Design Challenges in the Development of Fast Pick-and-Place Robots

NSF Workshop on 21st Century Kinematics

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Outline

1. Introduction
2. New Design Challenges
3. Alternative Architectures
4. Teaching & Research Topics
5. Conclusions

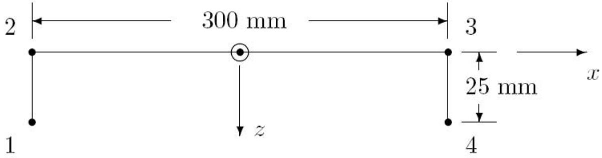
Background

Schönflies Motion Generators

- Schönflies Motion (SM): translation along three independent directions and rotation about an axis of fixed direction
  Think of the motions of the tray of a waiter
- SMs endowed with the group property: if a rigid body undergoes one SM followed by a second SM, the resultant displacement is also Schönflies
- First SM of the serial type: SCARA (Selective Compliance Assembly Robot Arm) systems for fast pick-and-place operations (PPO)

Background (Cont'd)

- Fastest SCARA system: Adept Technology COBRA s600 (ca. 1999): capable of 2 cycles/s over an industry-adopted test cycle



The industry-adopted test cycle for SCARA systems

- Turning requirement: while on the horizontal segment, moving plate (MP) must turn 180° ccw one way, cw when returning

Current Solutions

Serial Architectures

- RRRP architecture: Adept's COBRA s600, capable of 2 cycles/s (ca. 1999)
- RΠΠR: ABB IRB460, 110 kg capacity, 0.6 cycles/s, 2012

RRRP architecture

RΠΠR architecture

Current Solutions

Robots with Parallel Architectures

- ΔR architecture (parallel Delta in series with a R joint): ABB's Flexpicker & Fanuc M1iA

ABB's Flexpicker

Fanuc M1iA

Current Solutions (Cont'd)

Robots with Parallel Architectures

- Fully parallel architecture: Adept's Quattro, $\sim$ 3 cycles/s

Adept's Quattro

Current Solutions

Pros of Parallel Architectures

- Higher throughput: Quattro's speed is three cycles/s
- Lighter structure than serial robots

Cons of Parallel Architectures

- Larger footprint than that of serial robots
- Presence of four limbs a challenge to meet the *turning requirement*

Challenges

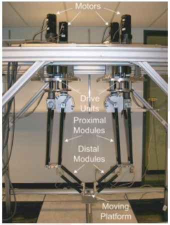
- Reduce footprint of parallel robots
- Meet turning requirement with a *simple* mechanism
- Simpler mechanisms $\Rightarrow$ reduce complexity. How to measure or define complexity?

Alternative Architectures—Two-limb SMG Robots

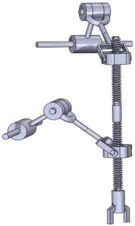
Underlying theme:

Innovate by means of minimally-complex designs that satisfy all the functional requirements and design specifications

- Two-limb SMG robots



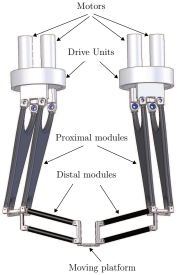
McGill SMG



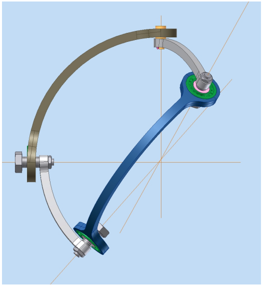
An isoconstrained SMG

- New design challenges brought about

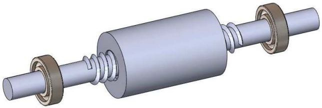
Design Challenge 1: The Drives



A planetary gear train



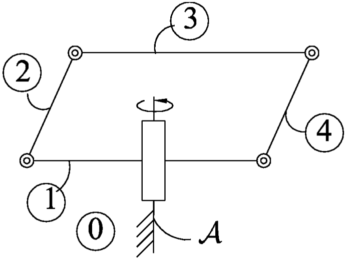
A spherical "homokinetic" mechanism



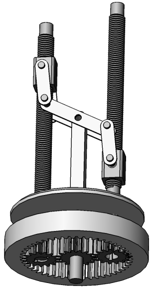
A RHHR linkage designed to drive a C joint

Design Challenge 1: The Drives (Cont'd)

Alternative Pan-tilt Mechanisms



Panning Π linkage



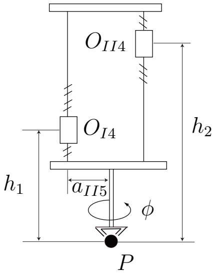
Five-bar tilting linkage

Design Challenge 2: A Stiff Structure

- link materials: carbon fiber
- the McGill SMG entails a symmetric structure of the RΠΠRRΠΠR type, with a home posture in which the four Π joints lie in the same plane. This renders the structure highly flexible in a direction normal to that plane
- the structure of two-limb isoconstrained SMG appears much stiffer, by virtue of the relative layout of the axes of its two C joints

Design Challenge 3: The Gripper-turning Mechanism

- H4 SMG — highly complex, with a multitude of gears
- two-limb isoconstrained SMG — extremely simple, suitable for the turning operation
- an alternative double-screw mechanism, proposed for McGill SMG — two parallel screws of identical leads, opposite hands, parellel axes



Teaching & Research Topics

- Link between engineering design and kinematic synthesis
  - Include Hartenberg & Denavit's *type synthesis* and *number synthesis* within the conceptual-design phase: *qualitative synthesis*
- Exact synthesis not a realistic approach to practical real-life problems: approximate synthesis
  - Computational-kinematics methods should be linked with optimization methods
  - Optimization methods target error minimization in the approximate synthesis
  - error-compensation by means of model-based kinematic control
  - Fundamental research needed in the formulation of optimization problems in the realm of dual algebra

Examples of Kinematic Synthesis Projects

- Assigned within MECH 541 Kinematic Synthesis at McGill University
- The term comprises 13 weeks, at 3h/week of lectures
- Three mini-projects assigned during the winter 2013 term
- Each mini-project mark counts for 25% of course mark, the balance 25% is assigned to a Class test (no final exam)

MECH 541 Kinematic Synthesis
Mini-project 1: The Design of the Actuation Mechanism of a Cylindrical Joint
Statement of Work

Assigned: Tuesday January 10th, 2012 Due: Wednesday February 9th, 2012

Shown in Fig. 1 are four instances of *Schönflies-motion generators* that are billed as *isoconstrained*. The latter means that each instance is *isostatic*. Each is composed of a moving plate (MP) or gripper, that is capable of Schönflies displacements of vertical axis. As well, each instance is composed of two limbs that connect the gripper with the base, onto which two horizontal shafts are rigidly attached. Moreover, in all four instances, the pitches of the two screws rigidly attached to the gripper are distinct.

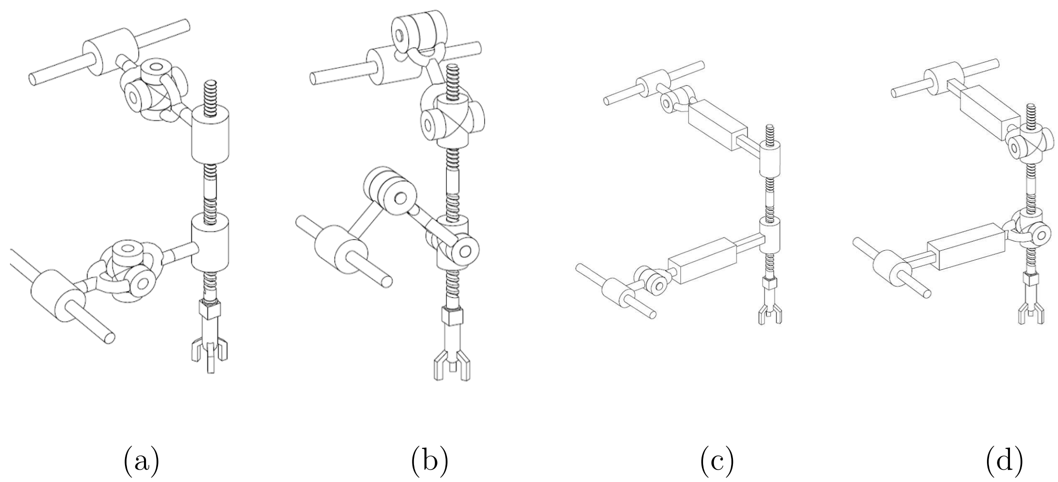
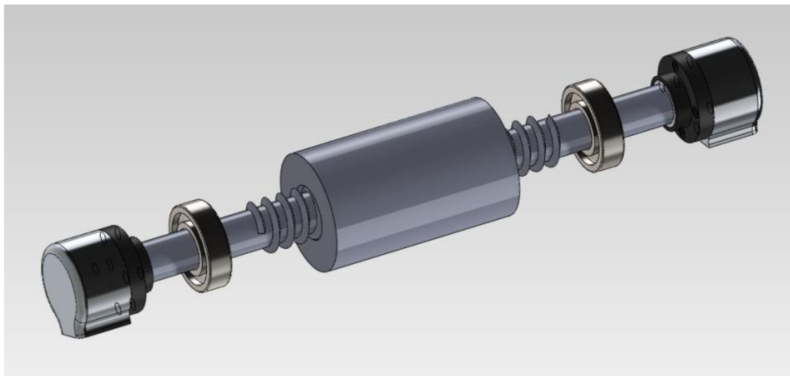
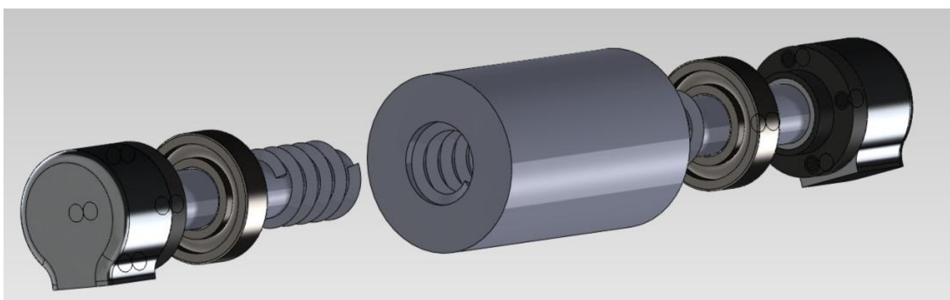


Figure 1: A novel pick-and-place robot in four instances: a) CUHHUC; b) CRRHHRRC; c) CRPHHPRC; and CPRHHRPC

1. Show that each instance is indeed a Schönflies-motion generator.
2. Show that each instance is isostatic. In other words, show that, if the statics equations are written for each individual rigid link, then the number of components of unknown reaction forces and moments equals the number of statics equations. this property is quite important, as it allows for *assemblability*, which an overconstrained chain does not.
3. Each instance is driven by two *actuated cylindrical joints*, which are not readily available off-the-shelf. Propose as many variants as possible of an actuated cylindrical joint, with its two motors mounted on the same base.
4. Of the variants that you propose, pick up one that you consider to be the best, giving reasons to support your choice. Then, produce an embodiment of this specific variant using commercial CAD software. Choose DC brushless servomotors capable of 3 turns/s, rated at 500 watt.





MECH 541 Kinematic Synthesis
Mini-project 2: The Design of a Quasi-homokinetic Linkage for Shafts with Skew Axes
Statement of Work

Assigned: Thursday February 9th, 2012 Due: Thursday March 8th, 2012

Ultimate Robotics Inc. (URI) is designing a parallel robot intended for Schönflies motion generation, with two limbs, each limb is driven by two actuators, to drive a *panning* Π joint, as depicted in Fig. 1. The pan axis $\mathcal{A}$ should pass through the mid point of link 1. A requirement of parallel robots is that all its actuators be mounted on the fixed base, 0 in the figure. The pan axis can be driven by directly coupling the pan shaft to the shaft of one of the two actuators. The tilt axis, one of the two joints of link 1, is to be driven with a second actuator coaxial with $\mathcal{A}$.

Given that *direct-drive* motors will be used as actuators, gears are ruled out in the driving system. Instead, a RCCC linkage is to be designed to drive the tilt axis from axis $\mathcal{A}$. You have been hired to design the linkage, which will function as a *quasi-homokinetic transmission*, that is, a linkage capable of *approximately* producing a 1:1 velocity ratio between actuator rate and tilt rate, for a 120° sweep of the tilt angle.

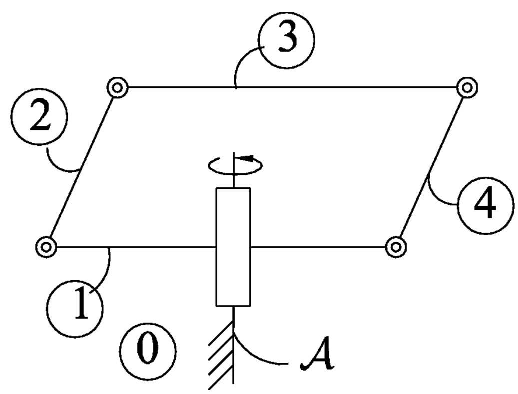


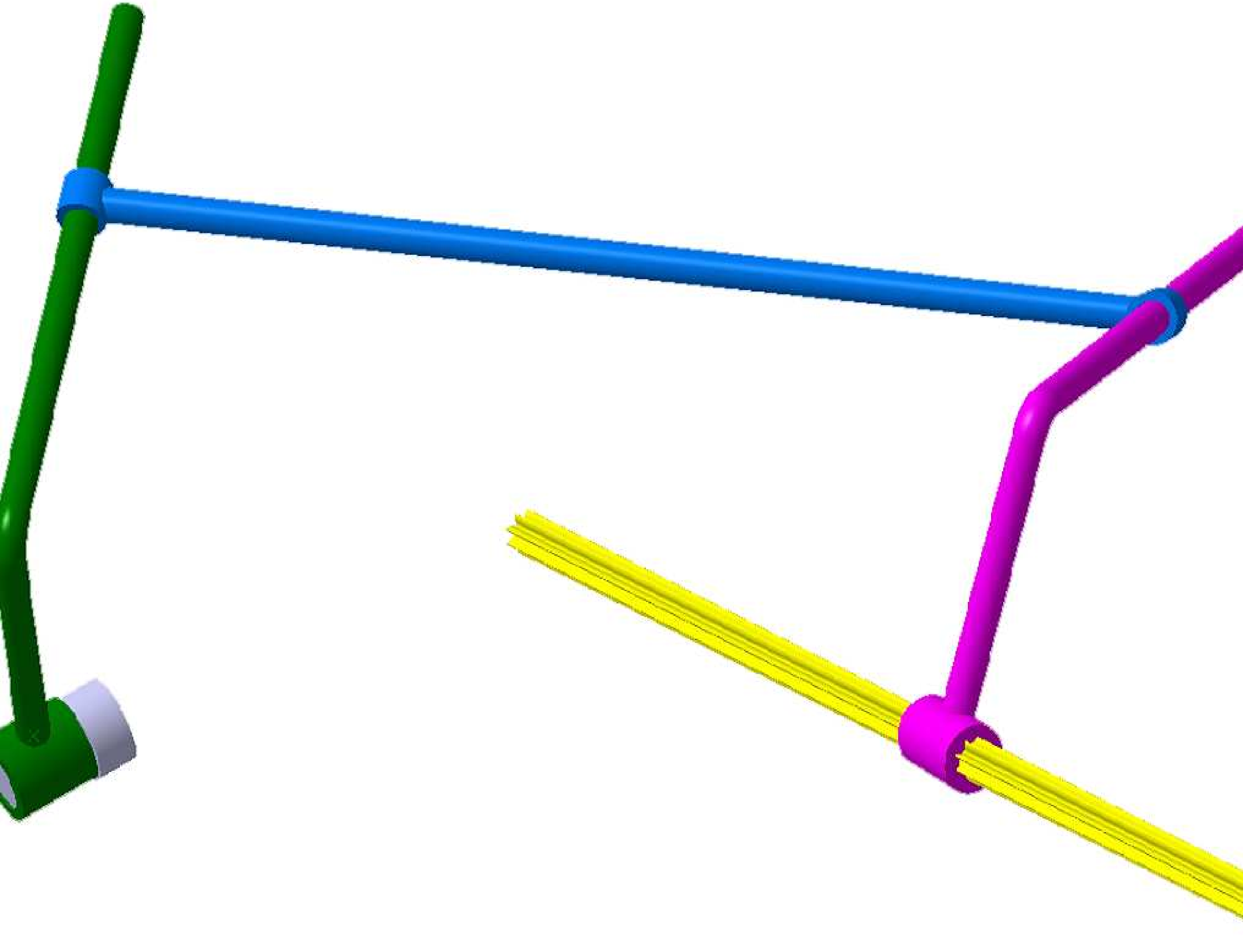
Figure 1: A panning Π joint

The R&D Department of the company reports that their records show that a location of the dial zeros of the input and output dials be set at values of 86° and −26°, respectively.

For the translation d_1 of the output joint, you are free to prescribe its motion program $\{ (d_1)_i, \psi_i \}_1^m$, but it is advisable that this program be symmetric with respect to $d_1 = 0$.

The client specifies that the distance between the two shafts is 400 mm, while d_2 in the Denavit-Hartenberg notation is to be given the same numerical value. An expert design engineer of URI claims that, given the homokinetic motion desired, the input an output axes should play the same role, and hence, $\alpha_4 = \alpha_2$ and, for symmetry, $a_4 = a_2$. Your job is thus

1. To find the optimum values of the remaining Denavit-Hartenberg parameters that best fit the prescribed homokinetic transmission in the *least-square* sense.
2. To produce error plots of the generated output angle-and-displacement values w.r.t. their prescribed counterparts, along with rms values of these errors, and
3. To produce a CAD rendering of the linkage thus designed. URI will give you a bonus if you produce an animation of the designed linkage.



MECH 541 Kinematic Synthesis
Mini-project 3: The Design of a Landing Gear for Small Aircraft
Statement of Work

Assigned: Monday March 19th, 2012 Due: Friday April 13th, 2012 at 5:00 p.m.

AeroDesign Inc. is developing a compact landing gear for small aircraft, consisting of a planar four-bar linkage. The linkage is to be anchored to the fuselage, indicated as the shaded region. Produce a design that will do the job, with the fixed R joints as close as possible to the fuselage boundary, and outside of the *working region*, i.e., the region swept by the wheel when it is being either retracted or deployed, as shown in Fig. 1. The client hasn't as yet decided what tyre model to use. For this reason, the client needs your design in terms of the tyre radius r. To this end, the client has specified the relations below:

$$a = 2r, \quad b = 3r$$

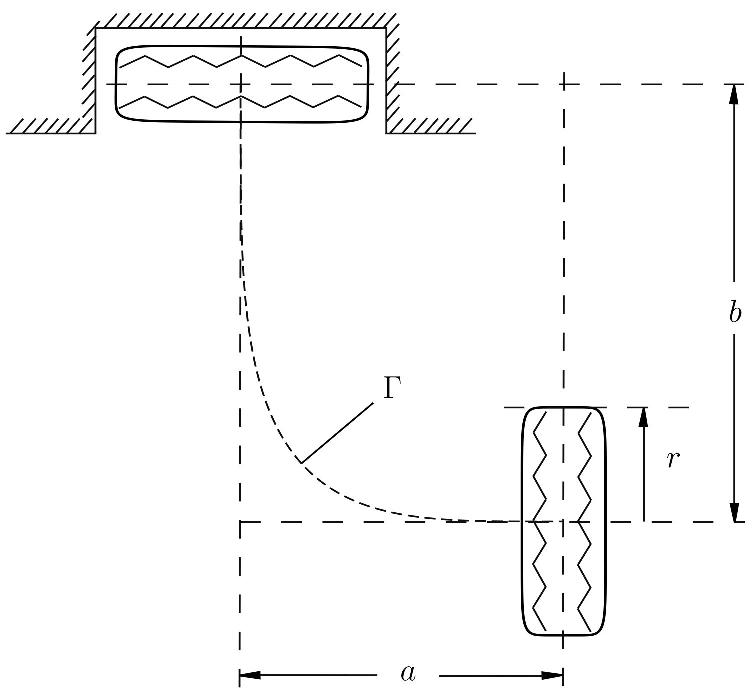


Figure 1: A landing gear for small aircraft

Moreover, the tyre can be assumed to fit in a rectangle of width $r/3$ and height r.

In order to make the operations of deployment and retraction as smooth as possible, the client wants a smooth trajectory Γ to be followed by the *midpoint* of the tyre, defined as the intersection of the tyre axis with the tyre midplane. An *AeroDesign Inc.* senior engineer has advised you to define Γ as a fourth-degree Lamé curve, namely,

$$\left(\frac{x}{a}\right)^4 + \left(\frac{y}{b}\right)^4 = 1$$