On the Use of Homogeneous Transformations to Map Human Hand Movements onto Robotic Hands

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Abstract—Replicating the human hand capabilities is a great challenge in telemanipulation as well as in autonomous grasping and manipulation. One of the main issues is related to the difference between human and robotic hand in terms of kinematic structure, which does not allow a direct correlation of the joints. We recently proposed an object-based mapping algorithm able to replicate on several robotic hand models the human hand synergies. In such approach the virtual object shapes were a-priori defined (e.g. a sphere or an ellipsoid), and the transformation was represented as the composition of a rigid body motion and a scale variation. In this work we introduce a generalization of the object-based mapping, that overcomes the definition of a shape for the virtual object. We consider only a set of reference points on the hands. We estimate a homogeneous transformation matrix that represents how the human hand motion changes its reference point positions. The same transformation is then imposed to the reference points on the robotic hand and the joints values obtained through a kinematic inversion technique. The mapping approach is suitable also for telemanipulation scenarios where the hand joint motions are combined with a wrist displacement.

I. INTRODUCTION

Robotic hands present a high variability of kinematic structures, actuation and control systems. They differ in the number of fingers, in the number of Degrees of Freedom (DoFs) per finger, in the type of joints and actuators, etc. [1]. In most of the telemanipulation scenarios, however, the motion of such a heterogeneous set of devices is related to the motion of a unique complex kinematic structure: the human hand. This has led to the development of several mapping strategies that strongly depend on the robotic hand structures. Examples of these approaches are the fingertip mapping [2], the pose mapping [3] and the joint-to-joint mapping [4]. The main drawbacks of these methods are mainly the lack of generality and the need of empirical or heuristic considerations to define the correspondence between human and robotic hands.

To overcome such limits, in [5] we presented a mapping defined in the task space and mediated by a virtual object (a sphere). The method was detailed in [6] and generalized in [7], considering an ellipsoid as virtual object and extending the possible transformations that can be imposed to it. The object-based mapping is obtained considering two virtual objects, one on the human and one on robotic hand. They are computed considering the minimum volume object containing reference points suitably defined, placed on the respective hands. A configuration variation of the human hand induces a motion and a deformation of the virtual object. Then we imposed that the object defined on the robotic hand moves and deforms according to that defined on the human hand. The mapped motion of the robotic hand is then obtained through pseudo-inversion techniques. This mapping procedure, was adopted to map human hand synergies [8] onto hands with very dissimilar kinematics. However, the definition of a shape for the virtual object implies that the method obtains better results if the manipulated object has a shape similar to the virtual one. Moreover, sharing deformation cannot be reproduced and only in-hand manipulation has been tested so far, since the few available parameters are not sufficient to describe both joints and wrist motions.

In this paper we introduce a new solution which overcomes the definition of a virtual object shape and allows replicating the motion of the human hand in a telemanipulation scenario where also wrist motion is considered. The mapping is based on the definition of a series of reference points, both on the human and on the robotic hand: the reference points on the human hand are necessary to evaluate the transformation produced by the hand motion, the points on the robotic hands are necessary to map such transformation on the robotic hand. A configuration change on the human hand causes a transformation of the reference point positions, which can be generally represented by a six-dimensional displacement and/or a non rigid deformation. In this paper, we assume that this transformation can be represented as a linear transformation, estimated from the displacement of the reference points. The same linear transformation is then imposed to the robotic hand reference points and the hand joint displacement is consequently defined by solving its
where

\[ \mathbf{p}_f = \mathbf{A} \mathbf{p}_i + \mathbf{b}, \]

where \( \mathbf{A} \) is a \( 3 \times 3 \) matrix representing the linear map and \( \mathbf{b} \) is a three-dimensional vector representing the translation in the transformation. Introducing the augmented matrix and vector notation, it is possible to represent both the translation and the linear map using a single matrix multiplication, i.e.

\[ \mathbf{\tilde{p}}_f = \mathbf{T} \mathbf{\tilde{p}}_i, \]

where \( \mathbf{\tilde{p}}_{i,f} = \left[ \begin{array}{c} p_{i,f}^T \\ 1 \end{array} \right] \) and

\[ \mathbf{T} = \left[ \begin{array}{ccc} A & p \\ 0 & 0 & 1 \end{array} \right]. \tag{1} \]

Homogeneous 4 × 4 matrices are widely used in 3D computer graphics systems to represent solid bodies transformations [11]. Homogeneous transformations are able to represent all the transformations required to move an object and visualize it: translation, rotation, scale, shear, and perspective. Any number of transformations can be multiplied to form a composite matrix. Transformation matrices are widely adopted also in continuum mechanics to describe material displacements and strains, and methods to decompose from the deformation gradient the contribution of rigid body motion and non rigid deformation are available in the literature, see for instance [12], [13].

Rigid body motions are particular types of transformation that preserve the distance between points and the angles between vectors. They can be represented as the combination of a rotation, defined by the rotation matrix \( \mathbf{R} \in \text{SO}(3) \), and a translation motion, defined by the vector \( \mathbf{p} \in \mathbb{R}^3 \). \( \text{SO}(3) \) (special orthogonal) is the set of all the \( 3 \times 3 \) orthogonal matrices with determinant equal to 1 [14]. The corresponding homogeneous matrix can be expressed as shown in Fig. 2-a. \( \mathbf{T} \) is in this case a representation of a generic element of the \( SE(3) \) group (special Euclidean).

Homogeneous matrices can be adopted also to describe non rigid transformations: isotropic transformations, which modifies the object size by a scaling factor \( \alpha \), without moving it; non isotropic transformations, which modify the object size by scaling factors \( [\alpha, \beta, \gamma] \), in the \( x, y, z \) directions respectively; and shear transformations, that displaces each point in fixed direction, by an amount proportional to its signed distance from a line that is parallel to that direction. A generic non rigid transformation is qualitatively represented in Fig. 2-b). In this study we do not consider perspective transformations for the sake of simplicity. These basic homogeneous transformations are usually referred to as primitive transformations. Each of them can be represented with a more meaningful and concise representation: a scalar for the isotropic transformation, a vector for translation, 3D scaling and shear, a quaternion for rotations. The recover of the concise form from the primitive transformation matrix is straightforward, but, on the other hand, once primitives have been multiplied into a composite matrix, the recovery of the primitive is not direct in general [15].

Different procedures to decompose a generic \( 4 \times 4 \) matrix into a series of primitive transformations are available in the literature. In this paper we consider the extraction of the rigid and non rigid motions contributions from a generic linear transformation matrix. Consider, for instance, the human hand/arm system moving along a trajectory while the hand is changing the grasp forces exerted onto an object. In this case a large rigid arm displacement is coupled with a smaller non rigid deformation. The displacements of the reference points on the human hand however contains both the contributions. So that, in the mapping procedure, when the arm and wrist is involved in the motion, we propose to extract the rigid part of the motion from the complete transformation matrix and to reproduce it with the robotic arm, while the non rigid contribution to the reference point configuration variation is reproduced acting on the robotic hand fingers. This decomposition will be be better explained in the second numerical experiment proposed in Sec. IV.

In this type of application we need to express the transformation matrix as follows

\[ \mathbf{T} = \mathbf{T}_{de,f} \mathbf{T}_{rb} \tag{2} \]

where \( \mathbf{T}_{rb} = \mathbf{T}_{tr} \mathbf{T}_{rot} \) represents the rigid part of the displace-
The matrix \( T_{rb} = \begin{bmatrix} R & p \\ 0 & 1 \end{bmatrix} \) and \( T_{def} = \begin{bmatrix} 1 & h_{xy} & h_{xz} & 0 \\ h_{yx} & 1 & h_{yz} & 0 \\ h_{zx} & h_{zy} & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \) can be written, with the polar decomposition, as the product of a rotation and a translation, and \( T_{def} \) takes into account the non rigid deformation, as shown in Fig. 2-a) and b) respectively. The extraction of the translation part of the rigid body motion from the starting matrix \( T \) is straightforward considering eq. (1). The matrix \( A \) in eq. (1) can be decomposed as the product of a rotation and a translation, and \( T \) is a part of the rigid body motion from the starting matrix \( T \). Fig. 2-a) and b) respectively. The definition of the following reference frames is necessary to identify hand motion. Let \{ \text{hand} \} \( = \{ N^w \} \) be an inertial reference frame, adopted to describe hand/wrist motion. Let \{ \text{hand} \} \( = \{ N^h \} \) indicate a frame on the human hand palm. The configuration of \{ \text{hand} \} \( = \{ N^h \} \) reference frame with respect to the inertial one depends on the arm motion, and is described by the homogeneous transformation matrix \( T_h \), which depends on six parameters, namely the coordinates of \{ \text{hand} \} \( = \{ N^h \} \) origin and the relative orientation between the frames, described for instance by Euler angles. Let \( p_w \in \mathbb{R}^6 \) be a vector containing \{ \text{hand} \} \( = \{ N^h \} \) position and orientation with respect to \{ \text{world} \} \( = \{ N^w \} \).

Various kinematic models of the human hand are available in the literature, we chose a 20 DoFs model, in which each finger has four DoFs [17]. Let us indicate with \( q^h_{i} \in \mathbb{R}^{n_h} \), with \( n_{hi} = 20 \), the generic configuration of hand joints. The number and position of the reference points on the human hand, \( n_{hi} \), can be arbitrarily set. Reference points can be placed on the fingertips, in the intermediate phalanges, in correspondence of the joint axis, etc. The fingertips represent a natural choice for the reference points, since they are at the end of the kinematic chains that define the fingers, so their configuration depends on all the joints [6].

Let us indicate with \( p_k \), with \( k = 1, \ldots, n_h \), the reference points on the human hand. The vector \( h_{k,c} \in \mathbb{R}^3 \) represents the coordinates of the generic reference point \( p_k \) with respect to \{ \text{hand} \} \( = \{ N^h \} \) when the hand assumes a configuration \( C \) and the joint values are \( q^h_{i} \). Let furthermore we indicate with \( h_{k,c} \in \mathbb{R}^4 \) the corresponding augmented vector, adopted to represent affine transformations, i.e. \( h_{k,c} = [p_{k,c}^h \ T] \). Finally, let us indicate with \( h_{c} \in \mathbb{R}^{3n_h} \) a vector containing the coordinates of all the reference points in the generic configuration \( C \). Let \( h_i \) denote the initial position of the reference points on the human hand. Their position is a function of hand initial configuration vector \( q^h_{i} \) and the wrist initial configuration \( p_{i,w} \), and can be evaluated by the direct kinematic analysis of the hand, i.e.: \( h_i = f_k(q^h_{i}, p_{i,w}) \). (4)

Let us then assume that, starting from this initial configuration, the hand and the wrist are moved, let \( h_{i} \) and \( h_{f} \) be the final hand joint and wrist configurations. The reference point positions on the human hand vary according to hand and wrist kinematics, i.e. \( h_{f} = f_k(q^h_{f}, p_{f,w}) \), [18].

We assume that the configuration variation of the reference points from \( h_{i} \) to \( h_{f} \) can be represented as a linear transformation, i.e., for each point \( p_k \), with \( k = 1, \ldots, n_h \), the following linear relationship can be written as \( h_{f} = T h_{i} \). (5)

Given the initial and final reference point configurations \( h_{i} \) and \( h_{f} \), we can evaluate the linear transformation \( T \) in eq. (5) by solving the following linear system

\[
T = \begin{bmatrix}
0 & 1 & 0 & 0 \\
1 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

and the system matrix \( M \in \mathbb{R}^{3n_h \times 12} \) is defined as

\[
M = \begin{bmatrix}
M_1 \\
\vdots \\
M_{n_h}
\end{bmatrix}
\]

in which the generic matrix \( M_k \in \mathbb{R}^{3 \times 12} \) is given by

\[
M_k = \begin{bmatrix}
0 & 1,4 & 0,1,4 \\
0,1,4 & 0 & 1,4 \\
0,1,4 & 0,1,4 & 0
\end{bmatrix}
\]

As already mentioned in Sec. II, \( T \) matrix can then be decomposed as the product between a rigid body transformation matrix \( T_{rb} \) and a non rigid transformation \( T_{def} \). The idea behind the proposed mapping procedure is then to reproduce, on the reference points defined on the robotic hand, the same linear transformation computed on the human hand. Note that the homogeneous transformation matrix \( T \) obtained by solving the linear system in eq. (6) depends on the hand and wrist configuration variation, and also on the initial configuration of reference points \( p_{i,w} \).
Let us indicate with $\{N^{w,r}\}$ an inertial reference frame, adopted to describe robotic hand and arm motion, and $\{N^r\}$ a reference frame on the robotic hand palm, let $p_{w,r}^k \in {\mathbb R}^6$ be a vector describing the position and orientation of frame $\{N^r\}$ with respect to $\{N^{w,r}\}$, and let $q_{h}^r \in {\mathbb R}^{n_r}$ indicate the robotic hand joint vector. In general, since the robotic hand has a kinematic structure different from the human one, $n_h \neq n_r$.

A set of reference points are defined also on the robotic hand, indicated with $P_r^k$, with $k = 1, \cdots, n_r$. In general, $n_h$ and $n_r$ are not related and $n_h \neq n_r$.

In the initial reference configuration the coordinates of the reference points on the robotic hand are defined by the vectors $\tilde{p}_{k,i}^r$, that can be collected in the vector $\tilde{p}_r^k \in {\mathbb R}^{3n_r}$. The final configuration of these points, according to the above defined linear transformation, can be evaluated as the composition of two motions

$$\tilde{p}_{k,f}^r = T_{def} T_{rb} \tilde{p}_{k,i}^r = T_{def} \tilde{p}_{k,rb}. \quad (7)$$

The reference point configurations after the rigid transformation can be collected in the vector $p_f^r \in {\mathbb R}^{3n_r}$, while $p_r^f \in {\mathbb R}^{3n_r}$ contains the final reference point configurations. The displacement vector $\Delta p^r$ due to the non-rigid part of the transformation is thus defined as

$$\Delta p^r = p_f^r - p_r^f.$$

This displacement has to be reproduced by modifying the robotic hand joint values, according to robotic hand inverse kinematics. If the displacement $\Delta p^r$ is sufficiently small, the linear approximation of the kinematics of the robot can be considered. Consequently, the displacement that has to be imposed to the robotic hand joints can be evaluated as

$$\Delta q^r = J_r \# \Delta p^r + N_{f_r} \alpha \quad (8)$$

where $J_r$ is the robotic hand Jacobian matrix, the index $\#$ denotes a generic pseudo-inverse, $N_{f_r}$ is a basis of $J_r$ nullspace and $\alpha$ is a vector parameterizing the homogeneous part of the inverse differential kinematics problem and managing the presence of eventual redundant hand DoF [14]. Robotic hand joint variation $\Delta q^r$ is the displacement that has to be imposed to the robotic hand joints in order to obtain, on the robotic hand reference points, the same linear transformation of the reference points on the human hand.

**IV. NUMERICAL EXPERIMENTS**

**A. Mapping human hand synergies on a three fingered robotic hand**

In the first part of numerical experiments we considered only in–hand motions and we did not take into account wrist motions. We simulated the mapping of human hand synergies onto a robotic hand with a non anthropomorphic structure. Postural synergies represent a way to simplify human hand structure, reducing the number of DoFs necessary to define its posture [19]. The synergy idea has been recently brought to robotics, to reduce the number of inputs necessary to actuate a robotic hand, thus simplifying their mechanical and control structure [20], [8]. Mapping human hand synergies on robotic hands with different kinematics in the task space using the definition of a virtual object was analyzes and discussed in [6].

The considered robotic hand is a three fingered modular hand composed of three identical planar fingers, each of them has three joints [7]. Globally the hand has 9 DoFs. Each finger can be represented as a three DoFs planar robot, so the motion of all the points on each finger is on a plane, normal to the revolute joint axes.

The numerical experiments were performed using and adapting the functions available in SynGrasp, a Matlab Toolbox for the simulation and the analysis of grasping with several hand models [21]. This tool includes functions for the definition of hand kinematic structure and of the contact points with a grasped object, the coupling between joints induced by a synergistic control, compliance at the contact, joint and actuator levels. Its analysis functions can be used to investigate the main grasp properties: controllable forces and object displacements, manipulability analysis, grasp quality measures. Furthermore, functions for the graphical representation of the hand, the object and the main analysis results are provided. The SynGrasp numerical models of the human and robotic hand adopted in the simulations are shown in Fig. 3.

We considered the first two synergies. We activated one synergy per time and we mapped the corresponding motion to the robotic hand. In synergy actuated hands, joint variable variations are constrained by a linear relationship

$$\Delta q^h = S \Delta z,$$  

in which $S \in {\mathbb R}^{n_h \times n_z}$ is the synergy matrix and $\Delta z \in {\mathbb R}^{n_z}$ represents the synergy input values. Synergy matrix for the used human hand model is available in the SynGrasp toolbox and has been computed from the data collected in [19]. A mathematical model of synergy actuated hands, and an analysis on the role of synergies in the controllability of force and object motions in grasp tasks were presented in [22].

We chose the fingertips of the first four fingers as reference points on the human hand. For the robotic hand we assumed the three fingertips. The dimensions of contact point vectors...
are $p^h_i \in \mathbb{R}^{12}$ and $p^r_i \in \mathbb{R}^9$ for the human and robotic hand, respectively. From eq. (6), it results that $M \in \mathbb{R}^{12 \times 12}$. As starting configuration of the human hand, $q^h_0$ we assumed the mean configuration obtained from the provided experimental measures in [19].

By applying the mapping procedure detailed in Sec. III, human hand synergies were mapped on the robotic hand. Fig. 4 shows the human hand motion and the displacements of the reference points when the first two synergies are actuated. Fig. 5 reports the corresponding robotic hand movements and reference points displacements. In particular, the red arrows represent the displacement evaluated by the homogeneous transformation, while the blue ones the displacements that can be effectively reproduced by the hand, due to its kinematic structure, that constraints the motion of each reference point on a plane.

The second simulation involves grasping. The human and robotic hands grasp an object and the reference points are the contact points with the object. The objects in this simulation is defined through its contact points and no specification on shape and size are reported. The human hand is actuated in order to produce a rigid body motion of the grasped object, and the corresponding motion of the object on the robotic hand obtained with the proposed mapping is analyzed. Rigid body motions are displacements of the grasped object that do not involve any variations of the contact forces. A more complete description of this type of motions is detailed in [20], [22], where it was also demonstrated that the subspace dimension of the controllable rigid body motions depends on the actuation and on the number and type of contacts. Let us assume that the human hand is grasping an object through the four contact points $p^h_i$ and that it moves it by maintaining invariant the contact forces. According to [20], it results that the internal force subspace dimensions is $n_e = 6$. Consequently, the minimum number of inputs necessary to generate at least one rigid body motion is $n_z = 7$. The synergy matrix considered in this simulation is then $S \in \mathbb{R}^{20 \times 7}$ and is given by the first seven columns of the complete synergy matrix.

In this configuration, the vector of synergies that allows to produce on the human hand model a rigid body motion, evaluated according to the procedure detailed in [20] is

$$\Delta z^{rb} = [0.1, 0.47, -0.13, 0.29, 0.23, 0.34, 0.71]^T$$
The homogeneous transformation is (mm): 

\[
\begin{bmatrix}
0.1 \\
0.2 \\
0.3 \\
0.4 \\
0.5 \\
0.6 \\
0.7 \\
0.8
\end{bmatrix}
\]

rotation [rad]

error

norm error
direction error [rad]

For the sake of simplicity, the object centers in the human and robotic hands are defined as the hypothetical centers of mass of the reference points, evaluated assuming a unitary mass for each point. Fig. 6 shows human and robotic reference points and object centers displacements when an object rigid body motion is imposed to the human hand. In the robotic hand diagram, the red vectors represent the displacements of the reference points predicted by the homogeneous transformation evaluated on the basis of human hand displacement, while the blue ones represent the displacements that can be effectively reached by the robotic hand, due to its kinematic structure. It is evident that robotic hand reference points are constrained to move on a plane, and then the required displacements, necessary to realize the transformation, cannot be realized. For this reason the actual object displacement, on the robotic hand, is different from the nominal one. More precisely, the displacement evaluated by the homogeneous transformation is (mm): \( \Delta o’_h = [-1.62 - 4.10 - 1.84]^T \) while the displacement obtained by the robotic hand is (mm): \( \Delta o’ = [0.31 - 1.56 - 1.68]^T \). The difference between displacement norms, normalized with respect to the first one, is 0.51, i.e. the actual displacement norm is about one half of the value predicted by the homogeneous transformation matrix, while the angle between displacement vectors is 0.62 rad.

The difference between the transformation predicted by the homogeneous transformation and the reached one depends on the kinematic limits of the robotic hand is sensitive to the relative configuration between the hands. As an example, Fig. 7 shows the object center displacement error obtained by rotating the robotic hand with respect to \( z \) axis, while keeping the human hand in the same orientation. The blue curve in the diagram represents the difference between the norms of the vectors, normalized with respect to the nominal displacement evaluated by the homogeneous transformation, while the green curve represents the angle (expressed in radians) between displacement vectors.

\[
\begin{bmatrix}
0 \\
1 \\
2 \\
3 \\
4 \\
5 \\
6 \\
7
\end{bmatrix}
\]

rotation [rad]

error

norm error

B. Teleoperating a three fingered robotic hand

The second set of numerical simulations are aimed at mapping on a robotic hand, a task in which the human hand is grasping a cubic object, its wrist moves along a given trajectory and, at the same time, the first hand synergy is activated. The synergy activation in this case produces both a variation of the contact forces and a displacement of the object center, which can be evaluated using the procedure discussed in [22]. This wrist and in–hand motions were mapped on a robotic system represented by a three fingered hand resembling the Barrett Hand but with eight actuated joints (two fingers with three joints and one with two), and a six DoF arm. Both the hands were grasping the same object, a cube with side 50mm. The two hands started from a given grasp obtained through the grasp planner available in Syngasp, which consider a procedure similar to that described in [23].

As reference points for the mapping we assumed the contact points of the hands with the object. In Fig. 8-a) human and robotic hand configurations are sketched, and in Fig. 8-b) contact points are shown. The grasp planner provided seven contact points on the human hand and three contact points on the robotic hand.

We considered a generic trajectory for the human hand wrist represented by a cosine arc whose length was 470 mm in the \( x \) direction and whose height in the \( z \) direction was 150 mm with respect to the \( \{N^o\} \) reference frame. While the human hand is following this trajectory, hand finger joint reference values are varied along the first hand synergy. The trajectory was sampled in a series of steps. For each steps, human hand and arm motion was mapped on the robotic system with the proposed mapping approach.

Fig. 9-a) shows the human hand trajectory. The blue line represents object center displacement. Fig. 9-b) shows the resulting motion on the robotic hand. The red curve represents robotic hand object center trajectory during the simulation. As it can be seen, the robotic hand is able to follow the
human hand trajectory, even if it is the combination of a generic six-dimensional wrist displacement with an in–hand motion.

Fig. 10 shows, for the first sampling step, the direction of the object center displacement produced by the activation of the hand synergies, i.e. without considering wrist motion, and the corresponding variations of the contact forces, evaluated according to [22]. While the object motion directions are quite comparable, a simple comparison between contact force variations is not possible, due to the different positions and number of contact points between the human and robotic hand.

Finally, Fig. 11 shows the sensitivity of the proposed mapping procedure with respect to some operative parameters. The upper diagram shows the effect of the applied synergies: the final reference values of the human hand joints were evaluated as $q^h_f = q^h + \alpha S \Delta z$, with $\alpha$ varying from 0.1 and 1 and $\Delta z = [1 \ 0 \ 0 \ \cdots ]^T$ for the first synergy, $\Delta z = [0 \ 1 \ 0 \ \cdots ]^T$ for the second one, etc.. As it can be seen, the sensitivity of $\alpha$ parameter on the trajectory error, defined as the distance between object centers at the end of trajectory execution, is quite evident. The sensitivity is furthermore different for the different synergies. This effect is due to the different kinematics between human and robotic hand, that was pointed also in the preceding set of simulations. The three fingered robotic hand, due to its kinematic constraints, is not able to fully reproduce the object in–hand motion produced by the human hand. The lower diagram shows the sensitivity of the trajectory error on the size of trajectory discretization step. In this case the sensitivity is quite lower, i.e. the proposed mapping procedure is quite robust with respect to the length of trajectory discretization step.

Fig. 11: Trajectory error sensitivities. Upper diagram: sensitivity of the trajectory error on the coefficient of synergy activation, for the first three synergies. Lower diagram: sensitivity on the trajectory discretization step.
V. CONCLUSIONS

The complex and different structures that characterize robotic hands require methods to unify their control. There are applications, e.g. telemanipulation or learning by demonstration, in which a mapping between the human hand and robotic hands is necessary. The development of a mapping function between human and robotic hands, even with dissimilar kinematics, is necessary to solve these issues. In this paper we describe a mapping procedure based on the task space, whose main requirement is the definition of a series of reference points both on the human and on the robotic hand. When the human hand is activated, through its synergies, the displacement of its reference points allows to define a homogeneous matrix that capture the transformation that the human hand produces on a set of reference points. The same homogeneous transformation matrix is adopted to evaluate the displacements of the robotic hand reference points, and consequently, through the inverse kinematics, the robotic hand joint variations.

The advantages of this type of mapping is that it does not requires empirical and heuristic considerations, it is general and can be applied to robotic hands with a kinematic structure very different from the anthropomorphic one. The mapping function is nonlinear, and depends on the initial reference configurations of human and robotic hand.

This is a preliminary presentation of a homogeneous transformation based mapping procedure. The numerical tests presented in the paper show that its performance depends on relative configuration of the hands and this aspect needs to be furthermore analyzed and compared with other mapping methods. However, since the method is based on the transformation of a virtual set of points in the task space, we expect that the dependency of mapping performance on the relative configurations between the hands is substantially due to the kinematic limits of the robotic hand and not on the mapping features, like, for instance, in the joint-to-joint mapping method. Other parameters have to be considered in the analysis, for instance the role of the number and location of the reference points on both the hands.

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