A Novel Obstacle Avoidance Control Scheme for Hyper-Redundant Manipulators

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Abstract. Hyper-redundant manipulators have large number of kinematic degrees of freedom (*DOFs*), thus possessing some unconventional features such as the ability to enter a narrow space while avoiding obstacles. In this article, we proposed a new obstacle avoidance control scheme for the hyper-redundant manipulator to avoid the existing static obstacles in environment while performing a pick-and-place task. Based on the analysis in the defined posture space where three parameters were used to determine the manipulator's configuration, the obstacle collision-free path has been well generated. To guarantee that the manipulator in motion has no collision with obstacles, the path-tracking control for the manipulator to trace the path in the posture space was also discussed. The joint torques were formulated in the parameter of the posture space path and the posture space path-tracking feedforward controller was introduced on the basis of the parameterized joint torque formulation.

1 Introduction

Hyper-redundant manipulators have very large kinematic DOFs. These robots, which are analogous in design and operation to the "Trunk of an Elephant", have some unconventional features such as the ability to enter a narrow space while avoiding obstacles. However, the realization of such a hyper-redundant manipulator is difficult because there are serious engineering problems involved. One is weight, another is control of their large degrees of redundancy. A novel tendon-driven manipulator mechanism was proposed [1] and a hyper-redundant manipulator called "CT-Arm" has also been developed [2] to solve the weight problem. The hyper-redundancy of the CT-Arm only exists in the vertical plane. The discussion of this study is thus limited to 2-dimension.

To solve the control problem of hyper redundant DOFs, an algorithm for the planar hyper-redundant manipulators where the hyper degrees of redundancy exists only in a plane, was introduced to resolve their kinematic redundancy in real-time [2–5]. In this article, we propose a novel obstacle avoidance control scheme for hyper-redundant manipulators to perform a pick-and-place task where the static obstacles exist in the environment. The scheme is based on analysis in the defined posture space and has the advantage over other possible ones, that this scheme can be used for the real-time control of hyper-redundant manipulators while they are utilized in a static environment. Moreover, to guarantee the manipulator in motion has no collision

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with obstacles, the path-tracking control for the hyper-redundant manipulator to trace the path in the posture space is also discussed. The joint torques are formulated in the parameterized parameter of the posture space path and the posture space path-tracking feedforward controller is introduced based on the parameterized joint torque formulation.

2 Control Scheme of Hyper-Redundant Manipulators

Curvilinear theory was used to represent the posture of kinematically hyper-redundant manipulators [2–5]. Therein, the arm posture of the hyper-redundant manipulator is modeled by a continuous curve with the curvature function $\kappa(s)$ and the torsion function $\tau(s)$, where s is the distance along the curve measured from the base. For controlling the planar hyper-redundant manipulators like the CT-Arm, we consider a curve only with the curvature function $\kappa(s)$ to model the arm posture of the planar hyper-redundant manipulator. As we explored, the serpenoid curve [6] is better utilized to define the arm posture of hyper-redundant manipulators, because the solution from the given boundary position and the length of curve to the form of curve is easily-obtained.

Consider a serpeniod curve, whose curvature is defined by

$$\kappa(s) = \frac{2\pi}{\ell}a_1 \cos(\frac{2\pi}{\ell}s) + \frac{2\pi}{\ell}a_2 \sin(\frac{2\pi}{\ell}s) \tag{1}$$

where a_1 and a_2 are the coefficients to define the curvature function, and ℓ is the curve length which is equal to the length of the manipulator arm that is to be configured. The angle $\alpha(s)$ that represents the inclination angle of the vector w.r.t. x-axis on the curvilinear length s, and the end-point position (x_ℓ, y_ℓ) can be derived through integration w.r.t. the curve length:

$$\alpha(s) = \alpha_0 + \int_0^s \kappa(u)du = \alpha_0 + a_1 \sin\frac{2\pi}{\ell}s - a_2 \cos\frac{2\pi}{\ell}s + a_2, \tag{2}$$

$$x(\ell) = \int_0^\ell \cos(\alpha(s))ds = \cos(a_2 + \alpha_0)J_0\left(\sqrt{a_1^2 + a_2^2}\right)\ell = x_\ell, \tag{3}$$

$$y(\ell) = \int_0^\ell \sin(\alpha(s))ds = \sin(a_2 + \alpha_0)J_0\left(\sqrt{a_1^2 + a_2^2}\right)\ell = y_\ell \tag{4}$$

where α_0 is the initial inclination angle of the vector w.r.t. x-axis at the arm base, and J_0 is the zero-order Bessel function [7].

While the end position of the curve is given, its form (*or posture*) given by the curvature $\kappa(s)$ corresponding to the given initial inclination angle α_0 can be defined by the coefficients a_1 and a_2. The coefficients a_1 and a_2 are derived by solving Eqs. (3) and (4), and given by

$$a_2 = \tan^{-1}\left(\frac{y_\ell}{x_\ell}\right) - \alpha_0, \quad a_1 = \left(\left[J_0^{-1}\left(\frac{(x_\ell^2 + y_\ell^2)^{\frac{1}{2}}}{\ell}\right)\right]^2 - a_2^2\right)^{\frac{1}{2}} \tag{5}$$