2026 IEEE/SICE International Symposium on System Integration (SII)
January 11-14, 2026. Cancún, México

Indirect Torso Posture Control and Force-Guided Singularity Avoidance for Humanoid Teleoperation System using Exoskeleton Cockpit

Hiroki Yoshioka[1], Tomoya Himeno[1], Kunio Kojima[1] and Kei Okada[1]

***Abstract*— Cockpit-style exoskeleton systems are a promising approach for the whole-body teleoperation of humanoid robots, yet they face two major challenges. The first is the difficulty of intuitive torso posture control, arising from the operator's seated and constrained posture. The second is the lack of transparent feedback for kinematic singularities, which do not manifest as physical forces. This paper proposes two novel methods to address these respective challenges: 1) an indirect torso control interface that converts the operator's foot-actuated torque into the robot's torso angular velocity, and 2) a haptic feedback scheme that guides the operator's arm away from singularities based on the gradient of the arm's manipulability measure. We implemented these methods into a teleoperation system and successfully demonstrated tasks such as picking up an object from the floor and an operator's active avoidance of singular postures.**

I. INTRODUCTION

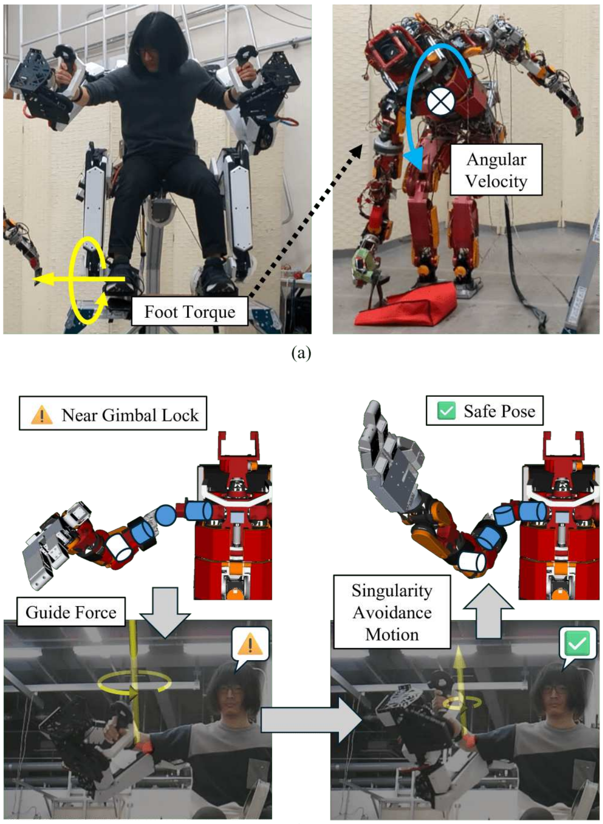
Cockpit-style exoskeleton systems are actively being researched as a promising approach for the whole-body teleoperation of humanoid robots, enabling high-fidelity control of limb motion and haptic feedback. Compared to standing-type systems, the cockpit-based interface is often favored for practical deployment, as it significantly reduces operator fatigue during long-duration tasks and offers a more stable platform for controlling locomotion over complex 3D terrain [1]. While foundational systems focus on end-effector position and force feedback [2][3], recent efforts have explored the transmission of more diverse command and state information, such as foot interactions [1] and arm redundancy [4].

However, significant challenges persist in these cockpit-based systems regarding both command input and state feedback. The first is the intuitive control of the torso posture. As the operator is constrained to a seat, their range of motion is significantly smaller than the robot's, causing direct motion mapping to fail. The second challenge is the feedback of robot-specific internal constraints, particularly kinematic singularities. Singular postures, such as a fully extended arm or gimbal lock, severely limit the robot's mobility but are difficult for the operator to avoid as they do not manifest as physical forces and thus cannot be conveyed directly.

This paper proposes two methods to solve these respective challenges:

1) **An indirect torso posture control method**: We propose an interface that converts the torque exerted by the operator's feet into the robot's torso angular velocity. This allows the operator to intuitively control the robot's torso without being limited by their own constrained range of motion in the cockpit.
2) **Singularity avoidance via force feedback**: We present a method that applies a guiding force to the operator's forearm, based on the gradient of the arm's manipulability measure, to steer them away from singularities. This enables the operator to unconsciously avoid singularities of the robot's redundant arm.

We implemented the proposed methods into our cockpit-based teleoperation system and conducted experiments. We successfully demonstrated a pick-up task from the floor, as shown in Fig. 1, and enabled an operator to actively avoid singular postures using the haptic feedback.



(a)

(b)

Fig. 1. Overview of the proposed teleoperation system's capabilities. (a) By commanding the robot's torso via torque exerted from operator's feet, the operator enables the robot to pick up a floor-placed object, demonstrating a significant expansion of the workspace. (b) Haptic feedback guides the operator to intuitively alter their motion and avoid a kinematic singularity.

---

[1] H. Yoshioka, H. Tomoya, K. Kojima and K. Okada are with Department of Mechano-Infomatics, Graduate School of Information Science and Technology, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan `yoshioka@jsk.t.u-tokyo.ac.jp`

978-1-6654-5784-2/26/$31.00 ©2026 IEEE

II. RELATED WORKS

This paper addresses two challenges in the teleoperation of humanoid robots using cockpit-style exoskeletons: the command of torso posture and the feedback of manipulability.

A. *Torso Posture Control for Cockpit-based Teleoperation*

In humanoids, torso posture is a critical factor that contributes to the size of the whole-body workspace, yet its control method is highly dependent on the teleoperation system's morphology. In standing teleoperation systems, where the operator moves in the same way as the robot, methods have been developed to directly transmit the center of gravity position [5][6][7] or to mirror the operator's whole-body posture [8][9]. While these standing systems offer intuitive mapping, the cockpit-style morphology provides distinct benefits for long-term operation (i.e., reduced fatigue) and robust navigation on uneven surfaces. However, despite these advantages, such direct mapping approaches are not feasible in cockpit-style exoskeleton systems, because the operator's torso range of motion is severely limited by being constrained to a seat, making it much smaller than the robot's. To solve this problem, an indirect interface that commands the robot's torso posture using a different somatic modality from the operator's own torso is required. In this study, we focused on haptic information from the operator's feet, as it is controllable within the cockpit and can be intuitively associated with leaning motions.

B. *Force Feedback of Manipulability for Singularity Avoidance*

Another significant challenge in robot teleoperation is how to transparently convey robot-specific internal constraints to the operator, particularly kinematic singularities. While interactions with the external environment, such as contact forces at the end-effector or pressure distribution on the feet, can be directly presented as haptic feedback, singularities stem from the robot's kinematic configuration and do not manifest as physical forces. To address this, methods have been proposed that present a repulsive force in response to a decrease in manipulability [10][11]. However, these methods often do not support redundant arms with seven or more degrees of freedom, particularly for complex singularities such as gimbal lock at the shoulder. On the other hand, methods also exist where the robot autonomously avoids singularities [12][13], but these present a trade-off with intuitiveness, as a discrepancy can arise between the operator's intent and the actual robot motion. Therefore, a feedback method is required that intuitively supports singularity avoidance for humanoid arms without overriding the operator's intent. In this work, we take the approach of providing haptic feedback to the operator's forearm based on the gradient of the manipulability measure.

III. TORSO CONTROL VIA OPERATOR'S FOOT TORQUE

A. *Operating Concept*

To intuitively command the torso posture, which is critical for whole-body humanoid manipulation, from within a cockpit-style system, we propose a method that utilizes the operator's foot torque. While seated, the operator can tilt the robot's torso by exerting force on the horizontally fixed footplates of the exoskeleton. To ensure this interaction is intuitive, we designed the control mapping based on the biomechanics of how humans use ankle torque to control their torso while standing upright, as illustrated in Fig. 2. We leverage the natural tendency of the operator's torso to tilt slightly in the opposite direction when they exert force with their feet. Specifically, the action of trying to lift the toes (applying a backward torque) corresponds to tilting the robot's torso forward. Therefore, as described in the following section, we invert the sign between the measured torque and the commanded torso angular velocity.

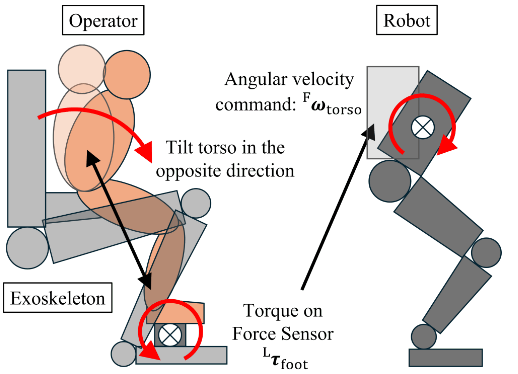


Fig. 2. Operating concept of the proposed torso control interface. The operator, while seated, exerts a torque on the footplates. This measured input, denoted as ${}^{\mathrm{L}}\boldsymbol{\tau}_{\mathrm{foot}}$, is converted into an angular velocity command, ${}^{\mathrm{F}}\boldsymbol{\omega}_{\mathrm{torso}}$, for the robot's torso. The mapping is designed to be intuitive by mimicking the natural coupling between ankle torque and body posture: an upward pull on the toes (red arrow) results in a forward torso tilt command, matching the operator's own reactionary forward lean.

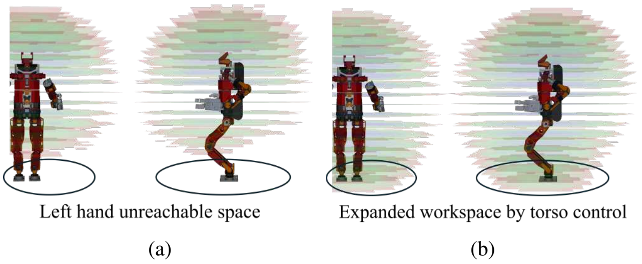

Left hand unreachable space
Expanded workspace by torso control
(a)
(b)

Fig. 3. Workspace expansion achieved by the proposed torso control. This figure compares the reachable workspace of the end-effector (left hand) for (a) a fixed, upright torso versus (b) an actively controlled torso using our method. The analysis reveals that active torso control dramatically increases the reachable volume, especially towards the floor. This result demonstrates that the proposed interface is essential for enabling tasks that require manipulation of objects near the robot's feet.

B. *Command Generation from Foot Torque*

The torso angular velocity command, ${}^{\mathrm{F}}\boldsymbol{\omega}_{\mathrm{torso}}$, is generated from the measurements ${}^{\mathrm{L}}\boldsymbol{\tau}_{\mathrm{foot}}$ of a 6-axis force-torque sensor installed in the exoskeleton's footplate. Here, the superscript F denotes the follower (robot) root link frame, and L denotes the leader (exoskeleton) local foot frame. The process begins by filtering the raw sensor signal with a Low-Pass Filter

(LPF) to remove noise. The filtered signal is then converted into a desired angular velocity, ${}^{\mathrm{F}}\boldsymbol{\omega}_{\mathrm{des}}$:

$$ {}^{\mathrm{F}}\boldsymbol{\omega}_{\mathrm{des}} = -\mathbf{K}\,{}^{\mathrm{F}}\mathbf{R}_{\mathrm{L}}\ \mathrm{LPF}\left({}^{\mathrm{L}}\boldsymbol{\tau}_{\mathrm{foot}}\right) \tag{1} $$

where ${}^{\mathrm{F}}\mathbf{R}_{\mathrm{L}} \in \mathrm{SO}(3)$ is the rotation matrix from the exoskeleton foot frame to the robot root frame, and $\mathbf{K} \in \mathbb{R}^{3\times 3}$ is a diagonal gain matrix for tuning the operational sensitivity. The gains in $\mathbf{K}$ are set based on the dimensions of the human foot and the sensor's position to compensate for the fact that humans can exert torque more easily in the pitch direction than in the roll direction. Finally, to ensure the robot's safe operation, the magnitude of the desired angular velocity vector, $||{}^{\mathrm{F}}\boldsymbol{\omega}_{\mathrm{des}}||$, is limited to a predefined maximum value, $\omega_{\max}$, using the following saturation function to determine the final command, ${}^{\mathrm{F}}\boldsymbol{\omega}_{\mathrm{torso}}$:

$$ {}^{\mathrm{F}}\boldsymbol{\omega}_{\mathrm{torso}} = \min\left(1, \frac{\omega_{\max}}{||{}^{\mathrm{F}}\boldsymbol{\omega}_{\mathrm{des}}||}\right){}^{\mathrm{F}}\boldsymbol{\omega}_{\mathrm{des}} \tag{2} $$

C. Evaluation of Workspace Expansion

To evaluate how our proposed method expands the robot's workspace, we conducted a reachability analysis using the JAXON humanoid model [14]. Fig. 3 compares the end-effector reachable workspace between two conditions: (a) with the torso fixed in an upright position, and (b) with the torso actively controlled using our proposed method. The results confirm that our method significantly expands the reachable workspace, particularly in the area near the robot's feet. This demonstrates that active torso control is essential for tasks involving object manipulation on the floor.

IV. FORCE FEEDBACK OF ARM MANIPULABILITY FOR SINGULARITY AVOIDANCE

A. Background and Objective

Avoiding kinematic singularities is essential for achieving stable robot motion, and this holds true for teleoperation. Mainstream research on singularity avoidance has focused on autonomous approaches, such as methods that incorporate manipulability into the inverse kinematics problem [15], [16], [12] or motion planning methods that consider manipulability [17]. However, these methods can lead to a discrepancy between the operator's intent and the robot's actual motion. In contrast, our study takes an approach that integrates the robot's constraints into the operator's own motion generation loop. As shown in Fig. 4, we propose a haptic feedback system designed to assist the operator in avoiding the robot's singularities. This allows the operator to intuitively grasp the robot's internal state and voluntarily perform operations to avoid singular postures.

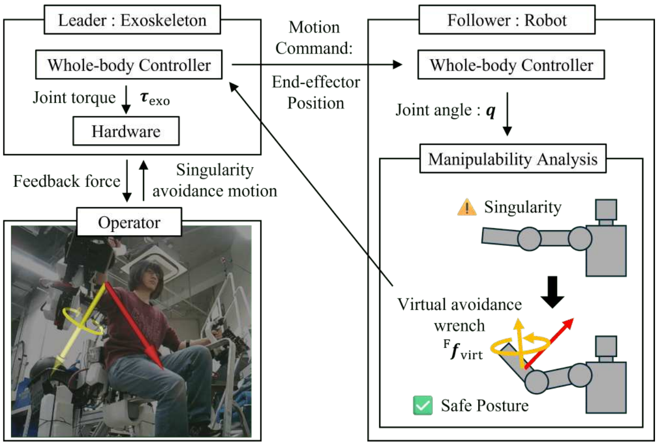


Fig. 4. Overview of the force feedback loop for intuitive singularity avoidance. (Right) On the robot side, the arm manipulability measure falls, a virtual avoidance wrench, ${}^{F}\boldsymbol{f}_{\mathrm{virt}}$, is generated in a direction that increases manipulability. (Left) This virtual wrench is then rendered as a haptic cue on the operator's forearm by commanding the required joint torques, $\boldsymbol{\tau}_{\mathrm{exo}}$, from the exoskeleton's motors. This feedback allows the operator to perceive the impending singularity as a gentle, guiding force, enabling them to intuitively modify their motion commands to maintain a safe and dexterous posture.

B. Feedback Wrench Generation

Our method generates a feedback wrench based on the following principles. As a metric to evaluate the proximity to a singularity, we use the manipulability measure $m(\boldsymbol{q})$ [18].

$$ m(\boldsymbol{q}) = \sqrt{\det(\mathbf{J}\mathbf{J}^{\top})} \tag{3} $$

Here, $\boldsymbol{q}$ is the joint angle vector, and $\mathbf{J}$ is the arm's Jacobian matrix. We compute the Jacobian from the torso to the forearm. This is because the wrist joints have a minor impact on arm-level manipulability, and our objective is to provide feedback to the forearm to guide the operator's use of the arm's redundant degrees of freedom.

The action that most efficiently moves the arm away from a singularity is given by the gradient of the manipulability in the joint space, ∇m. We compute this gradient using the method from Marani et al. [15]:

$$ \begin{aligned} \nabla m &= \frac{\partial m(\boldsymbol{q})}{\partial \boldsymbol{q}} \\ \text{where} \quad \frac{\partial m(\boldsymbol{q})}{\partial q_k} &= m(\boldsymbol{q})\,\mathrm{trace}\left(\frac{\partial \mathbf{J}}{\partial q_k}\mathbf{J}^{+}\right) \end{aligned} \tag{4} $$

Based on this gradient vector ∇m, we define a virtual joint torque $\boldsymbol{\tau}_{\mathrm{virt}}$ for singularity avoidance.

$$ \boldsymbol{\tau}_{\mathrm{virt}} = K_m\,\sigma(m, m_{\mathrm{t}})\,\nabla m \tag{5} $$

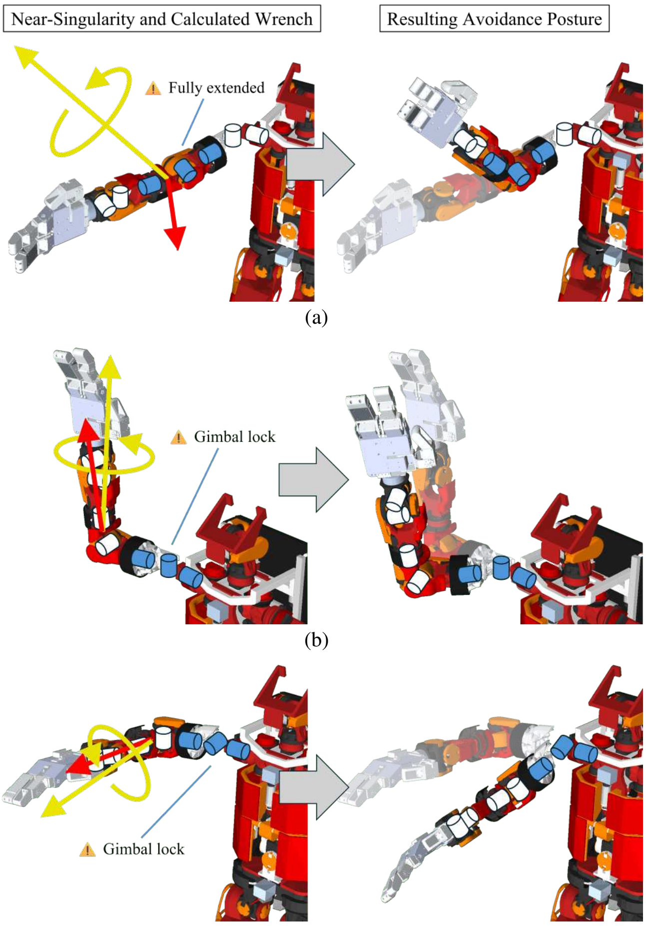
Here, K_m is a feedback gain. $\sigma(m, m_{\mathrm{t}})$ is a sigmoid function that activates the feedback when the manipulability m approaches a threshold m_{t}. These parameters, K_m and $\sigma(m, m_{\mathrm{t}})$, are tuned so that the final output force is clearly perceptible to the operator while remaining within a range they can safely resist. As the manipulability values vary by robot and the appropriate force magnitude differs by operator, these parameters need to be tuned for each robot-operator pair.

We then convert this joint torque into a virtual wrench ${}^{\mathrm{F}}\boldsymbol{f}_{\mathrm{virt}}$ in the robot's root frame (F) using the pseudo-inverse of the Jacobian transpose.

$$ {}^{\mathrm{F}}\boldsymbol{f}_{\mathrm{virt}} = \left(\mathbf{J}^{\top}\right)^{+}\boldsymbol{\tau}_{\mathrm{virt}} \tag{6} $$

Finally, to present this virtual wrench to the operator, we convert it into the required joint torques $\boldsymbol{\tau}_{\mathrm{exo}}$ for the exoskeleton.

$$ \boldsymbol{\tau}_{\mathrm{exo}} = \mathbf{J}_{\mathrm{exo}}^{\top}\,{}^{\mathrm{L}}\mathbf{X}_{\mathrm{F}}\,{}^{\mathrm{F}}\boldsymbol{f}_{\mathrm{virt}} \tag{7} $$



(a)

(b)

(c)

Fig. 5. Visualization of the virtual avoidance wrench and its corresponding corrective motion. Each row presents a "before-and-after" comparison for a representative singular posture. The left panels, titled "Near-Singularity and Calculated Wrench", display the initial problematic posture with the calculated avoidance wrench superimposed (red: force, yellow: moment). The right panels, titled "Resulting Avoidance Posture", illustrate the safe posture that the wrench guides the arm toward. The specific cases are: (a) fully extended arm singularity, (b), (c) two different configurations near a shoulder gimbal lock.

where $\mathbf{J}_{\mathrm{exo}}$ is the Jacobian of the exoskeleton from its root to the forearm, and ${}^{\mathrm{L}}\mathbf{X}_{\mathrm{F}}$ is the wrench transformation matrix from the robot frame (F) to the exoskeleton's local frame (L).

C. Verification of Generated Avoidance Wrench

To verify that the proposed algorithm generates appropriate avoidance wrenches, we visualized its output for three representative near-singularity cases in Fig. 5. This figure presents a "before-and-after" comparison for each case to clearly illustrate the correspondence between the problem and the solution.

The left-side images, which are now labeled "Near-Singularity and Calculated Wrench" in the figure, display the initial problematic posture. Superimposed on this posture is the calculated virtual wrench ${}^{\mathrm{F}}\boldsymbol{f}_{\mathrm{virt}}$ in Equation (6) (force in red, moment in yellow) that our algorithm computes to resolve that specific singularity. The right-side images, labeled "Resulting Avoidance Posture", illustrate the safe posture that the calculated wrench guides the arm toward, successfully escaping the singularity.

The three tested cases are: (a) a posture near a fully extended arm singularity, and (b), (c) two different configurations near a shoulder gimbal lock. In all scenarios, the wrench visualized on the left directly corresponds to the corrective motion shown on the right. This confirms that our algorithm generates effective and intuitive guidance for singularity avoidance.

V. EXPERIMENTS

The experiments were conducted using a cockpit-style exoskeleton capable of commanding forearm posture and rendering haptic feedback [4]. The JAXON humanoid robot [14] was used as the teleoperated platform. We performed two sets of experiments to validate the proposed torso posture control and the singularity avoidance feedback.

A. Torso Control via Operator's Foot Torque

1) Experimental Setup: The objective of this experiment was to validate the effectiveness of the proposed foot-torque-based torso control interface. As shown in Fig. 6, the constraints for the inverse kinematics solver used for posture generation included the center of mass, both feet, the right end-effector, and the commanded torso angular velocity. To independently evaluate the proposed interface, we limited the experiment to a single-arm manipulation task. Integrating our method with a whole-body IK solver that also considers arm redundancy to handle complex bimanual tasks remains an important area for future work.

2) Task 1: Qualitative Evaluation of Intuitiveness: First, we performed a qualitative experiment to verify the intuitiveness of the proposed interface. The operator was instructed to perform a series of fundamental maneuvers, (a) a distinct forward-and-backward pitch motion and (b) a distinct side-to-side roll motion, returning to the neutral posture after each maneuver. As shown in Fig. 7, we observed an emergent

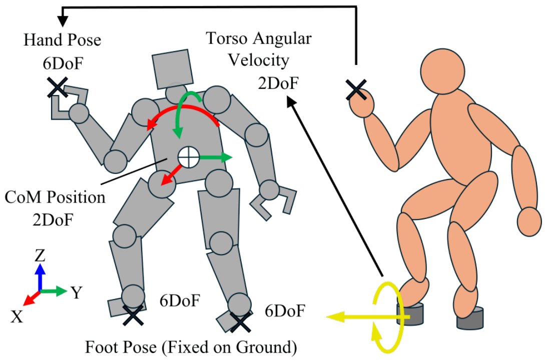
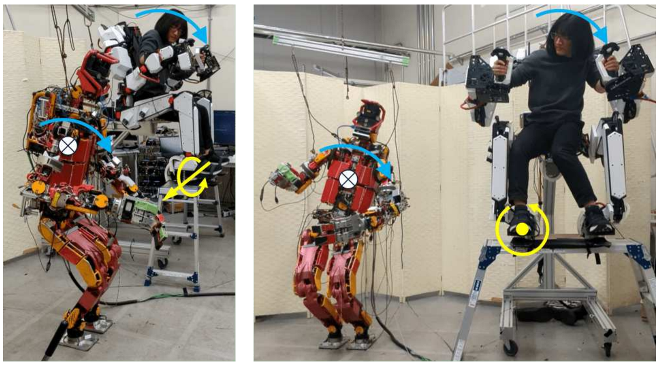


Fig. 6. Constraint setup for the whole-body inverse kinematics solver. The robot's posture was generated to simultaneously respect the fixed poses of both feet (6-DoF each), track the operator-commanded pose of the right hand (6-DoF), maintain balance via the horizontal Center of Mass (CoM) position (2-DoF), and follow the commanded torso angular velocity (2-DoF, pitch and roll) from our proposed interface.



(a) (b)

Fig. 7. Emergent synchronization between the operator and robot during torso control. The robot's torso is controlled in the (a) pitch and (b) roll directions via the operator's foot inputs. Notably, the operator's own torso naturally follows the robot's motion. This synchronization occurs even though the operator's torso is not measured, validating the high intuitiveness of the proposed interface.

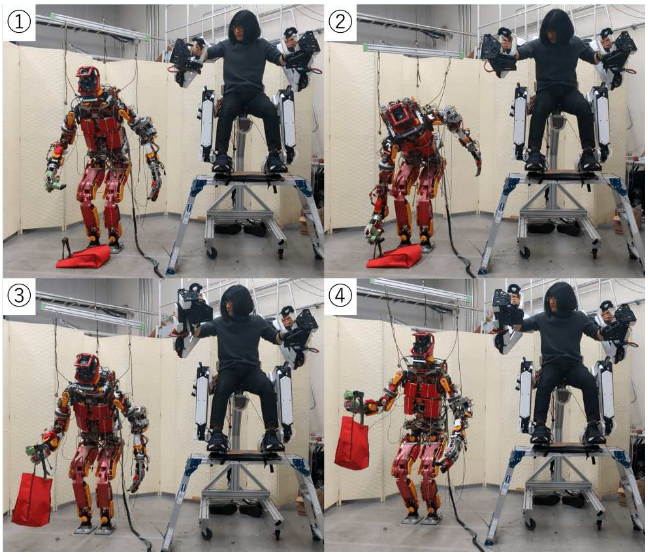
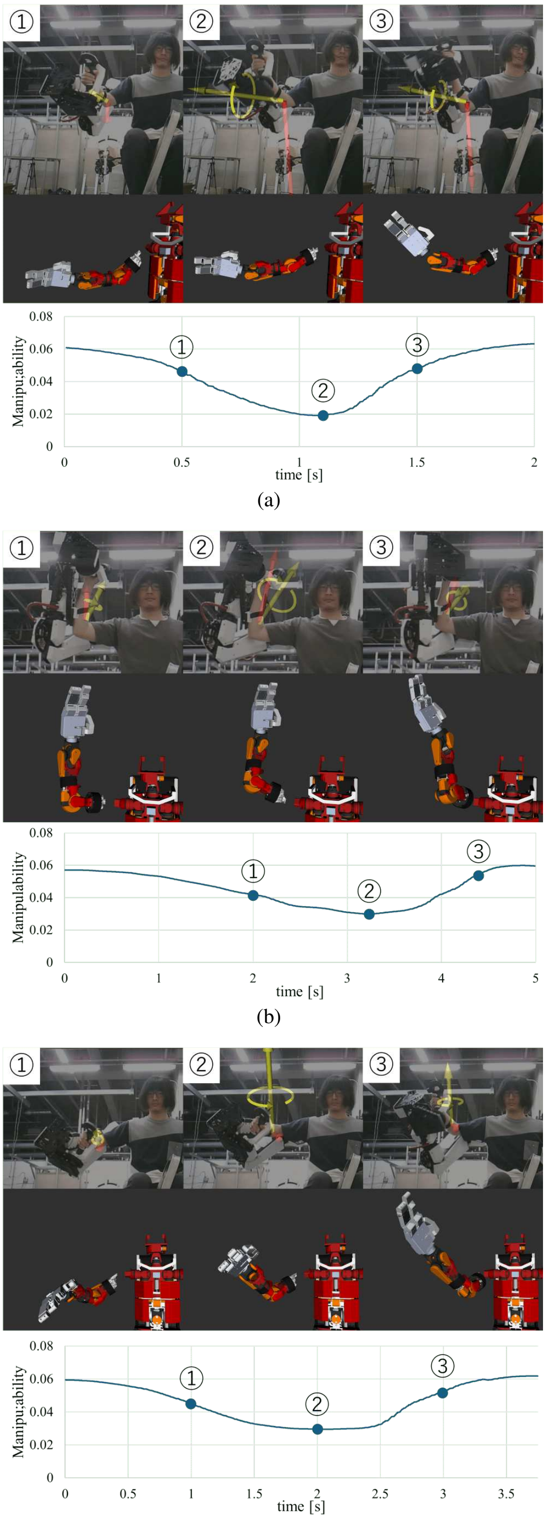


Fig. 8. Functional workspace expansion through torso control: Lifting a floor-placed bag. The operator commands a forward torso lean via foot torque, enabling the robot to reach and lift a bag that is otherwise inaccessible with a fixed torso. This demonstrates a significant expansion of the manipulable workspace.

synchronization between the operator's and the robot's torsos during these movements, even though the operator's actual torso posture was not measured. This result indicates the high intuitiveness of the proposed method, which leverages the operator's natural body mechanics.

3) Task 2: Functional Evaluation of Workspace Expansion: Next, we verified the workspace expansion enabled by our active torso control. As shown in Fig. 8, the operator successfully picked up a tote bag from the floor by significantly leaning the robot's torso forward. This task is impossible from a fixed upright posture. The result confirms that our method effectively expands the functional workspace for humanoid teleoperation from a cockpit, enabling a new range of tasks.



(a)

(b)

(c)

Fig. 9. Experimental results of operator-led singularity avoidance guided by the proposed force feedback. The three rows show trials corresponding to three distinct near-singularity cases. Each row displays: the operator reacting to haptic cues (top, with superimposed arrows), the corresponding robot motion (middle), and the time-series plot of the arm's manipulability (bottom). (a) Motion toward an extended arm singularity. (b), (c) Motion toward two different shoulder gimbal lock configurations. In all cases, the operator reacts to the feedback force, alters their motions command, and successfully steers the arm away from the singularity, causing the manipulability to recover.

B. Singularity Avoidance via Force Feedback

1) Experimental Setup: The objective of this experiment was to demonstrate that the proposed manipulability-based force feedback can effectively guide an operator to avoid singular postures. To enable safe, controlled, and repeatable trials of near-singularity conditions, the experiment was conducted using the JAXON humanoid in a simulation environment. This setup allowed us to record the operator's and robot's motion precisely without the physical risks associated with singularity instability.

2) Task and Procedure: The operator commanded the robot's 7-DoF arm, including the forearm's redundant rotation, from the exoskeleton cockpit. The operator was instructed to intentionally move the robot's arm toward the three representative singular configurations previously shown in Fig. 5 (i.e., a fully extended arm and two types of shoulder gimbal lock). We recorded the motion of the operator and the robot, as well as the time-series data of the robot arm's manipulability during this process.

3) Results: The experimental results are presented in Fig. 9. As shown in the graphs, in all trials, the magnitude of force feedback generated by our method increased as the robot approached a singularity and was presented to the operator's forearm. A key finding is that the operator consistently reacted to this haptic feedback by altering their command to prevent a further decrease in manipulability. This result indicates that the proposed feedback system successfully translates an abstract, internal constraint of the robot (i.e., singularity) into an intuitive, perceivable force for the operator. Consequently, the operator can unconsciously avoid singular postures without needing to explicitly think about the robot's manipulability, which validates the effectiveness of our approach.

VI. CONCLUSION

This paper aimed to solve two fundamental problems in cockpit-based humanoid teleoperation: the operator's physical limitations and the robot's kinematic constraints. Our contributions are twofold. First, we overcame the operator's limited torso mobility by proposing and implementing an indirect command interface that translates foot torque into torso motion. We demonstrated that this enables whole-body tasks, such as picking up an object from the floor, that are otherwise impossible from a seated position. Second, we addressed the feedback of kinematic constraints by proposing a haptic feedback system based on the manipulability gradient. We showed that this method presents imperceptible singularities to the operator as an intuitive, guiding force, enabling them to unconsciously avoid such configurations.

The two methods proposed in this study serve as a bridge to close the physical and kinematic gap between a seated operator and a humanoid robot. By allowing the operator to project their intent onto the robot while respecting its inherent constraints, our work represents a significant step toward making whole-body teleoperation systems more intuitive, capable, and practical.

REFERENCES

[1] Yasuhiro Ishiguro, et al. Bilateral humanoid teleoperation system using Whole-Body exoskeleton cockpit TABLIS. *IEEE Robotics and Automation Letters*, Vol. 5, No. 4, pp. 6419–6426, October 2020.

[2] Max Schwarz, Christian Lenz, Andre Rochow, Michael Schreiber, and Sven Behnke. NimbRo avatar: Interactive immersive telepresence with force-feedback telemanipulation. In *2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 5312–5319. IEEE, September 2021.

[3] Cheng Zhou, Longfei Zhao, Haitao Wang, Lipeng Chen, and Yu Zheng. A bilateral dual-arm teleoperation robot system with a unified control architecture. In *2021 30th IEEE International Conference on Robot & Human Interactive Communication (RO-MAN)*, pp. 495–502. ieeexplore.ieee.org, August 2021.

[4] Hiroki Yoshioka, Naoki Hiraoka, Kunio Kojima, Kei Okada, and Masayuki Inaba. Design of upper-limb exoskeleton with distal branching link mechanism for bilateral operation of humanoid robots. In *2024 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 184–184. IEEE, October 2024.

[5] Anais Brygo, Ioannis Sarakoglou, Nadia Garcia-Hernandez, and Nikolaos Tsagarakis. Humanoid robot teleoperation with vibrotactile based balancing feedback. In *Haptics: Neuroscience, Devices, Modeling, and Applications*, pp. 266–275. Springer Berlin Heidelberg, 2014.

[6] Albert Wang, Joao Ramos, John Mayo, Wyatt Ubellacker, Justin Cheung, and Sangbae Kim. The HERMES humanoid system: A platform for full-body teleoperation with balance feedback. In *2015 IEEE-RAS 15th International Conference on Humanoid Robots (Humanoids)*, pp. 730–737. ieeexplore.ieee.org, November 2015.

[7] Joao Ramos and Sangbae Kim. Humanoid dynamic synchronization through whole-body bilateral feedback teleoperation. *IEEE Trans. Rob.*, Vol. 34, No. 4, pp. 953–965, August 2018.

[8] Sylvain Bertrand, et al. High-speed and impact resilient teleoperation of humanoid robots. In *2024 IEEE-RAS 23rd International Conference on Humanoid Robots (Humanoids)*, pp. 189–196. IEEE, November 2024.

[9] Tairan He, et al. OmniH2O: Universal and dexterous human-to-humanoid whole-body teleoperation and learning. *arXiv [cs.RO]*, June 2024.

[10] Jiwoong Han and Gi-Hun Yang. Singularity avoidance in teleoperation system through force feedback of master device. In *2017 14th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI)*, pp. 470–472. IEEE, June 2017.

[11] Thavida Maneewarn and Blake Hannaford. Augmented haptics of manipulator kinematic condition. In Matthew R Stein, editor, *Telemanipulator and Telepresence Technologies VI*. SPIE, November 1999.

[12] Nikolaus Vahrenkamp, Tamim Asfour, Giorgio Metta, Giulio Sandini, and Rudiger Dillmann. Manipulability analysis. In *2012 12th IEEE-RAS International Conference on Humanoid Robots (Humanoids 2012)*, pp. 568–573. IEEE, November 2012.

[13] Rafael I Cabral Muchacho, Seongjin Bien, Riddhiman Laha, Abdeldjallil Naceri, Luis F C Figueredo, and Sami Haddadin. Shared autonomy control for slosh-free teleoperation. In *2023 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 10676–10683. IEEE, October 2023.

[14] Kunio Kojima, et al. Development of life-sized high-power humanoid robot JAXON for real-world use. In *2015 IEEE-RAS 15th International Conference on Humanoid Robots (Humanoids)*, pp. 838–843. ieeexplore.ieee.org, November 2015.

[15] G Marani, Jinhyun Kim, Junku Yuh, and Wan Kyun Chung. A real-time approach for singularity avoidance in resolved motion rate control of robotic manipulators. In *Proceedings 2002 IEEE International Conference on Robotics and Automation (Cat. No.02CH37292)*, Vol. 2, pp. 1973–1978 vol.2. IEEE, 2003.

[16] Kevin Dufour and Wael Suleiman. On integrating manipulability index into inverse kinematics solver. In *2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 6967–6972. IEEE, September 2017.

[17] Filip Maric, Oliver Limoyo, Luka Petrovic, Trevor Ablett, Ivan Petrovic, and Jonathan Kelly. Fast manipulability maximization using continuous-time trajectory optimization. In *2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 8258–8264. IEEE, November 2019.

[18] Tsuneo Yoshikawa. Manipulability of robotic mechanisms. *Int. J. Rob. Res.*, Vol. 4, No. 2, pp. 3–9, June 1985.