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3D Design Setup for Humanoid and Quadruped Robots

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Abstract

Deployment of mobile robots in dynamic environments remains a significant challenge in robotics. Currently, robotic grippers are not dexterous enough to perform tasks designed for humans. There are still significant challenges holding back the achievement of human-like dexterity. To achieve a faster large-scale deployment of mobile robots, alternative solutions to dexterous grippers need to be examined. One alternative solution is a tool grasp interface designed for robots. Using the grasp interface, mobile robots can perform tasks typically performed with human tools. This thesis provides an overview of mobile robots and the current state of robotic grippers, with particular focus on commercially available two-finger grippers. A literature review is conducted to examine existing gripper technologies and their actuation methods. Based on the review and analysis of gripper specifications from major manufacturers, the requirements for a grasp interface are defined to ensure compatibility with a wide range of grippers and to improve graspability during rotational tasks. Visual prototypes are made, and finally, three design iterations are presented and evaluated.

Keywords: Mobile robot, Tool grasp interface, Robotic gripper

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Tiivistelmä

Mobiilirobottien käyttöönotto muuttuvissa ympäristöissä on tällä hetkellä suuri haaste robotiikan alalla. Robottitarttujat eivät ole tarpeeksi käteviä suorittaakseen tehtäviä, jotka on alun perin suunniteltu ihmisten tehtäviksi. Jotta robottitarttujat voisivat olla yhtä käteviä kuin ihmiset, pitäisi ratkaista vielä useita ongelmia. Kätevän robottitarttujan lisäksi tulee tarkastella muita mahdollisia ratkaisuja, jotta mobiilirobottien käyttöönottoa muuttuvissa ympäristöissä voitaisiin nopeuttaa. Yksi mahdollinen ratkaisu voisi olla työkalun kahva, joka on suunniteltu robottien käyttöön. Robotit voisivat suorittaa ihmisten työkaluille suunniteltuja tehtäviä työkalulla, jossa olisi tällainen kahva. Kaksisormisille tarttujille soveltuva kahva suunnitellaan osana tätä tutkielmaa. Tutkielma antaa yleiskuvan mobiiliroboteista ja siitä, millaisia robottitarttujia nykyään on käytössä ja saatavilla. Tutkielmassa tarkastellaan erityisesti kaupallisesti saatavilla olevia kaksisormisia tarttujia. Kirjallisuuskatsauksessa tarkastellaan olemassa olevia tarttujatyyppejä ja niiden toimintaa. Tutkielmassa tarkastellaan myös suurimpien robottitarttujavalmistajien tarjoamien kaksisormisten tarttujien teknisiä tietoja. Niiden pohjalta määritellään vaatimukset suunniteltavalle kahvalle. Kahvasta tehdään visuaalinen prototyyppi ja lopuksi esitellään kolme erilaista mallia ja arvioidaan niiden soveltuvuutta haluttuun käyttötarkoitukseen.

Avainsanat: Mobiilirobotti, Työkalun kahva, Robottitarttuja

Tämä tutkielma on osittain Skya AI Finlandin tilaama. Lisäksi Grammarly-tekoälysovellusta käytettiin tutkielman kieliopin parantamiseen. Tutkielman kirjoittaja on tarkastanut tekstin ja ottaa täyden vastuun tutkielman sisällöstä.

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1 Introduction

Mobile robots are not stationary, like basic robotic arms, but can move around in their surroundings. There are many types of mobile robots, and depending on mobility requirements, they can be legged, wheeled, aerial, or underwater. Mobile robots were first introduced in the 1950s and have continued to advance since, driven by improvements in technologies such as sensor fusion and machine learning [1].

A humanoid robot is a legged mobile robot that resembles a human being. Thanks to this property, humanoids can be deployed in environments designed for humans. However, humanoid robots still require further development in many areas, such as manipulation [2]. More specifically, human-like dexterous hands and their manipulation [3]. Human-like dexterity has not yet been achieved, so alternative solutions for dexterous grippers are needed. The tool-grasp interface designed for simple two-finger grippers can enable robots to perform tasks typically performed by humans with human tools. Different tool tips can be attached to the grasp interface to enable different types of tasks.

Wheeled mobile robots can also be equipped with a robotic arm to interact with the environment [4]. Robotic arms are equipped with an end-of-arm tool (EOAT) to enable interaction between the robot and the environment. One common EOAT is a gripper, which is used for various manipulation tasks such as grasping objects [5].

The goal of this thesis is to provide an overview of mobile robots and the types of grippers currently in use. Also, a tool grasp interface is designed for two-finger grippers for tasks requiring rotational movement, such as screwdriving. The design process is iterative, and three separate designs from different phases of the process are presented. The literature review on mobile robots and grippers is necessary to understand the current state of the art, the challenges in human-like manipulation, and the need for different solutions, such as the grasp interface designed in this thesis.

The specifications for the grasp interface are defined based on the overview of the currently available commercial two-finger grippers. Parameters for grippers from some of the biggest gripper manufacturers are gathered from their datasheets. Visual prototypes are made with computer-aided design (CAD) software Creo Parametric.

To achieve the goals, the following research questions are addressed:

1. What is the current state of the gripper market?
2. What features are needed in the grasp interface to make it easy to grasp and compatible with a wide range of commercially available grippers?

The proposed design method involves a three-stage process. First, the primary dimensions are determined by reviewing currently available grippers. Based on the review of the grasping process, features that make the grasp interface easier to grasp are identified. Second, a visual model of the design is made using Creo Parametric, and the design is refined through iterative modeling. Three different designs are presented and evaluated.

The thesis is structured as follows. Chapter 2 presents a literature review on industrial mobile robots, robotic grippers, grasping processes, and the challenges related to dexterous robotic manipulation. Chapter 3 reviews commercially available two-finger grippers and analyzes their key specifications to define the requirements for the proposed grasp interface. Chapter 4 describes the proposed design method, design setup, and iterative development process, including the presented case studies and discussion of the final design solutions. Finally, Chapter 5 summarizes the conclusions of the thesis and discusses possible future development directions.

2 Industrial Mobile Robots

Mobile robots are getting attention. So far, the humanoids have mostly only been in the trial phases for manufacturing, warehouse, and other tasks. Boston Dynamics develops quadruped robots and humanoid robots. Their quadruped robot, Spot, has been deployed for different applications in industries such as energy and manufacturing. Spot has been deployed by Nestle Purina for packaging-line inspection automation [6] and piloted by Southern Company to collect temperature data around its power plant [7]. The Qingdao Fire Department in China has deployed two Unitree B2 quadruped robots [8].

BMW Group tested the Figure 02 robot in assembly tasks. A robot was used for repetitive assembly work such as sheet-metal loading. Figure 02 was running from Monday to Friday, 10 hours a day. In total, it ran for 1250 hours. Due to dexterity requirements and limited space for components, the robot's forearms were found to be the weakest point in its hardware [9]. That is one reason why a tool grasp interface for two-finger grippers could address the lack of dexterity in hands. BMW Group also began piloting AEON humanoid robots made by Hexagon Robotics [10].

ABB's Automated mobile robots (AMRs) are used in various industries, including automotive, retail, food and beverage, pharmaceutical, manufacturing, and logistics [11].

2.1 Types of Robotic Grippers

A gripper is a type of robot arm end-effector designed to grasp objects [12]. Robots equipped with grippers are capable of many different manipulation tasks [13]. However, to achieve the best possible results, the right type of gripper needs to be chosen carefully based on the characteristics of the tasks at hand. Grippers can be classified based on various factors, such as the number of fingers, actuation method, and size [5]. One simple way to classify robotic grippers is shown in Figure 1. Also, the number of degrees of freedom varies [13]. Robotic grippers can be actuated in several ways. They can be vacuum-actuated, pneumatically actuated, hydraulically actuated, or servo-electrically actuated [12].

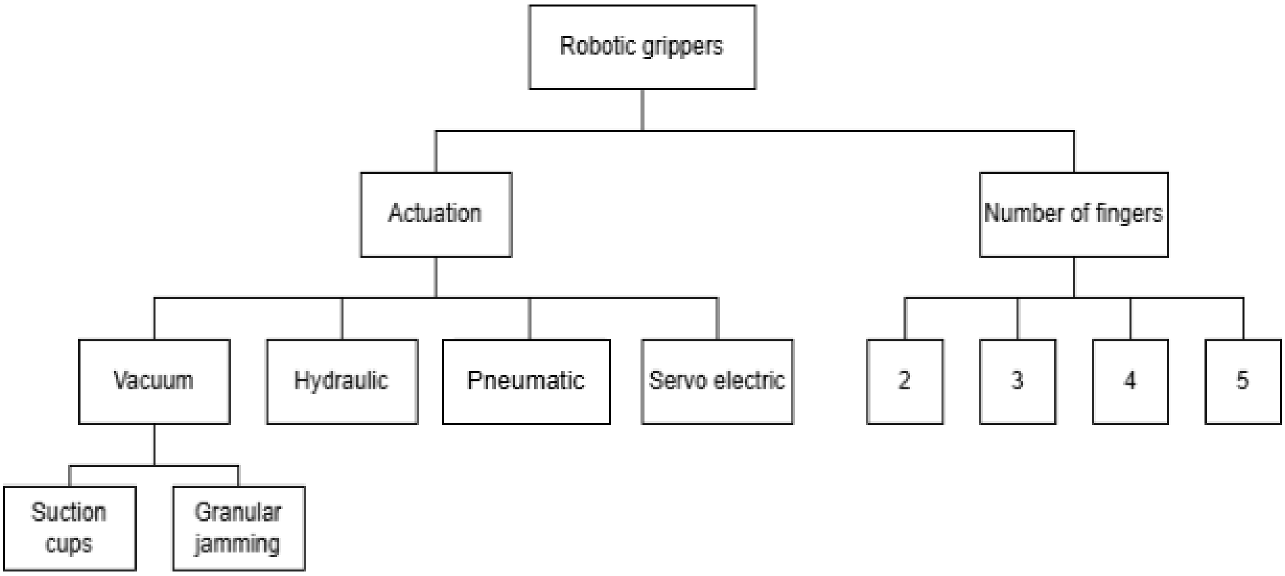

Figure 1: Classification of robotic grippers. Own illustration, based on [12].

2.1.1 Gripper Types Based on Actuation

Depending on the gripper's use case, its actuation can be selected differently. Usually, vacuum-actuated grippers grasp the target object using soft suction cups [5]. An airtight seal between the object's surface and the gripper is needed to achieve a tight grip. Such suction grippers are great for grasping objects with flat surfaces. Suction grippers can grasp objects much larger than the gripper itself, making them suitable for handling large items across various industries. In addition, suction grippers are great for manipulating and grasping fragile, small objects with smooth surfaces. The challenge for suction grippers is grasping objects with irregular shapes and rough, non-flat surfaces, as achieving the airtight seal required to create the pressure difference is difficult [14]. Depending on the mass and size of the object being grasped, the number and size of the gripper's suction cups vary [15].

A vacuum-actuated gripper can also be a grain-filled flexible ball gripper [12]. It is a gripper designed to grasp many different shapes, i.e., a universal gripper. The gripper operates on a mechanism called granular jamming. The granular jamming gripper consists of a flexible membrane filled with granular material. The grasping process with this type of gripper begins by pushing the gripper towards the object until the membrane conforms to the object's shape. Then the vacuum is created in the membrane by sucking the air out of the gripper using a vacuum pump. This hardens the previously loose membrane filled with the granular material. The gripping can happen through static friction between the gripper and the object, vacuum suction, or interlocking. These gripping modes are shown in Figure 2. Granular jamming-based grippers are effective at grasping objects of varying sizes and shapes. Also, multiple objects close to each other can be grasped simultaneously. Another feature of the granular jamming gripper is the ability to shoot objects out of the gripper without moving the arm itself. Shooting is done with a burst of pressurised air [16].

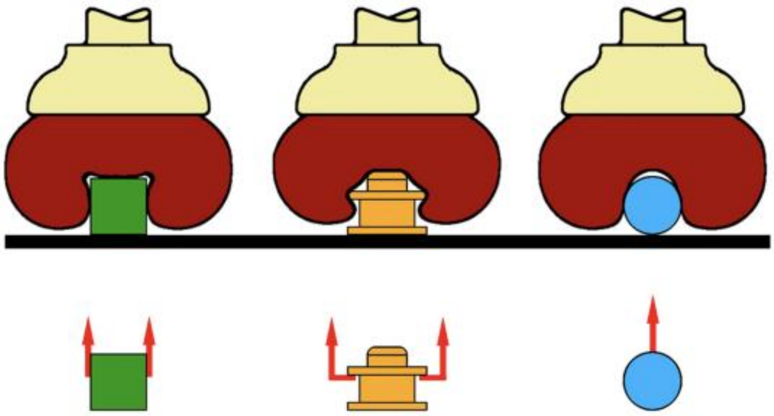

Figure 2: Gripping principle of differently shaped objects with a granular jamming universal gripper. Reproduced from [16] with permission, © [2012] IEEE

A robotic gripper can also be pneumatically actuated. Pneumatic grippers can be either soft or rigid. Pneumatically actuated grippers are most popular in industrial use according to Rocco et al. [17]. Pneumatic actuation is very popular in both soft and rigid grippers. For example, anthropomorphic humanoid hands can be actuated by multiple pneumatic artificial muscles, made to mimic the human hand's muscles [3].

Pneumatic soft grippers may consist of a varying number of fingers for grasping. The basic working principle of pneumatic soft grippers is that the fingers are made of elastomers that deform when air is exerted into the fingers of the gripper. The geometry of the chamber within the soft finger can cause the finger to bend when inflated, enabling grasping. This grasping process is illustrated in Figure 3. The structure of the gripper can vary a lot. Soft pneumatic grippers can have different numbers of fingers, and the geometry of the air chambers inside the fingers can vary, leading to different movement capabilities. Also, the materials used in the gripper affect the air-induced actuation [18].

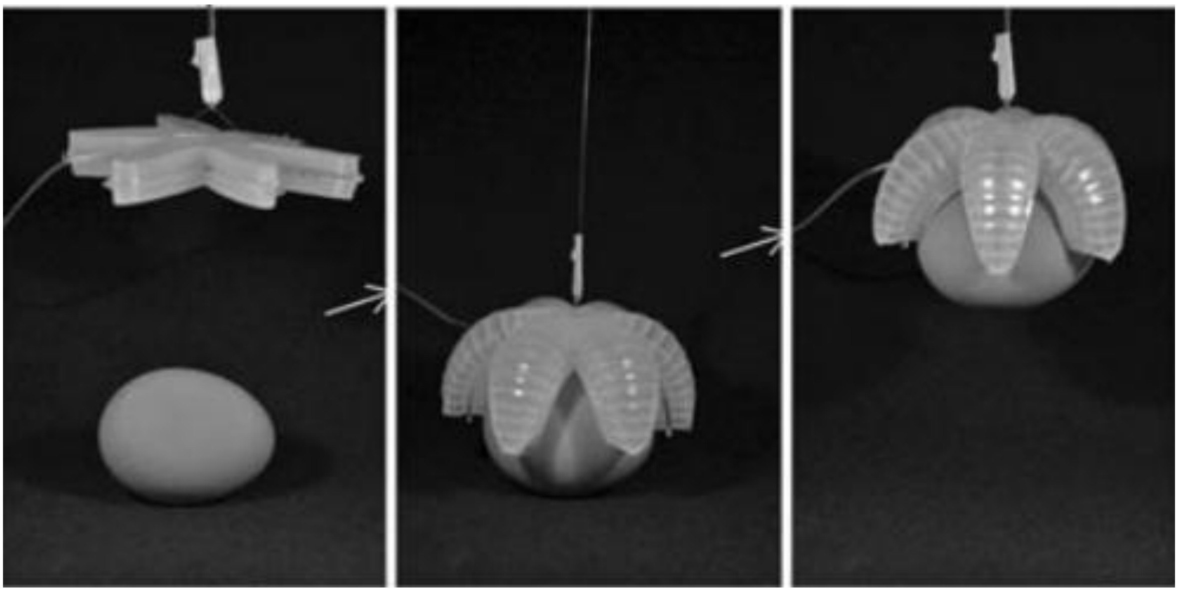

Figure 3: Grasping process of a soft pneumatic gripper with six fingers. Reprinted with permission from Ilievski, F., Mazzeo, A. D., Shepherd, R. F., Chen, X., & Whitesides, G. M. (2011). Soft Robotics for Chemists. *Angewandte Chemie International Edition*, 50(8), 1890-1895. Copyright © 2011 John Wiley and Sons. [19]

Pneumatic actuation can also be executed with artificial muscles. These are mainly popular in the development of anthropomorphic, dexterous humanoid hands. The goal of this type of actuation is to mimic human hands as closely as possible to achieve human-like dexterity. The anthropomorphic robotic hand, Shadow Hand, is shown in Figure 4 [3].

Figure 4: Shadow Hand with pneumatic artificial muscles. Reproduced from [3], used under CC BY 4.0.

A hydraulic gripper is similar to a pneumatically actuated gripper. The exception is that the fluid doing the work is not air but oil. Hydraulic grippers are used when large forces are needed [12]. The hydraulic gripper's biggest weakness is the frequent need for maintenance [5]. This weakness makes hydraulic grippers less cost-effective [12].

Servo-electric grippers are great for precision. Together with pneumatic grippers, electric grippers are the most used in industrial cases. Electrically actuated grippers are also advantageous because they can be easily integrated with various sensors to improve control precision and reliability [20]. Currently, many entities are developing dexterous anthropomorphic humanoid hands, most of which are actuated by electric actuators, such as direct current (DC) motors [21,22].

2.1.2 Gripper Types Based on the Number of Fingers

One way to categorize grippers is by the number of fingers they have. Basically, grippers with more fingers can handle more manipulation tasks [5].

The simplest gripper with fingers has two fingers. The stiffness of the fingers can vary from soft to rigid [12]. Because of the simple design and low cost, two-finger grippers are widely used in industry [5]. Another reason for their widespread use is that two-finger grippers are the most commonly offered by commercial gripper manufacturers

[20]. The gripping mode of a gripper with two fingers is usually a flat gripping mode, as seen in Figure 5 [13].

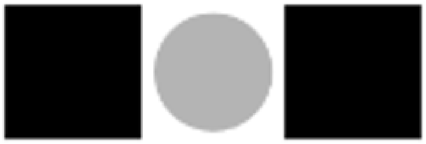

Figure 5: Flat gripping mode. Own illustration, based on [13].

A gripper can also have three fingers. Compared with two-finger grippers, three-finger grippers provide a more reliable grasp [20]. Depending on the shape of the grasped object, the fingers of a three-finger gripper can be arranged in many ways [12]. Some examples of arrangements are spherical gripping mode, used for grasping objects with circular profiles, and cylindrical gripping mode, used for grasping objects with flat or cylindrical profiles. In spherical gripping mode, three fingers are placed on the sphere 120 degrees apart [12,13], as shown in Figure 6.

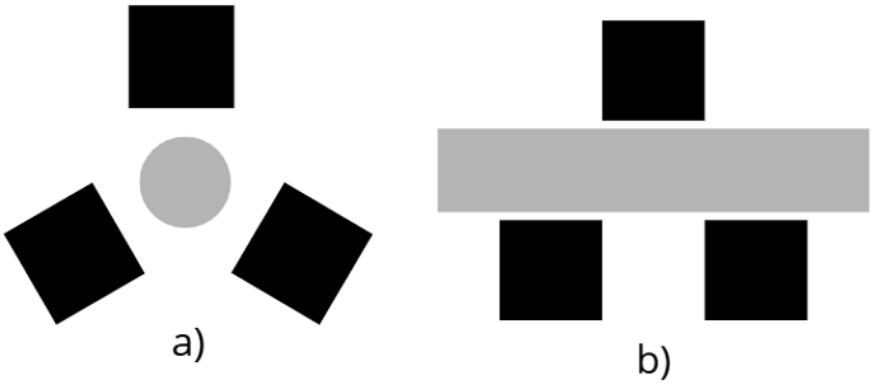

Figure 6: a) Spherical gripping mode, b) Cylindrical gripping mode. Own illustration, based on [13].

A four-fingered gripper can be an anthropomorphic humanoid hand or similar to a three-fingered gripper in spherical or cylindrical gripping mode. Currently, extensive research is underway on dexterous hands for humanoid robots. Dexterous hands have either four or five fingers. The working mechanism of fingers can differ. Also, the number of joints on fingers varies. Robotic hands/grippers with four fingers are often designed to mimic the human hand [3]. There are also designs of four-finger grippers that are not anthropomorphic. One possible arrangement is spherical gripping modes, where the fingers are in a circle, 90 degrees apart [20]. In the cylindrical gripping mode, the fingers are in a rectangle [12]. These two examples of finger arrangements for four-finger grippers are shown in Figure 7.

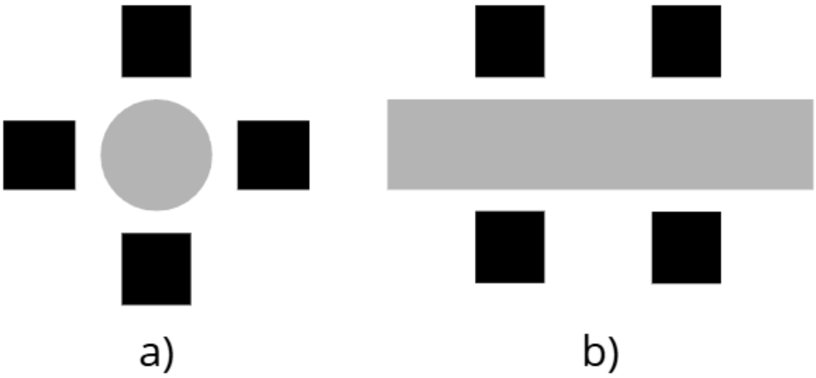

Figure 7: a) Spherical gripping mode, b) Cylindrical gripping mode. Own illustration, based on [13].

Robotic grippers with five fingers can, for example, be anthropomorphic hands. Even though a dexterous robotic hand can have fewer than five fingers, achieving absolute human-like dexterity requires five fingers [23]. As the gripper has more fingers and, therefore, more joints, its control becomes more complex [20].

Even though significant advancements in dexterous manipulation have been made in recent years, human-like dexterous manipulation remains one of the greatest challenges in robotics. Achieving large-scale deployment of mobile robots across different industries is, together with other limitations, constrained by gripper dexterity. To achieve efficient and versatile use of humanoids and other mobile robots in dynamic environments, human-like dexterity is vital [23]. High dexterity allows the use of human tools, which enables more sustainable implementation of robotics. There are a few different approaches to the mechanism of humanoid hand finger movement [3]. Some commercial humanoid and humanoid hand developers are Tesla, Unitree, Figure, 1X, and Boston Dynamics.

2.2 Grasping Process

The grasping process can be divided into 7 phases. First, the grasped object is approached. After that, the gripper gets in contact with the object's surface. After making contact, the gripper applies force to the object until sufficient force is reached for stable grasping. Then the object is moved to the desired location and released by opening the gripper, with gravity assisting. The grasping process is complex, in part because the object's pose must be correct for easy and secure grasping [20]. This is one problem that is addressed by the design of the tool grasp interface proposed in this Thesis. If the object's pose were always the same, it would be less complex to grasp it securely. Also, if the design of the object was made to guide the gripper in the right direction when the gripper approaches and gets in contact with the object, the grasping process would be more reliable.

The grasping process needs to be monitored using sensors such as tactile and visual sensors [20]. One method for increasing the success rate of secure grasping is visual servoing. It can be used to estimate the target object's pose with greater precision [3]. A simple visual servoing workflow can be seen in Figure 8. In visual servoing, images of the target object captured by the visual sensor are used to adjust the robot's position and orientation to perform grasping more accurately [3]. Visual sensors used for visual servoing can be

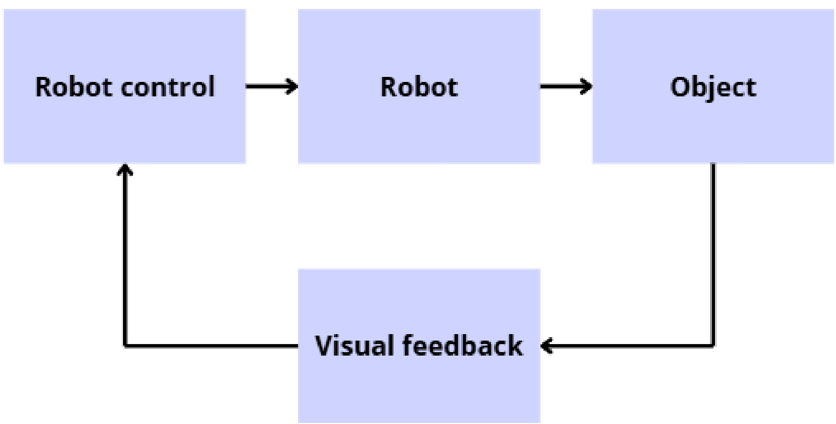

Figure 8: Visual Servoing Process. Own illustration based on [3].

monocular cameras or stereo cameras. Most robots are equipped with stereo cameras because they can capture 3D images of the target object, whereas a monocular camera captures only 2D images. The object's pose can still be estimated even with a monocular camera by capturing two images from different angles [20].

2.3 Challenges to the Broader Adoption of Mobile Robots

Multiple challenges are holding back the larger deployment of mobile robots in industrial use cases. The deployment of robots can be designed so that they are never in the area at the same time with humans. But if they are working with humans, the interaction between humans and robots is currently an obstacle. Also, a substantial drawback of current robots is the battery life. The high potential of humanoids across a wide range of industries stems from their similarity to humans [2]. One component that enables humanoids to perform tasks and operate in environments designed for humans is the hand. The hands need to have human-like dexterity, which is not yet achieved [24]. One thing holding back the large-scale deployment of humanoids is the reconfigurability of the humanoids [25]. One aspect of reconfigurability is hand dexterity. Dexterous hands are one focus of current robotic research. There are still difficult problems to be solved to achieve human-like dexterous robotic hands [23]. Human-like dexterity is, for example, needed for lifting and tool handling to operate in dynamic environments and in environments designed for humans. To perform precision tasks, haptic sensors can be integrated into the humanoid's hands or other types of grippers [24].

2.3.1 Development of a Dexterous Humanoid Hand

The development of humanoid hands and their control strategies is one of the biggest research topics in robotics [3]. Especially, autonomous manipulation is needed to achieve a larger scale of mobile robots' industrial use. Pre-programmed robots have been in industrial use in large-volume manufacturing for decades, but autonomous manipulation makes low-volume manufacturing with robots possible. Also, tasks carried out in dynamic environments are made possible with it [26]. Even though absolute human-like dexterity remains a challenge, the development of dexterous hands has been fast in recent years [3]. Both commercial and scientific approaches are seen in the field of humanoid hands. For example, Boston Dynamics is developing a pair of dexterous hands with three fingers for their humanoid robot Atlas. Even with three fingers, the hand can perform many human tasks [27].

Control of dexterous hands can be done by utilizing data obtained by visual sensors. Visual sensors are usually positioned to mimic human eyes. However, visual sensors can also be integrated into the fingers of the hands to expand the field of view [3]. To achieve fully autonomous dexterous manipulation, visual sensors alone are not enough. Sometimes, visual sensors can be obstructed, leading to the loss of crucial information [28]. Different sensors can be integrated into the robot to acquire additional data to use for controlling the hands. One of the most promising sensors, together with visual sensors for robotic grippers, is a tactile sensor [29]. Tactile sensors provide data from physical contact. Force and surface data are collected using tactile sensors and used for object recognition, along with vision sensors, force control, and slip detection [26]. These allow precise and more human-like object manipulation for robots. Tactile sensor data is used to adjust the grasping process during physical contact, whereas vision sensor data can also be used for grasp planning before the grasp execution [29]. The issue with tactile sensors is that they provide data from a single point, whereas human skin provides data across the entire surface, allowing for much more precise control of the grasping process [23]. To achieve human-skin-like sensory feedback, there has been academic research on a soft, multisensory artificial skin sensor that can detect humidity, pressure, and temperature [30].

As AMRs can’t be pre-programmed to do unpredictable tasks occurring in dynamic environments, they require adaptive and reactive control. Algorithms such as path-planning algorithms and various machine learning algorithms, together with sensor data, enable robots to perform tasks without pre-programming [23,29,31].

Achieving human-like object manipulation is also held back by the structure and mechanism of the hand’s joints and actuation [23]. Current approaches to dexterous robotic gripper actuation are, for example, pneumatic muscles and electric motors [3]. Shadow Robot is currently offering its Shadow Dexterous Hand with two, three, four, or five fingers. The five-fingered hand is actuated by 20 electric DC motors, whereas the hand with four fingers has 13 DC motors, the three-fingered hand has 10 of them, and the two-fingered hand is equipped with only 7 DC motors [22]. Unitree's most advanced humanoid hand, Dex5-1, is actuated electrically [21]. Together with the five-fingered Dex5-1 hand, Unitree offers a two-fingered gripper [32] and a three-fingered dexterous gripper [33]. Both of which are similarly driven by electric motors [32,33].

3 Two-Fingered Grippers

The goal of the tool grasp interface for robots is to allow as many types of two-fingered grippers as possible to grasp it and perform tasks. To make the grasp interface sustainable, the tool should be changeable. When the design is like that, the grasp interface can be used for various rotating tasks, such as screwdriving and other fastening tasks. Two-fingered grippers were chosen because they are the most common grippers with fingers offered by manufacturers. Also, grippers with more than two fingers can use the same grasp interface because they have the two fingers needed to grasp it.

The need for a tool grasp interface for robots stems from the lack of dexterous hands capable of efficiently using human tools. The goal of the design is to make the grasping process as easy and reliable as possible. Therefore, different features are needed to guide the fingers into the correct position to enable a secure grip of the grasp interface. Design is enhanced based on feedback and observations of the previous design's weaknesses. The design goes through a couple of versions until it is considered fit for purpose.

There are many commercial gripper manufacturers worldwide, offering grippers for a wide range of industries and tasks. Some of the biggest gripper manufacturers include OnRobot, Robotiq, and Schunk. These companies primarily focus on grippers and other end-of-arm tools and do not offer robots or robotic arms themselves. Mobile robot manufacturers can also offer their own grippers. As stated in the previous chapter, Unitree offers three different grippers for its humanoid robots. Also, other humanoid manufacturers offer their own grippers integrated into the humanoids.

OnRobot offers five different two-fingered grippers and only two different three-fingered grippers [34]. Some properties that distinguish the grippers from each other are the dimensions of the gripper’s fingers, Maximum stroke, and payload. These are also the properties to consider when designing a tool grasp interface suitable for as many two-fingered grippers as possible. The two-fingered grippers currently offered by OnRobot are RG2, RG6, 2FG14, 2FG7, and 2FGP20 [34]. Previously introduced properties of these grippers are gathered in Table 1. All of OnRobot's two-fingered grippers are electrically actuated. 2FGP20 is also equipped with a vacuum gripper for larger, smooth objects, eliminating the need to change the gripper [34]. OnRobot also offers different fingertips to provide a wider variety of grasping options for a single gripper.

Table 1: Comparison of key technical specifications for commercially available robotic grippers.

Name	Finger's width (mm)	Finger's length (mm)	Finger's thickness (mm)	Minimum stroke (mm)	Maximum stroke (mm)	Maximum payload (kg)
OnRobot						
RG2 [35]	20.20	29.80	11.40	0	110	2
RG6 [36]	25	37	13.15	0	160	6
2FG14 [38]	45	45.3	6.30	5	105	14
2FG7 [37]	32	45	5	1	73	7
2FGP20 [41]	186	220	11	170	430	20
Robotiq						
2F-85 [42]	22	38	7.8	0	85	5
2F-140 [42]	27	65.5	7.8	0	140	2.5
Hand-E [43]	24	20	8.2	0	50	4.7
Schunk						
Co-act EGP-C 40 [44]	30	50	19.5-25.5	0	24	0.7
Co-act EGP-C 64 [45]	34	80	29-39	0	40	1.15
Unitree						
Dex1-1 [32]	32	80	16	0	90	5

All finger dimensions given in Table 1 for RG2 and RG6 grippers are for the standard fingertip [35,36]. 2FG7 and 2FG14 fingers can be installed inwards or outwards, which affects the gripper's stroke properties. For these two grippers, the minimum stroke shown in Table 1 was obtained with fingers inwards, and the maximum stroke in Table 1 was obtained with the fingers outwards. This gives the full range attainable with those grippers [37,38].

Robotiq offers three different two-finger grippers, 2F-85 and 2F-140, and only two three-finger grippers. The properties of all 2F-85, 2F-140, and Hand-E can be seen in Table 1. All of these grippers are actuated electrically. Robotiq also offers different fingertips for various tasks. The finger dimensions depicted in Table 1 are the dimensions of flat rubber overmolded fingers [39].

Schunk offers 21 different two-finger grippers. Five of which are electric, and 16 are pneumatically actuated. Only one of these 21 grippers is suitable for collaborative operation, which is important for mobile robots deployed in dynamic industries. This gripper is called Co-act EGP-C. There are two different variants of this gripper, Co-act EGP-C 40 and Co-act EGP-C 64. Their properties are gathered in Table 1. Co-act EGP-C is electric and can be equipped with different fingers. [40] The dimensions shown in Table 1 are for their rigid gripper finger, which also has two variants that can be used depending on the desired stroke. The maximum payload for this gripper is the workpiece weight recommended by Schunk.

Robot manufacturer Unitree offers a two-finger gripper compatible with their humanoid robots G1, H1, and R1 [32]. Properties of Unitree Dex1-1 can be obtained from Table 1.

As shown in Table 1, the OnRobot 2FGP20 is much larger than all the other grippers. Therefore, it is not considered in the grasp interface design. When designing the tool grasp interface, the dimensions should be such that most of these grippers can use it properly. However, the grippers introduced in this thesis are only a small subset of the thousands available. Therefore, it is impossible to design a grasp interface for every available two-finger gripper. The review done provides a frame for the grasp interface dimensions to make it as versatile as possible.

4 Proposed Method for Grasping Interface

4.1 Design Setup

The design process begins by establishing a set of dimensional specifications. These specifications are based on the technical specifications of currently available grippers, presented in Table 1, Chapter 3. Dimensions need to be suitable for as many two-fingered grippers as possible. Mainly, it affects the dimensioning of the gripping feature. Both grasping and releasing the grasp interface need to be simple and easy to do without human assistance.

Simple sketches of the designs are made using pen and paper or graphic design software, Canva. Subsequently, these concepts are developed into detailed 3D models using Creo Parametric. Also, technical 2D drawing is made using Creo Parametric. The design undergoes several iterations based on feedback from the topic proposer. Each version is reviewed against the project objectives, with a focus on ease of use and simplicity. Following these reviews, refinements are made in the 3D environment until the design meets the necessary functional criteria.

4.2 Case Studies

A simple sketch of the first design is seen in Figure 9. This design is an active grasp interface equipped with two electric motors, batteries to power the motors, and a vacuum pump for granular jamming.

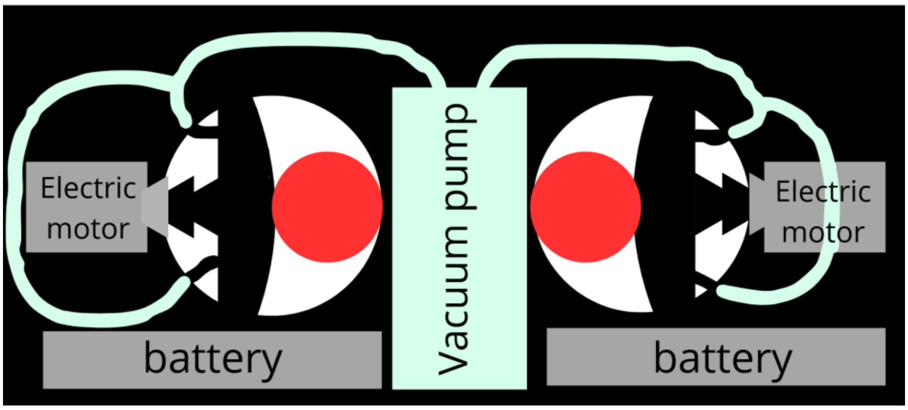

Figure 9: First design of the grasp interface made with Canva.

The red circles in Figure 9 indicate the two fingers of the robotic gripper. The fingers are inserted into the holes, and then the motors activate to move the pads that clamp the fingers tightly in place. To ensure fingers are secured in all directions, granular jamming is integrated into the pads. The pads are made of rubber film filled with granular material. The pad conforms to the finger, and when the air is sucked out of the pad, it hardens into the desired shape, preventing the finger from moving. The concept is the same as that of the universal gripper presented in Chapter 2.1.1. Before this concept is developed further, it is found to be too complex for this use case. There is no need for active components to clamp the fingers in place, as the fingers' gripping force is sufficient to secure the grasp interface. Also, active components make the grasp interface heavy, which is not ideal for a grasp interface designed for mobile robots. Based on these observations, the next design is passive rather than active.

The second design is based on the first design, as presented in Figure 10. It does not have active components such as motors or a pump. Rather, the power holding the grasp interface comes from the robot’s gripper itself.

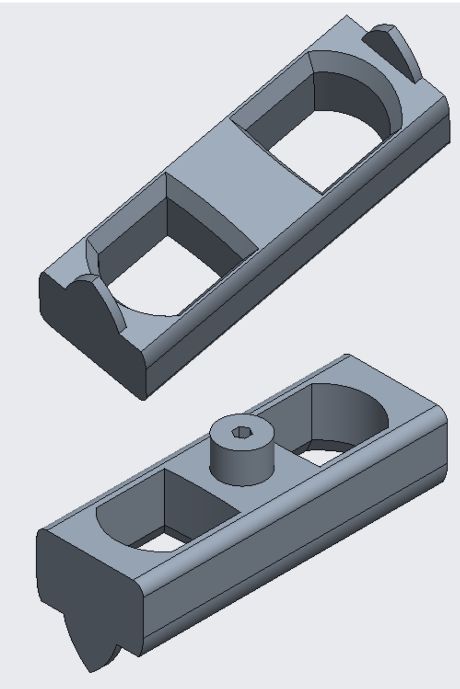

Figure 10: Second design of the grasp interface made with Creo Parametric.

In this design, chamfers around the finger holes guide the fingers consistently into the holes. Also, the grasp interface is triangular, so it always ends up in the same pose. This prevents the grasp interface from ending up in a pose where the gripper cannot approach the holes and properly grasp the interface. In this design, a place for the tool itself is proposed between the two holes in the middle of the grasp interface. The socket for the tool tip is dimensioned to fit commonly used changeable screwdriver tips. This is important because it allows the use of already existing bits. With various adapters, even more existing bits can be utilised. Even though this design ensures that the grasp interface never rests in a way that prevents the gripper from approaching it properly, the grasping process could be made even easier. Therefore, another concept is proposed.

The third and final design is seen in Figure 11. It differs from the two previous designs in shape, but the grasping process is similar. There are two holes into which the gripper's fingers are inserted, as in the other designs, but the holes do not go all the way through the grasp interface. The hole's four sides all end up in a single point at the bottom. This is done to position the fingers in the middle of the holes so the rotational task can be performed properly. The grasp interface is dimensioned based on the content provided in Table 1. A motivation for design is presented in Figure 12.

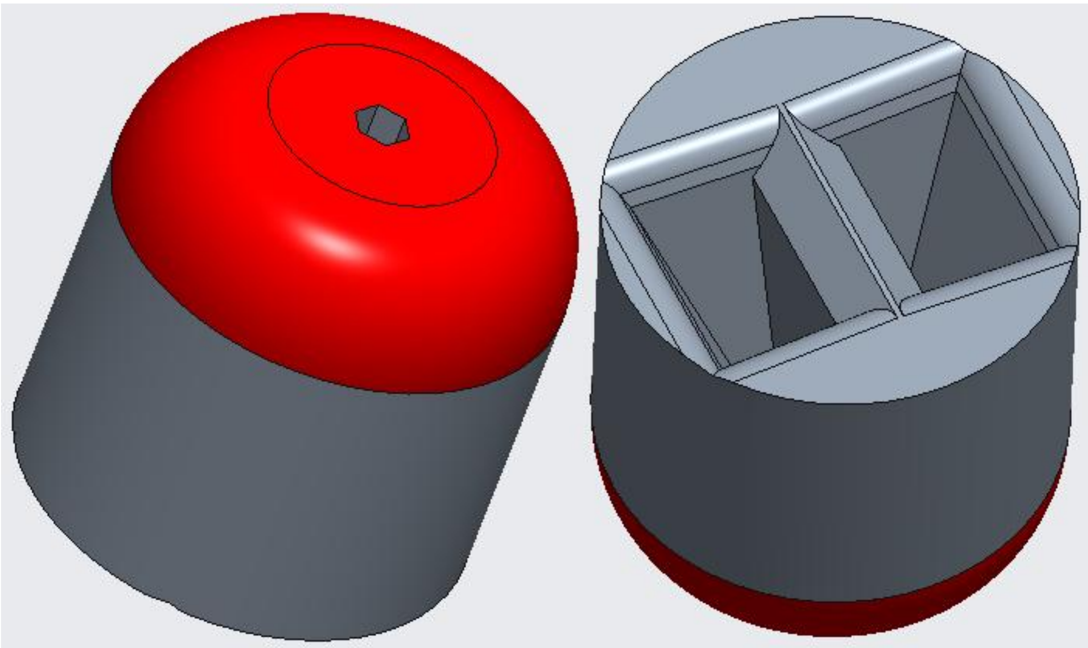

Figure 11: Third design of the grasp interface made with Creo Parametric.

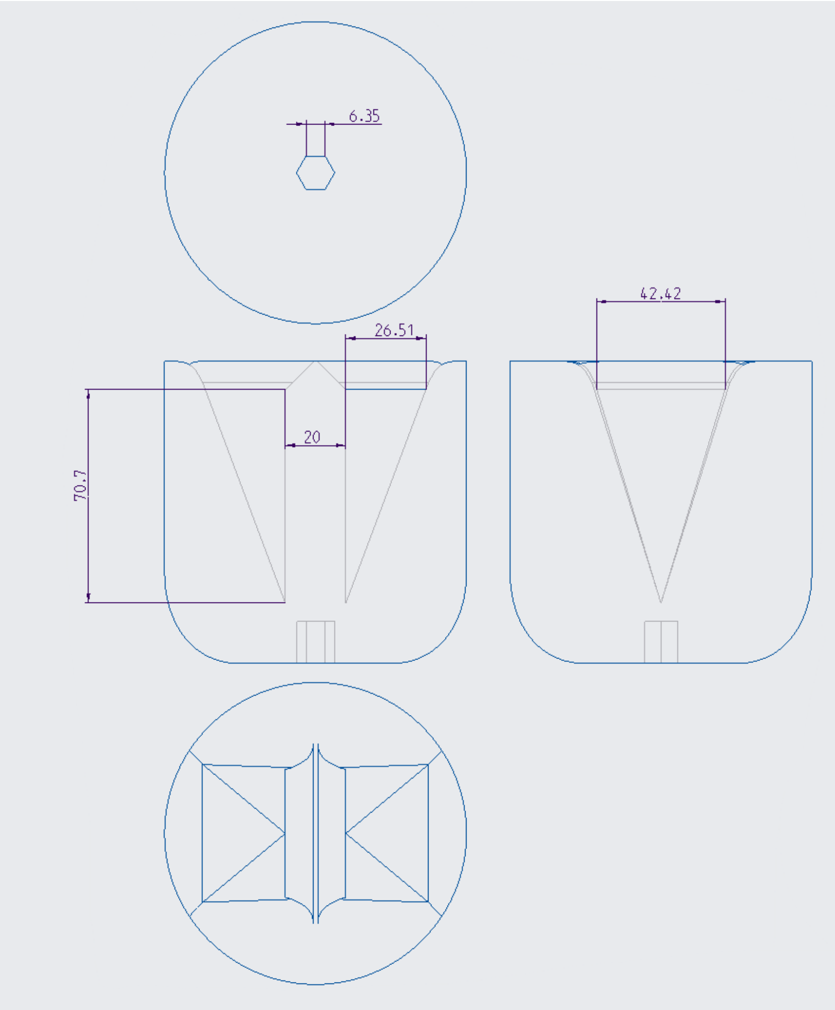

Figure 12: Dimensions of the third grasp interface design.

The main reason for the grasp interface's different shape is to ensure it always ends up in the same position when released. The inspiration for the mechanism that allows this comes from a toddler mug that always stands up even when laid on its side. To achieve this, the bottom of the grasp interface, represented in red in Figure 11, is heavier than the rest of the grasp interface. Also, the bottom has large-radius rounded edges, allowing it to stand up easily. When the grasp interface is always in the same pose, it is easier to grasp, since the gripper can always approach the tool-grasp interface from above, fingers pointing straight down towards the holes.

4.3 Discussion

The development of the tool grasp interface demonstrates a strategic shift from high-complexity active systems to a geometry-driven passive solution. The first design relied on active components, but this was ultimately deemed too complex. By removing these active components, the design utilises the robot's existing gripping force, which is found to be sufficient to secure the grasp interface.

The primary motivation for the final design, as shown in Figure 12, is to ensure that the grasp interface always returns to a consistent pose upon release. The grasp interface features a weighted bottom and large-radius rounded edges that allow it to stand upright even if laid on its side. This stable orientation is critical for autonomous operations because it allows the gripper to always approach from a top-down position, with its fingers pointing straight down toward the holes, simplifying path planning and grasping.

Precision is further enhanced by the internal geometry of the holes, which feature four sides that converge to a single point at the bottom, as shown in Figure 12. This self-centering feature guides the gripper fingers to the exact middle of the holes, ensuring that rotational tasks can be executed with the necessary accuracy. Additionally, the grasp interface is highly compatible with existing tools due to a socket dimensioned for standard 6.35 mm hexagonal screwdriver bits and a footprint designed to suit a wide variety of two-fingered grippers.

The design could be further developed by adding features that enable a wider range of grippers to securely grasp the grasp interface. Also, the design could include features that enable other types of tasks to be performed with the same grasp interface. These enhancements would make the grasp interface more sustainable, as there would be no need for multiple different grasp interfaces for different types of grippers and tasks.

5 Conclusion

In this thesis, a review of current gripper technologies was conducted. In this context, a design for a tool grasp interface for robots with a two-finger gripper was made. It became apparent that human-like dexterity remains a major challenge in robotics. A tool grasp interface for robots could address the lack of dexterity in currently available humanoid hands. That could accelerate the deployment of humanoid robots in dynamic environments in the future by allowing robots to perform tasks designed for humans. Based on these findings, a design for a tool grasp interface was made.

Two research questions were defined in the Introduction of the Thesis:

1. What is the current state of the gripper market?
2. What features are needed in the grasp interface to make it easy to grasp and compatible with a wide range of commercially available grippers?

In response to the primary research question, the findings suggest that simple grippers, such as two-fingered grippers, currently dominate the gripper market. Gripper manufacturers often make only grippers, not robots, but many humanoid manufacturers also make robotic grippers. Anthropomorphic five-fingered humanoid hands are already available, but their dexterity is far from the human-like dexterity needed to perform various tasks in dynamic environments designed for humans. There is no consensus on how long it will take to achieve human-like dexterity in robotic hands. Findings suggest that for the grasp interface to be easy to grasp, it needs features that correct small misalignments during grasping. Also, the grasping process was found to be simple and consistent if the grasp interface always rests in the same position. The design process followed an iterative three-stage approach. First, the primary dimensions and functional requirements of the grasp interface were determined through analysis of existing grippers and grasping processes. Second, visual prototypes were developed and refined using Creo Parametric CAD software. Finally, three design iterations from different stages of development were presented and evaluated.

The greatest challenge faced during the design process was the large quantity of two-fingered grippers available in the market. They come in many different sizes, which makes dimensioning the grasp interface difficult. The result of the design process was a tool grasp interface primarily for two-finger grippers. In the future, the grasp interface could be further developed to better suit tasks that do not require rotational movement. These tasks could need push or pull motion, for example. Also, the grasp interface could be further developed to better fit other types of grippers. For example, the grasp interface could have geometry that allows three-finger grippers in spherical gripping mode to grasp it securely. Future work could also focus on testing the proposed grasp interface concept using a physical prototype made by 3D printing, for example. Testing would be necessary to confirm the concept works as desired. It would also be necessary to test different materials for the grasp interface to achieve the desired weight and durability.

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