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Generation of Manipulability Ellipsoids for Different Configurations Using the Yoshikawa's Manipulability Index and Manipulability Ellipsoid

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Abstract

In this paper, we study different manipulating ways which can be used in Robotic Devices, to make the Robots Responsive to Obstacles while performing a given Task. Differential kinematics and the kineto-static manipulability indices of multiple cooperating robot arms, including active and passive joints and actuators are given efforts and researched for developing enhancive Robots. Therefore, manipulability analysis is done to check the performance of the robots. It has been shown that the ZMP manipulability ellipsoid can improve the humanoid-robot design process by choosing appropriate actuators. Algorithm to calculate the manipulability index results new manipulability indices which take into account under actuation and compliance.

Keywords: Manipulators, kinetostatic, Ellipsoid, Actuator.

I. INTRODUCTION

The motivation to study manipulability of robotic devices [1] comes from the fact that, in order to perform an end {effect or twist or to withstand a wrench acting on the end {effect or, the velocities and the efforts at the actuators are, in general, greater at configurations close to singularities. At singular configurations some twists cannot be executed and, as a consequence, some wrenches can only be passively resisted by the manipulator or the end {effector gains one or more degrees of freedom and, hence, one or more wrenches cannot be resisted even with the actuators locked. Therefore, maintaining a manipulator away from singularities is convenient to execute a task not known a priori.

Recent years, redundant manipulators are used for various kinds of tasks, for example, welding, sealing and contact tasks by using the redundancy. These kinds of tasks require the manipulator to track its hand on to the desired trajectories while avoiding the links from some other objects existing near the working object and also the target object itself, which is simultaneously thought to be obstacle. Preparations such as measuring the object's shape and positioning of working object are necessary for these tasks. However, when robots are used for automatic tasks, it is presumed that the position and shape of the object, have been known in the preparation procedures by workers, and besides they do not change in time. These procedures complicate the task of robots and are essential impediments standing against full automation process.

When the manipulator tracks a hand trajectory [2] on an object and avoids the obstacle not to crash. The system cannot obtain the whole shape of the object and the whole desired trajectory. Then the configuration of the manipulator should always be prepared to keep the highest avoidance manipulability to avoid the unknown object appearing suddenly by the restricted detecting area. Therefore, an index that can evaluate the avoidance ability of whole manipulator's shape is important. But discussions of avoidance ability include the shape-changing ability of the manipulator and the shape of the object to be avoided.

Although several criteria have been proposed to characterize the distance of a configuration from a singularity, many of them, such as condition number, minimum singular value, minimum Eigen-value of the Jacobian [3] are not invariant with respect to change of reference frames, scale or physical units and those that are invariant but do not require any arbitrary choices are inadequate to characterize manipulability. This is the case of the determinant of the Jacobian which is invariant with respect to changes of reference frame and, by normalization; it can be made invariant with respect to changes of scale and physical units. It is one of the most widely used manipulability indices since its introduction in Yoshikawa, 1985, and recent works based on this index are Lee etal., 1998, and Zhang et al., 2000. It is here in shown in Section 2,using elementary geometric considerations, that, in general, it

does not represent a measure of distance from a singularity. Other classes of manipulability indices can be defined that, rather than the proximity to a singularity, study other properties of the forward velocity kinematic map between joint and Cartesian spaces. Parkand Kim, 1998 interpreted manipulability as how closely the forward kinematic map of a manipulator approximates an isometric where as Bicchi and Prattichizzo, 2000 regarded manipulability as the efficiency of the velocity and force transmission between joint space and Cartesianspace at a certain configuration of the manipulator.

To simplify this complicated relation, we propose an index to evaluate avoidance ability of whole manipulator's shape in this paper. Manipulability ellipsoid [7] as an index to symbolize shape-change ability had been proposed. Based on the concept of manipulability so far we proposed avoidance manipulability ellipsoid [8] that represents shape-changing ability of each intermediate link while tracking the desired hand trajectory. This index indicates avoidance ability of each link by the size of corresponding ellipsoid. However this index is not enough to evaluate the shape-change ability of whole manipulator's shape.

II. LITERATURE REVIEW

This paper proposes trajectory tracking and obstacle avoidance control using avoidance manipulability of redundant manipulators [9]. We propose two evaluation indexes of whole shape of the redundant manipulators. First one is sum of singular value of avoidance matrix. Second one is sum of the volume of avoidance manipulability ellipsoid.We evaluate whole manipulator's shape by two indexes and compare the ability. We found the second one is better than the first. We call the second index Avoidance Manipulability Shape Index (AMSI). Finally, by using AMSI, we construct trajectory tracking/obstacle avoidance control system. And we confirm the performance of trajectory tracking by simulations.

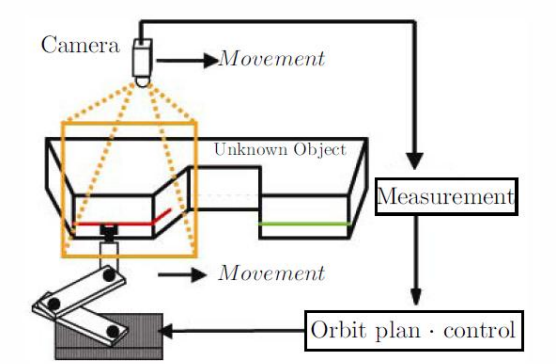

Fig.1. Processing system for unknown object

This study is aiming to build an adaptive processing system as shown in Fig.1 that does not require any preparation tasks such as measurements and positioning of unknown objects. In order to achieve this purpose, we had proposed preview control system [4] for redundant manipulators, which controls the current arm's configuration by referring the future trajectory and the future arm's configuration by using real-time optimization technique of "1-step GA (Genetic Algorithm)" [5] considering potential space [6] set around the measured object, to choose good configuration to avoid the collision with the objects.

A. Manipulability - Complete Avoidance Ellipsoids

Hiroshi Tanaka et al., proposed the Avoidance Manipulability Shape Index (AMSI), as a simple scalar index to evaluate the avoidance ability of the whole manipulator's shape, and evaluated the performances by using 4-link redundant manipulator. We proposed trajectory tracking / obstacle avoidance control system that manipulator could keep high shape-change ability evaluated by AMSI while working on an object. And we confirmed the performance of trajectory tracking by simulations.

The Inertia Matching Ellipsoid (IME) is proposed as a new index of dynamic performance for serial-link robotic manipulators [11]. The IME integrates the existing dynamic manipulability and manipulating-force ellipsoids to achieve an accurate measure of the dynamic torque-force transmission efficiency between the joint torque and the force applied to a load held by an end-effector. The dynamic manipulability and manipulating-force ellipsoids can both be derived from the IME as limiting forms, with respect to the weight of the load. The effectiveness of the IME is demonstrated numerically through the selection of an optimal leg posture for jumping robots and optimal active stiffness control, and experimentally through application to a pick-up task using a commercial manipulator. The index is also extended theoretically to the case of a manipulator mounted on a free-flying satellite [12].

B. Manipulability - Partial Avoidance Ellipsoids

- The IME [13] was proposed a new index for dynamic performance analysis of a serial-link manipulator. The IME provides a measure of the dynamic torque-force transmission efficiency between actuators at joint sand a load held by an end-effector, encompassing a wide range of existing concepts of manipulator performance. The DME and MFE can both be derived from the IME as limiting forms with respect to the weight of the load. The IME was demonstrated through numerical examples, including the selection of an optimal leg posture for a jumping robot and extension to a free-flying manipulator on a satellite in space. Experiments using a typical serial-link manipulator were also performed.

In this paper, we propose Zero Moment Point (ZMP) Manipulability Ellipsoid [14] as an extension to the existing ZMP balance criterion. The ZMP manipulability ellipsoid was developed by combining the ZMP balance criterion, the humanoid robot dynamics and the manipulability of robotic manipulators. The ZMP manipulability ellipsoid represents the ability of a humanoid robot to instantly move the ZMP from its current ZMP location within the balance criterion. The size and shape of the ZMP manipulability ellipsoid are a function of the joint-torque limitation of a humanoid robot. Thus, the ellipsoid forms an area in which the ZMP can be manipulated instantly and the larger the ellipsoid, the better the propensity of a humanoid robot will be to recover from an unbalanced situation. We also show that the gravity force of a humanoid robot affects neither the shape nor the translation of the ellipsoid. Furthermore, we show that the ZMP manipulability ellipsoid can aid the humanoid-robot design process by choosing appropriate actuators. Finally, a four Degree-of-Freedom walking robot was used to illustrate the proposed ZMP manipulability ellipsoid.

C. Zero Moment Point Manipulability Ellipsoid

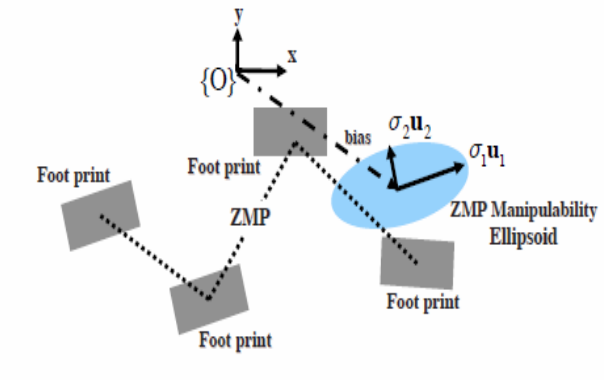

Fig.2. ZMP Manipulability ellipsoid

By combining the ZMP relationship, the humanoid-robot dynamics and the manipulability of robotic manipulators, we have derived a new measure called the ZMP manipulability ellipsoid. The ZMP manipulability ellipsoid is an area that represents the propensity of a humanoid robot [15] to recover from unbalanced situations. We have showed that the gravity force component of a humanoid robot affects neither the shape nor the translation of the proposed ellipsoid. We have also showed that the proposed ZMP manipulability ellipsoid can be used in determining appropriate size of actuators in the humanoid-robot design process. Computer simulations of a 4-DOF walking robot illustrated the concept of the proposed ZMP manipulability ellipsoid. By computing the ZMP manipulability ellipsoid while

walking in real-time, a humanoid robot not only knows its stability but also the margin, which indicates the amount of actuating power the robot has left to further move the current ZMP to any locations in the ellipsoid boundary. Computation of the ZMP manipulability ellipsoid might be computationally intensive especially for today's humanoid robots with a large number of DOF. A faster algorithm to reduce the computational complexity can also be helpful for future development.

D. Wrist-Partitioned Spatial Manipulators

Andrzej J. Cebula Paul J. Zsombor proposed a solution to one of the outstanding research issues in robotics, namely, that of derivation of the End-Effector (EE) workspace equation of a general wrist-partitioned serial manipulator has been presented in the paper. The equation-coupling manipulator's Denavit–Hartenberg (DH) parameters, joint variables and coordinates of the EE's poses has been derived in a seven-dimensional projective space, and then, in the EE's Cartesian space. The procedure used turns out to be general for any wrist-partitioned serial manipulator, whether redundant or not. Planning of a manipulator EE motion, as a fundamental assumption should be embedded in the EE Cartesian workspace. This is not yet the case as witnessed by absence of previous description of EE Cartesian workspace. Without description one does not know if, when tracking a trajectory, the EE encounters poses that do not belong to its workspace or boundary poses which constitute a physical barrier to the planned motion. Thus one does not know if the task is feasible (except in the case of simple architectures). The EE workspace equation turns out to be indispensable in the above cases, especially to examine the presence of singular poses in EE workspace of redundant architectures. For the latter, the task that may be practically impossible when using classical methods based on manipulator's Jacobian [16]. The situation is easy to avoid if the workspace equation is used a-priori to investigate the singular poses existence along the path. Applications of singular poses detection based on Cartesian workspace equation were presented by Cebula [10].To our knowledge this is the first exposure of an equation derivation of the projective workspace and Cartesian workspace for wrist-partitioned and planar manipulators, with Ranger DXM, PUMA and 3R architectures chosen as typical examples. Therefore, the results presented herein are believed to contribute to state-of-the-art in robotics workspace research. The analysis can be carried out for any wrist-partitioned and planar manipulators. Conjectures to this effect was stated explicitly. These results are widely applicable to manipulator kinematics, e.g., solving of inverse kinematics, investigation of singular poses and planning of motion inter plants that avoid boundary poses [10]. Other possible applications encompass a number of issues, e.g., interactive obstacle avoidance, designing interplant's for unstructured environment, interactive animation, interactive robot motion control and manipulation of deformable objects [17, 18].

E. On-Board Manipulators

Tas¸kınPadır and Jonathan D. Nolff introduce the manipulability and manoeuvrability ellipsoids for two underwater vehicles with on-board manipulators cooperating to carry a common rigid object. The forward kinematics problem for the system formed by the two underwater vehicle-manipulator mechanisms and the rigid load is studied in details. The assignment of the coordinate frames and the selection of a set of generalized coordinates to describe the system configuration are discussed. The pseudo velocities are introduced in order to incorporate the kinematic constraint equations into the kinematic velocity relations. A kinematic model is formulated for the system to be used for defining the manipulability and manoeuvrability ellipsoids.

In this paper, manipulability and manoeuvrability ellipsoids of the mechanical system formed by two UVM mechanisms cooperating to carry a rigid object are introduced. A kinematic model which relates the generalized velocities of the two UVM mechanisms to the task-space velocities is presented. The kinematic constraint equations are also formulated. The pseudo velocities whose selection is based on the kinematic constraints are also introduced in order to incorporate the constraints into kinematic velocity relations. Finally, the definitions of the aforementioned ellipsoids are provided. The results from a simulation example are presented. It should be noted that, this research illustrates the definitions of manipulability and manoeuvrability ellipsoids presented in literature for a single manipulator to the new mechanical system under consideration.

F. Homogeneous Manipulability Measure

Mansouri, M. Ouali presented Kinetostatic performance indices have been commonly used for many potential applications in robotics,i.e. optimal design purpose, trajectory planning, manipulation programming, redundancy treatment and dexterity analysis [19]. This has been successful when the mechanism has either fully rotational or translational joints. However, in case of a mechanism having both rotational and translational degrees of freedom; performance indices, such as Jacobian matrix, manipulability or condition number, may not be used due to the dimensional inconsistency with its elements. In this paper, by means of the power concept, anew kinetostatic performance index of robot manipulators is proposed. The power has the same physical units in either translations or rotations. Therefore, we can make use of it as a homogeneous or natural performance index of manipulators. Although it has never been considered as a subject matter of kinetostatic performance criteria, exploiting the behaviour of its basic components namely, force and speed, along the mechanism was likely interesting. On the other hand, the new concept of Oriented Power was introduced, in order to formulate the quadric vector of apparent power, leading to the final homogeneous performance index, which is no longer susceptible

to the physical units' choice. The main benefits of this approach are as follows: firstly there is no need for any restriction on the kinematics' limits; secondly, the new formalism is insensitive to joint types of mechanism, as well as it has the possibility of grouping translations and rotations of the operational space together. The new index is then both applied in a simple serial mechanism dexterity analysis, and extended to a planar parallel mechanism.

G. Manipulability Index Algorithm

The estimation of the performance characteristics of robot manipulators is crucial in robot application and design. Furthermore, studying the manipulability index for every point within the workspace of any serial manipulator is considered an important problem. Such studies are required for designing trajectories to avoid singular configurations. In this paper, a new method for measuring the manipulability index is proposed, and then some simulations are performed on different industrial manipulators such as the Puma 560 manipulator, a six DOF manipulator and the Mitsubishi Move master manipulator. A new method for measuring the manipulability index and some simulations are implemented on different manipulators such as the Puma560 manipulator, a six DOF manipulator and the Mitsubishi Move master manipulator. In addition, we describe how the manipulability measure is crucial in performing intelligent behaviour tasks. The manipulability index is considered as a quantitative and performance measure of the ability for realizing some tasks. This measure should be taken into consideration in the design phase of a serial robot and also in the design of control algorithms. Furthermore, we use the proposed method for measuring the manipulability index in serial manipulators to generalize the standard definition of the manipulability index in the case of mobile manipulators.

a. Algorithm 1 calculate the manipulability index

1. Find the joint(s) that may lead to a singular configuration assuming that the number of these joints = n.

2. for i = 1 to n do

a. Change the value of the ith joint from its initial to its final value using simulation software - Matlab robotic toolbox is used in our case.

b. Calculate the Jacobian (J) and singular (Σ) matrix.

c. Plot every normalized σ and also the rank of the Jacobian matrix. Normalized σi = σi Max{σi1,σi2, σi3, ..., σin}. Where: i is the order of the σ in the singular matrix and n is the number of steps during the simulation.

d. Check the rank of the Jacobian matrix.

3. end for

H. Manipulability Ellipsoids with Compliance

Domenico Prattichizzo et al. used under actuation in robotic hands is currently attracting a lot of interest from researchers. The challenging idea of under actuation in grasping is that hands, with reduced number of actuators, supported by suitable design and control, may not suffer from reduced performances. This trend is also strengthened by recent neuroscience studies which demonstrate that also humans use sensorimotor synergies to control the hand in performing grasping tasks. In this paper, we focus on the kinematic and force manipulability analyses of under actuated robotic hands. The performances of such hands, regarded as mechanical transformers of inputs as forces and speed into outputs as object wrench and displacements, are assessed by suitably defined manipulation indices. The whole analysis is not limited by rigid-body motion assumptions, but encompasses elastic motions and statically indeterminate configurations by introducing generalized compliance at contacts and actuation. Two examples show the validity of the proposed approach to evaluate under actuated hand performances.

Manipulability analysis is commonly used in robotics to measure the performance of a robotic system, expressed as the ratio between a measure of force/velocity in the task space and the corresponding effort in the input actuation system. The manipulability analysis allows to identify the directions, in the input and output space that maximize and minimize this efficiency measure. In this paper, the manipulability analysis has been extended to synergy-actuated hands, in which the dimension of the controlled inputs is much lower than the dimension of the contact forces. In this type of manipulation, the compliance has to be taken into account in order to solve the force distribution problem. This paper introduces a new manipulability indices which take into account under actuation and compliance. Finally, this more general definition of manipulability is discussed and applied in two examples: the first one is a simple gripper and the second is an anthropomorphic robotic hand.

I. Convex Hull-based Power Manipulability

Hee-Byoung Choi and Jeha Ryu present the convex hull-based power manipulability analysis of robot manipulators. Since the manipulability analysis is essential for the design and performance evaluation of robot manipulators, many researchers have focused on the well-known manipulability ellipsoid and polytope based on the Jacobian analysis to investigate the corresponding information. In spite of the good reputation of the manipulability ellipsoid, it does not provide the adequate information about how fast the manipulators can move along arbitrary direction, and the manipulability polytope also users from a physical inconsistency which arise when position and orientation information are combined into a single scalar performance parameter. To overcome the drawback of the physical inconsistency, the power

manipulability ellipsoid has been suggested based on a new parameter which does not depend on the physical unit choice of mechanisms. However, it still has the same drawback as the manipulability ellipsoid. Therefore, the purpose of this paper is to develop the convex hull-based power manipulability in order to provide the adequate information with the physical consistency. The proposed approach is applied to a 2-DOF serial manipulator and a 3-DOF planar parallel manipulator by comparing the ellipsoid approach and the polytope one.

J. Reactive Operation Considering Manipulability

Yan Liu et al. For humanoid robots, there exist a class of challenging tasks, e.g. playing table tennis, which are non-repeatedly, triggered randomly by sensor events, and compelling the robots to produce reactive operations in very short time. Additionally, some key poses of the robot are partially constrained to accomplish the operations, and are usually adjusted during the operation execution. In this paper, efforts are made to generate trajectory for these operations. Firstly, an extended manipulability index is proposed to optimize the key poses so that the humanoid robot has the manipulability considering joint limits at the key poses, which makes it convenient to adjust the trajectory. Secondly, a fast approach to generating the whole trajectory consisting of all the key poses and the strategies to realize the trajectory adjustment when specifications change are proposed. Finally, the ZMP (Zero Moment Point) displacement excited by the reactive operations is also given to decide whether the generated trajectory is feasible. The effectiveness of the method is demonstrated through simulations. In this paper, we have studied key poses optimization, multi-constrained trajectory generation and adjustment, and stability issues to plan the motion of reactive operations which are usually non-periodic, repeatedly triggered by sensor events. The work can be summarized as follows: The manipulability index penalized by the relative joint limit penalization matrix is used to optimize the unconstrained task specification at the key poses so that it is convenient to realize trajectory adjustment during execution if specification changes occur. A fast generation method for the whole trajectory consisting of the key poses and the strategies for trajectory adjustment are presented. The ZMP displacement excited by the operations is given to prevent the trajectories which will lead to the tipping over of the robot from practical use.

K. Omni directional Spatial Manipulator

Yuquan Leng et al. Space manipulators are mainly used in the spatial loading task. According to problems of the spatial loading diversity, the testing loading installing position and the utilization ratio of a test platform, the space manipulator is asked to evaluate the position and attitude of itself. This paper proposes the Point Omni

directional Coefficient (POC) [20] with unit attitude sphere/circle to describe attitude of the end-effectors, which evaluates any points in the attainable space of the manipulators, in combination with the manipulation's position message, and get relationships between its position and attitude of all points in the attainable space. It represents the mapping between sphere surface and plane for mission attitude constraints and the method for calculating volume of points space including attainable space, Omnidirectional space, and mission attitude space. Furthermore, the Manipulator Omni directional Coefficient based on mission or not is proposed for evaluating manipulator performance. Through analysis and simulation about 3D and 2D manipulators, the results show that the above theoretical approach is feasible and the relationships about link lengths, joints angles, attainable space, and Manipulator Omnidirectional Coefficient are drawn for guiding design.

III. SUMMARY

There are different issues about kinetostatic performances of serial and parallel manipulators. Issues regarding serial and parallel manipulators and its kinetostatic performances are solved by analyzing the actuators characteristics. These characteristics of actuators are described by its index or indices. The formulas and coding using MATLAB framework and The Algorithm(Manipulability Index Algorithm) used to calculate the manipulability index after finding the number of joints .Moreover Point Omni directional Coefficient (POC) with unit attitude sphere/circle to describe attitude of the end-effectors is proposed, which evaluates any points in the attainable space of the manipulators, in combination with the manipulation's position message, and get relationships between its position and attitude of all points in the attainable space. Manipulability Indices are further used in dynamic manipulability and manipulating force ellipsoids. The IME is then demonstrated numerically through the selection of an optimal leg posture, the posture is derived through the indices of actuator. Intermediate link found while tracking the desired hand trajectory is avoided using indices and the size of corresponding ellipsoid.

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