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A unified shared control architecture for underwater vehicle–manipulator systems using task priority

Key words: Unified shared control; Underwater vehicle–manipulator system; Human–robot interaction; Task priority

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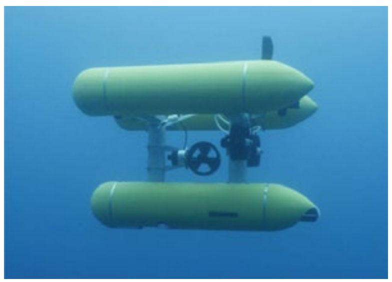
Underwater exploration

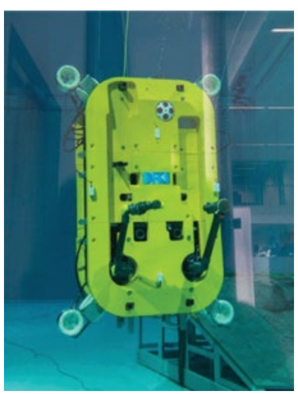
- With proliferation of ocean exploration, underwater vehicle–manipulator systems (UVMSs) have become essential for underwater operations.

Fully-autonomous



GIRONA 500[1]

Aquanaut[2]



Cuttlefish[4]

DexROV[5]

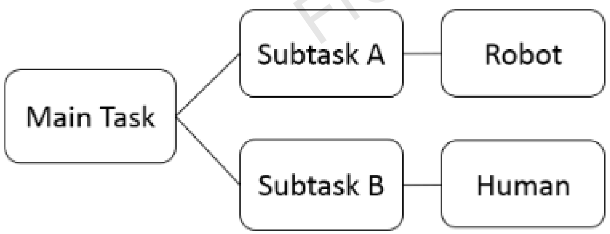
Semi-autonomous

SAUVIM[3]

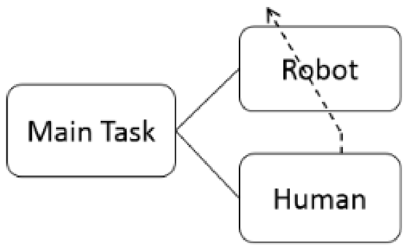
Ocean One[6]

Tendency and challenges

- Fully automated control is still inadequate for complex and delicate operations in open and unstructured underwater environments. Underwater operations continue to require human intervention.
- Shared control (SC)[7] leverages human high-level cognition and decision-making while integrating robotic capabilities for low-level task execution.
- Shared control methods are typically classified into divisible shared control (DSC) and interactive shared control (ISC)[8]. A comprehensive shared control method is proposed for UVMS to effectively improve work efficiency and reduce operational burden.



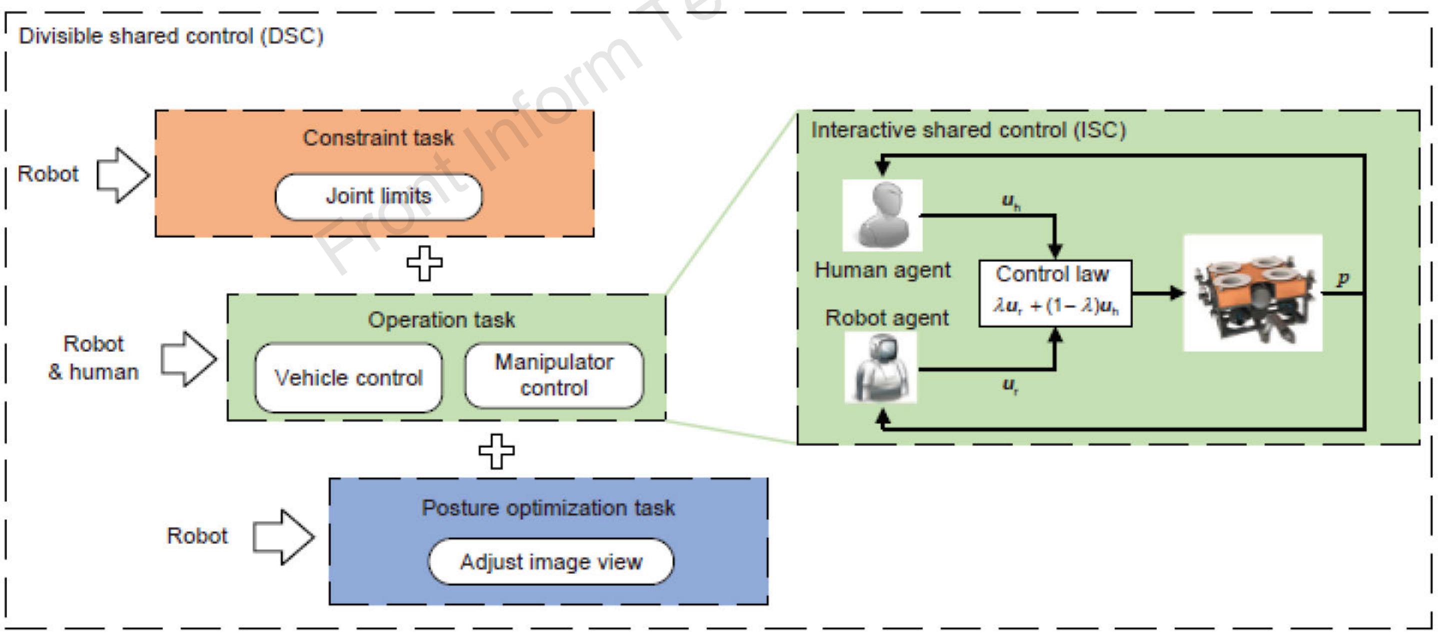
Divisible shared control



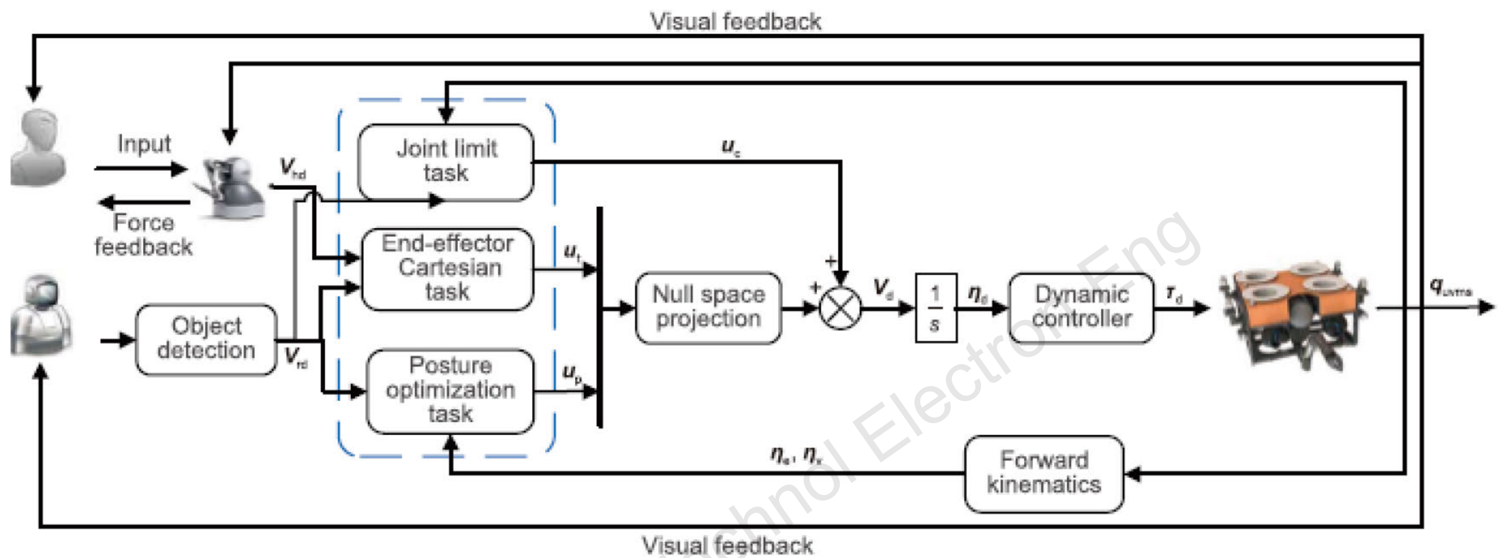
Interactive shared control

Motivation

- The study introduces a unified shared control (USC) architecture that combines DSC and ISC for the UVMS based on task priority[9] to further alleviate the operator's control workload.
- Methods are developed to reduce the operator's burden, including an input fusion method that incorporates human intention and a motion distribution scheme. Additionally, a haptic feedback guidance function is developed, and the posture of the UVMS is optimized based on operator inputs.



(1) Unified shared control architecture



- This study deploys three control objectives: constraint, operation, and posture optimization tasks. Task priority serves as a DSC redundant control method.

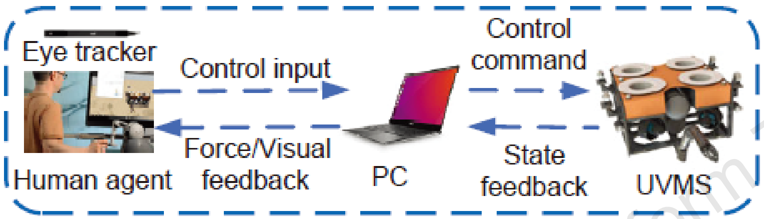
$$u = \underbrace{(u_{\mathrm{c}})}_{\text{constraint}} + \underbrace{(u_{\mathrm{t|c}})}_{\text{operation}} + \underbrace{(u_{\mathrm{p|t|c}})}_{\text{posture}}$$

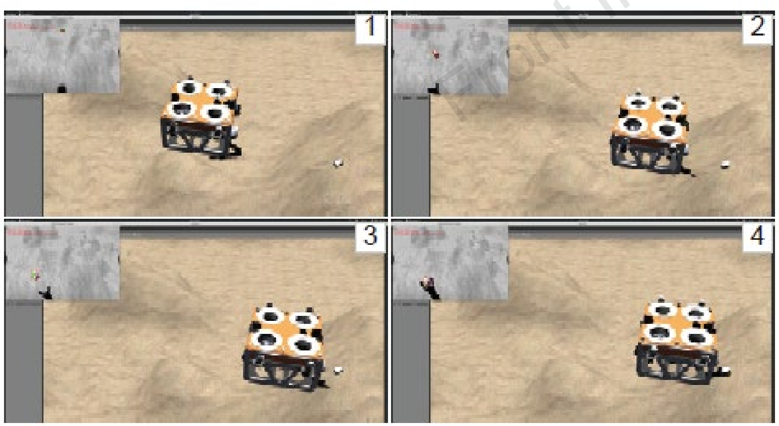
- A linear ISC-based approach is integrated into the operational task to combine the human input and robot input.

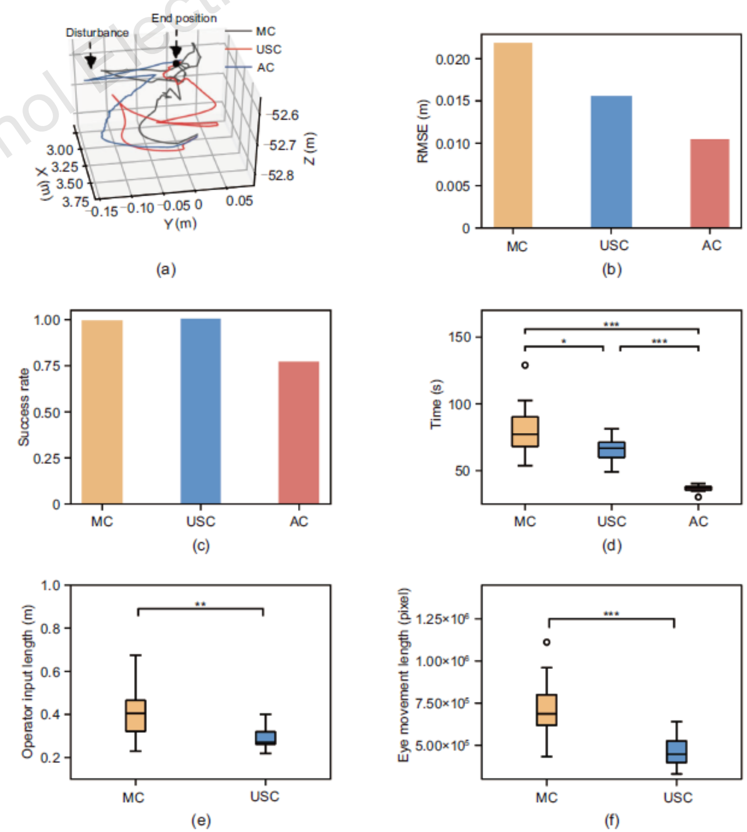
$$u_{\mathrm{s}} = \lambda u_{\mathrm{r}} + (1 - \lambda) u_{\mathrm{h}}$$

(2) Simulation

- Compared to manual control (MC), USC can effectively reduce RMSE, improve task completion efficiency, and reduce operator input and cognitive burden.
- While autonomous control (AC) offers advantages in execution efficiency, USC stands out as a more reliable option due to human intervention.

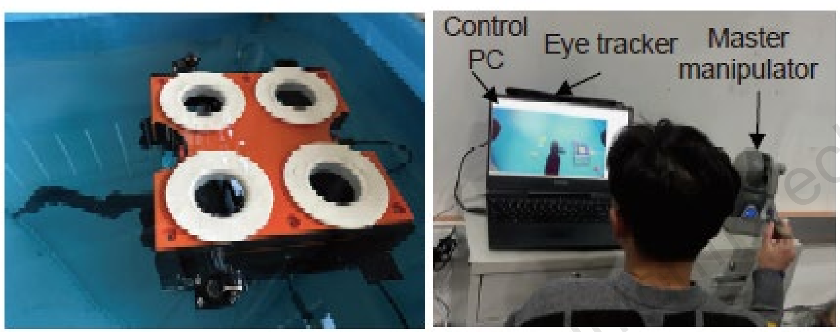




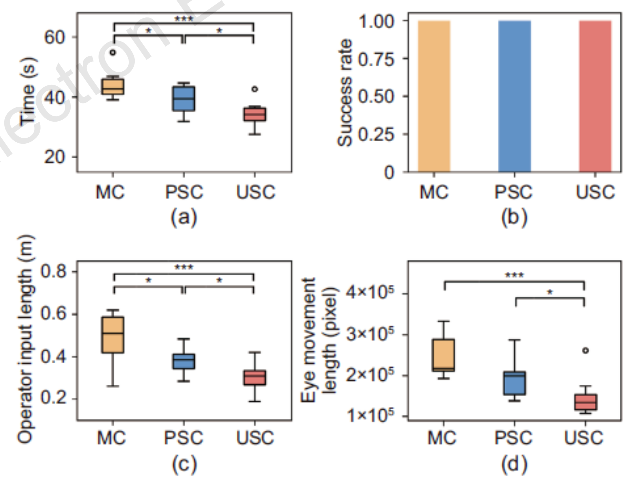


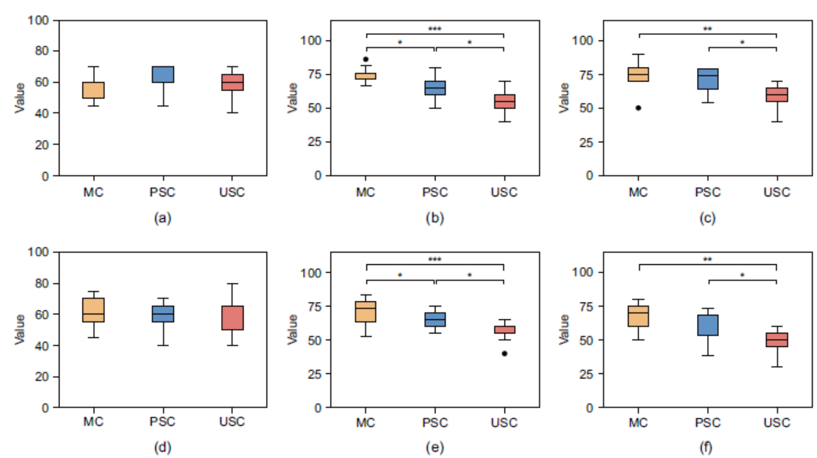
(3) Experiments

- Similar to the simulations, USC reduces task completion time, operator input, and cognitive burden compared to MC and PSC[10].
- NASA-TLX[11] subjective measurements indicate that increased automation reduces task load, with operator ratings following the order of USC > PSC > MC.



(a) (b)





(4) Summary

- This study presents a USC architecture for UVMSs, which incorporates task priority. The approach combines DSC and ISC, establishing a hierarchical relationship among subtasks based on their priority. A haptic feedback system is designed to assist the operator in completing tasks.
- A simulated object-grasping experiment is conducted to verify the effectiveness of the proposed method in comparison with AC and MC methods. Compared to MC, the completion time, operator input length, and cognitive load are reduced by 17.50%, 25.00%, and 35.53%, respectively.
- Based on the objective and NASA-TLX subjective evaluation results from the pool experiment, the proposed method outperforms both MC and PSC. The method reduces completion time, operator input length, and cognitive load by 22.73%, 40.00%, and 29.91%, respectively, compared to MC.

Future outlook

UVMS shared control research	Outlook
Human–robot interface	• Digital twin human–robot interface • Multisensory feedback for operators • VR and AR tangible environment
Robot perception	• Operator intent perception • Multimodal perception fusion • Environmental perception
Intelligent decision-making	• Learning skills from human operations • More effective guidelines for resolving human–robot conflicts • Learning operator preferences to adapt to operators with different styles and providing personalized operation services

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