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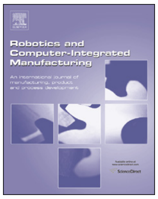

Enhancing the useful workspace of a reconfigurable parallel manipulator by grasp point optimization

S. Herrero [a,*], T. Mannheim [b], I. Prause [b], Ch. Pinto [a], B. Corves [b], O. Altuzarra [a]

[a] *Department of Mechanical Engineering, University of Basque Country, Spain*
[b] *Department of Mechanism Theory and Dynamic of Machines, RWTH Aachen University, Germany*

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ABSTRACT

Reconfigurable parallel manipulators combine the properties of parallel manipulators with high flexibility. However, the workspace of parallel manipulators is, compared to serial manipulators, relatively small and hence the optimization of the useful workspace is an important design factor. Different efficient algorithms for calculating the workspace for parallel manipulators have been developed, but they need to be adapted to reconfigurable systems with additional parameters. These variables for those systems are the parameters of the reconfiguration, e.g. the grasping points. This paper presents a method to obtain the grasping point combinations of a parallel reconfigurable manipulator that leads to a useful workspace containing the largest geometric object. The largest geometric object inside the useful workspace describes its regularity and represents a useful evaluation criterion. The method is introduced for a general reconfigurable parallel manipulator and then studied for the particular case of the PARAGRIP reconfigurable parallel manipulator. The workspace is obtained by applying a combined geometrical and discretization method. To reduce the possible grasping point combinations and thereby reduce computational cost, we apply the special requirements that the grasping point combinations must fulfil. By solving the inverse kinematic problem for each combination the useful workspace is calculated.

1. Introduction

In recent years, manufacturing industry has been influenced by fundamental changes in conditions, like progressive globalization and rapid technological development as well as changes in the state of resources [1,2]. Classical demands on handling systems are changing. In the past, higher load capacity, greater precision and higher speeds were the main demands. In the present situation, priorities are increasingly shifting towards customized production and flexible solutions to component dependent problems. Currently available handling systems are not completely efficient to fulfil the increased demands [3]. However, reconfigurable robotic systems can allow us to handle this problem of increased demands. Reconfigurability is usually realized by co-operating serial manipulators handling the same object. The concept of reconfigurable manipulators is more versatile as the objects can be gripped and supported at different points by several robots depending on the boundary conditions of the object. With Parallel reconfigurable manipulators we try to increase the usability of parallel manipulators, whose main limitation is small WS. This concept has the disadvantage of having more actuators than needed, e.g. 18 drives for 3 robots to perform a 6 degree of freedom (DOF) object motion. This leads to higher costs and complex control architecture.

Parallel manipulators have great advantages compared to serial manipulators, such as high stiffness, low inertia, high velocity, good accuracy and large payload capacity. However, they also present important disadvantages like smaller useful workspace (WS) and higher degree of design complexity [4,5].

Reconfigurable parallel manipulators combine the speed, stiffness, accuracy and low mass properties of parallel manipulators with the flexibility of reconfigurable serial manipulators. Many reconfigurable parallel manipulators have been studied to achieve the flexibility necessary in the manufacturing industry [6]. The majority of those systems are lower mobility mechanisms (less than 6 DOF) [7,8]. Some exceptions are: [9] characterized a reconfigurable Stewart–Gough platform, [10,11] studied 6-DOF reconfigurable parallel manipulators, [12] proposed a hybrid parallel robot, and [13–15] presented a reconfigurable parallel robot that changes its DOF depending on the application.

With the focus on high flexibility and versatility in manipulation and autonomous reconfiguration a novel reconfigurable

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[*] Corresponding author.

E-mail addresses: saioa.herrero@ehu.es (S. Herrero), mannheim@igm.rwth-aachen.de (T. Mannheim), prause@igm.rwth-aachen.de (I. Prause), charles.pinto@ehu.es (Ch. Pinto), corves@igm.rwth-aachen.de (B. Corves), oscar.altuzarra@ehu.es (O. Altuzarra).

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handling system, called PARAGRIP, is developed and presented in [2,16,17]. The object is integrated as a moveable platform into the kinematic chain, whenever the grasping is done. For motion analysis purposes the structure can be seen as a parallel structure.

As the workspace is considered one of the most important design factors of manipulators, it is essential to have an efficient calculation method to determine it [18,19]. This tool must take into account internal voids and the properties of the external boundary [20]. There are different methods to obtain the WS of a parallel manipulator: discretization methods, geometric methods, analytical methods or CAD variation approaches.

Discretization methods create a mesh of possible poses of the mobile platform. Each pose has to be checked, usually solving the inverse kinematic problem (IKP). The advantages are the simple computational implementation and the ability to implement all kinds of constraints. The disadvantages are their high computational cost and accuracy dependence on step size of the mesh.

Geometrical methods compute the WS of each limb separately and then calculate the intersection of all single-limb-workspaces to get the manipulators WS. The main disadvantages are that these methods can only be used for WS with constant orientation and that other geometric tools, such as CAD, are necessary.

Analytical methods are pose optimization problems that penalize the WS boundaries. Most of these methods are very dependent on the architecture of the manipulator, and thus, they are only useful for application to specific manipulators. CAD variation approaches can also get the WS and singularity maps of the manipulator.

In this paper, we present a combined geometrical and discretization method to obtain the configuration of the grasping points (GPs) of a reconfigurable parallel manipulator. The method yields a GP combination that leads to a useful WS containing the largest possible predefined geometric object. We can basically divide the method into six steps:

1. Get the set of possible combinations of GPs, as well as the set of candidate-poses for the WS.
2. Reduce the number of candidate-poses for the WS taking into account the simple geometric restrictions that apply to the limbs.
3. Obtain the WS of the manipulator solving the IKP for each candidate-pose.
4. Calculate the useful WS for each combination of GPs.
5. Find the biggest geometry object (GO) contained in the WS for the GP combination.
6. Compare the sizes of the GO of all WS in order to get the "optimal" WS.

This method is designed for any reconfigurable manipulator and, in this paper, we will show how it performs for the particular case of the PARAGRIP 6 DOF reconfigurable manipulator. Additionally, we choose this geometric object to be a sphere. Changing the object to be another geometric entity will yield a different GP combination.

In Chapter 2, we describe the method for general case. Then, in Chapter 3, we apply it to the particular case of the PARAGRIP manipulator, choosing GO to be a sphere, and we study its performance.

A list of brief definitions of the nomenclature and mathematical terms used in the paper is presented in Table 1.

2. Method description

To have bigger work flexibility, reconfigurable manipulators can be adapted to different applications. The disadvantage is that the number of variables is higher and therefore the complexity of the problem increases.

Table 1
Nomenclature and mathematical terms.

Nomenclature	
PM	parallel manipulator
DOF	degree of freedom
MP	mobile platform
MPP	mobile platform position
WS	workspace
GP	grasping point
GO	geometric object
IKP	inverse kinematic problem
Mathematical terms	
GP_j	grasping point combination we are studying
MPP_0	initial mobile platform position
WS_j	WS for current GP_j
S_{jmax}	maximum sphere in the useful WS for current GP_j
S_{max}	maximum sphere of the set S_{jmax}
$\mathbf{J}$	Jacobian matrix
$\lvert\mathbf{J}\rvert$	Jacobian matrix determinant
$\lvert\mathbf{J}\rvert_0$	Jacobian matrix determinant for MPP_0

To find the best configuration for each case, we take into account different factors. One interesting criterion is to obtain the combination of GPs that leads to the biggest useful WS which is singularity-free. The objective of this criterion is that one WS can be bigger than another one but much more irregular. To avoid this problem, it is interesting to compare WSs taking both size and regularity into account.

To have an idea of the regularity of the useful WS, we determine the biggest sphere inside the useful WS for each combination of GPs, S_{jmax}, and we compare the radii of these spheres S_{jmax}. A WS contains a sphere if the entire sphere is part of the WS. We denote the largest sphere from the set of all S_{jmax} by S_{max}. The best WS is the WS containing the biggest sphere of the set of S_{jmax}, S_{max}. Note that we can have multiple WS_j such that the radius of $S_{jmax}=$ radius of S_{max}.

We describe a general case for a parallel manipulator of N limbs with fixed base points and reconfigurable GPs, see Fig. 1. In the following discussion, we label the GPs as B_i and the base points as A_i. To calculate the WS for different GP combinations, we provide discrete candidate-poses for B_i and a set with all possible combinations is created. Checking all possibilities of the set would lead to high computational costs, but by applying some known criteria that the points B_i have to fulfil many of them can be rejected.

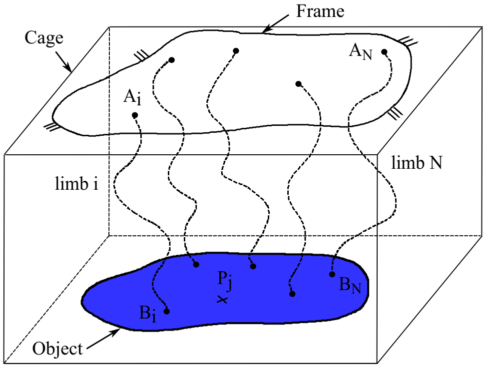

Fig. 1. Sketch of a reconfigurable manipulator.

1. The limb i has to be able to reach the point B_i: the range of each limb have to be checked.
2. Some manipulators have singularities for known positions of the end-effector: The points B_i should not be placed in those positions.