論文 / 著書情報
Article / Book Information

論題(和文)	
Title(English)	A Proposal of a Watch-like Attachable Device for Long-Reach Robotic Arm Enhancement
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出典(和文)	ロボティクス・メカトロニクス講演会2019講演論文集, , ,
Citation(English)	, , ,
発行日 / Pub. date	2019, 6

A Proposal of a Watch-like Attachable Device for Long-Reach Robotic Arm Enhancement

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This paper proposes a modular watch-like thrust-generating concept, called flying watch, which can be attached to a robotic arm to enhance arm strength. Multiple flying watches can be attached with an attachment style customized to a specific mission. Flying watch has a compact propulsion system in order to avoid collision and removable and adjustable watch bands similar to wristwatch in order to be attached to different robotic arms. After attachment, flying watches adapt their thrusts to cooperate with existing arm actuators to reduce their loads. Flying watch provides existing long arms higher strength and versatility to accomplish more missions and gives roboticists more flexibility to build more slim long arms. The important elements for realizing such concept will be detailed in this paper.

Key Words: Thrust Generating Device, Modular Design, Long-reach Robotic Arm

1. Introduction

Long robotic arms are important for applications such as nuclear plant decommissioning [1], inspection [2], and firefighting [3]. A major problem of designing and operating a long robotic arm is that a small distal external force on the arm can result in large torques on proximal joints due to large moment arms. Previous research focus on specialized arm designs to solve this problem. These designs include passively counteracting external forces using buoyancy [2] and spring [4] and actively counteracting external forces using tendons [1] and thrusts [3], [5].

However, these arm designs are difficult to be applied to existing arms or customized to different missions. For example, the long arm in [2] has helium body for counteracting gravity and tendons for actuation. Such specialize design is hard to be applied to the long arm in [1]. Also the arm in [2] can only be used for inspection since it can only support very small load. If we hope to use the arm to manipulate objects on the ground, the arm is difficult to be customized to such mission.

Therefore how to more easily improve the strength of a long arm and at the same time enable a long arm to accomplish more versatile missions is a practical and interesting problem. This paper proposes a concept call flying watch to solve this problem and discuss important implementation elements.

2. Flying Watch Concept

People wear different kinds of wristwatch for different missions (timekeeping, health monitoring, and communication, etc.). Wristwatches come with adjustable and removable watch bands to negotiate different wrist geometries and different abilities to satisfy people's needs. Similarly, robotic arms also have varieties of designs and need to accomplish different missions. Inspired by these facts and thrust driven robotic arms [3], [5], we propose a concept called flying watch.

A flying watch is a watch-like module with removable and adjustable watchband that can be attached to an arm with mission-dependent attachment styles and generates thrusts to enhance the arm.

The concept is illustrated in Fig. 1. When a long arm is required to lift up an object. Four flying watches are attached to generate thrusts in vertical directions to enhance the arm counteracting gravity. When the long arm is required to manipulate an object on the ground, since the reaction force may be from horizontal directions, two flying watches are attached to generate thrusts in horizontal directions and the other two flying watches are attached to generate thrusts in vertical directions. As a result, the arm can counteract reaction forces in both horizontal and vertical directions.

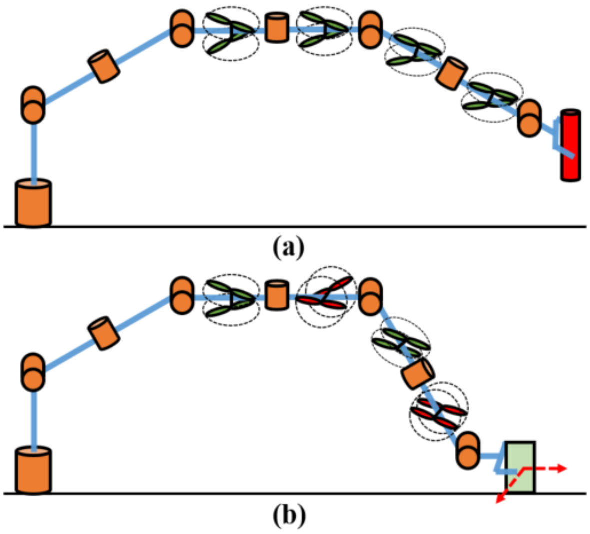

Fig.1 (a) Flying watches helping an arm lifting an object. (b) Flying watch helping an arm manipulate an object on the ground.

The main features of flying watch concept are as follows.

- Easily enhance different kinds of actuated arms by attachment.
- The attachment style can be customized to a specific mission.
- There are many options for watch cases and removable watch bands. Users can customize a flying watch based on their needs.

3. Implementation Elements

3.1 Propulsion Watch Case

For easy installation and avoidance of collision, the thrust generating system should be compact and safe. Some design options are shown in Fig. 2. Both air and water can be used as propulsion fluid and their possible directions are shown using arrows (white: air, blue: water).

For air propulsion, both propellers and ducted fan are available. Figure 2 (a) shows a sandwich-like design using propellers (propellers wrapping an arm link). Different from drone propeller designs, which usually arrange propellers on the same plane, the

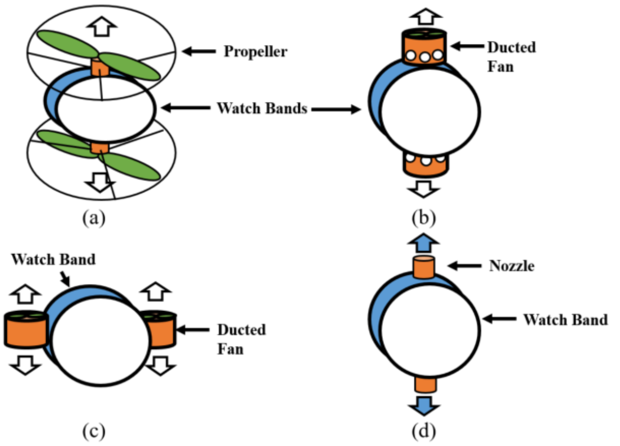

Fig.2 Example propulsion systems.

sandwich-like design is more compact and requires less attachment strength since half of the propulsion force is supported by the attached arm link. Such sandwich-like arrangement is also applied to Fig. 2 (b) and Fig. 2 (d). Figure 2 (b) and (c) show designs based on ducted fan. Compared with propellers, ducted fans can more efficiently generate thrusts with less noise, though the ducts increase weight and cost. The design in Fig 2 (b) uses side holes to suck air in and each ducted fan is only in charge of generating thrust in one direction. On the contrary, each ducted fan in Fig. 2 (c) can generate thrusts in two directions. With the same ducted fans, Fig. 2 (c) can generate more thrusts, though Fig. 2 (b) is more compact. For power supply, power cables instead of batteries should be used since the batteries that can support flying watch is too heavy and big to be attached on an arm. For water propulsion, the design is shown in Fig. 2 (d). Such watch may be useful for enhancing firefighting or underwater robotic arms. Each nozzle in Fig. 2 (d) is in charge of propulsion in one direction and the propulsion scale is controlled by valves. A major challenge for building such watch is that the reaction forces due to water hose stiffness is not negligible and should be modeled.

3.2 Watch Band

Typical wristwatch belts can be classified into two classes, pin belt and NATO belt. Pin belts use length adjustable pins to fix a watch belt with a watch case. On the contrary, NATO belts use an additional strap with end loop to fix a watch case. Each kind of watch belts can be closed with a certain adjustable closure, such as hook and loop tapes and Tang buckles.

Since a flying watch has two propulsion watch cases, we modified

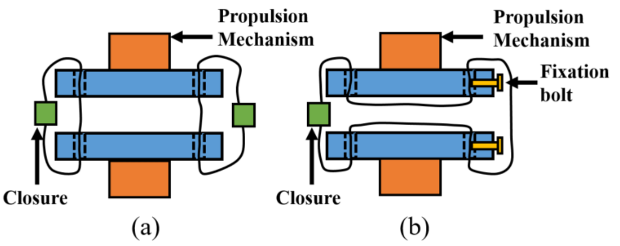

Fig.3 Attachment mechanism. (a) Modified pin belt. (b) Modified NATO belt.

pin watch belt and NATO belt so that they can be attached to two watch cases, as shown in Fig. 3. Both types of belts require two rectangle watch cases with two slots for belt fixation. Fig. 3 (a) shows modified pin belt and Fig. 3 (b) shows modified NATO belt. The green parts are a certain closure mechanism that could be hook and loop tapes, Tang buckles, lashing strap buckles, and tri-glide buckles. Rubber sheets should be glued to the watch cases or watch belts to increase friction.

3.3 Attachment Style

Attachment style means the position and orientation of flying watches with regard to corresponding local DH coordinates. For a certain mission, the trajectories of an arm and possible external forces should be investigated. A designing tool is necessary to take these information and generate an optimal attachment style. Also given an attachment style, an analysis tool is necessary for predicting what kind of end effector reaction force the flying watches are good or bad at counteracting.

3.4 Thrust Planning

Thrust planning is about planning appropriate flying watch thrusts in order to cooperate with existing actuators to improve arm strength. Our usage of thrusts is different from that of [3] and [5], since we use thrusts for cooperating with existing actuators and they use thrusts for actuating passive joints. Enhancing arm strength can be understood as reducing the maximum normalized actuator loads. The normalization should be done using actuator specifications such as gear ratios and maximum continuous torques.

Depending on whether thrust planning happens during arm operation, thrust planning can be classified into online thrust planning and offline thrust planning. Online thrust planning can make thrusts react to sudden external force changes. Offline thrust planning, on the other hand, can plan both arm trajectory and thrusts for a specific mission.

4. Conclusion

In this paper, we proposed a watch-like module, flying watch, which can be attached to a long robotic arm with mission dependent attachment styles and improve arm strength. The important elements for realizing flying watch is discussed in the paper.

Currently, we have built flying watch prototype based on Fig. 2 (a) and attached it on a 3 DoF arm, as shown in Fig. 4. The flying watch can properly generate thrusts. In the future, we will do physical experiment to verify the effectiveness of flying watch.

Acknowledgement

Present study includes the result of Advanced Research and Education Program for Nuclear Decommissioning (ARED) entrusted to Tokyo Institute of Technology by the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT). This work is partially based on results obtained from a project commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

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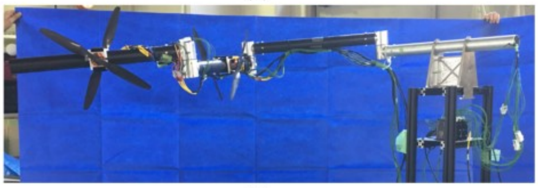
(a)



(b)

Fig.4 (a) Flying watch prototype. (b) Two flying watch prototypes attached to a 3 DoF robotic arm.

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