Robotic wrists mechanisms with bevel internal gears having a small difference in numbers of teeth

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Abstract. A robotic manipulator should be able to obtain an arbitrary orientation of the end-effector, action which needs a wrist mechanism with minimum two independent rotations about two intersecting axes, generally perpendicular. If the task performed by the manipulator is more complex, it may be necessary for the end-effector to rotate about its axis, it means that the wrist mechanism needs three degrees of freedom. Planetary bevel-gear trains can be used in the design of wrist mechanisms. The wrist mechanisms using bevel gears have been shown to have some advantages. More, a nutating gear drivetrain has some advantages over a conventional planetary gear train, including: a decreased number of drivetrain parts, an ability to use lower-strength gear materials, a higher overall reliability, and a decreased manufacturing cost. Based on some nutation geared mechanisms using bevel internal gears having small difference in numbers of teeth, in this paper some robotic wrists will be proposed.

1. Introduction

For a robotic manipulator it is desirable to be able to get an arbitrary orientation of the end-effector. This action needs a wrist mechanism with minimum two independent rotations about two intersecting axes, generally perpendicular. If the manipulator performs a mechanical task such as in manufacturing or assembly it may be necessary for the end-effector to rotate about its axis, it means that the wrist mechanism needs three degrees of freedom.

Robotic wrists should preferably be centered around a point, that means that they should be "spherical", because the resulting configuration is more dextrous and less cumbersome than the other configurations. Planetary bevel-gear trains can be adopted to derive the configurations of spherical wrist mechanisms. The bevel-gear spherical wrist mechanisms have been shown to have the following advantages: the closed form solution for the inverse kinematics is available; the workspace is easy to determine; the actuators can be mounted remotely from the wrist center to reduce the dynamic effect; the design requirements, such as stiffness, dexterity, and heavy payloads, are provided [1].

A nutating gear drivetrain has the potential to create comparable speed reductions and torque multiplications. The advantages of a nutating gear drivetrain over a conventional planetary gear train include: a decreased number of drivetrain parts, an ability to use lower-strength gear materials, a higher overall reliability, and a decreased manufacturing cost.

Several studies have been done on the design and mathematical modelling of geared mechanisms [2-5], in general, and of wrist mechanisms [6-12], particularly. Based on some nutation geared mechanisms using bevel internal gears having small difference in numbers of teeth, proposed in another paper of the authors, in this paper some robotic wrists will be proposed and discussed.
2. Proposed robotic wrist mechanisms

If we consider the schematics of a nutation planetary gear with two output shafts (figure 1), discussed in another paper of this journal, a robotic wrist mechanism with three degrees of freedom we may get (see figure 2). The main advantage of the mechanism is that a single motor is necessary to actuate it. From this motor the motion is transmitted to the driven links using the $C_1$ electromagnetic coupling, for roll motion ($\alpha$) of the end-effector, or using the $C_2$ electromagnetic coupling, for yaw motion ($\gamma$) of the end-effector. These couplings, which allow the mentioned rotational motions of the end-effector, can be operated simultaneously or alternatively, depending on the robot's work schedule.

![Figure 1](image1.png)

**Figure 1.** Nutation planetary gear with two output shafts: a) mechanism kinematics; b) its spatial schematics.

![Figure 2](image2.png)

**Figure 2.** Kinematics of a robotic wrist mechanism with two degrees of freedom.
The angular speeds of the end-effector according to roll and yaw motions may be computed using the next equations:

\[
\omega_{out_2} = \frac{z_5}{z_6} \left( \frac{z_2' - z_1'}{z_2'} \right) \omega_{in},
\]

(1)

\[
\omega_{out_1} = \left( \frac{z_2 - z_1}{z_2} \right) \omega_{in}.
\]

(2)

To write the equations (1) and (2), we considered \( z_3 - z_4 \) and \( z_3' - z_4' \). It means that these gears have been used only to avoid the rotation of the satellites \( z_1 \) and \( z_2 \) around their own axis.

A robotic wrist mechanism with three degrees of freedom we may obtain if a nutation planetary gear with three (figure 3) or four (figure 4) output shafts will be considered.

**Figure 3.** Spatial schematics of a nutation planetary gear with three output shafts.

**Figure 4.** Spatial schematics of a nutation planetary gear with four output shafts.

Comparing to the wrist mechanism shown in figure 2, additionally we will obtain the third motion, pitch (\( \beta \)), using the \( C_3 \) electromagnetic coupling and a transmission with toothed belt, noted with 1 (see figure 5), or the \( C_3 \) and \( C_3' \) electromagnetic couplings and two transmissions with toothed belts, noted with 1 and 2 (figure 6). This motion is possible thanks to an angular coupling (noted with 2 in figure 5 and 3 in figure 6).
Figure 5. Kinematics of the first robotic wrist mechanism with three degrees of freedom.

Figure 6. Kinematics of the second robotic wrist mechanism with three degrees of freedom.
For the wrist mechanism shown in figure 6 should exist the equality \( \omega_{out_3} = \omega_{out_4} \) (see also figure 5) and the \( C_3 \) and \( C_3' \) electromagnetic couplings should be operated simultaneously. Again, the couplings that allow roll, pitch and yaw rotational motions (\( C_1, C_2 \) and \( C_3 - C_3' \) couplings) of the end-effector can be operated simultaneously or alternatively, depending on the robot's work schedule.

The angular speeds of the end-effector according to roll, pitch and yaw motions may be computed using the next equations:

\[
\omega_{out_2} = \frac{z_5}{z_6} \left( \frac{z_2'-z_2}{z_2'} \right) \omega_{in},
\]

(3)

\[
\omega_{out_3} = \omega_{out_4} = \frac{z_5}{z_7} \left( \frac{z_2'-z_1}{z_2'} \right) \omega_{in},
\]

(4)

\[
\omega_{out_1} = \frac{z_2-z_1}{z_2} \omega_{in}.
\]

(5)

3. Conclusion

A robotic manipulator should be able to obtain an arbitrary orientation of the end-effector, action which needs a wrist mechanism with minimum two independent rotations about two intersecting axes, generally perpendicular. If the task performed by the manipulator is more complex, it may be necessary for the end-effector to rotate about its axis, that means the wrist mechanism needs three degrees of freedom. Planetary bevel-gear trains can be used in the design of wrist mechanisms. The wrist mechanisms using bevel gears have been shown to have some advantages. More, a nutating gear drivetrain has some advantages over a conventional planetary gear train, including: a decreased number of drivetrain parts, an ability to use lower-strength gear materials, a higher overall reliability, and a decreased manufacturing cost. Based on some nutation geared mechanisms using bevel internal gears having small difference in numbers of teeth, mechanisms proposed by the authors in another article, in this paper some robotic wrists have been proposed and discussed.

4. References

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