Design Morphology and Layout of the Drive Mechanism of a Generator of SCARA Motions

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1 Introduction

The Multi-Modular Manipulation System currently under development at McGill University's Centre for Intelligent Machines is an 11-dof manipulator for special tasks such as wide-body aircraft servicing and maintainance. The system consists of three modules: (a) a 4-dof gross manipulator (GM) providing a rough posing of its end platform; (b) an intermediate 4-dof serial manipulator, the Cuatro Arm, for fine posing; and (c) a 3-dof parallel manipulator, the Agile Wrist, for fine orientation.

The GM should be capable of moving its end-platform while keeping it horizontally. Thus, the base of the Cuatro Arm installed on this platform, will have three independent translations and one rotation about a vertical axis. The type of motion to be generated is characteristic of those produced by SCARA systems [1].

In our design [2] the actuation of the GM is based on a cascade of two *tilt-pan* motion generators, each providing one rotation about a horizontal axis, the tilt, and one about a vertical axis, the pan (Fig.1).

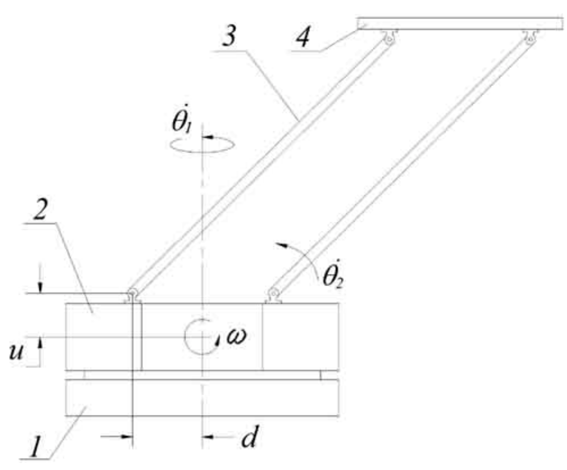

Fig.1. The tilt-pan motion generator

With the aim of generating these two independent motions with substantially different load conditions by means of identical motors, we decided to use a differential gear train. The train admits as inputs the motions of two identical DC motors, their outputs being the desired pan and tilt motions. The pan angle θ_1 is generated directly, but the tilt angle θ_2 is generated indirectly, by means of a mechanism that transmits the angular velocity ω of the horizontal output shaft of the differential gear train to a parallelogram (Fig.1).

We report here on the design of the mechanism used to implement the foregoing transmission.

2 Selection Criteria

The highest priority, apparently, should be given to load-balance and simplicity, followed by the stability of the manipulator, its reliability and self-locking capability. The latter is mandatory for any industrial robotic system for reasons of safety.

One of the highest priorities was given to simplicity. We need it, for sure, but it transcends the mechanical system and touches on the control algorithms to be developed. If we introduce a mechanism with a nonuniform velocity ratio, the control algorithm will be more complex due to the consequent increase in the complexity of the underlying Jacobian matrix. This will undoubtedly make the optimization of the whole system more cumbersome. So, simplicity relates to both the mechanical design and the control algorithm.

Compactness is also important, but need not be given the highest priority. The system will rest on the ground, in a reasonably large space. Nevertheless, the upper tilt-pan module of the GM should be lighter than the lower module because of stability reasons (the overall centre of mass should lie as low as possible). Besides, the workspace of the distal module must not intersect that of the proximal one, which brings about additional design constraints.

The speed-reduction ratio was also considered among the first priorities, for it allows one to reduce the number of gears in the differential units. Uniformity of link drive velocities is important too, but we had to compromise it in favour of some of the above-mentioned criteria.

Also, we have considered additional criteria, namely, accuracy, noise level, backlash, friction, and stiffness, but mostly as secondary.

In summary, we ended up with a few criteria: a) load balancing; b) simplicity; c) reliability; and d) self-locking capability.

3 The Resulting Layout

We considered 15 different designs from the viewpoints mentioned above, and zeroed-in on a layout with two main components (Fig.2):

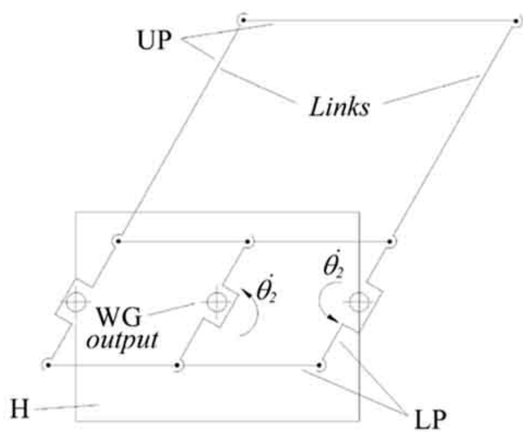

Fig.2. The layout of the differential and drive system

1. Worm gears (WG), converting two balanced output rotations of the differential unit into the motion of the lower parallelograms (LP).
2. Lower parallelograms, transferring the output rotations of the WG to the motion of upper parallelograms (UP).

The main method of selection was expert judgement, followed with virtual modeling and simulation. The layout thus obtained has some attractive features:

1. The LPs are kept on both sides of the housing (H), providing a synchronized motion of the two UPs.
2. The rotation of the WG output shafts is directly transmitted to the motion of the UPs, their velocities being identical.
3. The relation between the motions of each WG output and the driven link is linear, which results in more simplified control algorithms.
4. A LP pulls and pushes the two beams of an UP, thus driving them simultaneously. All these features provide a dynamically more stable system.
5. The LP is kept within the boundaries of the parallelogram, while a ball-screw shaft would move beyond.
6. The direct transmission of motion between parallelograms leads to a simpler and more reliable structure (without ball-screws and universal joints).
7. A 100-percent self-locking mechanism.
8. The WG allows for a higher gear ratio, thus doing away with extra gears in the differential unit, while reducing its mass and volume.

All the foregoing features have led to the conclusion that this layout is more suitable than a previous one, consisting of two ball-screws and two pairs of universal joints [2], which is the only possible alternative with self-locking capability.

The design of the gross manipulator, based on the above criteria, is shown in Fig.3.

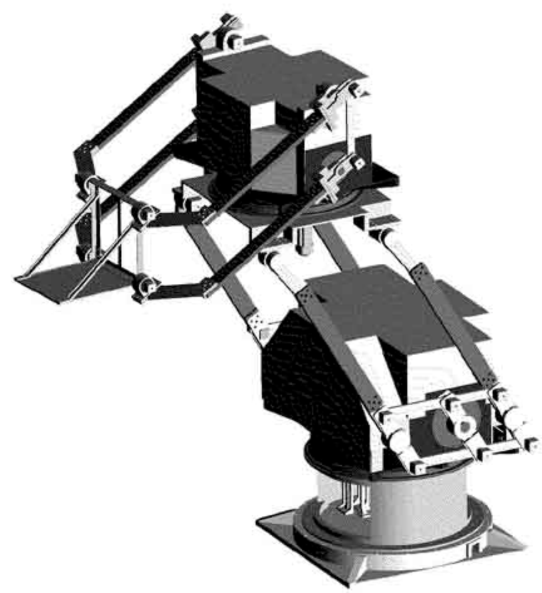

Fig.3. Pro/ENGINEER rendering of the GM

References

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[2] J. Angeles, A. Morozov, and O. Navarro, "A novel manipulator architecture for the production of SCARA motions", *Proc. IEEE Int. Conf. Robotics & Automation*, San Francisco, pp. 2370-2375. CD-ROM 00CH37065C.