AirExo Installation Guide

https://airexo.github.io/

A. Overview

AirExo is an open-source, portable, adaptable, inexpensive, and robust exoskeleton system. The system is developed for Flexiv Rizon arms initially, but it can be quickly adapted to other robotic arms according to their own specifications, such as UR5, Franka , and Kuka. The main components (*i.e.*, the internal structure of the joints) are standardized, and only the links are altered to accommodate different arm configurations. Here, we provide a component list for *AirExo*. Notice that most of the components are manufactured using 3D printing, significantly reducing the costs. In this guide, we will introduce how to assemble *AirExo* for a pair of Flexiv Rizon robotic arms.

B. Component List

In the following table, we list all components used in *AirExo* with the detailed descriptions (numbers, filenames or purchase links, and further explanations, *etc.*). Here, "[itw]" in the note column means that the component is only needed for in-the-wild demonstration collections, and it is not required for teleoperation and collecting demonstrations in the robot domain.

Note. Some of the components here were purchased from the Chinese e-commerce platform Taobao. If Taobao does not support your region, we can assist in purchasing and shipping to your location. Due to the availability of various alternatives for the tubes (C01 and C02), we do not include them in the purchasing list. Therefore, we can help purchase wires (W01 and W02), angle encoders (J01) and damping pivots (J02). Fill in the form if you need our assistance.

Tab. I. The component list of *AirExo*.

ID	Name	#	Filename / Purchase Link	Note
A00	*AirExo*	-	exo	Assembly file for *AirExo*.
A01	link 67	-	link6	Assembly file for link 6/7.
A02	gripper	-	gripper	Assembly file for grippers.
A03	left arm	-	arm1	Assembly file. The left arm of *AirExo*.
A04	right arm	-	arm2	Assembly file. The right arm of *AirExo*.
B01	base 1	1	base1	The central base.
B02	base 2	1	base2	The curved rod connecting left and right arms.
B03	base 3	2	base3	For connection between joint 1 and base.
B04	plate	4	plate	The support plate inserted into the vest.
C00	camera	⩾1	Intel	[itw] Type: RealSense D415/D435.
C01	support tube	1	tube2	[itw] The tube is taken from the adjustable tripod. Type: maximum length > 1m.
C02	plastic tube	⩾1	tube1	[itw] Type: 13mm (inner), 15mm (outer).
C03	mount holder 1	1	camera_holder1	[itw] Camera mount holder. Fix the camera mount on the exoskeleton base B03.
C04	mount holder 2	1	camera_holder2	[itw] Camera mount holder. Fix the camera mount on the exoskeleton base B03.
C05	camera holder 1	⩾1	camera_holder3	[itw] Camera holder. Fix the camera on the plastic tube.

C06	camera holder 2	⩾1	camera_holder4	[itw] Camera holder. Fix the camera on the plastic tube.
C07	tube holder 1	⩾1	tube_holder1	[itw] Tube holder. Fix the plastic tube on the support tube.
C08	tube holder 2	⩾1	tube_holder2	[itw] Tube holder. Fix the plastic tube on the support tube.
G01	gripper holder 1	2	gripper_holder1	Gripper holder (base).
G02	gripper holder 2	2	gripper_holder2	Gripper holder (holder).
G11	gripper 1	2	gripper1	Gripper base 1.
G12	gripper 2	2	gripper2	Gripper base 2.
G13	gripper 3	2	gripper3	Gripper base 3.
G14	gripper 4	2	gripper4	Gripper handle 1.
G15	gripper 5	2	gripper5	Gripper handle 2.
G21	gripper gear	2	gripper_gear	Gripper gear (module: 1).
G22	gripper rack	2	gripper_rack1x20	Gripper rack (module: 1).
G23	encoder holder	2	encoder_holder	Encoder holder for grippers.
J01	angle encoders	16	encoder / Tmall [CN] / Alibaba	Type: 5V, resolution: 4096, baud rate: 115200.
J02	damping pivots	14	damping_pivot / Taobao	Type: XK543-2-35T-1NM.
J03	limiter (base)	14	limiter2	For all joints.
J04	limiter	14	limiter1	For all joints.
J05	ball	~30	ball	For all joints. Diameter: 3mm. Use as needed.
J11	pre-joint 1	2	prejoint1	For joint 1.
J12	pre-joint 2	2	prejoint2	For joint 2.
J13	pre-joint 3	2	prejoint3	For joint 3.
J14	pre-joint 4	2	prejoint4_mirror	For joint 4. One of them needs to be mirrored. See assembly files (arm1, arm2, exo) for details.
J15	pre-joint 5	2	prejoint5	For joint 5.
J16	pre-joint 6	2	prejoint6	For joint 6.
J17	pre-joint 7	2	prejoint7	For joint 7.
J21	post-joint 1/3/5	6	postjoint_135	For joint 1/3/5.
J22	post-joint 2	2	postjoint2	For joint 2.
J23	post-joint 4	2	postjoint4_mirror	For joint 4. One of them needs to be mirrored. See assembly files (arm1, arm2, exo) for details.
J24	post-joint 6	2	postjoint6	For joint 6.
J25	post-joint 7	2	postjoint7	For joint 7.
L01	link 34/56-1	4	link1_95mm	For link 3/4, 5/6.
L02	link 34/56-2	4	link2_95mm	For link 3/4, 5/6.
L03	link 12/23/45-1	6	link1_110mm	For link 1/2, 2/3, 4/5.
L04	link 12/23/45-2	6	link2_110mm	For link 1/2, 2/3, 4/5.
L05	link 67-1	1	link6_1	For link 6/7.
L06	link 67-2	1	link6_2	For link 6/7.
L07	link 67-3	1	link6_1mirror	For link 6/7.
L08	link 67-4	1	link6_2mirror	For link 6/7.
W01	wires	~20	Taobao	Type: 4-Pin 0.8mm ~20cm.
W02	heat shrink tubes	~5m	Tmall	Type: 4mm.

Beside the 3D-printed parts, there are several components that need to be prepared.

1. **Wires**. Wrap the wires with the heat shrink tubes to prevent them from wearing out and causing circuit interruption or short-circuit during installation or use, as shown in Fig. B-1. See details at W01 and W02 in Tab. I.

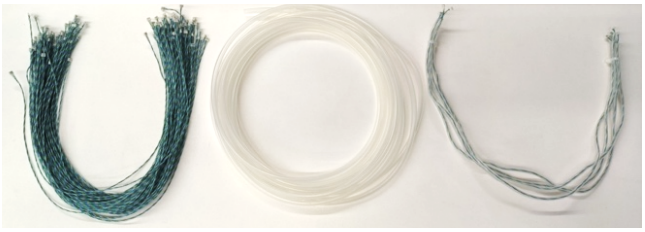

Fig. B-1. (left) 0.8mm 4-pin terminal wire; (middle) 4mm 4x heat shrink tubes; (right) wrapped wires.

2. **Angle encoders**. *AirExo* has one angle encoder for each joint and gripper (Fig. B-2). See details at J01 in Tab. I. You can also choose your own encoder if needed. In that case, some minor adjustments may be required on certain 3D-printed parts of the joint to accommodate the size of the selected encoder.

Fig. B-2. Angle encoders (voltage: 5V, resolution: 4096, baud rate: 115200) used in *AirExo*.

3. **Damping pivots**. *AirExo* has one damping pivot for each joint, whose details are shown in Fig. B-3 and J01 in Tab. I.

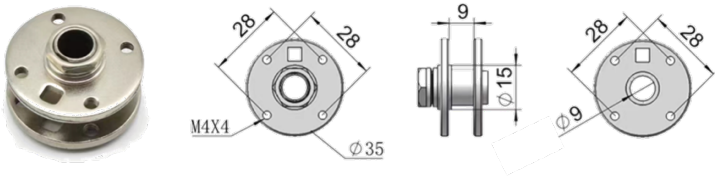

Fig. B-3. Details of the damping pivot used in *AirExo*.

4. **Height-adjustable support tube and plastic tubes (*optional*, for the camera mount)**. For the optional camera mount, we need a height-adjustable support tube with a maximum height of 1m. The diameter of the support tube is 16mm. Several plastic tubes with an outer diameter of 15mm and an inner diameter of 13mm are also required for camera mount. The size of these tubes can be modified according to your own requirements. In that case, some minor adjustments may be required on certain 3D-printed parts of the camera mount to accommodate the size of the selected tubes. See details at C01 to C08 in Tab. I and Section H.

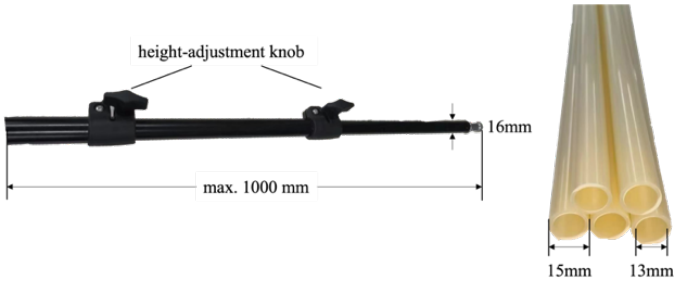

Fig. B-4. (left) Height-adjustable support tube, and (right) plastic tubes used for camera mount in *AirExo*.

5. **Camera (*optional*)**. We employ several Intel RealSense D415/D435 RGB-D cameras in *AirExo*. Therefore, the camera mount is designed to install these types of cameras. See details at C00 in Tab. I. For other cameras, you may need to modify the designation of the camera mount.

C. Exoskeleton

The exoskeleton part of *AirExo* includes joints, links, and grippers. In Section D, E, and F, we will introduce each part in detail. We recommend assembling the entire exoskeleton from the base to the end-effector (gripper) in the following sequences: joint1 → link1/2 → joint2 → link2/3 → … → gripper. After assembling the exoskeletons for both arms, please refer to section G to mount the exoskeletons onto the base, completing the entire exoskeleton. Then, you can install the camera mount on the exoskeleton if you want to collect human demonstrations in the wild, as described in the paper. Please refer to the assembly file of *AirExo* (A00) for details.

D. Joint

The joints of *AirExo* adapt a dual-layer structure, with the outer case divided into two parts: the portion proximate to the base is referred to as the *pre-joint*, while the other half is called the *post-joint*. These two components are connected via a metal *damping pivot*, and their outer sides are directly linked to the connecting rod. The motion capture of each joint is performed through the *angle encoder*, whose base is affixed to the *pre-joint*. The pivot of the *encoder* is connected to the *post-joint* through a *limiter*, which is comprised of a dual-layer disc and several steel balls to set the joint angle limit.

Preparation. Components started with "J" and "W", and screws (M4*14 flat head, M4*40 flat head, and screws provided by the encoders).

Installation Guide. The image illustration is shown in Fig. D-2.

1. Fix the *encoder* to the *limiter base* using the two screws provided by the encoders. Notice that you need to thread the wire through the circular hole on the *limiter base*.
2. Place one or more steel balls into the groove of the *limiter* base to restrict the angle range of the joint. Then, insert the pivot of the *encoder* into the *limiter*. After this step, you can try rotating the *limiter* to confirm that it is working correctly and can be rotated smoothly. If it is not working correctly, the reason may be (1) the steel balls not being placed in the groove, or (2) the pivot of the *encoder* not being inserted deep enough into the *limiter*. If the *limiter* cannot be rotated smoothly, you can add an appropriate amount of lubricant to the groove in the *limiter* base.
3. Insert the *limiter* into the hollow hole in the middle of the *damping pivot*. Then put the *encoder* (with the *limiter*) into the *pre-joint*. Thread the wire that came out of the *limiter* in the first step through the square holes of the *damping pivot*. In this step, you can adjust the tightness of the *damping pivot* to set the resistance experienced during joint rotation.
4. Check that the wire passing through the hole connects the *encoders* of the consecutive joints correctly. Then, align the screw holes on the *pre-joint*, *limiter,* and *damping pivot*, and secure them by tightening four M4*40 screws.
5. Adjust the *limiter*, *damping pivot,* and the wire within them to the appropriate positions, ensuring that the wire does not get stuck due to the insufficient length when rotating the *limiter* pivot within the pre-defined range. Thread the wire that came out of the *damping pivot* through the two wire holes of the *post-joint*, and then come out of the central hole of the *post-joint*, as illustrated in Fig. D-1.

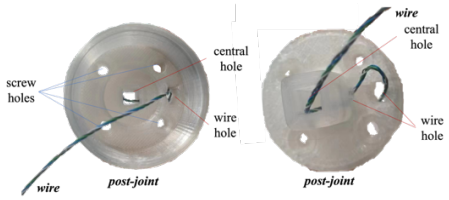

Fig. D-1. The *post-joint* (with wire) viewed from below (left) and above (right)

6. Align the square top part of the *limiter* with the central square hole of the *post-joint*, insert it into the central hole, and secure the *post-joint* and *damping pivot* together using four M4*14 screws. In this step, you can adjust the alignment of the square top with the central square hole to position the joint's dead zone roughly corresponding to the dead zone of the corresponding joint on the robotic arm, without affecting its operation functions.

7. The joint installation is complete now, and you can rotate the joint to test if the installation is correct.

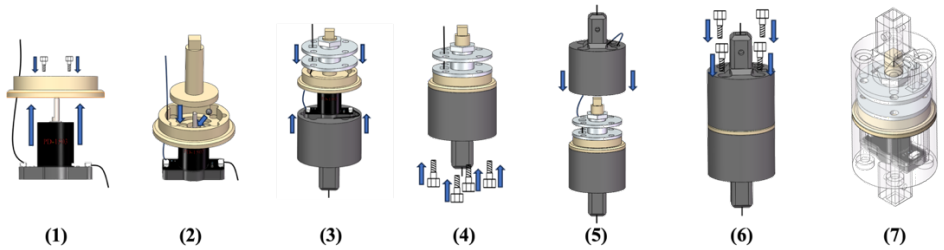

Fig. D-2. The image illustration of the joint installation process.

E. Link

The links of *AirExo* consist of two shells. The wires are enclosed within the shells to prevent external interference and result in a more robust exoskeleton.

Preparation. Components started with "L", screws (M3*25 and M3*30), and anti-loosening nuts.

Installation Guide. Assemble the two shells together (with the *post-joint* of the preceding joint and the *pre-joint* of the succeeding joint) using M3*25 screws and anti-loosening nuts (for joint 6, use M3*30 screws). Ensure that the wire is completely within the groove and pay attention to the wear of the wire during the process.

F. Gripper

In the end-effector of the exoskeleton, we design a handle and a scissor-like opening-closing mechanism to simulate the function of a two-fingered gripper, while also facilitating gripping actions by the operator.

Preparation. Components started with "G", screws (M2.5*14 and M4*5 self-tapping), and anti-loosening nuts.

Installation Guide. The image illustration is shown in Fig. F-1.

1. Insert the two fingers of the gripper into the T-shaped track. The finger on the right side should be installed together with the rack before passing through the track, with the rack being placed in the groove of the track.
2. Place the small slider on the track.
3. Thread the encoder holder to the T-shaped track using M4*5 self-tapping screws, but do not tighten them. Then insert the encoder into it.
4. Connect the gear to the pivot of the encoder and engage it with the rack. Once they are closely meshed, tighten the screws of the encoder bracket to maintain good engagement between the two.
5. Use two connecting rods to link the two fingers to the slider using M2.5*14 screws and anti-loosening nuts, ensuring the symmetry of the two fingers' movements.

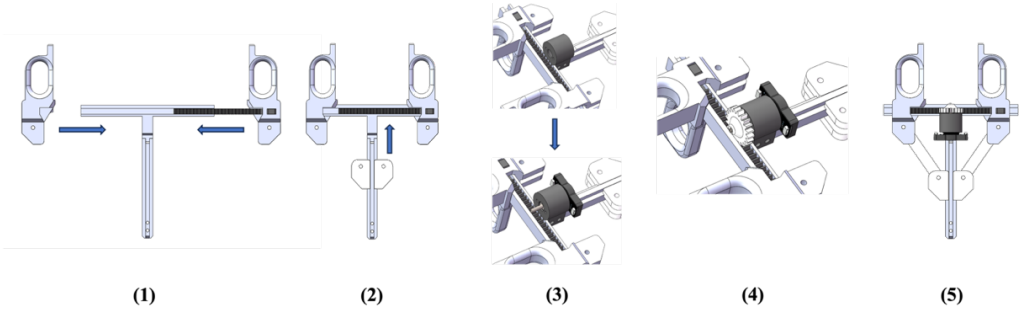

Fig. F-1. The image illustration of the gripper installation process.

G. Base

The two arms of the exoskeleton are affixed to a base, which is mounted on a vest. This allows the operator to wear it stably, and evenly distributing the weight of the exoskeleton across the back of the operator to reduce the load on the arms, thereby enabling more flexible arm motions.

Preparation. Components started with "B", pins (M4*40), screws (M4*20 self-tapping, M4*6 self-tapping flat head, M4*30), and anti-loosening nuts.

Installation Guide. With the help of the connecting components (B03), install the exoskeleton arms on the curved rod using M4*20 self-tapping screws and M4*40 pins. Then, install the dual-arm exoskeleton on the central base using M4*30 screws. Finally, install the whole exoskeleton on the plates using M4*6 self-tapping screws, and insert the support plate into the vest and secure it in place on the vest.

H. Camera Mount

We design an adjustable camera mount for *AirExo* on the exoskeleton base for image data collection during operations. The height of the camera can be adjusted using a height-adjustable supporting tube, and the place and orientation of the camera can be adjusted using the camera holders.

Preparation. Components started with "C", pins (M4*40), screws (M6*25, M4*40, M4*20, and M3 for cameras), and anti-loosening nuts.

Installation Guide.

1. Assemble the two mount holders together and attach the supporting tube using M6*25 screws and anti-loosening nuts. Then mount them onto the curved rod of the exoskeleton base using M4*40 pins.
2. Use M4*40 screws and anti-loosening nuts to assemble the supporting tube and plastic tube together using the assembled tube holder (also using M4*40 screws and anti-loosening nuts).
3. Assemble the two camera holders together using M4*20 screws and anti-loosening nuts. Then, attach the camera to the camera holders using M3 screws.
4. Attach the camera holders (along with the camera) to the plastic tube using M4*20 screws.

I. Contact Us

If you have any questions, do not hesitate to contact us. E-mails:

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