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Optimizing step climbing by two connected wheeled inverted pendulum robots

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Abstract

In manufacturing plants, automated guided vehicles (AGV) are in wide use. Wheeled inverted pendulum robots have advantages over the common AGV; they have high manoeuvrability on flat surfaces, and they have a self-balancing system such that height and weight of the payload do not have effect on the base size. Despite the aforementioned advantages, wheeled inverted pendulum robots have limited ability to overcome obstacles like staircases. Manufacturing floor requires a robot to have high manoeuvrability while being able to overcome obstacles. We used two wheeled inverted pendulum type robots, each with an extensible connecting arm. If there is an obstacle in its way the robot will call a nearby one, the two autonomously connect and after overcoming the obstacle separate. We investigated the effect of the distance between the two robots and different control algorithms on the required torque to climb stairs of different dimensions. We found the speed control to be most efficient.

Keywords: Mobile robots, cooperation, stairs climbing, optimization

1. Introduction

In manufacturing plants and automated warehouses, automated guided vehicles (AGV) are in wide use. The AGV are vehicles designed mainly to carry pallets with components or products from one spot to another while moving on a level floor. In most cases they move along a guide path, however, more advanced AGV are free

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ranging, thus have a wider range of tasks. In addition, advanced AGV have the ability to communicate with one another [1,2]. Most AGV are three or four wheeled platforms with base dimensions proportional to the height and weight of their maximal load for stability reasons, a fact that limits their ability to traverse crowded areas and narrow corridors and passageways.

Wheeled inverted pendulum robots have several advantages over the common AGV; they have high maneuverability on flat surfaces due to their small base, and they have a self-balancing system such that height and weight of the payload do not have a significant effect on the base size. In fact, they can carry a higher payload for the same base size of an AGV [3]. Modelling and design of two-wheeled inverted pendulum robot is presented in [4,5]. Despite the aforementioned advantages, two-wheeled inverted pendulum robots have limited ability to overcome obstacles like steps, and no ability to climb staircases or move in rough terrain.

The complexity of the modern manufacturing floor requires a robot to have high maneuverability while being able to overcome obstacles such as a step or two, and sometimes an entire staircase. These are contradicting requirements, since maneuvering a crowded and narrow environment requires small robots, while overcoming obstacles such as stairs requires large robots.

Cooperative robotics is a developing field where several robots, each with limited capabilities, have the ability to cooperate to perform tasks that each cannot perform on its own. Such cooperation may be useful in cases such as response to changing environmental conditions. In [6] two sets of experiments were performed. In the first, several robots (s-bots) cooperated to transport a load together similar to the way ants cooperate to carry heavy prey to their nest. In the second, an automated decision whether the robot can perform a task on its own or needs to cooperate with other robots was demonstrated. Another system is presented in [7] where cooperation between robots enhances the mobility of the robots in the field. In this system, the robots can dock and adjust their posture in relation to each other to execute force cooperation if necessary. Collaboration between robots to lift together payload is described in [8], and in [9] two robots cooperate to search for an object, and then carry it together to its destination. These are some sample projects where small robots cooperate to execute complicated tasks. Analysis of stairs climbing is presented in [11].

This paper describes the design of a robot that overcomes the inherent contradicting requirements of the manufacturing floor robots. This robot combines two highly maneuverable two-wheeled inverted pendulum robots, shown in Fig. 1, each with limited ability to overcome obstacles. When confronting an obstacle, the two robots physically join to overcome it, utilizing a detachable connection that allows the two robots to be small when traversing the crowded floor, and large when approaching obstacles such as stairs. In this paper, we present analytical analysis as well as simulation results for the required structural conditions allowing the two robots to climb stairs. The results of the yield constrains for the design of the connecting arm of the robots. Then, the climbing control is attended and various control schemes are addressed for power consumption optimization.

Fig. 1. Two inverted pendulum type robots connected together for stairs climbing