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·研究简报·

一种新型双吸盘机器人模型及控制系统的研究

Research on a new model of two-sucker wall-climbing robot

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近年来,随着国内经济的发展,渔业生产水平的不断提高,渔船的数量巨大,城市高层建筑成倍增长。但渔船外壁的检测、清洗、除锈以及高楼外壁的清洗由人工完成,不仅投入大,效率低,费工费时,而且极其危险。因此,需要研究开发一种能携带清洗装置或其他功能部件的爬壁机器人。我们研制了一种小型的双吸盘结构的爬壁机器人模型,与其他类型的爬壁机器人模型相比,这种模型具有结构简单、稳定可靠、操作方便、成本低廉,便于大量生产等特点。由于以上特点,该机器人可应用于大量渔船的清洗和养护,也可以在一只渔船上同时采用多个机器人作业,大大改善了工作效率,提高了渔船清理工作的自动化水平,具有一定的实用价值。

1 爬壁机器人模型简介

该机器人模型的系统总体结构如图 1 所示,由吸附元件、电机元件、减速器、气动元件和电控元件组成。由真空泵使吸盘产生负压,使机器人能吸附于壁面上,由电控系统控制电机的运动和气动阀的换向以实现机器人在壁面上的自由行走。位于控制系统核心的是 8031 单片机,它直接控制气动阀动作及电机的驱动,以实现两吸盘及步进电机和气动阀的协调交替动作。以下是本机器人模型和国内部分其他单位所研制的机器人模型的特点,可看出,该模型具有结构简单、稳定可靠、操作方便、成本低廉等特点,有一定的实用价值。

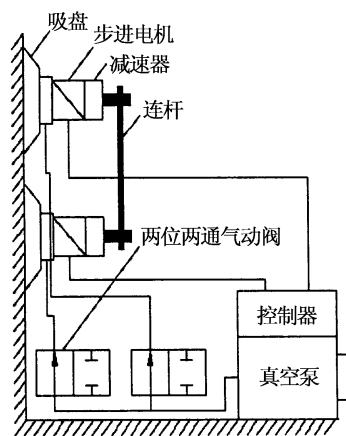


图 1 模型示意图

Fig.1 Sketch map of the model

表 1 国内几种爬壁机器人模型

Tab.1 Some domestic models of wall-climbing robot

单位	模型	特点
哈尔滨工业大学	单吸盘爬壁机器人	结构简单 移动速度较快 稳定性较差
哈尔滨工业大学	多吸盘爬壁机器人	结构复杂 稳定性较好
北京航空航天大学	螺旋桨式爬壁机器人	采用螺旋桨提供升力 结构复杂 稳定性较好
上海大学	多吸盘爬壁机器人	结构复杂 稳定性好
上海水产大学	双吸盘爬壁机器人	结构简单 稳定性较好 安全可靠

2 机器人基本参数的确定

2.1 步进电机的确定

根据机器人运动的准确可靠性要求,并考虑电机单位质量的输出扭矩指标,我们选用四海牌 42BGYG202 型永磁感应子式步进电机。其静转矩为 $2.4\text{kg}\cdot\text{cm}$,在同级步进电机中具有较大的输出扭矩。

2.2 真空吸盘半径的确定

要机器人模型能稳定吸附工作于壁面,应满足^[1]式(1)

$$A \cdot \Delta P \cdot u_m \geq f \cdot (M_z \cdot g + 2M_d g) \quad (1)$$

上式中, A 为吸盘面积, $A = \pi r^2$,单位为 m^2 ; ΔP 为吸盘的内外压差,近似取 $0.9 \times 10^5 \text{Pa}$; u_m 为吸盘与壁面的静摩擦系数,取 0.5 ; f 为安全系数,取 8 ; M_z 为爬壁机器人在墙壁上系统的总重量,取 0.6kg ; M_d 为单个步进电机的重量, $M_d = 0.24\text{kg}$

算得 $r \geq 0.0245\text{m}$,因为根据市场的实际情况选吸盘的半径为 0.025m 。

2.3 真空吸盘的切换周期

固定的吸盘容积,其达到内真空所需的时间 t_1 和解除真空的时间 t_2 之和,称为该吸盘的切换周期,切换周期的倒数称为切换频率,切换频率的大小反映了吸盘的动作快慢程度。对于采用真空泵做真空源的系统,时间 t_1 可以近似由下式^[2]确定:

$$t_1 = \frac{V}{Q} \ln(p_0/p) \quad (2)$$

式中, V 为真空系统的容积(管径 $\phi 5\text{mm}$,管长 10m),近似为

$$\frac{1}{3} \pi (2.5 \times 10^{-1})^2 \times 0.5 \times 10^{-1} + \pi (2.5 \times 10^{-2})^2 \times 10 \times 10 = 0.1996\text{L}$$

Q 为泵的平均抽吸流量,取 1L/s ; p_0 为大气压强,取 $1.01 \times 10^5 \text{Pa}$; p 为终止压强,取 $0.1 \times 10^5 \text{Pa}$;求得 $t = 0.4616\text{s}$ 。

3 机器人的运动姿态

3.1 机器人的欧拉变换

选取机器人左吸盘中心在壁面上的投影点为坐标原点,机器人的初始位置时从左吸盘指向右吸盘方向在壁面上的投影为 y 轴,建立坐标系如图 2 所示。

$$\text{Euler}(\phi, \theta, \varphi) = \text{Rot}(z, \phi) \text{Rot}(y, \theta) \text{Rot}(x, \varphi) \quad (3)$$

式中^[3] ϕ 为机器人绕 z 轴旋转的角度, $\dot{\phi} = \omega t$ (ω 为

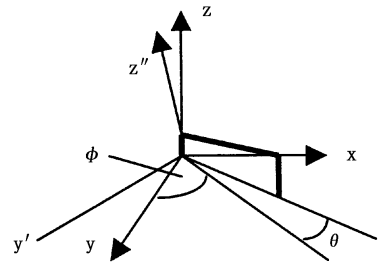


图 2 坐标系

Fig.2 Reference frame

绕 z 轴旋转的角速度), θ 为机器人绕新的 y 轴 (y') 旋转的角度 取 $\arctg 1/6$, φ 为机器人绕新的 (x'') 轴的旋转角度, $\varphi = 0$

$$Euler(\phi, \theta, \varphi) = \begin{bmatrix} \cos\phi\cos\theta\cos\varphi - \sin\phi\sin\varphi & -\cos\phi\cos\theta\sin\varphi - \sin\phi\cos\varphi & \cos\phi\sin\theta & 0 \\ \sin\phi\cos\theta\cos\varphi + \cos\phi\sin\varphi & -\sin\phi\cos\theta\sin\varphi + \cos\phi\cos\varphi & \sin\phi\sin\theta & 0 \\ -\sin\theta\cos\varphi & \sin\theta\sin\varphi & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} 0.986\cos\omega t & -\sin\omega t & 0.164\cos\omega t & 0 \\ 0.986\sin\omega t & \cos\omega t & 0.164\sin\omega t & 0 \\ -\sin\omega t & 0 & 0.986\sin\omega t & -1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

3.2 机器人的运动位置描述

取机器人左吸盘工作,右吸盘在连杆带动下运动状态分析,平移矢量 $P^T = [0, 0, -1, 1]$,变换矩阵

$$T = \begin{bmatrix} 0.986\cos\omega t & -\sin\omega t & 0.164\cos\omega t & 0 \\ 0.986\sin\omega t & \cos\omega t & 0.164\sin\omega t & 0 \\ -\sin\omega t & 0 & 0.986\sin\omega t & -1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

4 爬壁机器人控制系统的实现方案

爬壁机器人的控制系统以 8031 单片机为核心,微处理器输出高速脉冲通过两个步进电机驱动器对两个电机进行精确控制。当使用者按动功能键,向 8031 单片机发出中断信号进入不同的中断子程序状态,实现机器人的前后左右不同运动。电机驱动系统采用步进电机控制,具有精度高、便于编程等优点。控制系统结构如图 3。

5 结论

本文所讨论的机器人模型及控制方案模型实物能在玻璃等光滑壁面上行走,具有结构简单功能稳定等优点,但在实际运行中也发现亟待解决改进之处。其一是摩擦阻力大,为此机器人模型配置了双级齿轮减速装置,但这样又会增加机器人的成本和重量,最好的办法是在电机和连杆间增加转动自由度,以实现机器人的抬腿动作,大大减少摩擦阻力。其二是吸盘尚未装备真空度传感器和反馈装置,不能对吸盘实现精确的定量控制。这些都将在今后的工作中进行研究和改进的。

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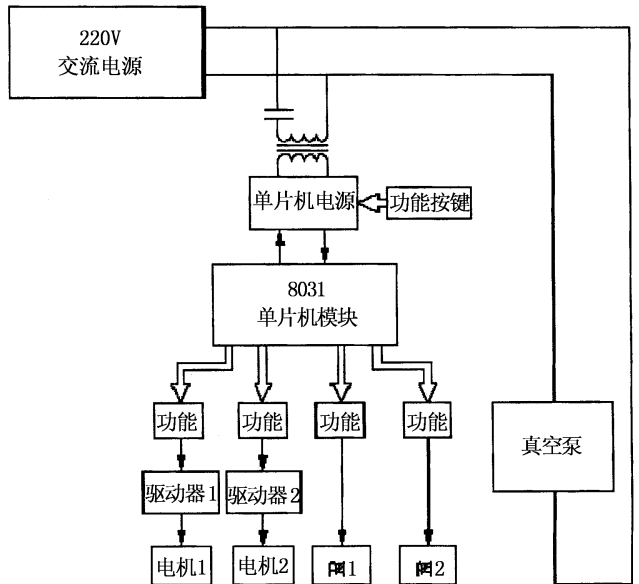


图 3 控制系统

Fig. 3 Control system

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