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Penicilliform Anthropomorphic Manipulator

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***Abstract* — In the article a description of robot-equipped manipulator functionally and outwardly similar with human hand is introduced.**

***Key words—robot-equipped manipulator, antropomorphic, servomotor, accelerometer, hand*.**

I. INTRODUCTION

Long ago mechanical manipulators occupied their own niche in modern world. They're used in the most diverse domains of human activities, starting with machines with toys and finishing with space shuttle tentacles. They help people to perform work quicker, more precisely and of higher quality. Thus, for example, in the medical field mechanical manipulators are used to remotely conduct surgeries. One of the examples of such robotic devices is the da Vinci surgical system, developed by the US military.

Manipulators are rampant in industry. They are used on the final products assembly, coloring and verifying lines.

The given work is dedicated to design of a manipulator externally and functionally corresponding to the real human hand. In the process of creation the manipulator mechanism, its electronics and control algorithms will be worked over. Subsequently this knowledge could be applied in the development of electronically-controlled artificial arms or exoskeletons.

II. DRIVE TYPES

A major challenge in the construction of suchlike manipulator is the drive selection along with choice of a method by which the drive's force will be passing onto mobile components. Virtually all properties of the manipulator will depend on the chosen technological concept.

There exist several most popular drive types, which are used in home-made robotics. They're based on cimpletly different operating principles.

Pneumatic power drive

The basis of the pneumatic drive is an air-driven muscle. It is a pneumatic device which is able to linearly decrease during the supply of compressed air into the system [1]. Advantages of the pneumatic muscles are their light weight, large reduction amplitude, high power-weight ratio and structural flexibility.

A negative side of such muscles is the necessity of pressed-air system which results in considerable increase of mass-dimensional characteristics.

Hydraulic drive

That sort of drive type is premised on hydraulic cylinders usage. System with such drive allows manipulating sufficiently large and heavy objects, but is cumbersome itself. Furthermore, during active operation such a system produces higher level of noise [2].

Drive based on the conversion of rotational movement into sliding

A drive using this kind of method consists of an electric motor, a pin, a nut or another moving part, whereon a thread is cut [3].

One end of the pin attaches to the motor's shaft while the other, most commonly, lodges inside of a joint. Spinning along with the motor's shaft the threaded pin forces a nut or another threaded detail to move back and forth, this sets manipulator fingers in motion. Incidentally, in order to provide the required velocity of fingers movement it is necessary to use motors, designed for work under high speed.

Servo drive

Servomotor is a device used in the modeling to control a model's moving parts, such as robot limbs joints or dummy car wheels turning. It consists of an electromotor, confined in a single casing with reduction gear and controlling electronics, which consists of feedback potentiometer and control board [4, 5]. Such a hand design is rather compact as the servomotors can be anchored straight on the palm. That sort of drive is the most optimal at value and working methods. This is exactly why it shall be used in the given project.

III. CONTROL SYSTEM DEVELOPMENT

The manipulator control unit can be divided into two groups: operation microcontroller and sensors.

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Sensors

In order to know on which angle the servomotors should be turned, it is required to know which position fingers of a real hand have. For this purpose, a glove with sensors will be put on a human hand to determine which angles the fingers of this hand have.

With such device characteristic aspects two types of sensors can be used: resistance strain gages or integral accelerometers-gyroscopes.

Usage of resistance strain gages as bend sensors is preferable due to the lack of complexity with their connection, simple data processing algorithm and high linearity of counting. However, for the reason that it's necessary to use fairly long sensors (nearly 8-12 centimeters) in the project, there appear several problems concerning their inaccessibility and high price.

Integral accelerometers represent special microcircuits, containing microelectromechanical system within themselves, which is able to determine the sensor's apparent acceleration. That sort of solution has a number of advantages such as high speed of operation, accuracy, compactness and low price.

But it also has disadvantages, such as more complex data processing algorithms and small creep of output parameters. In our work we chose accelerometer microcircuits LIS3DSH which might allow expanding the device functionality in the future.

Operating microcontroller

The microcontroller will collect data from the sensors, perform computations and control the drives. It must have high performance, necessary interfaces for the communication with the accelerometer and the other hardware peripherals (timer clocks, AD converter, etc.).

Nowadays, the microcircuit market is full of controllers from different manufacturing companies. However, taking into account that six sensors will be attached to the glove (one on the back of the hand and one on every fingertip), with optional increase to the amount of 15 sensors (one on the back of the hand and one on every finger phalange), it's necessary to choose a microcontroller with large functional capabilities (clock speed, interfaces quantity, etc.). In our work we chose the STM32F407VGT6 microcontroller. This controller has 32-bit data bus, clock rates up to 158MGz, built-in data transmitting protocols SPI and I2C.

IV. MATHEMATICAL MODEL OF CONTROL SYSTEM

In order to determine the required position of the manipulator fingers we use six triaxial accelerometers (one on the back of the hand, acting as zero of coordinate system and one on every fingertip).

Here appears a problem of finding α, β and γ rotation angles of finger phalanges about the coordinate axes. It's necessary to point out that we know the lengths $|\overrightarrow{OA}|$, $|\overrightarrow{AB}|$ and $|\overrightarrow{BC}|$ of every phalange. To simplify the problem, the finger position will be calculated in a plane (Fig.1 and Fig.2).

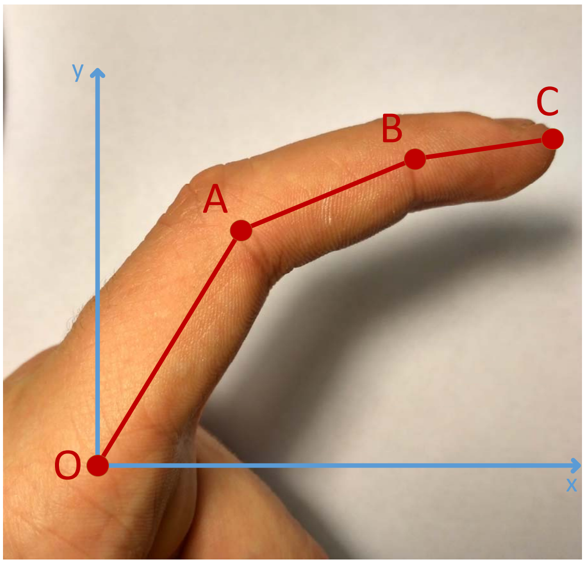

Fig. 1. The problem's graphical interpretation

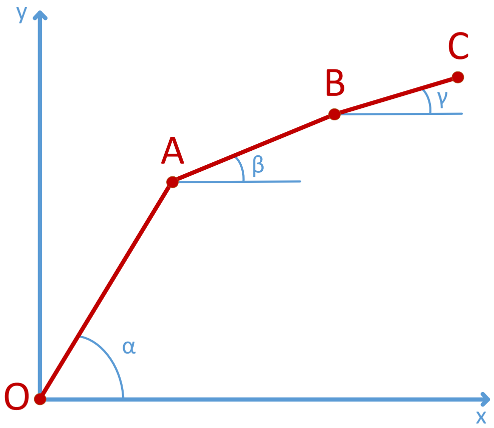

Fig. 2. Designation of angles of inclinations of two phalanges

From the accelerometer output data we obtain projections of its accelerations A_x, A_y and A_z on the coordinate axes. Using them we calculate the coordinates of point C and the angle γ [6]:

$$C(x_3, y_3);\ \gamma = \arctan\left(\frac{A_x}{\sqrt{{A_y}^2 + {A_z}^2}}\right)$$

Utilizing the data obtained, find projections of the vector $\overrightarrow{BC}$ on the coordinate axes and the coordinates of point B:

$$BC_x = \left|\overrightarrow{BC}\right| \cos \gamma$$
$$BC_y = \left|\overrightarrow{BC}\right| \sin \gamma$$
$$B(x_2, y_2);\ x_2 = x_3 - BC_x;\ y_2 = y_3 - BC_y$$

All operations with the distal phalange are finished and we can exclude it (Fig.3).

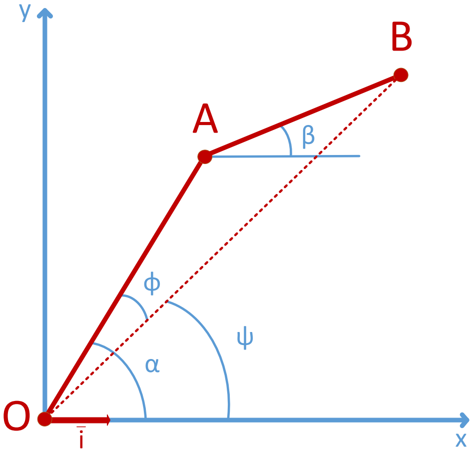

Fig. 3. Finding angles of inclination of two phalanges

Knowing coordinates of point B find vector $\overrightarrow{OB}$:

$$\overrightarrow{OB} = \{x_2, y_2\}$$

Multiplying vector $\overrightarrow{OB}$ scalarwise by the unit vector $\vec{\imath}$, which lies on the x axis, find the vector $\overrightarrow{OB}$ projection onto this axis:

$$\left(\overrightarrow{OB}, \vec{\imath}\right) = x_2$$

Using the vector projection on an axis and vector length calculation formulas we obtain the cosine on the angle in between the vector and the axis:

$$\cos \psi = \frac{x_2}{\sqrt{{x_2}^2 + {y_2}^2}}$$

With the cosine theorem we will calculate the cosine of angle ϕ:

$$\cos \phi = \frac{\left|\overrightarrow{OA}\right|^2 + \left|\overrightarrow{OB}\right|^2 - \left|\overrightarrow{AB}\right|^2}{2\left|\overrightarrow{OA}\right|\left|\overrightarrow{OB}\right|}$$

And now obtain the angle α:

$$\alpha = \arccos(\cos \psi) + \arccos(\cos \phi)$$

Knowing the angle α, find coordinates of point A:

$$A(x_1, y_1);\ x_1 = \left|\overrightarrow{OA}\right| \cos \alpha;\ y_1 = \left|\overrightarrow{OA}\right| \sin \alpha$$

Find the vector $\overrightarrow{AB}$, its projection on the axis x and the angle β:

$$\overrightarrow{AB} = \{x_2 - x_1, y_2 - y_1\}$$

$$\left(\overrightarrow{AB}, \vec{\imath}\right) = x_2 - x_1$$

$$\cos \beta = \frac{x_2 - x_1}{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}}$$

$$\beta = \arccos(\cos \beta)$$

The conducted mathematics demonstrate the applicability of minimum amount of accelerometers to control the manipulator. In addition to the above the usage of a microcontroller with floating point module will allow performing the calculations faster.

V. PRACTICAL RESULTS

Trial experiments were carried out using a simplified model of a manipulator hand. All parts were designed in SolidWorks program and made out of 4-millimetric plywood. Servomotors are attached to a square underplate with has slots cut in it where finger anchors are inserted. The fingers themselves have only two phalanges for the purpose of simplifying the construction (Fig.4).

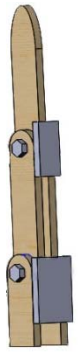

Fig. 4. Manipulator finger contrstucion

The distal phalange has a form of vastly elongated ellipse and has an anchor hole near one of its edges. The proximal phalange consists out of two elements, which also have form of vastly elongated ellipses. These elements are placed in parallel with the distal phalange inserted in between.

In order to control the fingers positions the servomotors and the phalanges are connected with a nylon thread. One rim of the thread is attached to a bowl on a servomotor and another – to the bottom of the distal phalange. The second nylon thread is used to return the finger into the origin position. It's connected to the upper part of the distal phalange. Therefore, when the servomotor's bowl starts to spin – it pulls the thread which runs through the fingers. Under the action of tension force, the finger has to bend on a value which depends on the servomotor's rotation angle.

Further a glove with sensors was assembled. Rubber coated cotton glove was used as a framework. A circuit with a sensor was attached to every fingertip and the back of the hand via double-sided duct tape. Each plate is connected to the microcontroller via wires.

The current appearance of the device is shown on the Fig.5.

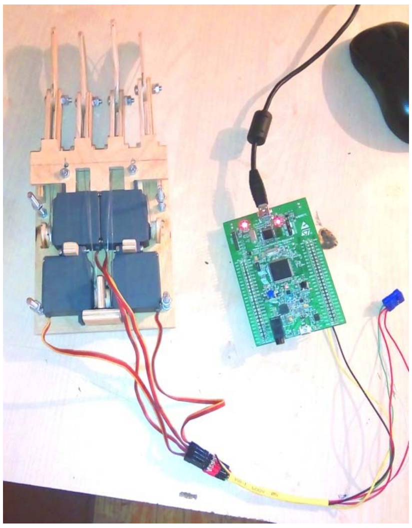

Fig. 5. Device prototype

The device control is performed in the following way. Accelerometers on the glove read the gravitational acceleration projection onto the X, Y and Z axes. The sensor on the back of the hand plays the function of a “ground”, which means that the fingers positions will be determined in relation to this sensor, but not to the surface. This allows us to effectively control the manipulator without dependence on the glove’s location in space. Hereafter the microcontroller puts all the data into a single coordinate frame, filters it and calculates the new position of the manipulator fingers [7].

The servomotors in the manipulator are controlled with pulse-time modulation. The most optimal control signals are signals with 50Gz frequency and pulse duration from 0.9 to 2.1 ms. The pulse duration has a direct impact on servomotor’s axis rotation angle.

VI. CONCLUSION

At this point the hand is already capable of operations of grabbing and holding objects. It also can perform various gestures since every finger controls independently. At the moment the construction has only four fingers because of the servomotors large size which doesn’t allow attaching five of them onto the hand without increasing its size.

In the future the hand’s construction will be changed. The ability to independently control every phalange will be added. Also the whole mechanism will be 3D-printed which allows us to increase the manipulator’s functionality.

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