FUNCTIONAL CHARACTERISTICS OF A NEW SPECIAL GRIPPER WITH FLEXIBLE FINGERS

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Abstract:

Functional characteristics of an originally proposed design of multifingered gripper with flexible fingers is presented in the paper. The design work concentated on ensuring that the hand can contact with a variety of different shape objects made of flexible materials of different properties as well as fragile objects requiring particular caution when manipulated. Additionally it was assumed that the gripper should ensure a satisfactory reliability level, required high functionality and easy maintenance. The gripper design ensures beneficial variability of characteristics of the forces acting upon the object irrespective of the openning distance of fingers i.e. of the manipulated object size.

Keywords: *multifingered gripper, flexible fingers, service robotics, force-feedback manipulation.*

1. Introduction

Modern robotics takes up new challenges to ensure that the robots are capable of executing more and more difficult tasks and manipulators of performing new prehension functions. Nowadays, service robotics is one of most interesting fields of robot applications, involving the desire for substituting for a human being in uncomplicated manipulation processes that require precise object identification, gentle grasping and precise object handling for manipulation. There arises the need for the application of special grippers provided with sensing capability. To ensure that the gripper could execute manipulation tasks typical of human being to perform, it seems reasonable to use the one with antropomorphic shape. A human hand has 5 fingers and up to 23 degrees of freedom, while the whole hand with the arm and forearm has 30 degrees of freedom [5]. According to the literature, available the minimal number of fingers necessary for successful performance of the prehension, i.e., the process consisting in grasping the object with a simultaneous leaning against the palm surface is equal to three (four-point grasp) [1], [5]. Each human finger has 3 to 4 degrees of freedom, therefore, requiring proper control. Additionally, the control of fingers should ensure their proper cooperation, corresponding to the object shape. Therefore, on the one hand a solution to the grasping problem should reveal adequate generality level, and on the other hand, a general approach should be able to perform using a number of specific, relatively simple methods. Primary analysis of the grasping process proves that application of three-finger-grasp is most profitable.

When manipulating different objects in the course of a service task a human being uses two arms, and his/her hand are most frequently engaged. For such a task, typical of human work should be executed by a robot, it requires appropriate adaptation of both the manipulator robot kinematical structure and grasping devices, as well as working environment in the way ensuring that a robot not only can replace a human being in specified manual operations but also can execute the task faster, with better accuracy and more precision. Therefore, the system should reveal a high level of adaptability and be provided with a number of sensing devices of different types allowing for gathering the information from environment that is necessary for manipulation performance. Modern 3D CAD systems allow for a general approach to the design process including determination of basic characteristics of the designed systems and the integration of subsystems. Therefore high qualities of the design (like, high functionality and aesthetics) can be achieved as early as at the design stage.

At the initial stage of the developed design of multifingered gripper it was assumed that a gripper consisting of a thumb (with additional revolution relative the longitudinal axis in its starting position) and two fingers with redundant DOF's pressing against the object. The fingers were actuated by means of the flexible elements that ensured automatic control of the pressure exerted by particular phalanges upon the object. However, the initial tests proved that the above hand-like design with a smaller number of fingers reduces substantially the grasping capabilities of the gripper. It occurred more profitable to apply one supporting finger and two thumb-type fingers, having the possibility of revolution about the finger longitudinal axis. The driving systems were situated in the gripper body, while the phalanges were driven through connecting rods provided with additional systems of elastic clutches. By adding flexibility to the fingers, we improve substantially the gripper functionality through rising its level of anthropomorphism. The fingers will be covered with a special flexible glove with embedded contact pressure force sensors and other measurement gauges. The gripper was designed for grasping an object by means of hooking clamping, grasping, supporting - stabilized by the other hand/gripper (like in a typical two-hand manipulation). Additionally, the design was supplied with the following means:

- force sensors, pressure sensors, contact sensors,
- six-axis-wrist force/moment sensor for identification of body forces,
- image processing methods for identification of geometry of the manipulated object to achieve optimal prehension and grasping processes, as well as optimal control of the manipulation task execution.

To ensure highest performance of the system, in the developed design, is was assumed that all mechanical, electric and electronic elements (necessary driving systems, gear and transmission systems, joints, sensors, etc.) will be integrated with the mechanical system of a gripper. The mechanical part was designed using the ProEngineer system and then the initial simulations were performed using the ADAMS package, allowing for estimation of basics characteristics and their optimisation according to the assumed criteria. A general scheme of the gripped of the properties described above, that performs a grasping prehension is shown in Fig.1.

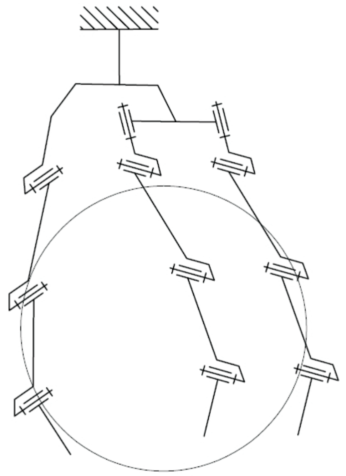

Fig. 1. Basic scheme of the gripper performing a grasping prehension.

To simplify the control process when manipulating the object, it was assumed that the performance of one finger is subject to kinematic control and it plays a the leading role, while the other two fingers are situated on the opposite side of the manipulated object and they stabilize the object through the flexible shape adaptation to the remaining surfaces of the object. The finger presented in Fig. 1 on the left side of an object plays the superior role. It is a simple plane mechanism (2D) with 3 DOFs and it consists of three phalanges. In the course of grasping process, the finger has to execute the task of supporting the gripped object at three points situated in the plane of its motion, grasping it at the same time in the way preventing it from slipping out. Hereinafter, the finger will be considered as the so-called leading one. The two other fingers are similar mechanisms, but having an additional degree of freedom, i.e., rotation (over vertical axes in Fig. 1). They are also capable of grasping object but in contrast to the leading finger their working planes may be turned and adapted for cooperation purposes with the object to allow for grasping it from three directions. In a general case, the grasping task formulated in the above way should ensure that each phalange contacts with the object, that would require a separate drive for each phalange, as well as measurement of the contact force acting upon the object at many points. Since it was planned that driving systems provided with additional sensors to measure contact forces would be situated in the gripper base, a design of a single finger following the above concept with transmission systems might occur extremely complex. Additionally, the determination of current configuration of the object-gripper system might be difficult; namely, for such a system with rigid links the rigid problem of dynamics (kinetostatics) is statically undefined. When attempting at control of such a gripper one may be confronted with obstacles resulting in damage of the manipulated object or gripper failure.

2. The assumed structural solutions of a gripper with flexible fingers

From the both design and kinematics viewpoints a gripper of grasping type is a complex mechanism comprising a few fingers - small manipulators, a smart cooperation between which is necessary for grasping and holding a manipulated object. The gripper task, after ensuring that the arm configuration is proper, consists in safe prehension and firm grasping of the object along the whole trajectory and then precise and safe releasing the object at the target. A proper grasping of the object, that frequently depends on many factors [4] is of crucial importance in the process. A precise control of the cooperation between fingers requires the prior determination of accurate kinematical and dynamical models of each finger and the updated information on parameters of particular parts of kinematical chain of the gripper. In particular, the measurements of forces are affected by non-linear friction components, mostly of undetermined nature, while the force measurement performed by means of surface sensors suffer from large errors due to noises and other influences in the signal processing channels. Therefore, in the design process special attention was focused on choosing the mechanical system structure that allowed for minimisation of measurement errors arising from its work.

In a mechanical part of the gripper each given kinematical task may be executed by mechanisms of different types; like cams, levers, rods, toothed mechanisms or mixed (combined) [5], [6]. Therefore some types of simple mechanisms were chosen that allow for minimisation of both mechanical noises and mechanical hysteresis. In the design process of gripper, the following phases were considered:

- choice of the mechanism type;
- selection of a structure within that type;
- determination of geometrical parameters.

with special attention focused on minimisation of the undesirable effects mentioned above. That required the ball bearing to be introduced into the design, which additionally complicated the solution. Since a gripper, especially that of the grasping type, is a very complicated mechanism, for simplification purposes it was assumed that the leading finger would be the simplest possible open serial chain ensuring the possibility of reducing a number of drives to the minimal one.

The link mechanism with three degrees of freedom has occured to be most profitable. The initial concept of a finger in the multifingered gripper was developed on the assumption that the gripper would be used to grasp cylindical objects of the sizes comparable to those of the objects manipulated by a human of average capabilities. The average mass of the object was assumed as 0.5 kg with the size fitting easily into a sphere (cylinder) with up to 80 mm in diameter. Fig. 2a presents the basic kinematical scheme of the "leading" finger shown in Fig.1.

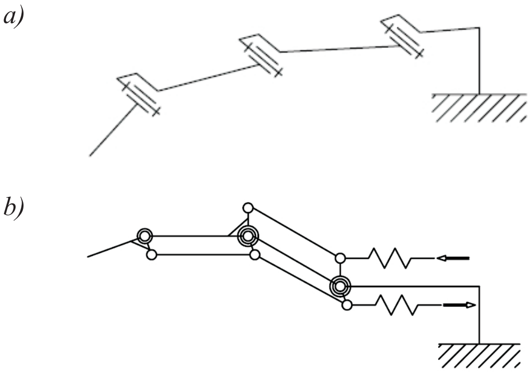

Fig. 2. Kinematical scheme of the "leading" finger.

To simplify the control process and reduce the number of drives, a parallelogram mechanism was introduced into the kinematical system of gripper ensuring that the orientation of second (medium) phalange relative to the gripper body remained the same (see Fig. 2b)). Connecting rods for drives are equipped with springs assuring elasticity of the structure. It was realized by special clutches with springs. By measuring elastic deformations of springs we can measure internal forces of connecting rods. Parallelogram reduces the number of finger drives by one, improving the possibility of loading the second phalange by adapting the characteristics of load carrying capacity of the finger to the object size. In the same way it reduces a total necessary driving power, improves the control process *via* decoup-ling the model of dynamical behaviour of the finger. Addi-tionally, it rises the levels of stiffness and load carrying capacity of the finger and allows for reducing a total mass of the gripper, fostering as well the introduction of flexibi-lity that eliminates the effects of statical indeterminability and additionally it allows for direct measurement of the forces acting upon a finger.

In similar way, the structure of the rotational finger was developed. Simplified structure of this finger is shown in Fig. 3. The transmission system of this finger is a little more complicated.

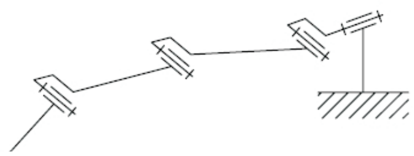

Fig. 3. Kinematic structure of the rotational finger.

According to the above three-finger gripper concept, the design of "leading" finger was developed (see Fig. 4). The finger comprises 3 phalanges; the first one has the form of parallelogram, the orientation of the second one remains constant, and the third one is provided with a separate drives and connected in series with the second phalange. The orientation of the second phalange remains the same and it moves according to the end of the first phalange; both the phalanges first and second, are driven by the same actuator. The drive of the third phalange is transmitted through a series connection of two parallelogram mechanisms situated inside the first and second phalanges, respectively.

In the proposed design the MAXON miniature DC electric motors were applied, supplied with planetary gears and additional external sensors of rotation.

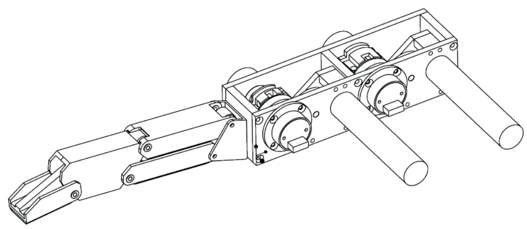

Fig. 4. 3D "leading"finger design together with drive systems, elastic clutchs and measurement sensors (transducers) developed within the ProEngineer software package.

Between each motor and the corresponding drive transmission system an elastic clutch has been introduced, ensuring on the one hand the compliance of crocodile clip type, and on the other hand direct measurement of the forces acting upon the manipulated object. The angle of elastic deflection of the coupling corresponds to the magnitude of external loading moment acting upon the jaw. A main advantage of the proposed design consists in reduction of both the number of variables determining the object size and the number of drives. To reduce the mass and size of the finger and to ensure that its functionality is high enough, it was assumed that drive systems would be mounted in the gripper body. That required the application of transmission mechanisms. To solve the problem the plane lever mechanisms were applied. Owing to which the crank motion was transmitted to the corresponding phalange. The design was developed using the ProEngineer software package v.4.0. It should be emphasized that since the parallelogram mechanisms were applied, thus in the proposed design, the mechanical moment is measured as relative angle of the elastic clutch which is, in fact, directly the moment transmitted from the gripper jaw.

The other fingers were designed in a similar way, supplied with an additional revolution, however in their mechanisms of revolution no elastic clutches were introduced. It means that there is no elasticity and it is impossible to measure the external torque in the direction of this rotation.

3. Gripper prototype

According to the developed design, the mechanisms of finger, both the leading finger and the revolute one of the thumb type supplied with their drives were built.

Elements of the phalanges were made of typical duralumin. Particularly phalanges of the fingers and structural elements of the both driving system and the transmission one were equipped with miniature ball bearings. The gripper driving system comprised miniature motors supplied with toothed gears, produced by the MAXON Co. A very high efficiency of drive transmission was ensured both from motors to jaws and from the external torque produced by each phalange and measured by elastic deformations of special clutches, thus the system offers very good backdriveability. Fig. 5 shows an assembled prototype of the gripper to be tested on the experimental stand.

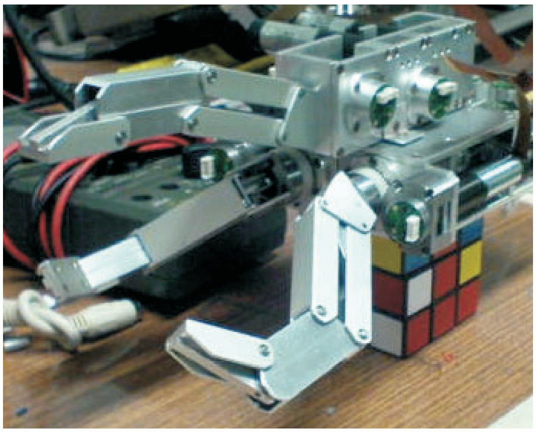

Fig. 5. Prototype of the developed gripper.

4. Functional characteristics of the gripper

Functional characteristics of the gripper show the sizes and masses of the objects, which the gripper can grasp and manipulate. Those characteristics are developed with taking into consideration the driving system and at the assumed size limits of the manipulated objects. In the developed gripper design those characteristics depends on the corresponding characteristics of particular fingers. In the operation of a single finger the most important role plays the second phalange, which maintains constant orientation relative to base. That phalange during the revolution of the first phalange (parallelogram) translates at a constant orientation outwards/inwards opening/closing the gripper. It exerts the pressure upon the object in the direction perpendicular to the internal surface of phalange, while the clamping force is produced by the moment from the first phalange motor.

The magnitude of that moment is limited by the maximum moment of the drive unit and due to elastic deformation of the clutch assumes the values between zero and maximal value of the motor moment

$$M_u \in \langle 0, M_s \rangle \qquad (1)$$

depending on the phalange loading and current value of the control signal. Magnitude of the force generated by the driving system depends on the angle of the phalange opening. Fig. 6a) presents the characteristics of the second phalange extension versus the angle of revolution of the first phalange. It can be clearly seen that the phalange opens the gripper to a size of about 80 mm, which during operation of the opposing fingers ensures that the gripper can grasp the object of the sizes corresponding to a spherical object of about 150 mm in diameter. Fig. 6b) and Fig. 6c) presents characteristics of the clamping forces of the gripper fingers in the course of manipulation. The maximal value of the force varies in almost parabolic way (more precisely it is inverse-cosine) depending on the object size and for the maximal value of the fingers extension reaches the magnitude of 14 N. In the case when the phalanges are covered with a rubber glove, the coefficient of friction, of which is about 0.35, the value of additional load carried due to friction reaches about 5 N). It is worthwhile to note that the characteristics varies depending on the gripper opening and is approximately coincident with the characteristics of mass versus the object size. It is worthwhile to note that some manipulated object of complicated shapes can be grasped in a proper way, despite their relatively too high mass (weight).

To determine the external load acting upon the robot end-effector, between the arm end flange and a gripper, an additional sensor of six force/moment components has been mounted. The developed gripper was mounted on the robot Irb-6 located at the Laboratory of Robotics at the Institute of Automatics of Warsaw University of Technology. Initial tests have proved that the assumed assumptions were correct and the developed gripper is working properly. Now the gripper is being used most often in developing the project performed under the Polish Ministry grant.

5. Final remarks

The design was made using the software package Pro-Egineer v. 4.0. It should be emphasized that the 3D system was applied which allowed for performing at the same time various activities; namely, developing the design concept, making analyses and calculations within the scope of material strength and dynamics, as they are necessary. First of all, it was possible to reach optimal arrangement of particular elements as a result of minimisation of the space occupied by the considered assembly, as early

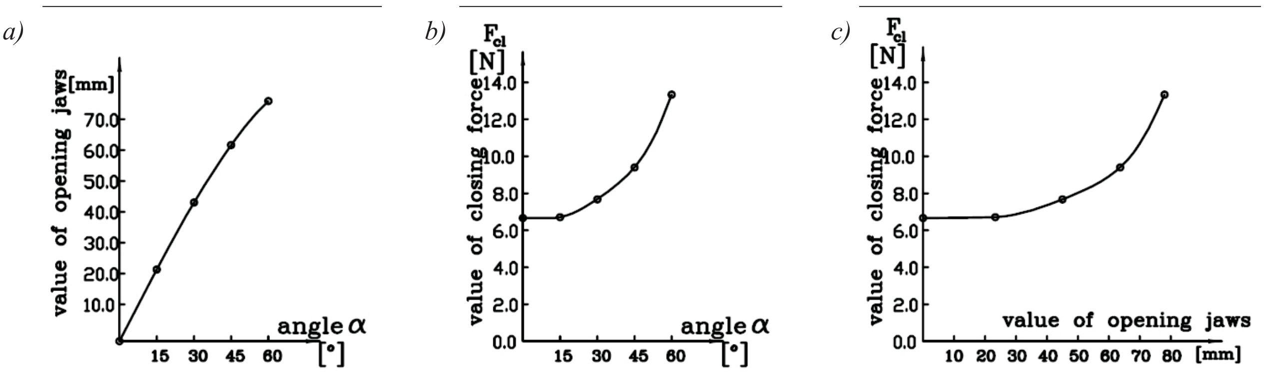

Fig. 6. Functional characteristics of the gripper: a) extension of the second phalange versus the angle of revolution of the fist phalange, b) maximum clamping force of the second phalange versus the angle of revolution of the first phalange, c) maximum clamping force of the first phalange versus the magnitude of gripper opening.

as at the designing stage. In particular, the driving motors with gears and their equipment; like limit and synchronisation microswitches, wiring, electric connectors were integrated with the gripper body in an aesthetical way, obtaining a compact mechatronic design.

Animation of cooperation between particular sub-assemblies allowed for making optimal use of the space available for mechanisms, as well as for integration of all parts and placing them in one aesthetical casing.

ACKNOWLEDGMENTS

The presented research is part of the project carried out under grant No. 514128733 by the Ministry of Science and Higher Education ”Problems of active sensing, interpretation of sensor gathering information and manipulation in service robots”, at the Institute of Automatics, Warsaw University of Technology.

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