

A Wire-Driven Robotic Hand with Mode-Switchable Planetary Transmission for Dynamic Manipulation

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Abstract—Dynamic hand manipulation requires both precise motion control and rapid actuation capability, yet most existing robotic hands are primarily optimized for dexterity and accuracy, often sacrificing speed performance. To address this limitation, this work presents a mode-switchable wire-driven robotic hand incorporating a planetary transmission mechanism capable of continuously varying output speed and torque characteristics. The proposed system operates in two distinct modes: a torque-enhancing mode for stable and precise grasping, and a speed-amplifying mode for agile dynamic motions such as flicking and throwing. A dedicated mechanical switching mechanism enables real-time transition between the two transmission modes according to task requirements. A full prototype of the five-finger robotic hand is currently under fabrication and system integration, and preliminary analytical results demonstrate the feasibility of both precise grasping and enhanced high-speed manipulation capability. These results validate the proposed transmission architecture as a promising solution for robotic hands requiring both dexterous and dynamic manipulation.

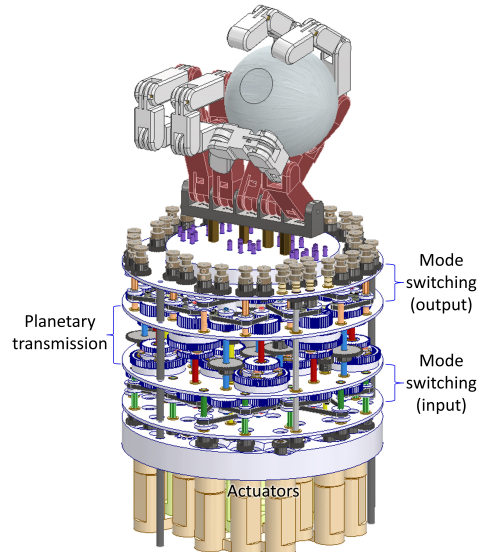


Fig. 1: Overview of the proposed system architecture: finger module, planetary transmission, mode-switching mechanisms, and actuation unit.

I. INTRODUCTION

A. Background

Robotic hands have been extensively studied to achieve dexterous and precise manipulation capabilities, particularly in human-like multi-finger configurations [1], [2]. Recent developments have demonstrated highly advanced grasping and in-hand manipulation performance. However, most existing robotic hands primarily focus on accuracy and dexterity rather than rapid actuation and dynamic hand-level manipulation. In contrast, many real-world tasks require not only precision but also rapid motion transitions, such as flicking, throwing, and dynamic contact interactions. Existing dynamic manipulation studies often rely mainly on the robotic arm rather than the hand itself, due to the limited speed capability of conventional hand mechanisms [3], [4]. To address this limitation, this work proposes a mode-switchable wire-driven robotic hand with a planetary transmission system that enables both torque enhancement and speed amplification through mechanical mode switching.

B. The concept and novelty of proposed robotic hand

In this section, the main concept and novelties of the proposed robotic hand are introduced. The ultimate goal of this study is to perform not only precise motions but also high-speed, dynamic manipulations. Rather than producing a few discrete levels of speed and torque outputs, the proposed design aims to provide a wide and continuous range of output characteristics. To achieve this, two operating modes based on planetary gear systems are adopted, as shown in Fig. 1, and described below:

- Torque mode: The sun gear serves as the input, and the planet carrier acts as the output. For achieving a continuous output range, an additional(second) input is applied to the ring gear.
- Speed mode: The planet carrier serves as the input, and the sun gear acts as the output. Similar to torque mode, an additional(second) input is applied to the ring gear.

Moreover, to switch between torque mode and speed mode for reduction and acceleration, a mode-switching mechanism based on a belt and belt pusher is applied in this study. Detailed information on the mode-switching mechanism will be presented in the following sections.

Consequently, the proposed mode-switchable wire-driven robotic hand with a planetary transmission achieves a continuous and wide range of speed and torque outputs, enabling it to perform not only precise motions but also high-speed, dynamic manipulations.

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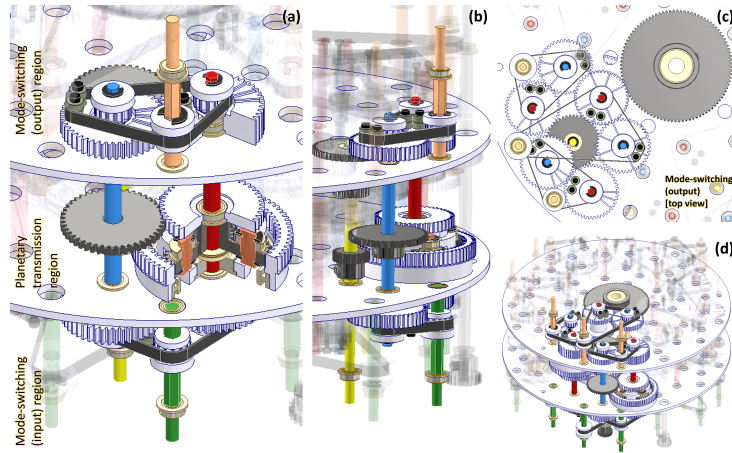


Fig. 2: Proposed planetary transmission and mode-switching mechanism of the robotic hand: (a) exploded view, (b) side assembly view, (c) top-view switching configuration, and (d) integrated transmission module.

II. PROPOSED SYSTEM

In this section, we briefly introduce the overall system configuration to provide a clearer understanding of the proposed hand. Fig. 1 illustrates the full system architecture. From bottom to top, the system consists of the actuation unit, the input-side mode-switching mechanism, the planetary transmission system, the output-side mode-switching mechanism and the fingers.

The robotic hand has five fingers, each consisting of five links. Each finger is actuated by three primary input actuators and one secondary input actuator. The three primary actuators drive each finger through individual planetary gear systems, while all links within a finger share a single secondary input actuator. In addition, the thumb includes an extra actuator dedicated to its manipulation; this actuator directly drives the thumb links without transmission or secondary-input coupling. Moreover, a single motor actuates the mode-switching mechanism, allowing all link modes to switch simultaneously. Overall, a total of 22 actuators are employed in the proposed robotic hand. To generate continuous speed and torque outputs, a planetary gear-based continuously variable transmission (CVT) is adopted in this study. As explained previously, either the sun gear or the planet carrier serves as the input, while the other acts as the output. A second input is applied to the ring gear, and the combination of the main and secondary inputs produces the desired output characteristics.

As shown in Fig. 2, (a), (b) presents the planetary transmission system, while (c) and (d) illustrate the mode-switching mechanism based on the belt and belt pusher, which enables proper switching between Mode-1 and Mode-2. As mentioned earlier, the sun gear and planet carrier are mounted on separate shafts. In the mode-switching mechanism, the belt pusher moves (rotates) along a circular path, thereby engaging or disengaging each shaft with the output shaft through the belt.

III. VALIDATION PLAN AND CONCLUSION

The proposed robotic hand is currently under full prototype fabrication and system integration. To validate the effectiveness of the proposed mode-switchable transmission mechanism, experimental evaluation is planned in three stages. First, the transmission-level validation will be conducted to verify the output speed and torque characteristics in both operating modes. In particular, the speed amplification ratio and torque enhancement performance predicted by the analytical model will be compared with the measured motor and output shaft responses. Second, hand-level validation will be performed through precision grasping and mode-switching experiments. These tests aim to confirm the stability of the torque mode for grasping tasks and the reliability of the belt-based mode-switching mechanism. Third, dynamic hand manipulation experiments, such as flicking and object throwing, will be conducted to evaluate the effectiveness of the speed mode for rapid hand-level motion generation. The proposed robotic hand is expected to demonstrate both precise and high-speed manipulation capability through the mechanically switchable planetary transmission architecture. This work provides a promising framework for future robotic hands requiring both dexterous precision and high-speed dynamic manipulation capability.

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