Intent Inference in Human-Machine Collaborative Teleoperation Systems under Packet Disorder

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Introduction

With the development of artificial intelligence, teleoperation systems have gradually evolved from the traditional master-slave mode to the human-machine collaborative mode. The intent inference module is an essential component of many human-machine collaborative teleoperation systems. However, time-varying communication delays may induce packet disorder, thereby degrading intent inference performance. To address this issue, we propose the human command repair-based intent inference (HCRII) method. We integrated timestamp alignment, redundant command filtering, mean interpolation, and adaptive sliding window update rules to compensate for the impact of bidirectional packet out-of-order. An LSTM-based intent inference model was constructed. The effectiveness of the method was verified in a vehicle remote-controlled lane change task.

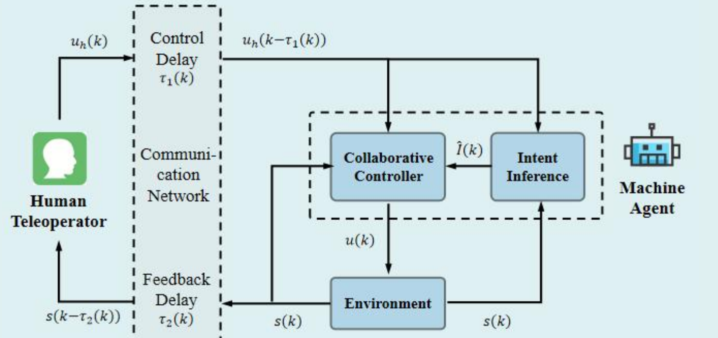

Figure 1: The human-machine collaborative teleoperation system with an intent inference module.

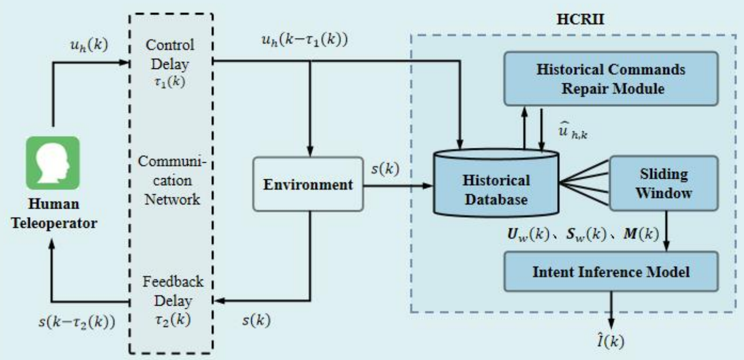

Figure 2: The framework of proposed HCRII method.

Main Method

1)Construction of Historical Database

On the machine side, we built a database to collect historical environmental states and human commands, with their temporal alignment achieved via timestamps.

2)Historical Commands Repair

To address redundant human commands, we propose a filtering mechanism:

$$\hat{u}_{h,k_1} = \begin{cases} u^{*}_{h,k_1}, & \| u^{*}_{h,k_1} - u^{1}_{h,k_1} \| > \theta_1 \\ u^{1}_{h,k_1}, & \text{otherwise} \end{cases}$$

Mean imputation is employed to address missing human commands:

$$\hat{u}_{h,k_2} = \begin{cases} \frac{1}{|V_{k_2}|} \sum_{u_{h,i} \in V_{k_2}} u_{h,i}\,, & V_{k_2} \neq \emptyset \\ \bar{u}_h, & V_{k_2} = \emptyset \end{cases}$$

3)Design of Sliding Window Update Rule

The update rule for the sliding window's latest timestamp t_k is as follows:

$$t_{k+1} = \begin{cases} t_k + d, & \text{if } u_{h,t_{k+1}} \neq \emptyset \\ t_k, & \text{otherwise} \end{cases}$$

where d denotes the number of consecutive non-missing commands that appear after t_k in the repaired historical database.

4)Intent Inference Model

We develop an intent inference model based on LSTM. We construct a mask sequence $\boldsymbol{M}(k)$ with 1s/0s: 1 denotes a real command in input sequence $\boldsymbol{U}_w(k)$, 0 denotes an imputed one. $\boldsymbol{U}_w(k)$, state sequence $\boldsymbol{S}_w(k)$ and $\boldsymbol{M}(k)$ are used as inputs to the model, and the model outputs the predicted intent along with the confidence score.

Experiment

The remote driving system is a typical human-machine collaborative teleoperation system. We designed a lane-change scenario and compared the lane-change intent inference performance of two methods:

HCRII: human command repair-based intent inference.

DUII: disorder unaware intent inference, which utilizes LSTM, but directly uses the human commands received by the vehicle in their original order.

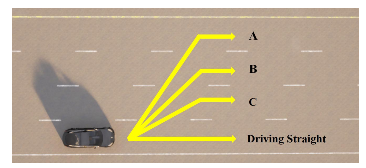

Figure 3:The vehicle lane-changing scenario.

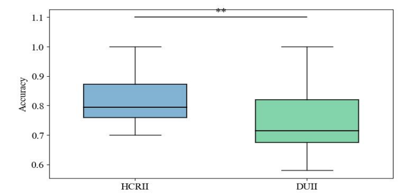

Figure 4:The inference accuracy within 8 s.

Survey Questions	DCRII	DUII
The vehicle's actions match my intent.	8.2	7.5
I rarely face uncomfortable interventions.	7.9	7.1
The vehicle agent is helpful for lane changing.	9.1	8.3
I trust the vehicle agent.	8.3	7.2
The vehicle understand my intent quickly.	5.6	5.7

Table 1:Responses to survey questions.

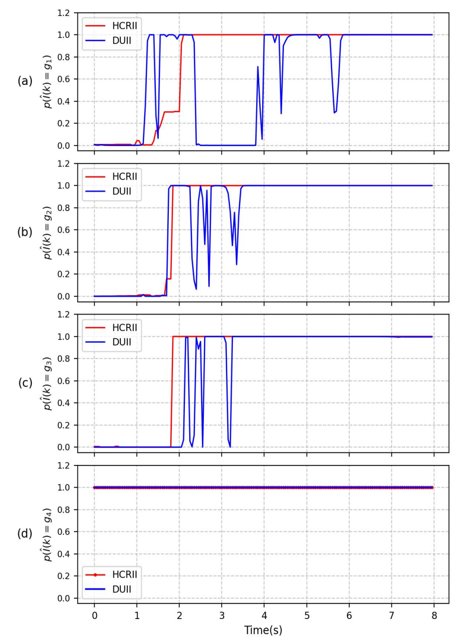

Figure 5:The inference probability of the true intent for typical cases.

Conclusion

This study proposes the HCRII method for human-machine collaborative teleoperation systems to address intent inference accuracy degradation from packet disorder. Validated in a remote lane-changing scenario, the method achieves superior intent inference accuracy relative to the method that disregards packet disorder.

A limitation is that it only accounts for packet disorder but not intent lag from time delay itself, which will be the focus of future work.

References:

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