference poses with adjustments based on real-time information.

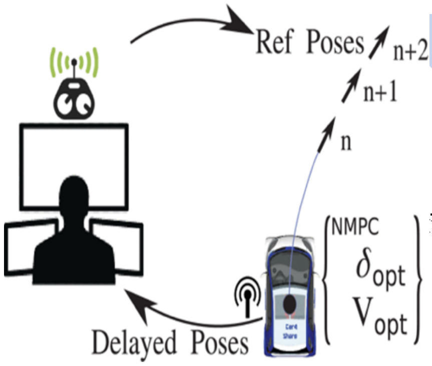

Fig:4 SRPT Model

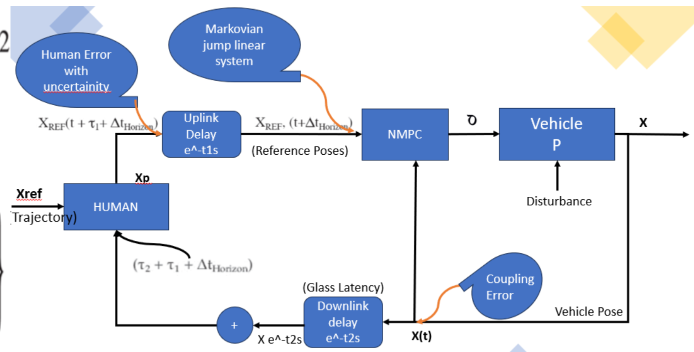

Fig:5 Suggested Architecture to handle the latency situations in real-time.

- Adding to the little more to the model suggested, firstly the human error is added with standard deviation for calculating the uncertainty and then added to the other delays. Later when the whole delay is passed through the NMPC, we have involved another factor called the **markovian jump linear system** which helps capture different delay states where each state represents a different level of delay (e.g., short delay, moderate delay, long delay). It also helps in implementing adaptive control strategies within the NMPC to dynamically adjust the control inputs based on the predicted delay mode. A graphical interface could display the **real-time status of the communication delays**. For example, a color-coded indicator might change from green (low delay) to yellow (moderate delay) or red (high delay) based on the current delay state.
- It helps in understanding of the expected delays, allowing the system to proactively adapt to different delay scenarios.[11]
At the end, **the coupling error**, Picture someone playing a video game, and there's a delay between pressing a button and seeing the action on the screen. The difference between what the player expects and what actually happens is the coupling error. We want to predict and reduce this error so that when someone is controlling a vehicle remotely, there's minimal delay or difference between what they want to do and what actually happens.[10]

➢ Embodiment Issues:

- For the **realistic sense of the speed at which the AV's are operated** remotely we can use the visualization on the HUD of RO for the reaction to the force felt by the passenger while in the AV, the blue human figures to the left of the compass and to the right of the speed restriction should move left and right.

Fig:6 Sensory updates of the moment of passenger at a particular speed for the RO.

- Another interesting solution while the weather is foggy and there is no proper visualization of the remote operator, the RO can have **vibrotactile sensor along with their hip**.

Fig:7 Picture of a car-simulation having bad weather

- At this point the remote operator might not have any clue about the situation and surrounding cars. So, we can have slightly sensing/vibrating sensors belt around the hip. If there's a vehicle from the left side the left part of the sensors would vibrate and so, for the right and opposite occurring vehicles. There can also be the audio to have better situational awareness.
  But there are few limitations that I could think of is, as age increases the cognitive and sensory skills might decline. So, tasks like this should be limited to age less than 40 years.

➢ Safety Operation:

Having good training for the remote operators to handle the job patiently without exhausting is the major task. During the non-peak hours of operation, the RO's must have the access to be able to look at their performance and reaction time to the situation, so that there might be collectively staff analysis, and this would also work like a reward system for the employees to actively work in an environment.

Conclusion:

Thus we have analyzed the teleportation, modes of operation, different companies participation in each mode, their latest implementation on teleassistance analysis and finally looked into the challenges for the teleoperator in terms of situational awareness, visualization and realistic behavior at different situations. There can be better solutions, and different models to tackle the major challenge that is latency.

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