# Robotic Backpack System with Pluggable Supernumerary Limbs

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***Abstract*— This demonstration aims to introduce a robotic backpack system that is controlled by a wearer's upper body motions. Depending on applications, up to four robotic manipulators with a plug-and-play feature can be set and operated. It is designed as a standalone system, including a backpack-like platform with docking mounts, robotic manipulators, a mini PC, and a LiPo battery. The robotic arms' motions are determined with human head and arm gestures, and several aspects to ensure safety were considered.**

## I. Hardware

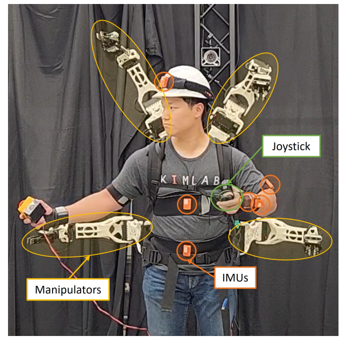
This wearable robotic system is designed to broaden human users' physical ability through extra artificial limbs (Fig. 1). In order to allow users to choose the number of robotic arms for different uses, the docking mounts, which are compatible with Plug-and-Play Robotic Arm System (PAPRAS) [1], are placed on the base frame. The orientation of docking mounts is determined considering the workspace of each manipulator and human operator. This system can detect an object or a human face using Intel RealSense cameras, which are attached to the end-effectors of robotic manipulators. For standalone operation, it includes a mini PC (Intel NUC 10) and a LiPo battery.

## II. Human Skeleton Estimation

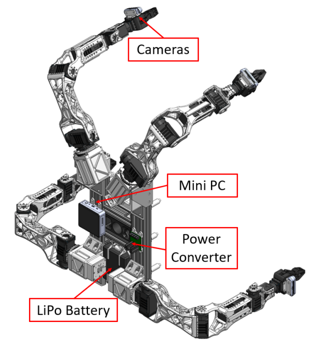
The user's upper body pose is estimated using joint angles obtained through IMUs (i.e., Xsens MTw Awinda) and a human skeleton model. In order to estimate human joint angle, nine IMUs are attached to the operator to obtain the absolute orientations of upper body segments, which are a head, a torso, a pelvis, upper arms, lower arms, and hands. During the initialization step, each body segment's orientation is calibrated about the pelvis frame to abstract upper body motions with simple equations. From the operation state, the rotation matrices among the calibrated body segment orientations are obtained. The matrices are converted to angles of selected joints - neck, torso, shoulders, elbows, and wrists - of which degrees of freedom are 3, 1, 3, 2, and 1, respectively. The obtained joint angles are applied to a human model [2] to estimate human postures and visualize them in the simulation environment.

## III. Human-Interactive Controllers

The robotic arms are controlled by human upper body motions. To be specific, the robots' wrist joints are controlled by human head movements. That is, end-effectors face the same direction as a human operator's head, and the wrist joints can duplicate human head motions such as nodding, shaking, and tilting to deliver stronger communicative cues




(a) Overall setup




(b) Backpack overview

Fig. 1: Robotic backpack system

compared to those of a single human head. In addition, the robotic arms are stretched out or bent controlled by the human arm gestures while executing the wrist motions.

Considering the features of this robotic system - wearable and running in real-time, safety issues between the robotic manipulators and the wearer are managed as the highest priority. For example, the joint limits are set not to invade the human head and torso workspace [3] – it was determined based on the robot system workspace analysis. Additionally, a joystick and an emergency stop are used to switch the modes (i.e., pause, calibration, and operation) and to cut off the system power, respectively.

## IV. Conclusion

This robotic system implies the expansion of human physical ability with extra limbs. Although current robot motions are confined to mimicking the user's head and arm movements, they can be broadened by designing the motions with more complicated human gestures. Future research may include using additional sensors to perceive human intention from different modalities and sophisticated robotic arm motions for varied situations.

## References

[1] J. Kim, D. C. Mathur, K. Shin, and S. Taylor, "Papras: Plug-and-play robotic arm system," *arXiv preprint arXiv:2302.09655*, 2023.

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[3] M. Khoramshahi, A. Poignant, G. Morel, and N. Jarrassé, "A practical control approach for safe collaborative supernumerary robotic arms," in *2023 IEEE Conference on Advanced Robotics and its Social Impact (ARSO 2023)*, 2023.

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