Design and Development of a Triggered Type Underactuated Grasping Mechanism and Its Application to an Experimental Test Bed

Steven Grech and Michael Saliba

Abstract Gripping devices that employ less actuators than they have degrees of freedom, i.e. those that employ underactuated mechanisms, can contribute significant savings in size, weight, complexity and cost of the device. Furthermore, the use of underactuated mechanisms gives the property of passive conformance of the gripper to objects of unknown shape and size. This work addresses two problems relating to underactuated gripping devices. The first problem is that there are very few designs of switching mechanisms for triggered type underactuated hands available in the literature. In this work four innovative concepts for these mechanisms are presented and are added to the literature. The second problem is that most design optimization work for underactuated hands in the literature is based on simulation, particularly for the case of triggered type devices. This work presents briefly the ongoing design and development of a versatile test bed for the experimental optimization of underactuated gripper design parameters, and for the validation of the simulation based approaches.

Keywords Robotic grasping · Underactuated mechanisms · Clutch based switching mechanisms · Experimental design optimization test beds

1 Introduction

An underactuated mechanism is one that has a smaller number of actuators than it has degrees of freedom, and when applied to grasping devices exhibits a number of desirable features [1]. Grippers that are based on this approach can be made to be lighter, less bulky, simpler, and less expensive than their fully actuated counterparts, and moreover have the general capability of conforming passively to various

S. Grech · M. Saliba (✉)
University of Malta, Msida, Malta
e-mail: michael.saliba@um.edu.mt

S. Grech
e-mail: steven.grech.11@um.edu.mt

P. Wenger and P. Flores (eds.), *New Trends in Mechanism and Machine Science*,
Mechanisms and Machine Science 43, DOI 10.1007/978-3-319-44156-6_39

shapes of object without prior programming or complex control algorithms. Underactuated mechanisms can be classified into three different types (e.g. [2]): *differential*, where classical elements distribute the actuator motions to different kinematic members as required; *compliant*, where elastic members such as springs distribute the grasping forces among the members; and *triggered*, where the actuator drive is switched between different kinematic members through clutch devices.

Analytical work in the literature has focused mainly on the first two types of underactuated hand (e.g. [3, 4]). In more recent work, a detailed quasi-dynamic analysis and a simulation based design optimization exercise have been carried out in the context of a triggered type underactuated hand [5]. A natural extension of this latter work involves the development of a physical test bed based on a triggered type switching mechanism, in order to test experimentally some of the simulation results that have been obtained.

A literature review reveals only a limited number of designs that have been presented for the operation of triggered type underactuated mechanisms. In [5–8] the operation of the mechanisms is based in each case on the disengagement of a breakaway clutch in the form of a screw thread, and incorporating transmission mechanisms that are inherently non-backdrivable; with the mechanism described in [7, 8] later developed into the commercially available Barrett hand [9]. In [10] switching of the actuator drive occurs through the automatic engagement/disengagement of brake mechanisms, based on the traversal of torque thresholds in the resistance to motion of the kinematic members of the mechanism.

The purpose of the present paper is firstly to present a number of different novel concept mechanisms that can be used to switch an actuator drive between different joints in a triggered type underactuated device. These solutions have resulted from the conceptual design phase for the development of an experimental test bed for a planar underactuated robot hand. The different concepts for the drive switch have been evaluated with respect to a number of pre-established criteria, and a decision matrix has been drawn up to select the preferred concept. The selected concept is then applied to the design and development of a versatile experimental test bed for a planar, underactuated, two-finger, four-joint gripper. The gripper is driven by two actuators (one per finger), and is intended to investigate the effect of varying a number of gripper design parameters on grasping performance. The design and ongoing development process for the test bed is also presented briefly in this work.

The basic configuration of the underactuated hand test bed, showing also the parameters that can be varied, is given in Fig. 1. This test bed will be mounted on a horizontal surface and is required to incorporate the following specific features: (i) two rotary joints in the palm, one for each finger; (ii) variable width P of the palm; (iii) variable depth E of the palm; (iv) two fingers, each composed of two links separated by a rotary joint as shown; (v) a triggered type switching mechanism between the links for each finger, meaning that the actuator drive is first directed to the lower, or first, joint, and then when this joint becomes impeded the drive switches automatically to the upper, or second, joint; (vi) each of the four links to have variable effective length (L_L or L_U); (vii) each of the four links to have variable thickness T; and (viii) the capability to vary the friction between the link contact

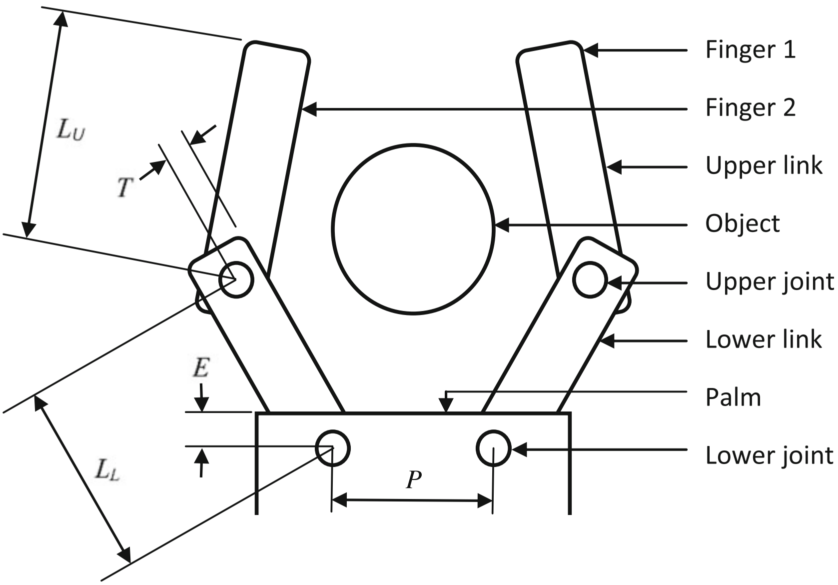


Fig. 1 Basic configuration and variable parameters of the test bed

surface and the object being grasped. In addition it was desired to employ a design approach that is extendible to more links per finger; to avoid physical interference between different links on each finger, or between fingers; and to employ some degree of modularity.

2 Switching Mechanism: Concept Generation and Selection

A number of new and different concepts were generated for the triggered type switching mechanism. Four of these were shortlisted and are presented below. In cases where the mechanism is not inherently non-backdrivable (Concepts 1, 2 and 4), further transmission elements such as worm and wheel drives can be added to the drive train to achieve this property.

Concept 1 (*Toggle switch*) is shown in Fig. 2. It consists of a pair of input spur gears, the second (larger) of which is fixed to a toggle part that is in the first instance coupled to the first output disc. When rotation of this output disc is no longer possible, the drive torque forces the toggle part to disengage from the output 1 disc and to ratchet to and engage output disc 2, switching over the drive.

Concept 2 (*Cable driven clutch*) is shown in Fig. 3. The cable transmission from the drive is fixed to the output pulley that drives the second joint (labelled “Output 2 pulley” in the figure). This output pulley is coupled to the output pulley that drives

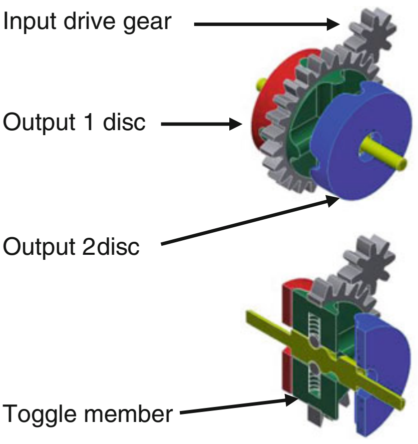
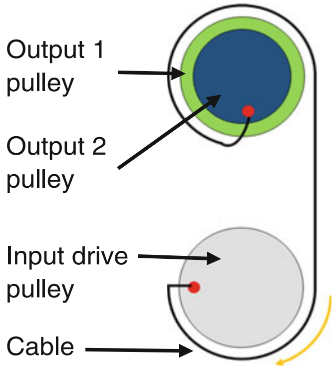


Fig. 2 Concept 1: Toggle switch mechanism

Fig. 3 Concept 2: Cable driven clutch



the first joint ("Output 1 pulley"), via a friction clutch surface. When both joints are free to move, this mechanism results in motion of only the first joint, since the rotation of the second joint is compensated by a reverse rotation tendency that is due to coupling with the cable transmission of the first joint. When motion of the first joint becomes impeded, the clutch slips and the second joint starts to rotate. This motion compensation (i.e. sequential motion) effect has been demonstrated on a physical model of the finger (consisting of three moving links to demonstrate also the extendibility of this effect), and is shown in Fig. 4. Figure 3 shows the mechanism for rotation in only one direction. A second cable is needed to achieve rotation drive in both directions.

Concept 3 (*Dual worm and wheel drive*) is shown in Fig. 5. It consists of two worm gears rigidly fixed to the drive shaft. The output pinion of the right hand worm gear is connected to the first joint via a torque limiter (shown above the pinion) and cable drive, while the output pinion from the left hand worm gear is connected directly to the second joint via a second cable drive that passes over an

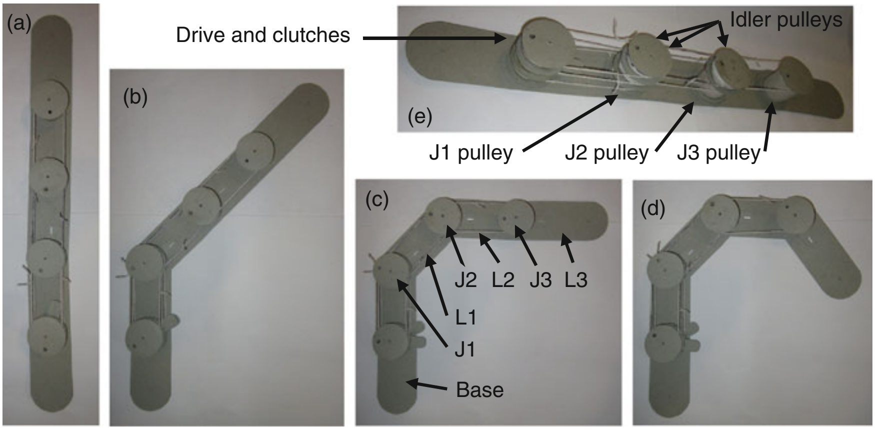


Fig. 4 Motion compensation effect. **a** Starting position; **b** all phalanges rotated by 45°; **c** +45° and 1st phalange locked; **d** +45° and 1st and 2nd phalanges locked; **e** view of pulleys. J1, J2 and J3 denote joints, and L1, L2 and L3 denote links

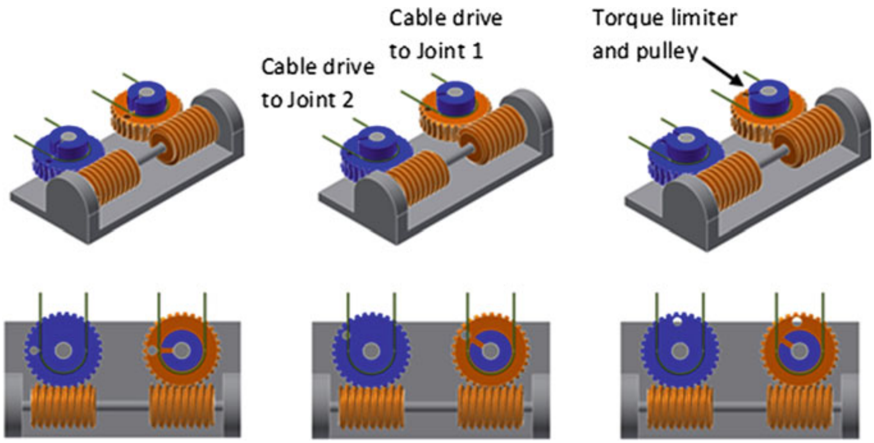


Fig. 5 Concept 3: Dual worm and wheel drive

idler pulley on the axis of the first joint (not shown in Fig. 5). When both joints are unimpeded, both output pulleys rotate but only the first joint actuates due to the motion compensation effect described for Concept 2 above. When the motion of the first joint becomes impeded, output 1 pinion stops rotating and the torque limiter slips, and the drive is directed only to the second joint which then starts to rotate.

Concept 4 (*Linear sliding friction plates*) is shown in Fig. 6. It involves members that travel linearly on tracks, and that are coupled via a friction surface that serves as a clutch. Each member is coupled to a joint via a cable drive, and when both members move, only the first joint actuates due to the motion compensation

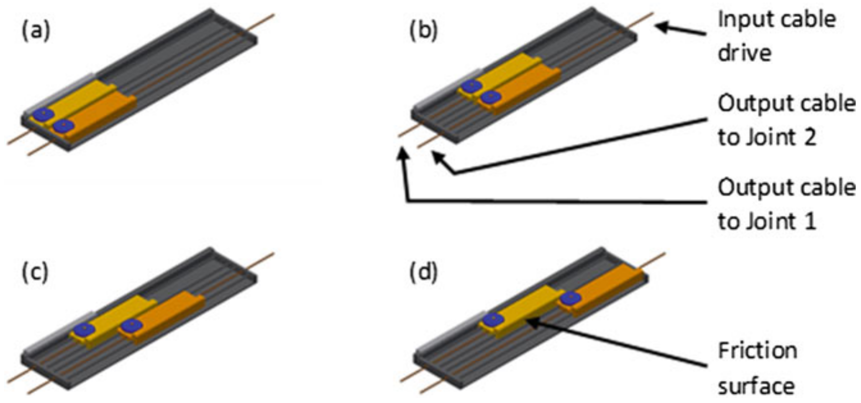


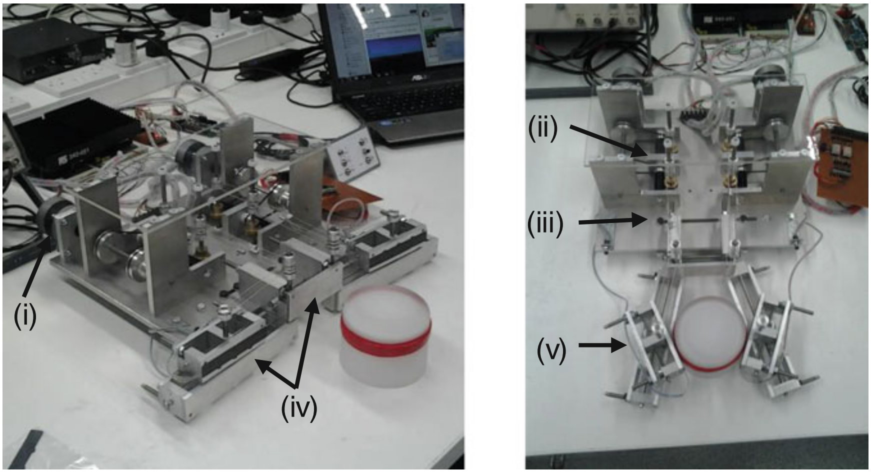
Fig. 6 Concept 4: Linear sliding friction plates. **a** Initial position, start of motion; **b** First output locks; **c** Friction force exceeded, further motion for second output; **d** maximum travel possible

effect explained above. When motion of the first member is no longer possible, the clutch slips and the second member continues to move, initiating actuation of the second joint.

Sixteen criteria were used to evaluate the generated concepts, and these were compared through the *digital logic* method [11] and ranked as follows: (1) extendibility of concept to more than two outputs; (2) ease of setting initial output angles; (3) maintaining output torques; (4) ease of setting of threshold torques; (5) available range of threshold torques; (6) compatibility with preferred transmission method; (7) wasted time during actuation cycle; (8) ease of maintenance; (9) potential accuracy/mechanical issues that may require substantial effort to address; (10) cost; (11) manufacturability; (12) use of standard components; (13) ease to change output ratios; (14) size and weight; (15) ease to reconfigure from sequential to simultaneous outputs; and (16) opposite output sequence for opening and closing. Following the application of appropriate weighting factors to these criteria, all of the generated concepts were compared in a *decision matrix*, and the preferred solution was found to be Concept 3.

3 Design and Development of the Experimental Test Bed

Separate morphological charts were drawn up for the design of the fingers and palm, and for the transmission of motion to the joints, in either case involving the generation of different alternative concepts for each desired property of the design. Solution selection to satisfy each requirement was carried out using a methodology similar to that described in Sect. 2 above, involving the generation, ranking and weighting of design criteria, and the use of decision matrices.



(a) (b)

Fig. 7 Prototype of the underactuated hand test bed: **a** start of the grasping process; **b** grasped object. Figures show (*i*) motor; (*ii*) switching mechanism; (*iii*) variable palm width setting; (*iv*) variable palm and link thickness; (*v*) variable link lengths

Variable effective length of the links (i.e. variable distance between joints) was achieved through the use of prismatic joints that could be set as required. A similar approach was used to vary the width of the palm. Interference between consecutive links was avoided by using single shear joints between the links, and having the links operate in different planes. Variable palm depth and effective link thickness were achieved through the use of adjustable contact plates that were attached to the inside surfaces of the palm and links. Variable frictional properties of the links were achieved through the use of different contact materials that could be attached using double-sided tape. Transmission of motion and torque was achieved through the use of miniature pulleys and elastic belt drives.

Actuation of the fingers was effected using two stepper motors, and linear force sensing strips were attached to the links to give both force and position feedback regarding contact with an object during grasping. Control of the system was achieved through the use of an Arduino microcontroller. Photos showing the grasping of a disk shaped object by the gripper, and showing also the mechanical and transmission components of the test bed, are given in Fig. 7.

4 Conclusion

This work makes two contributions to the study of underactuated grasping mechanisms. Firstly, four new concepts for the design of a triggered type switching device are presented and added to the literature. Secondly, the development of a versatile test bed that can be used for experimental work on planar grasping by an underactuated hand is presented briefly. The test bed has involved the solution of challenging mechanical problems in order to satisfy the design objectives that were set. The work on the test bed that is presented here is targeted mainly at proof of concept. Ongoing work involves refinement of the test bed to optimize its performance, and this will be followed by its application to rigorous experimental work to validate the simulation results on the influence of the various hand parameters on grasping performance.

References

1. Laliberté, T., Gosselin, C.M.: Simulation and design of underactuated mechanical hands. Mech. Mach. Theory **33**(1/2), 39–57 (1998)
2. Bégoc, V., Krut, S., Dombre, E., Durand, C., Pierrot, F.: Mechanical design of a new pneumatically driven underactuated hand. In: Proceedings of the IEEE International Conference on Robotics and Automation ICRA2007, pp. 927–933. Rome, Italy (2007)
3. Krut, S., Bégoc, Dombre, E., Pierrot, F.: Extension of the form-closure property to underactuated hands. IEEE Trans. Rob. **26**(5), 853–866 (2010)
4. Dollar, A.M., Howe, R.D.: Joint coupling design of underactuated hands for unstructured environments. Int. J. Robot. Res. **30**(9), 1157–1169 (2011)
5. Saliba, M.A., de Silva, C.W.: Quasi-dynamic analysis, design optimization, and evaluation of a two-finger underactuated hand. Mechatronics **33**, 93–107 (2016)
6. Saliba, M.A., de Silva, C.W.: An innovative robotic gripper for grasping and handling research. In: Proceedings of the IEEE International Conference on Industrial Electronics, Control and Instrumentation IECON'91, vol. 2, pp. 975–979. Kobe, Japan (1991)
7. Ulrich, N., Kuman, V.: Grasping using fingers with coupled joints. ASME Trends Dev. Mech. **3**, 201–207 (1988)
8. Ulrich, N.T.: Methods and apparatus for mechanically intelligent grasping. US Patent No. 4 957 320 (1990)
9. Townsend, W.: The BarrettHand grasper—programmably flexible part handling and assembly. Ind. Rob. Int. J. **27**(3), 181–188 (2000)
10. Lee: Artificial dexterous hand. US Patent No. 4 946 380 (1990)
11. Farag, M.M.: Materials Selection for Engineering Design. Prentice-Hall, New York, NY (1997)