Tethered Detachable Hook for the Spiderman Locomotion (Design of the Hook and Its Launching Winch)

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Abstract. This paper introduces a new concept of "tethered detachable hook (TDH)" and its launching winch. TDH system is the device which will be mounted on a mobile robot and enhances its traversability over extremely hostile terrain by launching detachable hook to nearby objects, producing large traction force by the tether and detaching/recovering the hook to the launcher again. In this paper the authors first of all introduce several prototype models of the TDH. We then discuss the design of latest model which features pneumatic detaching mechanism, the pneumatic launcher and the reel mechanism having three motion states; active rotation, free rotation and braking. Finally, the result of several experiments of constructed TDH model will be explained.

1 Introduction

Many types of mobile robots have been developed so far to move on off-the-road terrains, such as modified wheel, track, legs, and snake-like configuration. Even jumping can be considered as one of the means for high mobility [1]. However, if long and steep slope or ditch much wider than the size of the robots is on the way, terrain adaptability of these conventional methods is not enough. In this paper, we propose a new type of locomotion method which assists the mobility of these mobile robots. It consists of "tethered detachable hook" and its launcher and winch system, which assists the mobile robot as shown in Fig.1(a). Here the mobile robot is going to climb the steep slope and the "tethered detachable hook" is launched to

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the branch of a tree. When the hook is connected to the branch, the winch winds the tether and produces large traction force to assist the robot to go over the steep slope. After the motion is over, the hook is detached from the branch by changing the shape of the hook to smooth and linear shape, rewinding the winch, and finally restoring the hook in the launcher again to prepare for the next launching task. If the mobile robot has more than two tethered detachable hooks and their launcher-winch system, it can even lift itself from the ground and move from branch to branch as shown in Fig.1(b). This is like the motion of long-armed ape in forest or the spiderman flying from building to building.

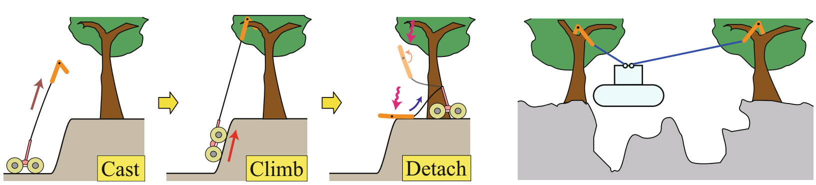
Until now several tethered robots were already proposed, such as TITAN VII [2] or DANTE II [3]. They are supported by tethers which are anchored beforehand at the top of the slopes. Cliffbot [4] is supported by an anchor robot which stays at the top of the cliff and connected by the tether. Casting manipulator [5] has the tether with a gripper at the end and casted to catch an object. Although the objective of this casting manipulator was for the manipulation of a remotely located object, the concept can easily be extended to the supporting system for mobile robot. The automated tether management system [6] is most closely related to our concept. It used a tether with a gripper which can be remotely operated to lock or detach it and help the flying motion of a space robot. But as it is designed for the activity in micro-gravity environment, the system can not directly apply for the application of field robotics which we are targeting in this paper.

This paper is organized as follows. Section 2 describes the design of former models of TDH. Section 3 presents design of the latest model of TDH and its launching winch. Section 4 reports experimental results of the constructed TDH and its launching winch. Section 5 concludes the results and proposes future works.

2 Former Models of Tethered Detachable Hook

2.1 Model I

As the first model of the "tethered detachable hook", the authors developed the Model I as shown in Fig.2(a). Although we call it as "tethered detachable hook", we did not selected the hook but gripper. As shown in Fig.2(a) and (b), the gripper is designed to grip an object when the tip end of the rod contact the object and hold



(a) Slope climbing by using TDH (b) Ditch crossing by using a pair of TDHs

Fig. 1 Concept of tethered locomotion by using tethered detachable hook(TDH) its gripping state by the ratchet mechanism. Ability to hold the object tight was the main reason why we selected gripper configuration for this first model. Release of the gripping motion is designed to be done by a mechanical memory system. The mechanical memory system is already used in the ballpoint pen with different colors. It consists of a cylindrical cam with zigzag grooves (Fig.2(c)) in which the pin fixed to the external cylinder is inserted. When the tension of the tether connected to the cylindrical cam changes and drives the cam to make reciprocating motion, the cam is driven by the pin and starts to rotate in one direction. In the three zigzag grooves, one of the grooves is made longer, so the ratchet release rod is inserted in the ratchet trigger to release the ratchet and open the finger every three times of the pulling motion of the tether.

For this Model I we also made simple launcher and made the experiment to cast it to the branch. Once it is gripped the branch, it showed strong connection and release motion was also very smooth. But the problem of this first model was its difficulty of aiming at the target object (branch). The gripper should be aimed at the object precisely in position and also in orientation; otherwise the gripper could not hold the object successfully. This is the big problem if we hope to make automatic launching system. Another problem of this first model was the shape of the gripper in open state. It is not streamlined and there is always the danger to be stacked in narrow gap.

2.2 *Model II*

To solve the difficulty of precise aiming of the target, we selected hook for the following models. The Model II of the tethered detachable hook is shown in Fig.3. As shown in Fig.3, the Model II also adopted the mechanical memory system, and it could be released by pulling the tether for few times. Repeated traction of the tether rotate the cylindrical cam and it drives the lock lever, and release the stopper to open the claws.

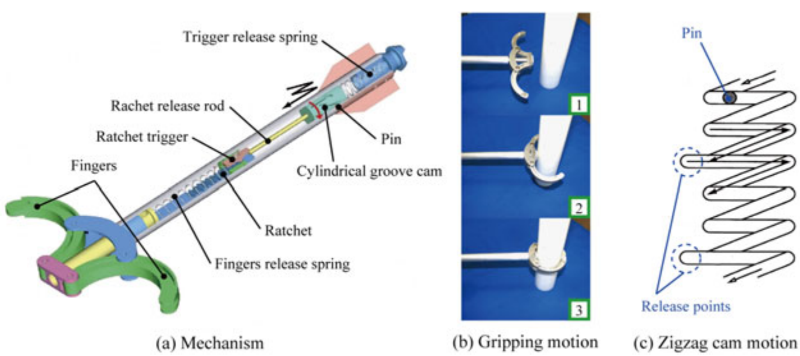


Fig. 2 Mechanism of the TDH model I

The Model II has four claws attached radially at the end of the hook so that the hook can be anchored to the target object much easier than the gripper. It can be hooked the target object only by throwing it over the target. The Model II was much easier to connect to the target objects than former model, however it still remained several problems. One of them is its weight. As there are four claws, it is heavy and powerful launcher is needed. The second problem is the shape of the hook in release state. Although the shape is more streamlined than that of Model I, the shape is still in wedge like and there remained the possibility to be stack in narrow gap while it is recovering to the launcher. The third problem is the possibility of mal-operation of the mechanical memory system, for the tether will always be affected by accidental pulling and releasing motion and it may be released by chance.

2.3 *Model III*

To solve the problems mentioned above, we developed Model III. The model III has three important modifications as follows;

1. reduce the number of claws from four to one
2. change the shape of the hook as a simple rod in the release state
3. introduce active detaching mechanism

Modification 1 is done to reduce the weight of the hook. We selected four claws configuration for the Model II to secure reliable anchor action in any posture of the hook. However, we found that even one claw hook can exhibit similar action only by adding enough length and weight to the claw. Effect of this configuration is observed in the experiment of Fig.10. In this experiment, when the hook pulled slowly over a branch (in this case a pipe), the hook will rotate around its stem and let the claw lower on the branch as the claw is heavy, and thus the claw grips the branch.

Modification 2 is done to minimize the stack action while the hook is in retracting state. As shown in Fig.4, the hook is designed to change from L-shaped state to linear-shaped state. Difficulty of realizing this shape was in the joint design of the claw. As large torque is applied at the joint to support large traction force of the tether, the joint mechanism has to produce large torque and the joint tends to be bulky and heavy. To solve this problem, we introduced tether supported joint

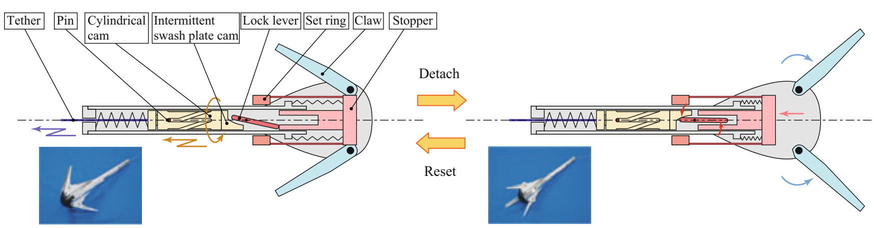


Fig. 3 Mechanism of the TDH model II

mechanism. In this mechanism, the end of the tether is connected to the claw and joint torque is directly supported by the traction of tether as shown in Fig.4. The tether is designed to go out of the joint to produce large torque in this hooked state. In the linear-shaped state, to the contrary, the tether retracts inside the joint and the joint is made slender.

Modification 3 is done to eliminate the expected malfunction of the release motion depending upon the accidental pulling action of the tether. The mechanical memory system was ideal because normal rope can be used as the tether and lock-and-release mechanism of the hook in Model II, or gripper in Model I could be made comparatively simple. To make comparative system with high reliability, we considered electric and pneumatic types of trigger driving mechanisms.

Design of the electric detachable mechanism is shown in Fig.5. A stopper is connected to the tether and the stopper is locked by a trigger that is fixed by the rod (Phase 1). In this state, the hook holds L shaped configuration and act as an anchor. Release motion of the hook is done by rotating the screw by the small motor and slides the rod fixing the rotation of the trigger. This motion frees the stopper and the tether automatically slides to open the claw in a release state by the spring attached around the joint (Phase 2). Required electric current is very small and it can be supplied by small diameter electric wire inside the tether. As the tether has to support large traction force, we used a Kevlar® fiber-reinforced wire together with the fine electric wires. The authors have already used it as the "Hyper Tether" system [7] and Anchor climber [8].

A pneumatic detachable mechanism is shown in Fig.6. The tether consists of air tube and wire, and the end of the tube is connected to a small air bag which is located inside a stopper. The stopper can slide inside a pipe fixed to the hook and the stopper

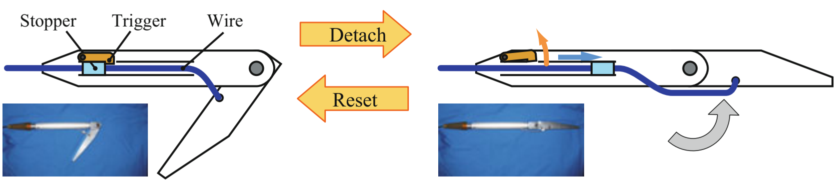


Fig. 4 Basic structure of the TDH model III

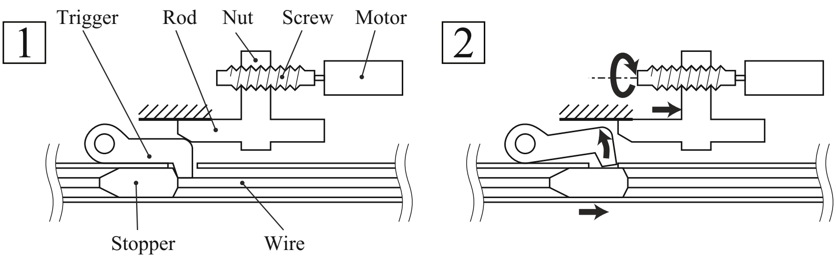


Fig. 5 Electric detach type of the TDH model III

Table 1 Specifications of the TDH model II & III

Type	Mass	Total length	Length of claw
Model II	840 [g]	435 [mm]	85 [mm]
Model III (Electric)	395 [g]	325 [mm]	150 [mm]
Model III (Pneumatic)	390 [g]	345 [mm]	150 [mm]

is locked by the trigger as shown in Fig.6 (Phase 1). The wire inside the air tube is connected to the stopper and the end of the wire is connected to the claw. Detaching motion of the hook can be done by supplying pressurized air in the air tube and expand the airbag. Expanded airbag pushes out the projection point of the bag and drive the trigger out of the hole and release the stopper (Phase 2). It enables the stopper and the wire connected to slide freely and open the claw. Although the gap between air tube and wire (polyethilene line) is small, we found that the pressurized air could easily be transmitted along the air tube longer than 10[m] with ease.

We successfully made both types of detachable mechanisms and verified their motions. Specifications of these types are shown in Table 1 with those of Model II. Between these types, we selected the pneumatic type, because tether of the pneumatic type can be lighter and driving mechanism of the hook can be lighter and rugged enough to be protected against the shock.

3 Design of Launching Winch for the Tethered Detachable Hook

A casting device developed for TDH Model III is shown in Fig.7. It consists of a launcher for the hook and a winch to wind the tether.

First we describe a launcher. Among the spring type and pneumatic cylinder type, we found that the pneumatic one is better because it can generate powerful and high speed launching motion with lightweight mechanism. We already adopted pneumatic hook detachable system and selection of the pneumatic system for the launcher will have other effect to make the total system simple. One of the most

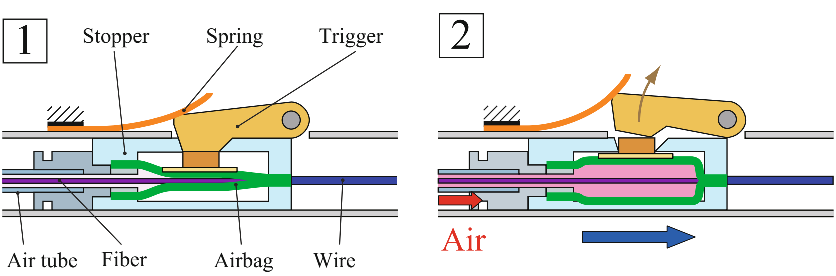


Fig. 6 Pneumatic detach type of the TDH model III

important parts of the launching system is in its trigger mechanism, and designed mechanism is shown in Fig.8. At first, a piston is locked by a ball type trigger, and is pressed by high-pressured air from "Port A" as shown in Fig.8(a). At this time, high-pressured air from "Port B", that is for the control rod, is also supplied. Launch motion can be done by decompress the air for "Port B" and drive the control rod out of the balls and let the air pressure from "Port A" drives the piston go right direction and launch the hook(Fig.8(b)). Compared with the trigger mechanism using normal valve, introduced mechanism can makes the trigger motion smoothly and as the pressurized air gives pressure to the hook from the beginning, it can increase the initial speed of the hook and enable it to cast in longer distance.

Next we explain a winch for the TDH. It is designed to have three modes; drive mode, free mode and brake mode.

The "drive mode" is used when it is used as winch, and large traction force should be generated to support a robot. The "free mode" is used when the hook is going to be launched. As the spool have to rotate in high speed, the actuator to produce large traction force in drive mode should be mechanically disconnected. The "brake mode" is needed for two reasons, one of them is to support the suspended robot without energy loss and the other is to adjust the rotational speed of the winch when it is in "free mode" and launching the hook. As the hook is launched by pneumatic pressure, winch in free mode tends to keep rotating while the hook is flying. However the speed of the hook decelerates while flying and the tether tends to excessively goes out of the reel and entangle around the reel. This phenomenon

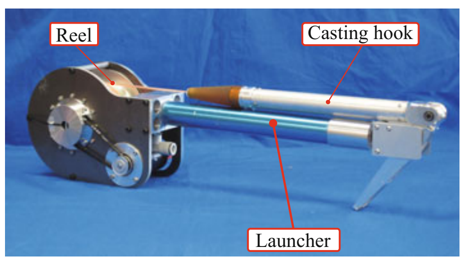


Fig. 7 Overview of a launching winch with pneumatic TDH model III

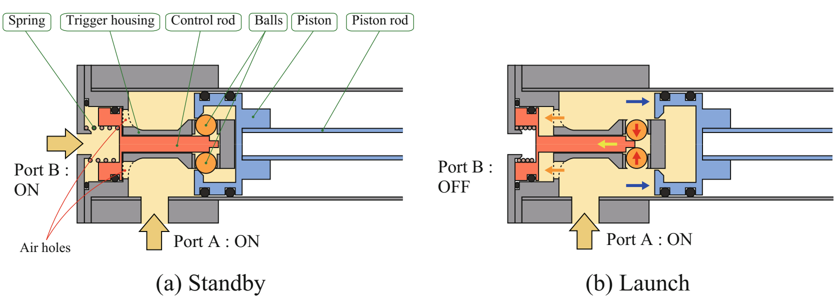


Fig. 8 Pneumatic trigger mechanism of the launcher

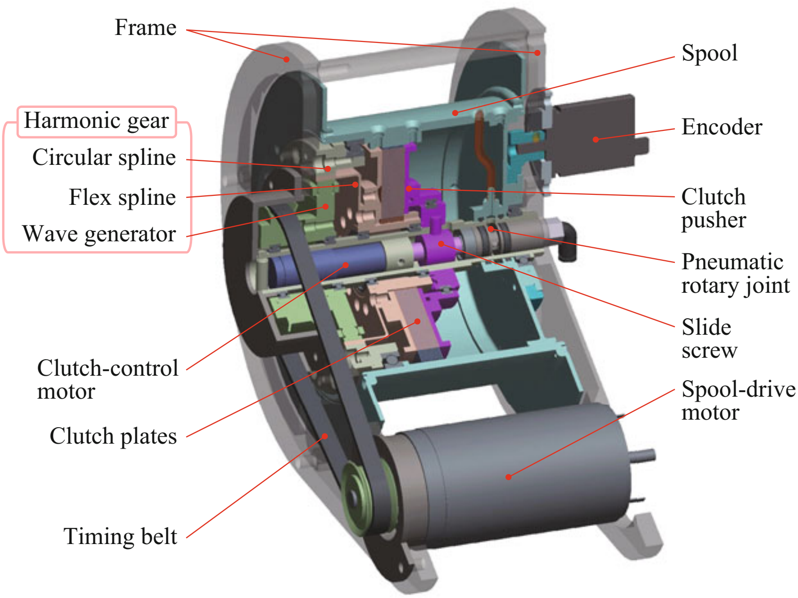


Fig. 9 Mechanism of the winch

is called as ”backrush” among anglers for their fishing reel motion. To prevent the backrush we need proper braking of the winch in the free mode.

To switch these 3 modes, we adopted a multi-plate clutch mechanism which is installed inside the spool as shown in Fig.9. Multiple input and output clutch plates are piled up to increase the braking torque. Maximum torque of this clutch mechanism T_c can be estimated as follows;

$$T_c = N_p \mu F_p r_e \quad (1)$$

where, N_p is the number of friction surfaces between clutch plates, μ is the coefficient of static friction, F_p is a pushing force for clutch plates generated by the motor thrusting force and r_e is an effective radius of friction surfaces.

As the winch rotate infinitely and pressurize air have to be supplied to the air tube to connect the hook, a rotary pneumatic joint is introduced. Air is supplied from a joint in right section of the figure, and it pass through holes on a hollow shaft. Two movable O-rings are installed to prevent the leak of the air.

4 Experiment

The authors confirmed motion performance of tethered detachable hook of Model III. Basic motion to hook the object was examined as shown in Fig.10. As is discussed before, the claw was automatically lowered and gripped the branch when the hook was pulled and located above the object. From this experiment, we confirmed the validity of introducing the one claw configuration for the TDH.

Next, the authors made a simple experiment of casting the Model III TDH to the real branch of the tree as shown in Fig.11. From this experiment, the anchoring function of the hook and its detaching motion was successfully demonstrated. Besides, smooth collection was achieved because of its straight shape after the detaching motion.

With the casting device mentioned above, the authors also made the experiments to verify the effectiveness of the prevention of "backrush" by the braking. Fig.12(a) shows the comparison of the tether on the after launching the hook. Left is the result without braking and right is the result with proper braking. From the comparison of these results, we know the importance of the braking of the winch in free mode. Fig.12(b) shows measurement results of outer circumferential velocity of the winch. They were measured by an encoder connected to the winch. From this figure too, we can know that proper braking enable to increase the launching speed. In Fig.12(b) we can observe the speed change of the reel at the time near the 1.2[sec]. It is caused by the falls of the hook on the ground.

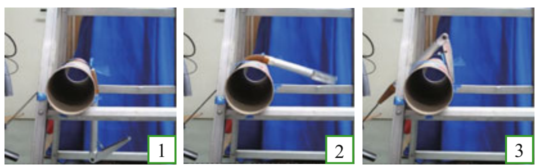


Fig. 10 Sequential motion to show the self adjustment of the claw direction to the target branch

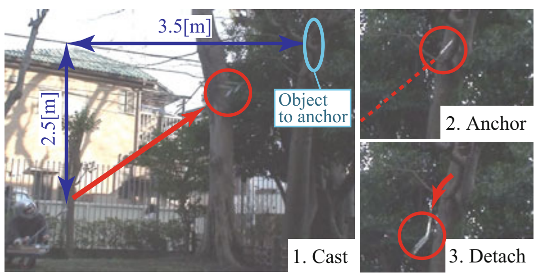
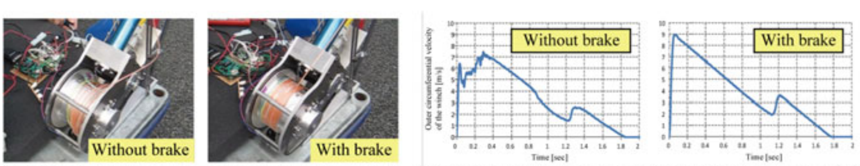


Fig. 11 Real launching experiment of the TDH model III to the branch of a tree



(a) Comparison of the tether with and without braking control (b) Measurement results of outer circumferential velocity of the winch

Fig. 12 Comparison experiment with and without braking control

5 Conclusions and Future Works

This paper introduces a new concept of ”tethered detachable hook (TDH)” and its launching winch for use as the locomotion assisting device for mobile robots. This paper firstly discusses about several prototype models of the TDH and elaborate latest model, such as pneumatic lock and release mechanism of the hook, pneumatic launcher and the reel mechanism which exhibits three motion states; active rotation, free rotation, and braking of the rotation. Performance of developed TDH and its launching winch are successfully demonstrated by the constructed mechanical model. Study of the proposing gtethered detachable hook (TDH)h is still at the starting point, and there remained many interesting research subjects to be studied on the hook, launcher, and winch mechanisms and their control. We are hoping to study further on these points and realize the mobile robots having TDH and move around mountainous area or disaster site by successively casting the tethers around the environment just like Spiderman does among buildings in near future.

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