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Design and Analysis of an Adaptive Grasping Device Based on Parallelogram Mechanism

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Abstract. Aiming at the defects of traditional rigid grippers, such as poor environmental adaptability, easy damage to fragile and flexible objects, cumbersome structure and high driving redundancy, an adaptive grasping device based on the parallelogram mechanism is designed in this paper. Based on the traditional parallelogram mechanism, an adaptive parallelogram mechanism is improved and constructed, which realizes passive adaptive grasping relying on the elastic deformation of springs, and can effectively adapt to objects of different sizes and protect the integrity of grasped workpieces. A 2-RRR planar parallel mechanism is adopted as the driving mechanism of the gripper unit. The degree of freedom and constraint characteristics of the mechanism are analyzed through screw theory and kinematic model. Meanwhile, a linkage transmission structure with bevel gear sets is applied to optimize the traditional six-motor driving scheme into a dual-motor driving mode, which significantly reduces driving redundancy and overall control cost. The analysis of grasping conditions for objects with different sizes verifies that the device possesses excellent dimensional adaptability and grasping stability. The research results can provide a reliable theoretical basis and technical reference for the innovative optimization of traditional mechanical mechanisms and the design and engineering application of flexible adaptive grasping equipment.

1 Introduction

Robot automation technology keeps evolving, and various end-effector grasping devices are gradually replacing human workers in tasks such as sorting, handling, and assembly. Under harsh working conditions like frozen-goods sorting and high-intensity assembly-line operations, prolonged manual work may easily cause irreversible injuries such as frostbite and musculoskeletal strain. By imitating human hands to perform tasks, grasping devices can not only greatly improve production efficiency but also free operators from high-risk and high-intensity working environments, which carries important practical significance for promoting the upgrading of social production modes. In a broad sense, all equipment capable of object clamping can be defined as grasping devices, including highly anthropomorphic hardware such as multi-fingered dexterous hands. In unstructured working scenarios, target objects to be grasped are diverse with a wide size range, and their required clamping-force thresholds vary greatly. Fragile items are particularly sensitive to grasping force:

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excessive clamping force will lead to object fracture, while insufficient clamping force results in object shaking or even slipping and dropping.

At present, self-adaptive grasping devices are mainly divided into two major categories: rigid-structure self-adaptive grasping devices and flexible/soft-structure self-adaptive grasping devices. Taking the number of fingers, degrees of freedom, number of actuators, and joint coupling relationships as the core performance evaluation indices for the joint-coupling design of underactuated hands, Dollar et al. (2006) investigated the design principles for robust grasping in unstructured environments. Liu et al. (2024) proposed a novel bistable single-vertex, multi-crease origami flexible gripper. Driven by tendons, it enables rapid-response grasping and suits high-speed food sorting and fruit picking. Li et al. (2024) proposed a linkage-driven underactuated three-finger robotic hand mimicking human joint motions, which supports adaptive grasping and in-hand manipulation after spherical-mechanism parameter optimization. Yoon et al. (2022) designed a passively adaptive finger mechanism retrofittable to parallel grippers, realizing human-inspired pinching and scooping for constrained-environment object grasping. Yasuda et al. (2022) developed a bistable leaf-like origami structure inspired by Venus flytrap, achieving tunable, power-free autonomous and self-adaptive grasping for robotic applications. Cai et al. (2023) developed a novel hummingbird-jaw-inspired bistable gripper, which enables millisecond-level fast adaptive grasping with low driving force, requiring no sustained external force and suiting complex unstructured working environments. Lerner et al. (2024) developed programmable-stiffness origami modules utilizing shape memory polymer composites, enabling tunable deformation, multimodal locomotion and adaptive grasping for versatile origami robotic systems. Wang et al. (2023) presented a fully rigid GXU-Grasper with self-locking and single-actuation characteristics. Its kinematic model and grasping workspace are analyzed, and experiments verify its excellent adaptability for grasping irregular objects. Jiang et al. (2026) proposed a single-actuator gripper based on an antagonistic cable-driven differential mechanism, which effectively reduces contact force and improves accuracy for adaptive fixed-position grasping. Qiao et al. (2019) investigated a 3-DOF underactuated finger with tendon-pulley transmission and parallel four-linkage, analyzing its self-adaptive grasping processes, equilibrium configurations and workspace, which are validated by grasping experiments. Liu et al. (2023) developd a novel underactuated Hoecken's gripper integrating Hoecken linkage and differential mechanisms, achieving stable straight parallel pinch and shape self-adaptability with a wide grasping range. Sun et al. (2022) developed a design principle for a two-actuator five-fingered robotic hand. Using a differential palm mechanism mimicking human eigengrasps, the prototype realizes adaptive anthropomorphic grasping and dexterous in-hand manipulation. Nassar et al. (2021) designed and optimizes four types of four-bar-based underactuated fingers compatible with industrial translational grippers. Kinetostatic analysis and force-oriented optimization demonstrate that these simple single-DOF linkages achieve grasping performance comparable to more complex multi-DOF designs. Birglen (2011) proposed a general kinematic preshaping method for linkage-driven self-adaptive fingers using triggered passive elements, realizing customized closing motions such as pinch grasping and human-like finger movement. Rigid grasping mechanisms feature high overall load-bearing capacity and relatively straightforward kinematic modeling and control solving. Nevertheless, conventional rigid grippers lack inherent passive compliance, yielding limited self-adaptive performance.

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In contrast, flexible/soft-structure self-adaptive grasping devices achieve conforming enveloping of objects through material deformation, and thus inherently possess favorable self-adaptive clamping capability. Wu et al. (2022) proposed a glowing sucker octopus-inspired soft gripper with tactile sensing for adaptive grasping in underwater and industrial scenarios. Wang et al. (2023) proposed a gesture-adaptive soft-rigid robotic hand with pneumatic segmented fingers and a rigid palm skeleton, which achieves optimized grasping postures and reliable adaptive grasping of diverse objects. Byun et al. (2025) developed a compact, lightweight, tendon-driven underactuated three-fingered robotic hand with compliant joints, which achieves passive shape adaptation and versatile grasping using only a single actuator. Li et al proposed. (2026) a conical spiral continuum robot with multi-degree-of-freedom flexible joints, which achieves stable and adaptive helical grasping for irregular objects with lightweight structure and high load capacity. A cable-driven rigid-flexible combined manipulator is developed by Wei et al. (2023) to realize active switching between two-point clamping and envelope grasping, with its adaptability validated by simulations and prototype tests. Yi et al. (2021) developed a scalable, magnetically actuated kirigami soft gripper with rapid millisecond-level grasping performance. Featuring modular series–parallel assembly, it enables multi-object grasping and alignment, and holds promising applications in robotics and healthcare. Accordingly, flexible/soft-structure self-adaptive grasping place demanding performance requirements on soft constituent materials. Additionally, large-deformation-induced geometric nonlinearity poses considerable challenges for constructing precise kinematic and dynamic control models.

Overall, high-precision rigid grasping (Chen et al., 2016), soft grasping (Huang et al., 2017), and adaptive grasping schemes including cable-driven and origami-inspired (Wang et al., 2021) designs each have inherent limitations, making it difficult to simultaneously achieve simple structure, easy control, and favorable adaptive grasping performance. Existing underactuated adaptive grippers rely on passive mechanical deformation to realize multi-degree-of-freedom conformable grasping with few actuators, making them a popular research topic. Nevertheless, they still suffer from problematic grasp-mode transition, insufficient pinching accuracy, and suboptimal stability during enveloping grasping.

To address these drawbacks, this paper proposes an adaptive mechanical gripper featuring simple structure, easy-to-implement control, and prominent adaptive performance. Targeting enveloping grasping of regular-shaped objects, this work completes mechanism configuration design and kinematic analysis. A physical prototype is fabricated to verify structural rationality, hoping to offer design references for the engineering application of low-cost adaptive grippers. The rest of this paper is organized as follows. Sect.2 elaborates on the adaptive design and working principle of the grasping mechanism. Sect.3 analyzes the driving mechanism matching the adaptive structure. Sect.4 conducts the kinematic analysis of the adaptive grasping mechanism. Sect.5 presents the prototype, investigates its adaptive grasping process, and validates the rationality and correctness of the proposed gripper.

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2. Design and Principle Analysis of the Adaptive Grasping Mechanism

For mechanical fingers and grippers, adaptive adjustment of contact force between the end-effector and target objects is essential when handling workpieces with fragile surfaces, so as to prevent damage to their surfaces or even the objects themselves. Human hands possess highly dexterous grasping capacity, and their key structural characteristic is the multi-segment configuration with three phalanges for each finger. Therefore, drawing on the bionic structure of human fingers, this study adopts a design scheme of three-phalange bionic mechanical fingers.

To illustrate the force conditions, the grasping of an object by the three-phalange gripper is simplified as the planar schematic diagram shown in Fig. 1. When the fingers grasp the object, each phalange comes into contact with the object. The contact force between each phalange and the object acts through the contact point and is perpendicular to the object contour. As shown in Fig. 1, the contact forces exerted between phalange 11, phalange 12 and phalange 13 of finger 1 and the object are denoted as F_{11}, F_{12} and F_{13}, respectively. Similarly, the contact forces between phalange, phalange and phalange of finger 2 and the object are denoted as F_{21}, F_{22} and F_{23}. To adjust the magnitudes of contact forces F_{11}, F_{12}, F_{13}, F_{21}, F_{22} and F_{23}, phalange, phalange 12, phalange 13, phalange 21, phalange 22 and phalange 23 are allowed to produce certain displacements along the x_0 direction, whereby the magnitude of each contact force between the phalanges and the object can be regulated.

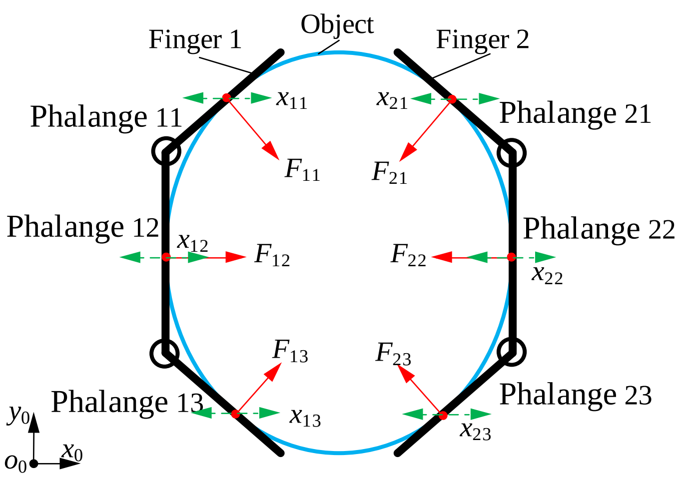

Figure 1: Schematic diagram of force analysis for three-phalange gripper grasping an object

Based on the above analysis, the motion characteristics of the parallelogram mechanism are taken into consideration, as illustrated in Fig. 2. The parallelogram mechanism consists of connecting links L_{P0}, L_{P1}, L_{P2} and L_{P3}. When connecting link L_{P1} serves as the driving link, L_{P0} and L_{P1} always maintain parallel geometric relationships with L_{P2} and L_{P3}, respectively.

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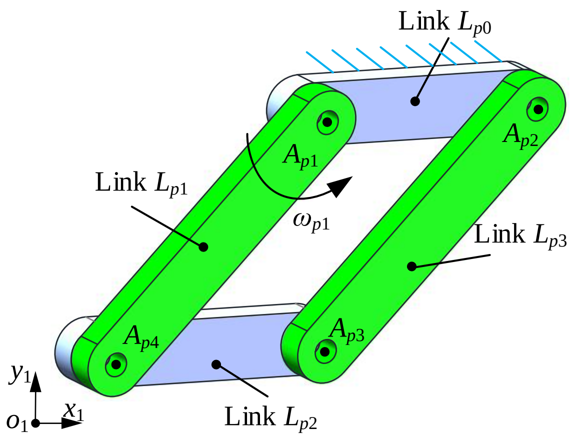
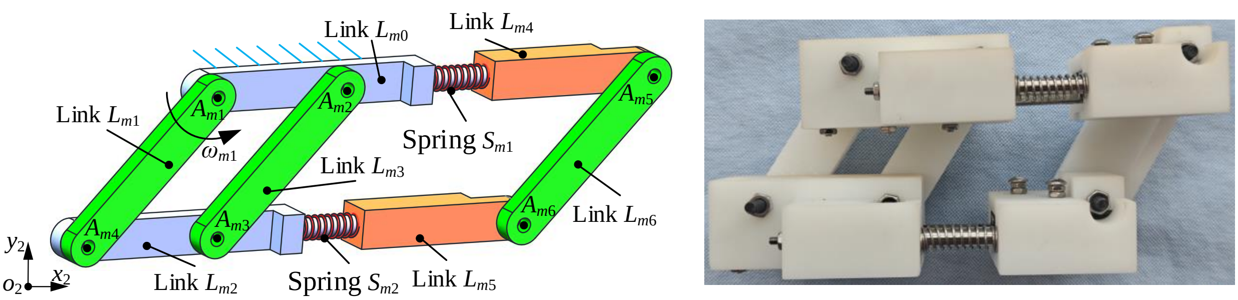


Figure 2: Schematic diagram of the parallelogram mechanism

Based on such motion characteristics of the parallelogram mechanism, structural modifications are carried out to develop an adaptive parallelogram mechanism, as shown in Fig. 3. The adaptive parallelogram mechanism comprises links L_{m0}, L_{m1}, L_{m2}, L_{m3}, L_{m4}, L_{m5} and L_{m6}, spring S_{m1} and spring S_{m2}. Among them, links L_{m0}, L_{m1}, L_{m2} and L_{m3} form a conventional parallelogram mechanism. Additional links L_{m4}, L_{m5} and L_{m6} together with springs S_{m1} and S_{m2} are incorporated to construct the adaptive parallelogram unit. Owing to the kinematic property of the conventional parallelogram mechanism, links L_{m0} and L_{m1} always stay geometrically parallel to L_{m2} and L_{m3}, respectively. Meanwhile, link L_{m6} remains parallel to link L_{m1}. Links L_{m4} and L_{m5} form prismatic pairs with links L_{m0} and L_{m2}, respectively. Benefiting from the springs, the contact force between link L_{m6} and external objects can be adjusted via the displacement-induced deformation of the springs. This mechanism possesses two degrees of freedom. Apart from the motion degree of freedom inherited from the conventional parallelogram mechanism, it has an additional translational degree of freedom along the x_2 direction. The adaptive parallelogram mechanism contains six moving links and eight lower pairs. Its degree of freedom is calculated by the planar-mechanism degree of freedom formula (Uicker et al., 2016): $F=3\times6-2\times8=2$.



(a) (b)

Figure 3: The adaptive parallelogram mechanism. (a) Schematic diagram of the adaptive parallelogram mechanism. (b) 3D-printed prototypes of the adaptive parallelogram mechanism.

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When link L_{m6} in Fig. 3 grasps an object, the springs can modulate the displacement between link L_{m6} and the object. This corresponds to adjusting the phalange displacement along the x_0 direction illustrated in Fig. 1, whereby the grasping force can be tuned. Consequently, reliable object grasping is guaranteed while the adaptive-grasping capability is achieved.

Suppose the stiffness of the grasped object is k_o, the maximum allowable displacement (i.e. deformation) that the object can sustain without damage is $\Delta x_{o\max}$, the spring stiffness within the adaptive parallelogram mechanism is k_s, and the deformation generated during adaptive object grasping is Δx_s. The force exerted on the object by link L_{m6} of the adaptive parallelogram mechanism must be less than or equal to the product of the object stiffness and its maximum allowable non-destructive deformation, i.e.,

$$k_s \Delta x_s \le k_o \Delta x_{o\max} \tag{1}$$

Based on the adaptive parallelogram mechanism shown in Fig. 3, an adaptive grasping module is designed by taking a finger with three phalanges as an example, which integrates three identical adaptive parallelogram mechanisms. Figure 4 presents the schematic diagram of two adaptive grasping modules performing enveloping grasping on an object. Subsequently, adaptive grasping module 1 and the enveloped target object are taken as the research subject for further illustration. The contact points between the three adaptive parallelogram mechanisms of adaptive grasping module 1 and the enveloped object are C_{11}, C_{12}, and C_{13}, respectively. The springs inside these three adaptive parallelogram mechanisms all possess the same stiffness K_1, with deformations of Δx_{11}, Δx_{12} and Δx_{13}, and output forces F_{c11}, F_{c12} and F_{c13}. The angles between the normal direction of the object contour at each link-object contact and the corresponding output forces are α_{11} and α_{12} (α_{12}=0 as shown in Fig. 4) and α_{13}. Accordingly, the actual forces directly applied onto the object surface, denoted as F_{o11}, F_{o12} and F_{o13}, are expressed as follows:

$$\left.\begin{aligned} K_i \Delta x_i &= \boldsymbol{F}_{c1i} \\ \boldsymbol{F}_{c1i}\cos\alpha_{1i} &= \boldsymbol{F}_{o1i} \end{aligned}\right\} \quad i = 1,2,3 \tag{2}$$

Although the finger incorporates three identical adaptive parallelogram mechanisms, each adaptive mechanism can independently adjust its grasping force according to the shape of the grasped object. That is, the force $\boldsymbol{F}_{o1i}$ exerted on the object can be regulated by varying the magnitude of Δx_i.

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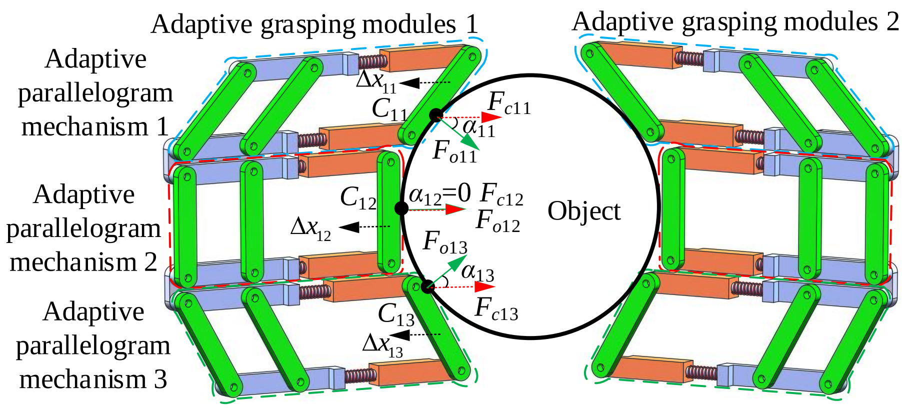

Figure 4: Schematic diagram of enveloping grasping for the adaptive grasping device

3 Driving Mechanism of the Adaptive Grasping Device

According to the analysis in Section 2, during the motion of the adaptive parallelogram mechanism, links L_{m1}, L_{m3} and L_{m6} always maintain a parallel geometric relationship. Accordingly, the adaptive grasping module in Fig. 4 is essentially composed of three groups of permanently parallel links. Each group forms an RRR (R denotes a revolute joint) serial mechanism, which possesses three degrees of freedom within the plane orthogonal to the axial direction of the revolute joints. For serial mechanisms, mounting driving motors at every joint degrades the dynamic characteristics and overall operational performance of the whole system (Li et al., 2017). On the other hand, only the end-effector position of the RRR serial mechanism needs to be guaranteed during grasping, while its orientation is not required. Therefore, a 2-RRR planar parallel mechanism with two translational degrees of freedom is adopted in this paper as the driving mechanism to determine the terminal position of the gripper, as illustrated in Fig. 5.

This 2-RRR planar parallel mechanism consists of link L_{02}, limb 1, limb 2, and a moving platform. Limb 1 is composed of links L_{11} and L_{12}, incorporating revolute joints R_{11}, R_{12}, and R_{13}. Limb 2 consists of links L_{21} and L_{22} with revolute joints R_{21}, R_{22}, and R_{23}. Link L_{12} forms revolute joint R_{13} with the moving platform, and link L_{22} forms revolute joint R_{23} with the moving platform. Joints R_{13} and R_{23} are coaxial. The global coordinate system is $o_3\text{-}x_3y_3z_3$, and the coordinate systems for the two branch chains are $o_{31}\text{-}x_{31}y_{31}z_{31}$ and $o_{32}\text{-}x_{32}y_{32}z_{32}$, respectively.

For the 2-RRR planar parallel mechanism serving as the driving mechanism, its degrees of freedom can be calculated based on screw theory (Gogu, 2005). The kinematic screws of limb 1 are expressed in the local coordinate system of limb 1 as follows:

$$
\begin{aligned}
\$_{11} &= \left(0 \quad 0 \quad 1 \quad 0 \quad 0 \quad 0\right) \\
\$_{12} &= \left(0 \quad 0 \quad 1 \quad n_1 \quad m_1 \quad 0\right) \\
\$_{13} &= \left(0 \quad 0 \quad 1 \quad n_2 \quad m_2 \quad 0\right)
\end{aligned}
\tag{3}
$$

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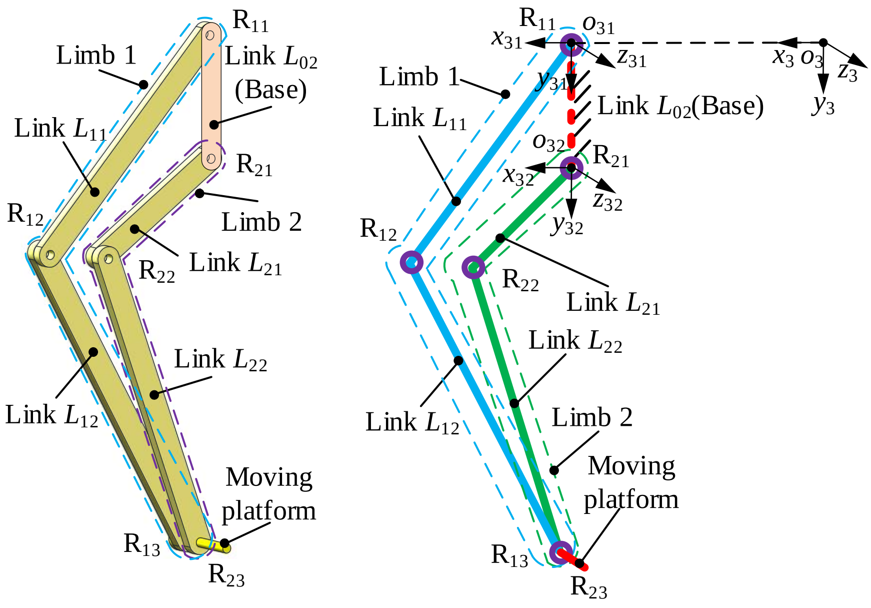
The reciprocal screws are derived from Equation (3), yielding the constraint screws of limb 1.

$$\begin{aligned} \$_{11}^{r} &= \begin{pmatrix} 0 & 0 & 1 & 0 & 0 & 0 \end{pmatrix} \\ \$_{11}^{r} &= \begin{pmatrix} 0 & 0 & 0 & 1 & 0 & 0 \end{pmatrix} \\ \$_{11}^{r} &= \begin{pmatrix} 0 & 0 & 0 & 0 & 1 & 0 \end{pmatrix} \end{aligned} \quad (4)$$



(a) (b)

Figure 5: Schematic diagram of the 2-RRR parallel driving mechanism. (a) Schematic of 3D model of the driving mechanism (b) Schematic diagram of the driving mechanism

Although the two limbs are not strictly symmetric, they possess identical kinematic pairs. Accordingly, limb 2 has kinematic-screw and constraint-screw expressions similar to those of limb 1. In the global coordinate system o_3-$x_3y_3z_3$ shown in Fig. 5(b), both limbs can supply couples about the x_3 direction and y_3 direction, which restrict the rotational motions around x_3 direction and y_3 direction. They also generate forces along the z_3 direction, and the forces provided by the two limbs are parallel to each other, thus constraining the translational motion along the z_3 direction. Consequently, the moving platform can perform translational motions along the x_3 direction and y_3 direction, as well as rotational motion around the common axis of R_{13} and R_{23}. Since the moving platform is arranged on the co-axis of revolute joints R_{13} and R_{23}, its rotational motion is regarded as a local degree of freedom and has no influence on determining the terminal position of the gripper.

By assembling the driving mechanism and the adaptive grasping module, a gripper unit is obtained. Mounting the gripper unit on the base yields the parallelogram mechanism based adaptive grasping device shown in Fig. 6. In this work, three gripper units (namely three jaws) are evenly distributed about the central axis A_0 for object grasping. When the driving mechanism drives the adaptive grasping module to a predefined position, the link segments of the adaptive grasping module

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that contact the object perform the grasping task. Benefiting from the springs, the contact force can be adaptively adjusted to achieve the ultimate goal of protecting the object surface and even the entire object.

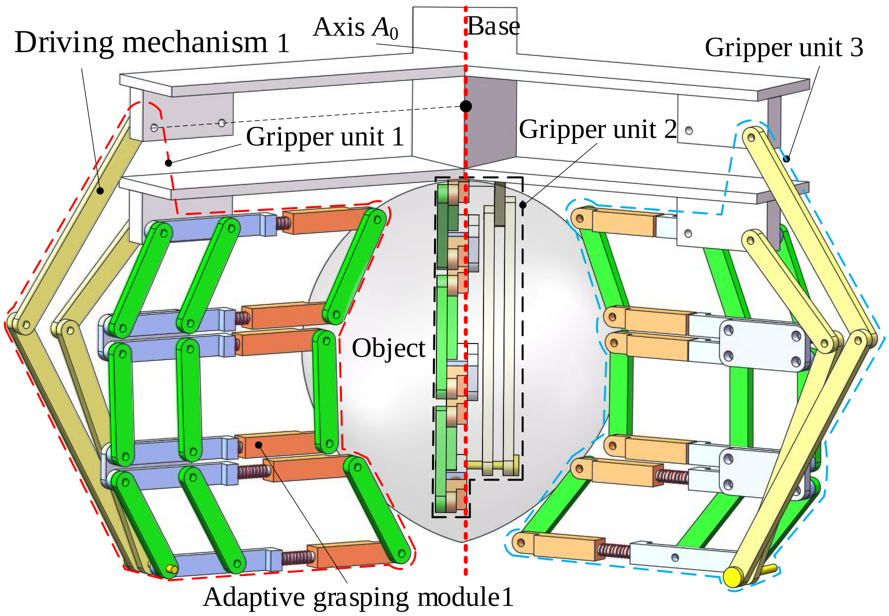

Figure 6: Schematic diagram of enveloping grasping by the adaptive grasping device

4. Grasping Kinematics Analysis of the Adaptive Grasping Device

This adaptive grasping device consists of three uniformly-arranged gripper units; hence, only the driving mechanism of one gripper unit needs to be analyzed. For the driving mechanism shown in Fig. 5, according to the degree-of-freedom analysis in Section 3, the position of the moving platform can be determined by applying actuation to revolute joints R_{11} of limb 1 and R_{21} of limb 2. The lengths of links L_{02}, L_{11}, L_{12}, L_{21}, and L_{22} are l_{02}, l_{11}, l_{12}, l_{21}, and l_{22}, respectively. The angles between link L_{11}, link L_{21} and the y_3 axis, denoted as ω_1 and ω_2, are taken as the actuation angles of revolute joints R_{11} and R_{21}, as illustrated in Fig. 7. The positional analysis of the driving mechanism aims to determine the position (x_3, y_3) of the moving platform within plane x_3y_3 given the two actuation angles ω_1 and ω_2.

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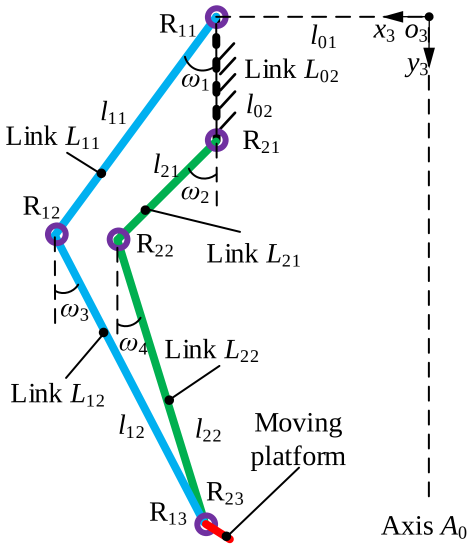

Figure 7: Schematic diagram of driving-mechanism parameters

According to the geometric relationships shown in Fig. 7, the equations for limb 1 are as follows:

$$\begin{aligned} x_3 &= l_{01} + l_{11}\sin\omega_1 - l_{12}\sin\omega_3 \\ y_3 &= l_{11}\cos\omega_1 + l_{12}\cos\omega_3 \end{aligned} \tag{5}$$

The equations for limb 2 are as follows:

$$\begin{aligned} x_3 &= l_{01} + l_{21}\sin\omega_2 - l_{22}\sin\omega_4 \\ y_3 &= l_{02} + l_{21}\cos\omega_2 + l_{22}\cos\omega_4 \end{aligned} \tag{6}$$

By simplifying Equation (5) and Equation (6) and eliminating ω_3 and ω_4, the algebraic relationship between the terminal position (x_3, y_3) of the moving platform and the actuation angles ω_1 and ω_2 can be obtained. Meanwhile, the correctness that the mechanism possesses two degrees of freedom is verified.

$$\begin{aligned} &\frac{1}{2}\left(l_{11}^2 - l_{12}^2 - l_{21}^2 + l_{22}^2 - l_{02}^2\right) + l_{01}l_{11}\sin\omega_1 - l_{01}l_{21}\sin\omega_2 - l_{02}l_{21}\cos\omega_2 \\ &-l_{11}x_3\sin\omega_1 + l_{21}x_3\sin\omega_2 - l_{11}y_3\cos\omega_1 + l_{21}y_3\cos\omega_2 + l_{02}y_3 = 0 \end{aligned} \tag{7}$$

By differentiating Equation (7), the algebraic relationship among the terminal velocities v_x, v_y of the moving platform and the actuation angular velocities θ_1, θ_2 is obtained.

$$\begin{aligned} &\left(l_{01}l_{11}\cos\omega_1 - l_{11}x_3\cos\omega_1 + l_{11}y_3\sin\omega_1\right)\frac{\mathrm{d}\omega_1}{\mathrm{d}t} + \left(l_{21}\sin\omega_2 - l_{11}\sin\omega_1\right)\frac{\mathrm{d}x_3}{\mathrm{d}t} + \\ &\left(l_{02}l_{21}\sin\omega_2 - l_{01}l_{21}\cos\omega_2 + l_{21}x_3\cos\omega_2 - l_{21}y_3\sin\omega_2\right)\frac{\mathrm{d}\omega_2}{\mathrm{d}t} + \left(l_{02} - l_{11}\cos\omega_1 + l_{21}\cos\omega_2\right)\frac{\mathrm{d}y_3}{\mathrm{d}t} = 0 \end{aligned} \tag{8}$$

Where,

$$\frac{\mathrm{d}\omega_1}{\mathrm{d}t} = \theta_1,\quad \frac{\mathrm{d}\omega_2}{\mathrm{d}t} = \theta_2,\quad \frac{\mathrm{d}x_3}{\mathrm{d}t} = v_x,\quad \frac{\mathrm{d}y_3}{\mathrm{d}t} = v_y \tag{9}$$

Then the following is obtained:

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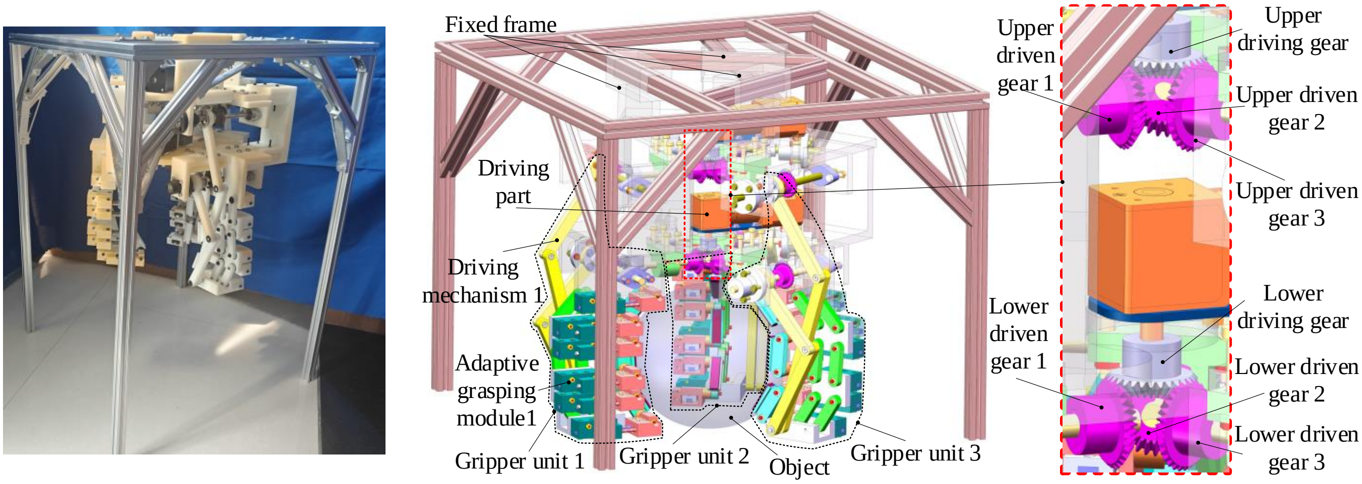
$$\begin{aligned}&\left(l_{21}l_{11}\cos\omega_1-l_{11}x_3\cos\omega_1+l_{11}y_3\sin\omega_1\right)\theta_1+\left(l_{21}l_{11}\cos\omega_2-l_{21}x_3\cos\omega_2+l_{02}l_{21}\sin\omega_2\right)\theta_2+\\&\left(-l_{11}\sin\omega_1-l_{21}\sin\omega_2\right)v_x+\left(l_{02}-l_{11}\cos\omega_1+l_{21}\cos\omega_2\right)v_y-l_{21}y_3\sin\omega_2=0\end{aligned} \tag{10}$$

5. Prototype Construction and Grasping Application Analysis of Adaptive Grasping Device

According to the foregoing analysis, the adaptive grasping device contains three adaptive grasping modules, and the driving mechanism of each adaptive grasping module has two degrees of freedom. Hence, the entire adaptive grasping device requires six motors for actuation. Nevertheless, since the three adaptive grasping modules are uniformly and symmetrically arranged, a scheme employing one bevel gear to drive three driven bevel gears is adopted to reduce the number of motors, as shown in Fig. 8. Consequently, only two driving motors are finally needed to determine the terminal position of the gripper and realize object grasping.



(a) (b)

Figure 8: Schematic diagram the adaptive grasping device. (a) Physical prototype model of the adaptive grasping device. (b) The detailed structure of the adaptive grasping device

Considering the large overall dimension of the adaptive grasping device, the self-adaptive displacement variation cannot be obviously displayed. Therefore, the schematic diagram shown in Fig. 6 is adopted for illustration. The schematic diagram of the adaptive grasping device performing adaptive grasping of objects with different sizes is presented in Fig. 9. The size of the grasped object lies between object 1 and object 2, and the maximum size difference between object 1 and object 2 is Δl. Benefiting from the adaptive characteristics of the grasping device, the drive parameters of the gripper are set for grasping the minimum-size object in this group, namely the state of grasping object 2 in Fig. 9. Under such drive parameters, when the adaptive grasping device clamps the larger-size object 1, the springs of the first, second and third adaptive parallelogram mechanisms are further compressed by $\Delta x'_{11}$, $\Delta x'_{12}$ and $\Delta x'_{13}$, respectively, so as to realize adaptive grasping for larger-size objects.

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When the target object is a glass product, the adaptive characteristics of the adaptive grasping device can effectively preserve the integrity of the glass product. For easily-deformable objects, the adaptive grasping device can maintain the original shape of the object without damage owing to its adaptive features.

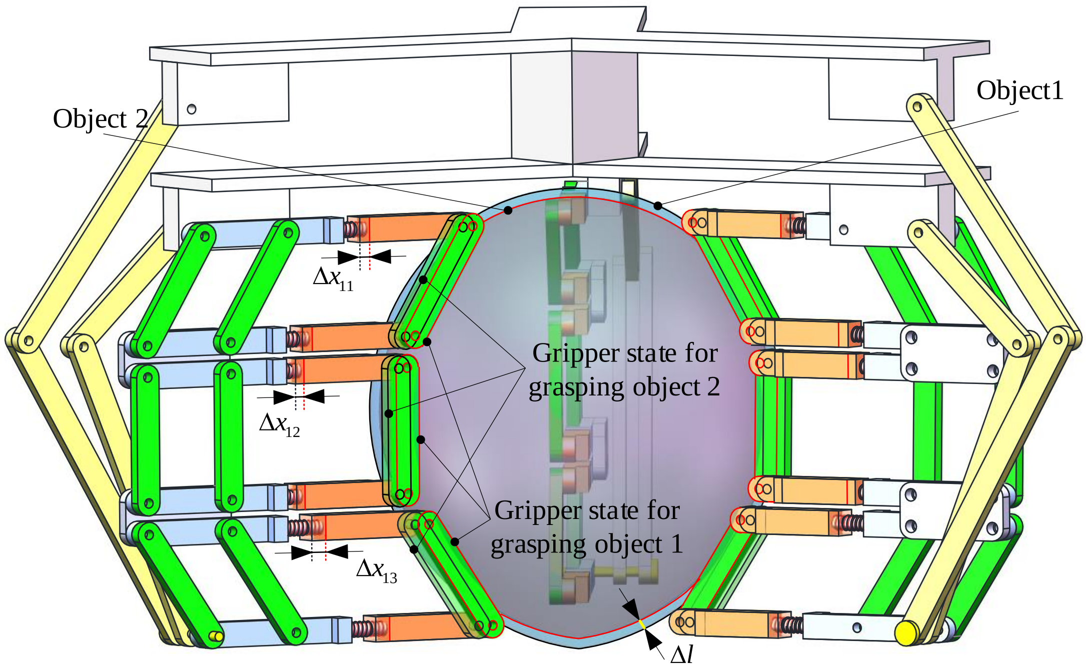

Figure 9: Schematic diagram of driving-mechanism parameters

6. Conclusions

In this paper, a novel grasping device with adaptive characteristics is designed based on the parallelogram mechanism. On the basis of the parallelogram mechanism, an adaptive parallelogram mechanism is constructed, and its design procedure and adaptive working principle are systematically elaborated. Considering the layout of driving motors and the kinematic performance of the mechanism, a 2-RRR planar parallel mechanism is adopted as the driving mechanism to realize the accurate positioning and motion control of the adaptive gripper unit. The kinematic analysis of the 2-RRR driving mechanism was established. Combined with the parametric relationships of positional equations and the screw theory, the degree of freedom and constraint characteristics are analyzed, which verifies the rationality and feasibility of the driving mechanism design. Finally, an experimental prototype of the adaptive grasping device is fabricated. By introducing a bevel gear set to optimize the driving layout, the number of driving motors is effectively reduced. The working conditions and application scenarios of the adaptive gripper are demonstrated through schematic diagrams, which further validate the effectiveness of the adaptive grasping function. The proposed adaptive grasping device based on the parallelogram mechanism can provide effective theoretical references and engineering application ideas for the innovative application of traditional mechanisms and the research of adaptive grasping technologies.

Data availability

The data used in this study are not publicly available due to laboratory confidentiality requirements. Relevant information may be made available by the corresponding author upon reasonable request and with permission from the laboratory.

Author contributions

Dabao Fan and Haibing Feng proposed the research design and framework of the paper. Dabao Fan drafted the initial manuscript. Yuming Zhao drew the model. Yunjiao Deng and Ya Liu reviewed the entire paper and provided guidance for the revisions. Daxing Zeng contributed to the literature review and model construction.

Competing interests

The contact author has declared that none of the authors has any competing interests.

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