# A 2-dof Spherical Remote-Center-of-Motion Manipulator for Haptic Interaction

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**Abstract.** Surgery simulators comprising virtual reality and haptic feedback provide an environment for sophisticated training of minimally invasive surgery (MIS) and represent an alternative to traditional training methods. One key element of surgery simulators is the force rendering at the surgeon's instrument handle by a haptic device for the training of the surgeon's hand-eye coordination. The displacement of MIS instruments has often 4-degree-of-freedom or more, however in many cases it can be based on two spherical degrees-of-freedom. In this paper a 2-dof spherical manipulator is presented as base device for surgery simulation. Design features for high-quality force-feedback are discussed. The remote-center-of-motion permits to hide the actuation linkage within a torso, while the pivot point remains freely accessible. Kinematics are analyzed. The prototype is presented and possible applications are outlined.

## 1 Introduction

Minimal-invasive surgery has introduced many benefits for the patient, like reduced trauma, lower infection risk and faster recovery time. However instrument manipulation is complex, as the instrument displacement is inverse to the movement of the surgeon's hand and as the 3D scenery is reduced to a 2D camera image.

Virtual reality and haptic feedback offer new possibilities to minimal invasive surgery training and education: While a surgery scenery is displayed on the screen, a force-feedback or haptic device creates force sensations at the tool handle of the surgeon's instrument. Therefore the same perceptive channels like in a real intervention are provided with information. Such training systems are presented e.g. in [10] or in [11], which is also commercially available. With difference to so far common training methods, scenarii can be repeated without limit and both standard as well as exceptional situations can be selected.

The design of the haptic manipulator is one of the key parameters for high-quality force-feedback. Singularity free workspace and forces must fit the application and mechanical disturbances have to be minimized. Inertia, friction and compliance distort the forces and decrease realism and therefore have to be reduced where possible. Furthermore the device has to be displaceable not only by the actuators or drives, but also by the surgeon - it has to be backdriveable.

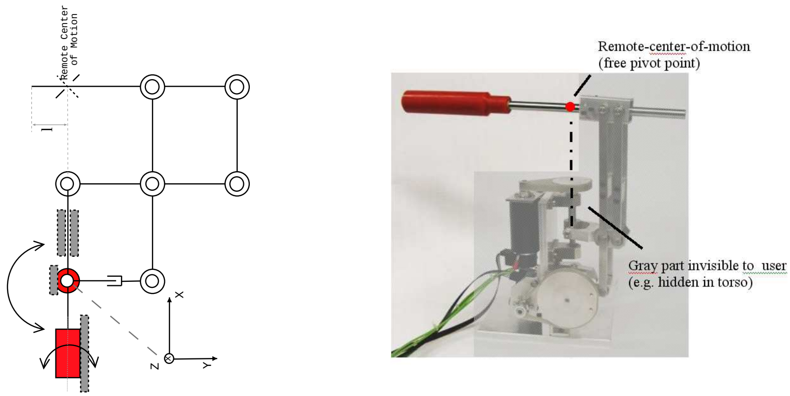


**Fig. 1.** The proposed 2-dof spherical mechanism with free pivot point

## 2 The Proposed 2-Degree-of-Freedom Manipulator

In this paper a pantograph-based spherical mechanism (fig. 1) is proposed, which satisfies the most important specifications, as outlined above, for high quality force- or haptic feedback devices. The remote-center-of-motion (RCM) architecture keeps the pivot point free from mechanical interferences and allows to completely hide the actuation linkage from eyeview within a training torso.

The structure is compact and inertia is minimized as both actuators are fixed to the base ('grounded'). Like the related manipulator presented in [2], the mechanism is singularity free within half-sphere workspace and adds advantages like e.g. the compactness of the serial device presented in [5]. In [8] a linkage similar to the proposed concept is introduced with both actuators fixed to the base. The linkage is actuated by a differential gear, which may introduce backlash and decrease backdriveability. In [9] several variations of RCM mechanisms are presented, while grounded direct drives are not considered. In [1] a 3-dof device with grounded actuators is presented. However, an application as remote-center-of-motion pointing device, as presented here, is not discussed. The well known manipulator mentioned in [6], concepted as a bimanual device, is not based a remote-center-of-motion architecture.

**Kinematic Displacement** In the following the kinematics of the 2-dof spherical mechanism with both actuators fixed to the base are considered.

The displacement angles of the pivoting linkage are denoted $\alpha$ and $\beta$, the displacement angles of the actuators fixed to the base are $\alpha and \gamma$. The angle $\gamma$ represents the angle $\beta$ projected into the x-y plane (fig. 2). The relation between $\beta$ and $\gamma$ is described by (1).

$$\cos\gamma = \frac{\cos\alpha\cos\beta}{\sqrt{\sin^2\beta + \cos^2\alpha\cos^2\beta}} \quad \sin\gamma = \frac{\sin\beta}{\sqrt{\sin^2\beta + \cos^2\alpha\cos^2\beta}} \tag{1}$$