Available online at www.sciencedirect.com
SCIENCE DIRECT®
Mechanism and Machine Theory 41 (2006) 170–190
Mechanism and Machine Theory
www.elsevier.com/locate/mechmt

Three degrees-of-freedom joint for spatial hyper-redundant robots

Elie Shammas [a], Alon Wolf [b,c,*], Howie Choset [b]

[a] *Mechanical Engineering, Carnegie Mellon University, Pittsburgh, PA 15213, USA*
[b] *Robotic Institute, Carnegie Mellon University, Pittsburgh, PA 15213, USA*
[c] *Institute for Computer Assisted Orthopedic Surgery, Western Pennsylvania Hospital, Pittsburgh, PA 15213, USA*

Received 16 September 2004; received in revised form 15 March 2005; accepted 26 April 2005
Available online 6 July 2005

Abstract

We present a new mechanical design for a compact three degrees-of-freedom joint mechanism. This joint design is ideal for use in robotic devices, especially hyper-redundant or snake-like robots. This joint exhibits an unprecedented range of motion: the origin of a coordinate frame attached to the output link of the joint can move on a spherical cone whose apex angle is 120° and this coordinate frame can be rotated around an axis passing through its origin and the center of the sphere. Moreover, the joint is optimized for strength, compactness and accuracy. These characteristics are verified by exploring the magnitude of the wrenches and errors that the joint can produce in its effective workspace. Finally, we present a mechatronic integration of four of our joints to construct a 12 degrees-of-freedom spatial hyper-redundant robot.

Keywords: Robotic joint; Mechanical design; Degrees-of-freedom; Hyper-redundant robot; Snake robot; Kinematics

* Corresponding author. Address: Mechanical Engineering, Carnegie Mellon University, Newell-Simon Hall, 5000 Forbes AV, Pittsburgh, PA 15213, USA.

E-mail addresses: eshammas@andrew.cmu.edu (E. Shammas), alon.wolf@cmu.edu (A. Wolf), choset@cs.cmu.edu (H. Choset).

0094-114X/$ - see front matter
doi:10.1016/j.mechmachtheory.2005.04.008

1. Introduction

Snake-like robots, technically termed as *hyper-redundant* robots, are, as their name suggests, elongated robotic devices that are designed to mimic their biological counterparts not only in shape but also in functionality. These types of robots are highly maneuverable, have inherent high mechanical redundancy, and are flexible. This allows such robots to easily maneuver through complex environments cluttered with many obstacles when compared to conventional robots. Generally, hyper-redundant robots are constructed by connecting several rigid links via robotic joints. Thus, designing a highly maneuverable and strong, yet compact, robotic joint is the main mechanical design challenge for constructing hyper-redundant robots.

Designing a *three-dimensional* hyper-redundant robot impacts several design choices for the robotic joint. At the very least, the robotic joint should be strong enough to produce high torque to counteract not only the static loads due the robot's own weight but also the dynamic loads produced by the robot's spatial motions. Moreover, since snake robots have a serial kinematic structure, any external load will be resisted by all joints throughout the snake robot as opposed to parallel kinematic structures where the external loads are divided among several limbs. This high strength requirement should not add to the joint's size and weight. Moreover, the joint should have high maneuverability to demonstrate complex motions and attain small radii of curvature. Finally, each of the joints should have a reasonable speed of motion. Our joint design satisfies all the above conflicting requirements.

A three-dimensional section view of our joint can be seen in Figs. 1 and 2. The basic mechanical components of our joint are two connected angular shafts. Rotating these shafts will produce a conic motion. By coordinating the rotation of these two shaft we can get useful degrees-of-freedom: in-plane bending, orienting. These degrees-of-freedom will be explained in more details later in the paper. Moreover, the joint uses three motors: Motor 1 actuates angular shaft 1 directly, Motor 2 actuates angular shaft 2 via an angular bevel gear train, and Motor 3 directly controls an additional twisting degree-of-freedom (Fig. 2). The angular bevel gear train not only reduces

Fig. 1. A section view of our joint showing the wire passage.