Mechanism and Machine Theory 128 (2018) 382–394

Contents lists available at ScienceDirect

Mechanism and Machine Theory

journal homepage: www.elsevier.com/locate/mechmachtheory

Research paper

On the feasibility of utilising an array of planar parallel robots to service adjoining workspaces

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ARTICLE INFO

Article history:
Received 22 September 2017
Revised 1 June 2018
Accepted 2 June 2018

Keywords:
Parallel kinematics
Screw theory
Additive manufacturing
Subtractive manufacturing
3D printing

ABSTRACT

Parallel robots feature several favourable properties, including the potential for high acceleration and accuracy. However, in order to minimise cycle times and optimise the usage of factory space, industrial applications commonly include multiple closely mounted robots, working on the same or closely located objects. As parallel robots generally suffer from a limited workspace-to-footprint ratio, attempting to utilise parallel robots for such applications typically leads to issues with mechanical interference. This paper investigates the feasibility of dividing a planar workspace into several smaller areas, each of them serviced by a dedicated planar parallel mechanism. Applications where this arrangement could be beneficial include 2D manufacturing operations, such as water jet cutting and laser cutting. Additionally, the proposed arrangement could be extended by actuating either the work object fixture or the entire array of mechanisms in one additional degree of freedom. The resulting architecture could be beneficial for 3D manufacturing operations, such as additive or subtractive manufacturing. The presented analysis studies the limitations of such architectures in terms of mechanical interference and achievable kinematic performance. Solutions to reduce mechanical interference are introduced and screw-theory-based indices are employed to evaluate the achievable kinematic performance.

1. Introduction

In order to optimise the usage of factory space, industrial robots are commonly mounted closely together. Cycle time and production cost can often be reduced if several robots perform different tasks on the same object. A recent trend is the utilisation of coordinated collaborating robots [1]. Typical application for such robots include arc welding, where one robot manipulates the work object while other robots perform the welding [1–3]. Such an approach can save floor space and improve accessibility of the work object [3]. Coordination may be achieved by robot-to-robot communication or by utilising a single controller for all participating robots. The latter option saves additional floor space and provides several other benefits, including the possibility for improved collision avoidance [1].

Parallel robots [4] exhibit several benefits compared to similar-sized serial robots [5], including the potential for high stiffness and low moving mass, which enables higher acceleration and reduced cycle times. As the position errors of the actuators are not cumulative, the position accuracy is typically high. Additionally, the actuators are commonly mounted on the fixed base, leading to straightforward cabling solutions. However, parallel robots also suffer from several limitations,

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https://doi.org/10.1016/j.mechmachtheory.2018.06.001
0094-114X/

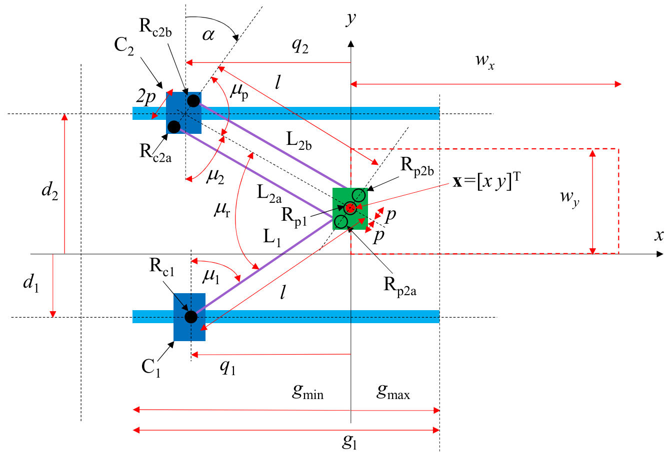

Fig. 1. Parameters of the studied 2-DOF planar parallel mechanism. The view is from the intended work object. The manipulated platform can pass below the guide-ways. The single link and the parallelogram operate in different vertical planes. The only potential mechanical interferences are between the link L_1 and the cart C_2 and between the links L_{2a} and L_{2b}; however, such configurations are outside the intended workspace of the mechanism.

typically including a limited workspace-to-footprint ratio [6]. Due to mechanical interference, workspace sharing is difficult, and even attempting to arrange parallel robots to service separate but adjoining workspaces is challenging. Herein, we make a distinction between the reachable workspace, which is the entire workspace that the tool can service without mechanical limitations or singularities, and the utilised workspace, which is a subsection of the reachable workspace where the kinematic performance is considered acceptable. Typically, the utilised workspace excludes the border regions of the reachable workspace. Potential interference between the tools of two neighbouring mechanisms at the border of each mechanism's utilised workspace is unavoidable; however, such interference is straightforward to handle with software algorithms, leading to only minor constraints on the independence of each mechanism. The challenge for a parallel mechanism is that its arm system is often closer to a neighbouring mechanism than its tool, leading to potential interference also between the arm systems of the mechanisms. Modelling all such interferences is complex and introduces additional constraints on how independently the two mechanisms can service their respective workspace. In terms of collision avoidance, it is preferable that when the tool is in its border regions, it is the section of the mechanism that is closest to the neighbouring mechanism. This is only possible for some parallel mechanisms and typically means utilising the outer regions of the reachable workspace, where the kinematic performance may not be adequate.

Research and development of parallel robots that can be mounted closely with minimal mechanical interference is of significant industrial interest [7]. In this paper, we focus on applications requiring two or three degrees of freedom. We investigate the feasibility of dividing a planar workspace into several smaller areas, each of them serviced by a dedicated two-degree-of-freedom (2-DOF) planar parallel mechanism. Applications where such an arrangement could be beneficial include water jet cutting and laser cutting. Additionally, this arrangement could be extended by actuating either the work object fixture or the entire array of mechanisms in one additional degree of freedom. The resulting architecture could be beneficial for additive manufacturing, as the utilisation of multiple print heads could dramatically reduce the build times. As a 3D printing platform with multiple print heads does not require independent 3-DOF mechanisms to manipulate each print head, the proposed architecture could be a cost-efficient solution. In addition to reduced number of actuators, such an architecture has several other potential benefits, including improved accuracy, space savings, and low-cost components.

This paper provides an evaluation of the described architecture for a particular choice of the individual 2-DOF mechanisms. It is demonstrated how the objectives of optimal kinematic performance and low risk of mechanical interference are inversely correlated. By utilising intuitive screw-theory-based performance indices, the potential and limitations of the proposed architecture are fully quantified. The remainder of this paper is organised as follows. Section 2 introduces the individual 2-DOF parallel mechanisms, including their kinematic parameters. Section 3 reviews the screw-theory-based performance indices employed for the subsequent kinematic analysis. Section 4 begins with a kinematic analysis of a single mechanism and continues to study the feasibility of utilising multiple mechanisms of the same type, first arranged in a one-dimensional array and then in a two-dimensional array. Finally, Section 5 provides conclusions and ideas for future work.

2. Individual planar mechanism

The individual unit of the proposed architectures is the mechanism illustrated in Fig. 1. It is a planar parallel mechanism with two positional DOFs and constant orientation of the manipulated platform. It includes two actuated carts on parallel linear guide-ways. Possible actuation schemes include screws, belt or rack-and-pinion. One actuated cart C_1 includes a revolute joint R_{c1}, while the second actuated cart C_2 includes two revolute joints R_{c2a} and R_{c2b}. The manipulated plat-