Realization of a Statically Balanced Compliant Planar Remote Center of Motion Mechanism for Robotic Surgery

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Objective

To realize a one Degree of Freedom (DOF) statically balanced, monolithic compliant planar RCM mechanism that can be used in tele-operated surgical robots, and automated endoscope holders

Remote Centre of Motion (RCM) mechanism

In Robotic assisted laparoscopy an RCM mechanism helps maintain a kinematic constraint about the insertion point. This is typically achieved by a parallelogram based RCM mechanism in commercial robots.

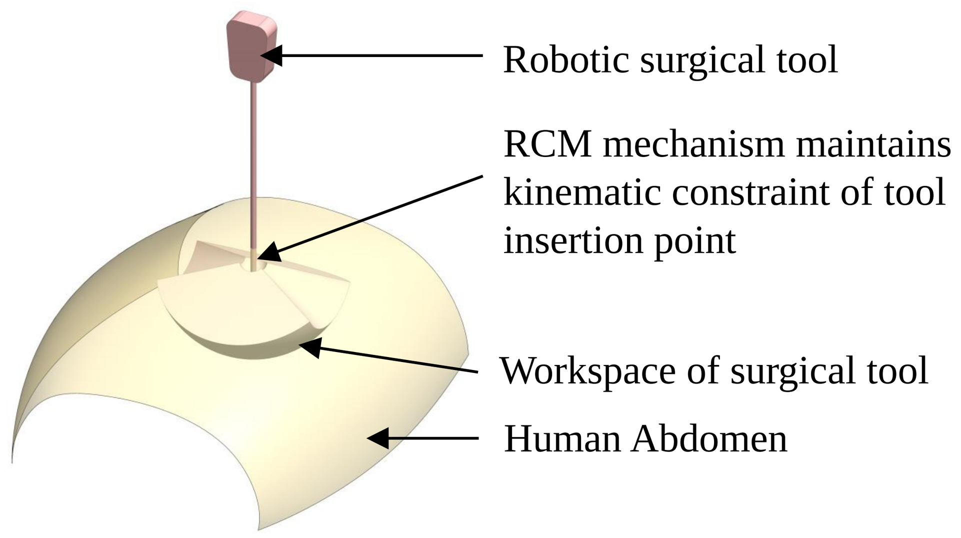

Fig 1. Role of RCM mechanism in robotic surgery

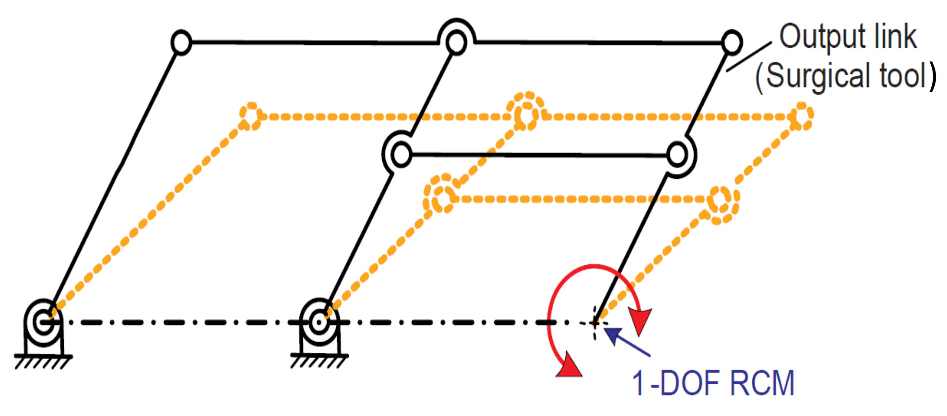

Fig 2. Parallelogram based RCM mechanism[1]

Compliant RCM design methodology

A standard rigid body based planar RCM is converted to compliant RCM by replacing all revolute joints by large displacement compliant flexures. Four flexures capable of large displacement were identified from literature and were used to model four separate compliant parallelogram based RCM mechanisms. Parasitic drift of each flexure is used to determine the most suitable flexure for the compliant RCM mechanism. Finite Element Analysis (FEA) was carried out to determine the parasitic drift of the RCM point of all four mechanisms and the results are listed in Table 1. The stiffness of all flexures were kept same by varying their dimensions within available packaging dimensions.

Flexure	Drift of RCM along *x* axis (mm)	Drift of RCM along *y* axis (mm)
Corner filleted	2.94	-1.77
Cruciform	0.89	-2.12
Cross pivot	5.44	-2.68
Split tube	0.73	-4.94

Table 1 Comparison of parasitic drift of large deflection flexures

The cruciform flexure is chosen to model the compliant RCM since it has the least net drift and has superior off axis stiffness compared to other flexures.

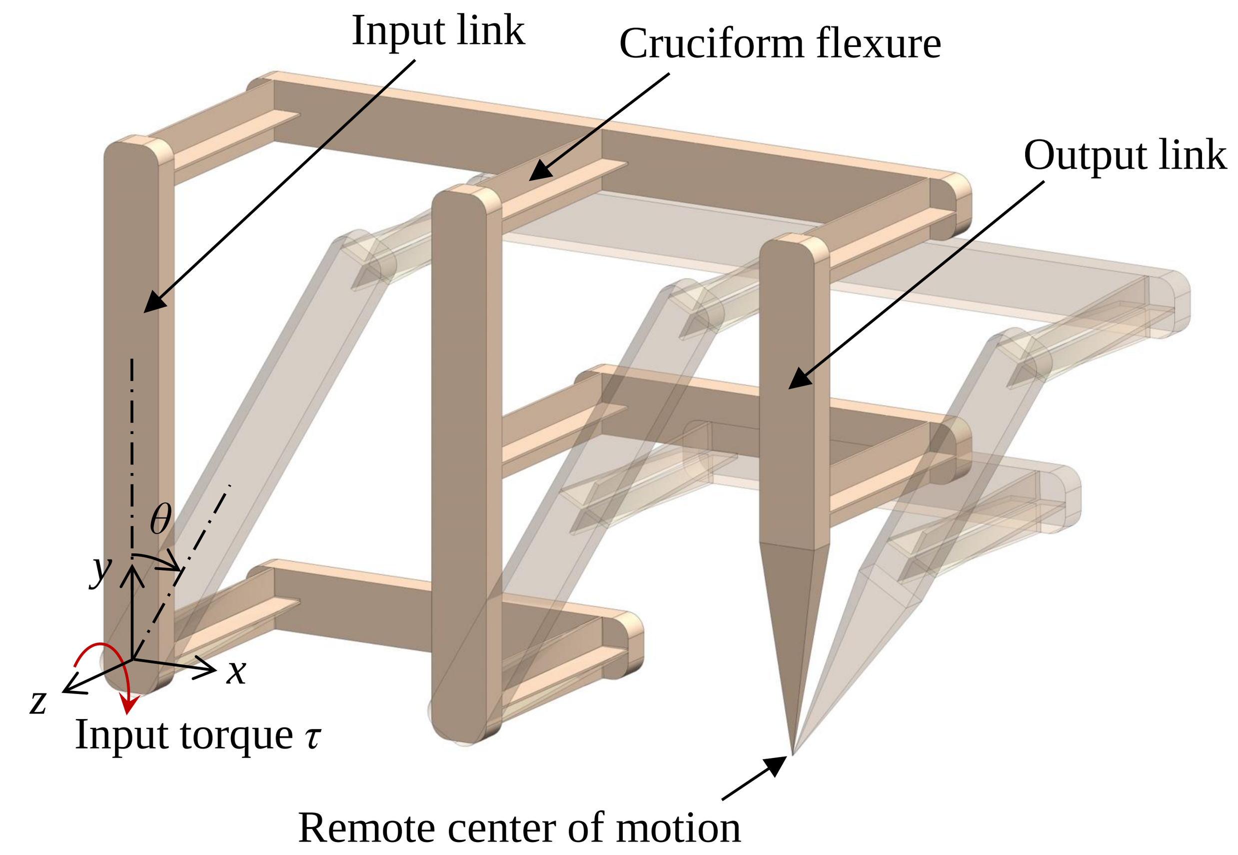

Fig 3. CAD model of Compliant RCM mechanism

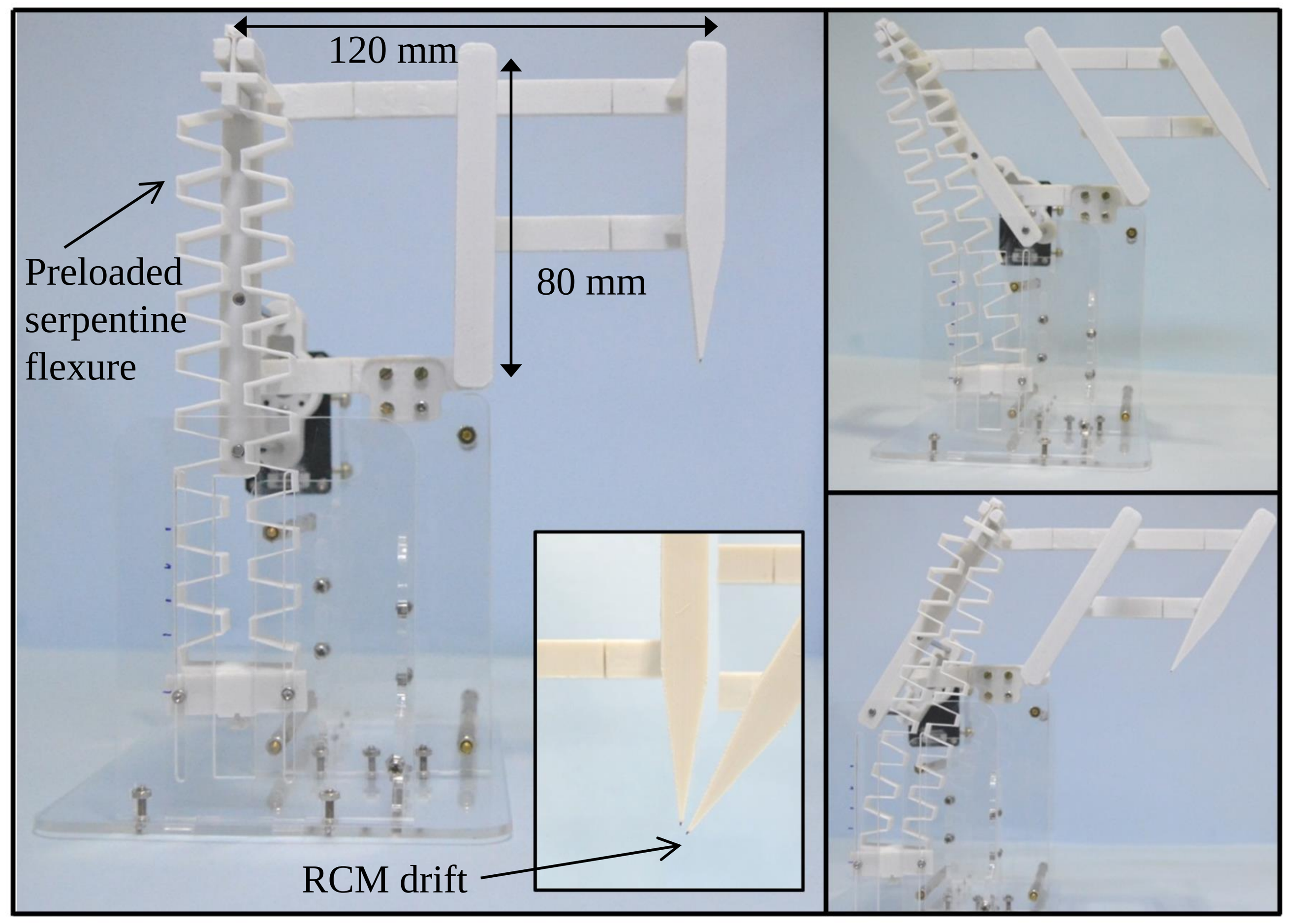

Fig 4. Statically balanced prototype demonstrating its range of motion

Static balancing of RCM and results

The compliant RCM mechanism stores strain energy when deflected and is not energy free. A negative stiffness mechanism obtained by utilizing a toggle mechanism with a serpentine flexure serves to counter balance the compliant RCM mechanism. The length, stiffness and preload of the toggle based counterbalancing mechanism was determined by a numerical optimization procedure. Fig. 5 shows the decrease in holding torque at the input joint of the compliant RCM mechanism with the counterbalancing serpentine toggle mechanism. Fig. 6 & 7 show the drift of the RCM mechanism obtained by experimental and finite element analysis along *x* and *y* axes. A total of 5 trials were conducted and the mean value is reported in the figures.

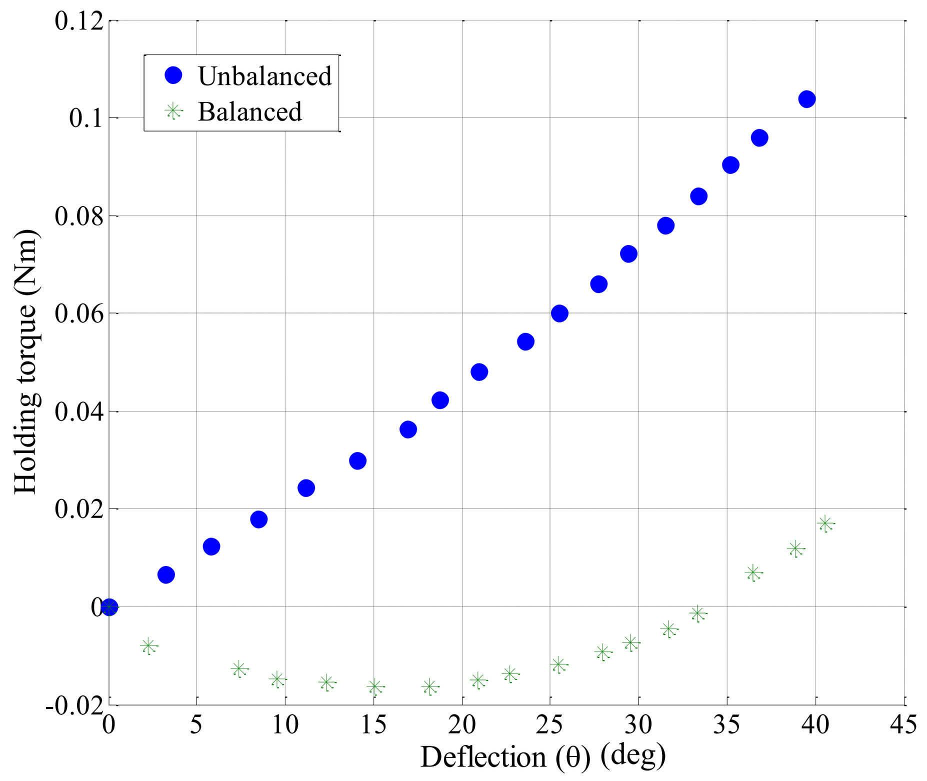

Fig 5. Holding torque reduction by static balance

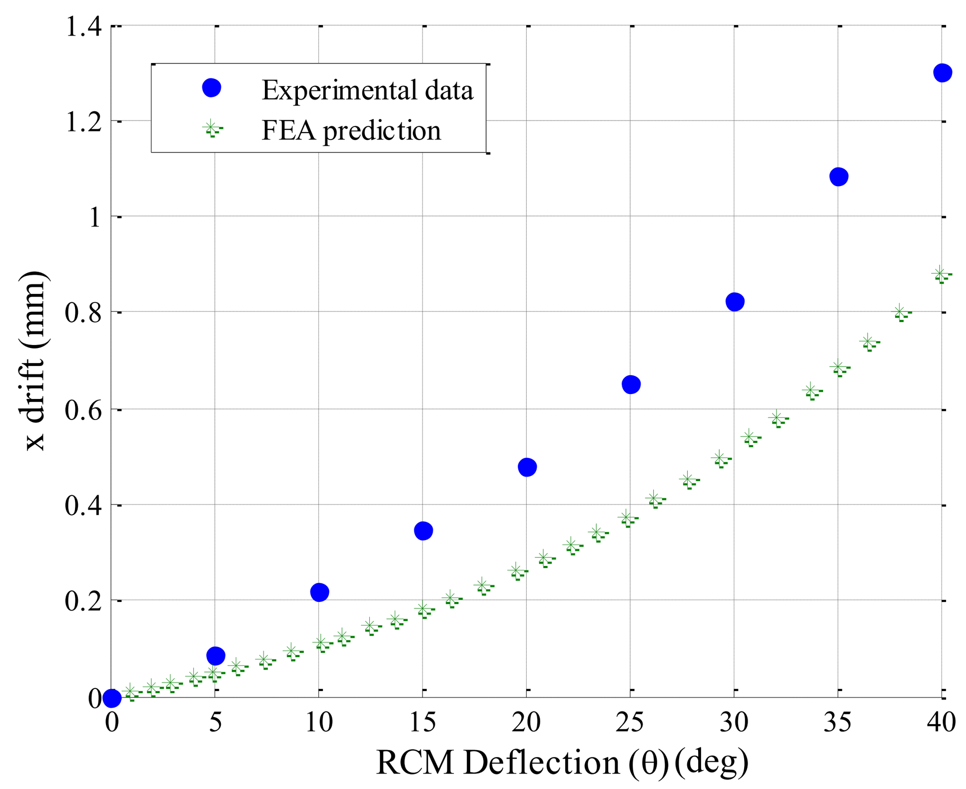

Fig 6. Drift of RCM along *x* axis

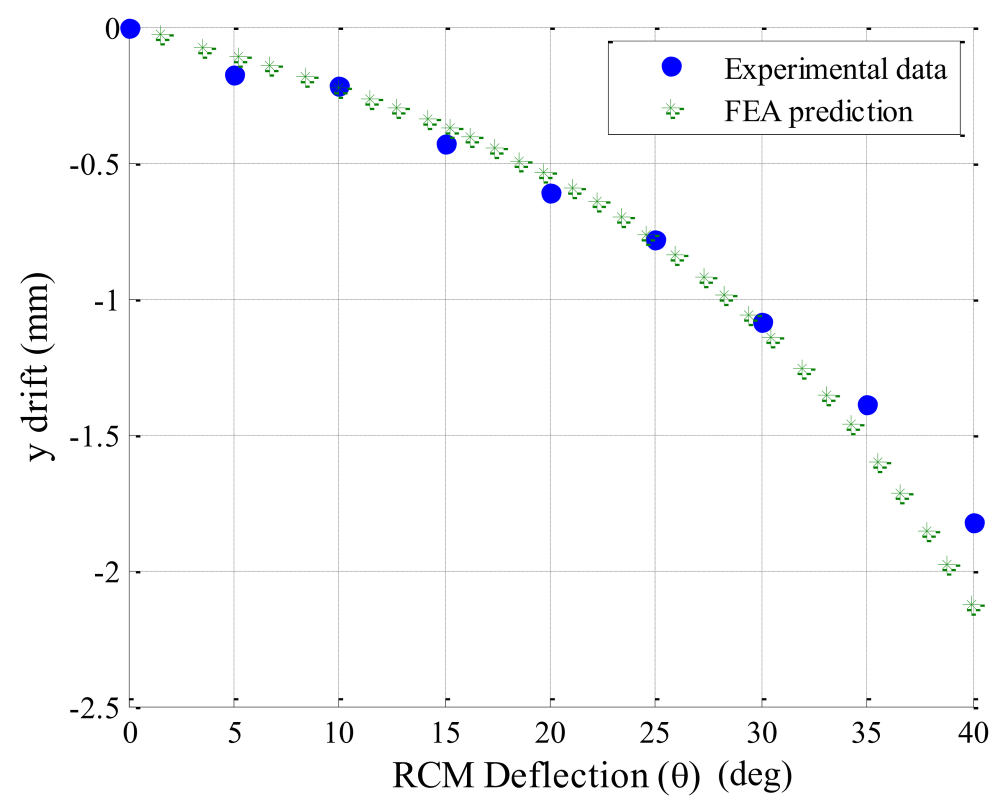

Fig 7. Drift of RCM along *y* axis

Conclusions and future work

- Compliant RCM mechanism prototype is capable of rotating ± 40° either side from vertical
- Additional FEA simulations confirmed that scaling the mechanism does not significantly change the RCM drift
- Static balancing was performed to make the mechanism energy free and hence improve safety and reduce torque input for actuation
- Further design changes are in the works for possibly achieving static balancing of the mechanism without any auxiliary body by utilizing preloaded flexures to reduce extracorporeal work space of the RCM mechanism

Image courtesy

1. Kuo, Chin-Hsing, and Jian S. Dai. "Robotics for minimally invasive surgery: a historical review from the perspective of kinematics." In International symposium on history of machines and mechanisms, pp. 337-354. Springer, Dordrecht, 2009.

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