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Design and Construction of a Robot Hand Prototype for Underwater Applications

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Abstract: This paper describes the design process and the construction stages of a multi-fingered robot hand prototype, named GUH14, to be used in underwater environment. The prototype was developed in collaboration by the University of Calabria and the University of Girona, with the goal of designing and building an underwater robotic hand that can be implemented on robot arms. This project is aimed to develop prototype solutions for grasping and manipulation operations in a submarine environment. The hand is composed by a palm and three independent fingers, each with three degrees of freedom (hereinafter, DoF), actuated by servomotors through hybrid transmission, tendons and gearing. The design and manufacturing procedures that allowed for the operation of the prototype will be discussed. This paper summarizes the obtained results.

Keywords: Underwater application, AUV, Manipulation, Robot hand, Hand design.

1. INTRODUCTION

In the world of scientific research, there is a particular attention to innovative robotic manipulators for next-generation robots. These devices should be able to compete with the human hand in terms of functionality. This field of robotics has recently known a notable development, thanks to the growing interest towards its multiple applications, including medical implants or automated devices capable of replacing human intervention in activities such as manipulation and exploration in hostile environments.

There are two types of robotic hands: humanoid and industrial. The former are based on the anatomical principles of the human hand, and are usually equipped with 2, 3 or 4 fingers, plus an opposable thumb. The latter are instead comparable to grippers for grasping objects, cutting cables, etc. In the last twenty years, many results - sometimes surprising - have been achieved, but the new generation of robotic hands requires a qualitative leap, both in terms of functional ability (dexterity) and application compatibility, i.e. reliability, constructive simplicity, low cost, reduced size and weight, and, in particular, the ability to operate in extreme environments.

The Robotiq Robot Gripper, Schunk 2-Jaw Gripper (2013) and flexible robotic Gripper (Sam et al., 2008) models are a good example of industrial robotic hands suitable for performing repetitive tasks with extreme precision, as required in industries such as pharmaceutical research or food processing. The Barret Hand (William T. Townsend et al., 2000) and NU Hand (Kappassov et al., 2013) models are instead an example of anthropomorphic hands, more flexible and suitable for carrying out various tasks. In fact, these models are able to grasp rigid and non-rigid objects, as they're equipped with multiple fingers. In the case of the DLR-Hand (Liu et al., 2008), each finger is actuated by an independent mechanism. The motor transfers the motion via tendons, in a way that replicates the function of muscles and ligaments. The Gifu Hand III (Mouri et al., 2002) is instead equipped with 5 fingers - 4 DoF for the thumb and 3 DoF for the fingers. All 16 joints feature an independent motorization.

The growing interest shown by oil & gas, military and oceanographic research industries for submarine technologies has led to the development of new tools for improving underwater operations; among them, underwater end effectors have emerged as indispensable devices for many vehicles such as ROVs, AUVs, and so on. In contrast to terrestrial applications, there are few references in the literature for underwater robotic hands (Lane et al., 1997; Gad at al., 2004; Meng et al., 2006; DFKI, 2010). Most models described in literature are simple end effectors equipped with a gripper; therefore they are classified as industrial hands. But if one takes into account the typical tasks to be carried out underwater, the scope of functions offered by industrial hands is quite narrow, since many applications require operations that currently can be performed only by anthropomorphic hands, such as turning valves, grasping cables, or retrieving objects or archaeological finds. The "Three-fingered gripper" (Bemfica, 2014) is an underwater anthropomorphic hand capable of performing the typical functions of this category. A commercially available device is the HDT's Adroit (HDT Global), used by the US Navy's Office of Naval Research (ONR).

The main goal of this project was to minimize weight and size of the robot hand, in order to make it usable on small-sized ROVs (when coupled with robotic arms) and with neutral buoyancy. Starting from the study of the literature, the proposed solution presents some original concepts for the

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actuation mechanisms and the manufacturing process, featuring an intensive use of rapid prototyping techniques.

This paper is organized as follows: the first part will introduce the design specifications and the construction technologies. In the second part, we will describe the proposed design solutions, focusing on the gearing elements. The last section presents the construction and testing of the prototype.

2. REQUIREMENTS

The project goal was the creation of an underwater anthropomorphic hand capable of being coupled with robot arms on small to medium size ROVs and AUVs.

In order to achieve this goal, the hand was equipped with two fingers, plus an opposable thumb. This solution was intended to satisfy the functional requirements related to operations such as opening and closing valves, connect or disconnect connectors, activating and deactivating switches, recovering or laying cables and/or hoses on the seabed, and collecting objects - also of irregular shape - and samples of the seabed. At the same time, it was also possible to minimize as much as possible the problems related to waterproofing and space/weight requirements of the hand.

In this phase of development of the first prototype, we decided to design a hand capable of operating up to 60 meters; so, we have defined materials and geometric dimensioning of the hand for this operative condition. Another very important issue was the neutral buoyancy of the joint in the water, in order to prevent any actual reduction of the force generated by the arm and to facilitate the manipulation of large and neutrally buoyant items. The selected materials have subsequently driven the choice for the manufacturing technologies to be employed for the various components of the hand. These techniques were: a) machining with conventional machine tools, and b) additive manufacturing (Kruth, 1998). The choice of the most suitable technology has been driven by the analysis the design constraints and the different functional characteristics for each component. It should be noted that the techniques described above are very different from each other, in terms of design approach, times and systems of production.

In order to satisfy the requirements for the gripping of objects of any size and shape on the seabed, the hand has been designed to allow the fingers to flex on the palm. Therefore, the solution required 3DoF and an independent actuation for each finger. Finally, the implementation of the finger kinematics required two different transmission architectures typically used in terrestrial applications, i.e. "tendons" and gears, so as to ensure the maximum flexibility, a good clamping force, a greater reliability and simplicity of construction. It must be noted that while the use of a motor for each of the 3 joints ensures a greater control, the complexity of the joint is also increased, not to mention the risk of possible failures of the prototype if any water infiltration occurs. For this reason, the tendon transmission was adopted for the last two phalanges, which require no special precautions to avoid contact with the water, while the gearing has been implemented only on the first phalanx. The mixed solution proposed in this paper, based on servomotors, gearings and tendons, appears to be an original and cost-effective solution to solve the problems related to the articulation of the underwater robotic hand.

3. HAND DESIGN

For the articulation of the first phalanx, the architecture of the specific finger was built inside the palm of the hand, featuring a driving gear (A) connected to the servomotor (B) that transfers the motion to a driven gear (C) by means of a belt (D); the drive torque, suitably amplified by a gearing (E), is transmitted to the articulation of the finger (see Figure 1).

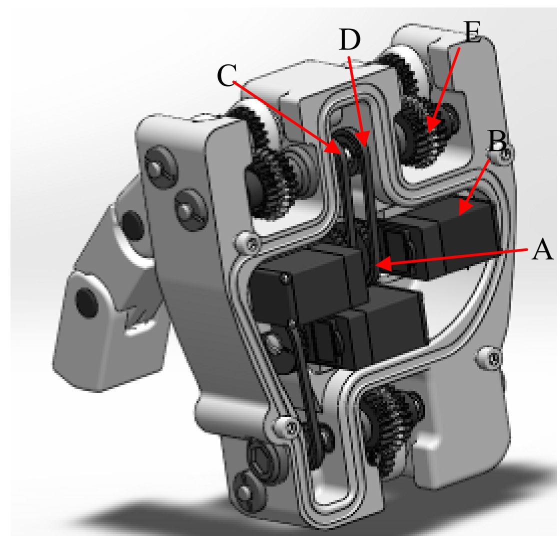

Fig. 1. Layout of the hand

For the actuation system, the choice fell on programmable servomotors hitec hs5646, not specific to underwater applications, but capable of expressing a maximum torque of 12.5 kg*cm at 7V; this value can ensure a good tightening for each finger, and also a good speed of opening and closing (equal to 0.2 sec/60°). The chosen servomotors work in a range that varies approximately of ± 60°. Belts are used to couple servo motors and drive shafts for the transmission of power. They are made with elastomer reinforced by glass fibers and they are particularly suitable to ensure a correct kinematics and the flexibility of the fingers.

For the articulation of the last two phalanges, a comparative analysis was conducted on tendons made of nylon and carbon fibre: the former has proven to be the best choice for ensuring a greater elasticity of the filament and minimizing the danger of breakage of the finger in case of accidental impacts. The filaments have been designed to pass through two ducts, located in the front part and in the back of the finger itself (Figure 2). In this way, each tendon, while appropriately balancing the pulling forces, is able to open or close the phalanges.