The McGill Schönflies-Motion Generator

Stéphane Caro and Waseem A. Khan

Robotic Mechanical Systems Laboratory, Centre for Intelligent Machines, McGill University, Montreal, Canada

McGill Centre for Intelligent Machines

Abstract

The McGill Schönflies-Motion Generator (McGill SMG) is a parallel robot capable of a special class of motions, those produced with serial robots termed SCARA (Selective-Compliance Assembly Robot Arm): three independent translations and one rotation about an axis of fixed direction. Such motions form a ***subgroup*** of the displacement group of rigid-body motions, termed the ***Schönflies subgroup***.

Schönflies Motions

The McGill SMG is a manipulator that can produce four-degree-of-freedom displacements of its moving platform. The Schönflies subgroup was first studied by the German mathematician-mineralogist Arthur Moritz Schönflies (1853–1928), who found that these displacements have the algebraic structure of a group. The subgroup comprises three independent translations and one rotation about an axis of fixed direction, similar to the motions undergone by the tray of a waiter.

Figure 1: An example of Schönflies motions

Applications

- Pick and place operations
- Palletizing
- Machining
- Medical manipulators
- Educational platforms
- Pharmaceutical setups

Figure 2: An industrial SCARA system, the Adept Cobra 600

The Need of a Parallel Architecture

Advantages when compared to a serial architecture, like that of the Cobra 600:

- Higher stiffness (increased structural stability)
- Motors fixed to the base
- Compact and lighter links
- Shorter cycle times
- Higher accuracy

Design

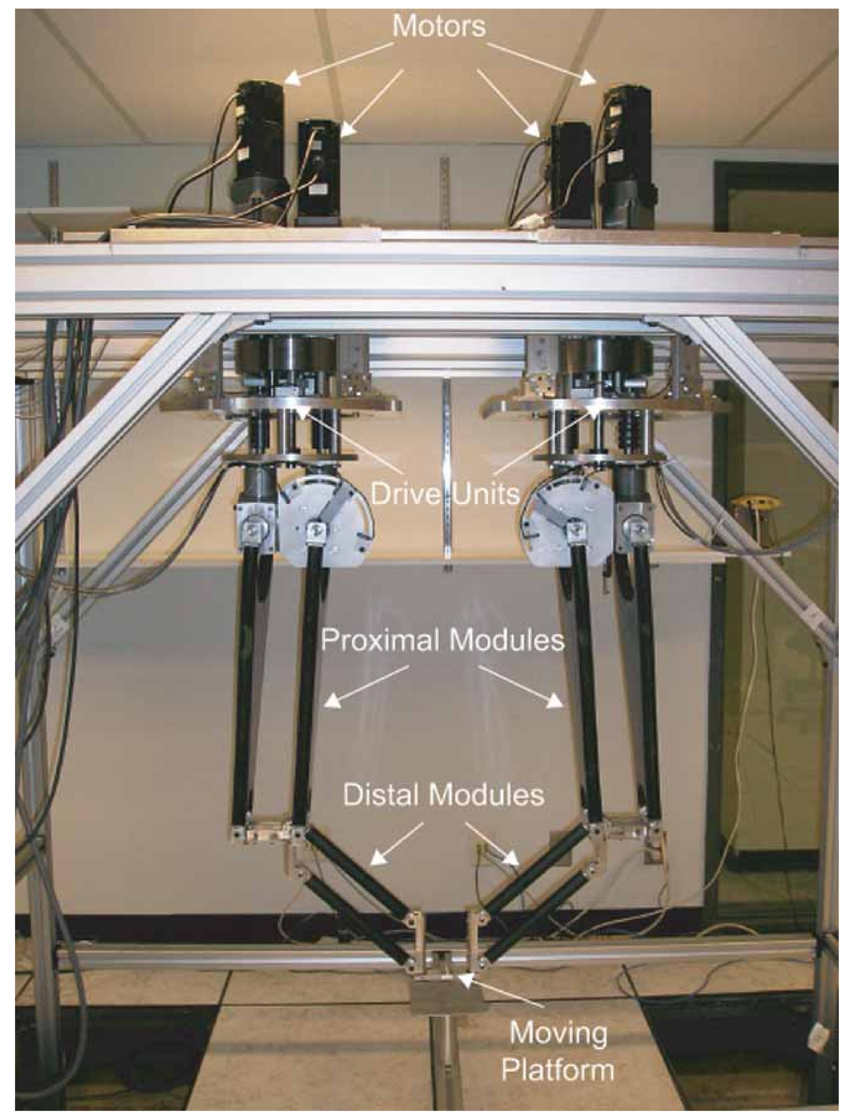

Figure 3: The McGill Schönflies-Motion Generator

The McGill SMG is composed of two identical four-degree-of-freedom serial chains. The two chains share one common base and one common moving platform, which leads to a parallel architecture. The links are made very light and are fabricated with carbon fiber composite. The prototype of the system is displayed in Fig. 3. Each leg of the manipulator is driven by a drive unit, which is made up of one epicyclic gear train driven by two motors attached to the frame, as depicted in Fig. 4. The *pan* motion is produced by the rotation of the planet-carrier, the *tilt* by the rotation of the planet gears about their axes. As a result, it is possible to combine the full power of both motors for any of the independent motions.

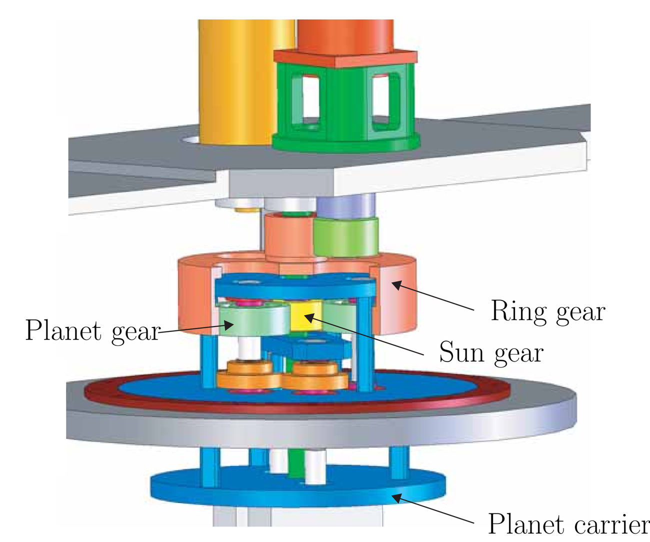

Figure 4: Drive unit

Specifications

The McGill SMG is designed for pick-and-place operations. A standard test cycle path is shown in Fig. 5. The robot is expected to beat the record-setting 500-ms cycle time. The test cycle consists of: (1) 25-mm vertical displacement up; (2) 300-mm horizontal displacement with a concomitant 180° turn; (3) 25-mm vertical displacement down; (4) 25-mm vertical displacement up; (5) 300-mm horizontal displacement with a reversed 180° turn; (6) 25-mm vertical displacement down. Moreover, the system has to be capable of attaining a kinetostatically robust configuration.

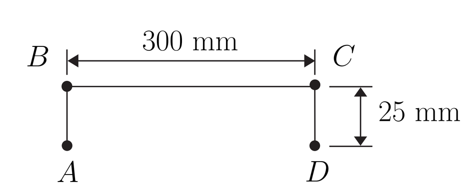

Figure 5: Path adopted for the manipulator design

The Kinetostatic Design

The kinematic relation for the whole system is given by

$$\mathbf{A}\mathbf{t} = \mathbf{B}\dot{\boldsymbol{\theta}}$$

where $\mathbf{t}$ is the twist—point-velocity and angular velocity—of the moving platform, $\dot{\boldsymbol{\theta}}$ is the vector of active joint rates, $\mathbf{A}$ is the *forward Jacobian* and $\mathbf{B}$ is the *inverse Jacobian* of the manipulator, respectively.

The McGill SMG meets a singular configuration whenever $\mathbf{A}$ or $\mathbf{B}$ become rank-deficient. We thus have two types of singularities, namely, *serial* and *parallel*. The former occur when $\mathbf{B}$ is rank-deficient, thus indicating the presence of a direction along which no Cartesian velocity can be produced (Fig. 6).

Parallel singularities, in turn, occur when $\mathbf{A}$ is rank-deficient, thus indicating a posture where the robot loses control over the moving platform (Fig. 7).

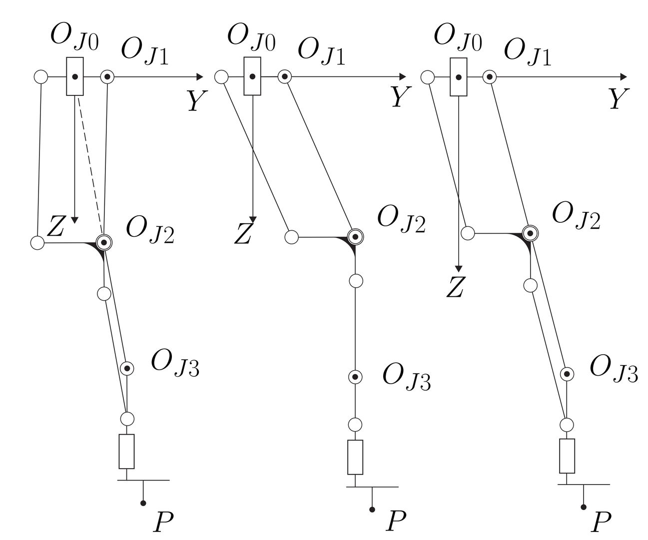

Figure 6: Three serial singular configurations

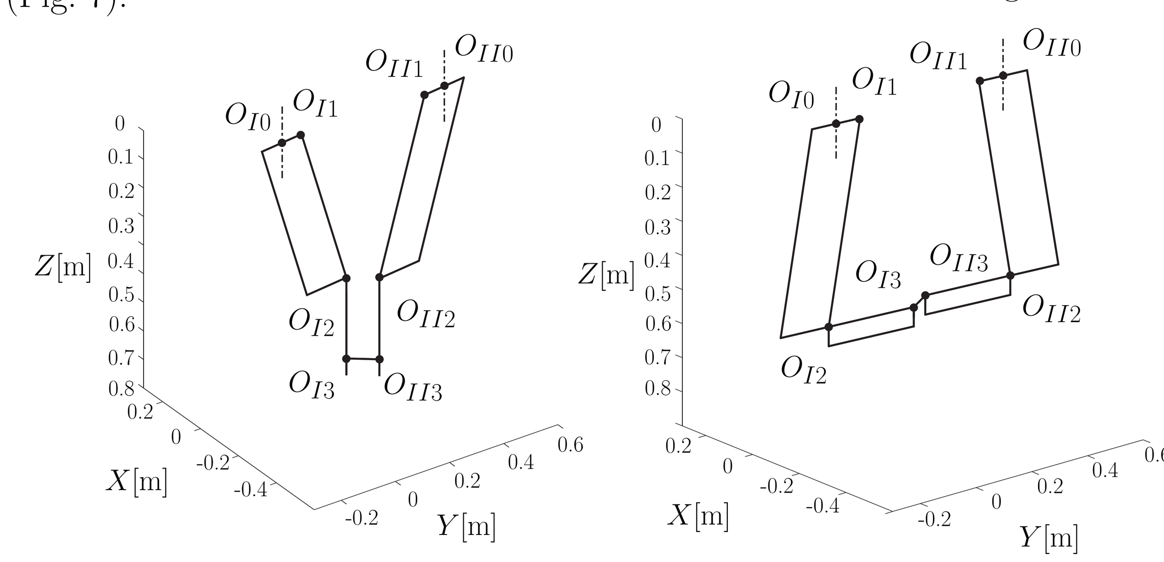

Figure 7: Two parallel singular configurations

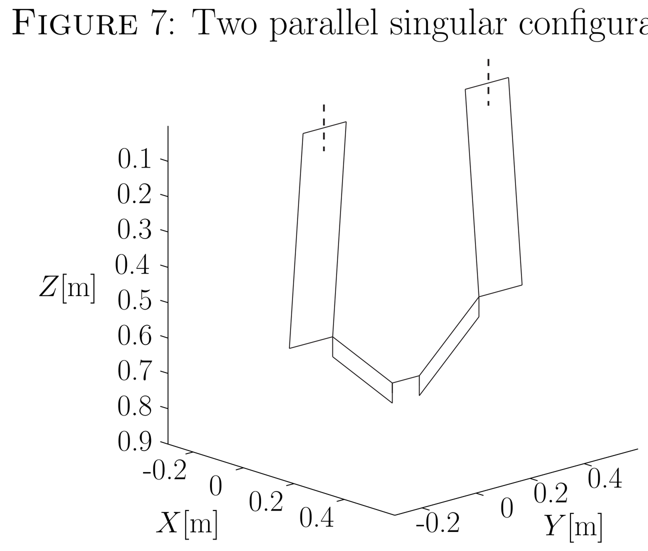

Figure 8: Kinetostatically robust posture

Project Team

- Prof. Jorge Angeles
- Prof. Larry Lessard
- Dr. Stéphane Caro
- Dr. Alexei Morozov
- Khalid Al-Widyan
- Guillaume Hirigoyen
- Waseem A. Khan
- Fayçal Lawayeb
- Yu Liu
- Imran H. Malik
- Rija Ndrialisoa
- James Smith
- Eric St-Amant
- Yibin Zhu