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SIMILARITIES AND VARIETIES IN HUMAN MOTION TRAJECTORIES OF PREDEFINED GRASPING AND DISPOSING MOVEMENTS

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Human movement is characterized by smoothed trajectories and individual solutions in terms of joint angle configurations. Knowledge about basic strategies and the nature of human motion is essential to transfer human movement characteristics to a humanoid robot. The objective of this study is the inter-individual and intra-individual comparison of movement trajectories and time series of joint angles for several predefined object manipulations. For that purpose the kinematics of arm, hand, and finger motion was measured and analyzed. A video-based motion capturing system was used to acquire 3D motion data. We present graphs of object trajectories, joint angles, and finger tip distances (grasp state) for an example motion: moving to a cuboid, grasping the object, and putting it to a heightened target position. The varieties in motion of different subjects and within repeated motion cycles of one and the same subject are presented. Besides, we show how test subjects with different body height solve the motion task.

Keywords: human motion; grasping movement; kinematic analysis; inter-individual varieties

1. Introduction

Human life is more and more influenced by technical systems executing common operations in daily life. For instance, robots in factories are used for welding, varnishing, or assembling parts of a car body. They are an essential component of assembly lines. The efficiency is highly valued not only because some capabilities of robots are out of reach for humans. The motion of robots is optimized according to criteria such as minimization of trajectory length or minimization of energy consumption. Based on a sophisticated automatic control of closed loops, robots can manipulate at high speed and much more precise than their antetype – human beings.

Robots with the ability to communicate and to interact with humans are an essential precondition for making them attractive to offer services in offices or in the household. It seems to be only a question of time until robots will be generally integrated in families and serve as cleaner, steward, or workman.

To achieve a high level of acceptance, especially among elderly people, service robots must be "humanized". Size, geometry, and arrangement of the limbs should be similar to humans as well as the number of degrees of freedom and the range of movement amplitude. Besides anthropometric resemblance, the motions of a robot must be comparable to those of a human.[1] [2] This claim was only insufficiently accounted for motion generation of humanoid robots, so far.

In contrast to industrial robots, principles of minimization (trajectory lengths and energy costs) are not suitable for designing humanlike movement of service robots. Only less evidences can be used for description and generation of interaction of upper arm, fore arm, hand, and fingers during a simple manipulation of a cuboid for example.[3] The trajectories of movement differ from person to person. The motion patterns depend on time limits given to the subject. Additionally, the trajectories of hands and fingers are significantly influenced by the field of vision and the position of the manipulated objects, respectively.[4] [5] Until now, the manner how people manipulate objects, which strategies they use for timing, and the principles of designing movement trajectories is still unclear. This study is focused on the analysis of selected human grasping and disposing movements. Subject specific and inter-individual varieties in time series of joint angles of simple movement tasks (coordination of arm, hand, and fingers) are investigated and quantified.

2. Material and methods

The analysis of varieties in timing and movement trajectories between subjects and within a subject is based on the measurement of arm and finger joint kinematics of 10 persons (ages between 21 and 28 years). Each test person was asked to perform 6 types of predefined object manipulations (grasping, displacement and rotation of wooden cuboids, bottles, and cups). For that purpose, both shoulders, the right elbow, the carpus, and the finger joints of the right hand were prepared with colored hemispheres. This allows the detection of markers in video frames. The kinematical analysis was based on video coordinate tracking. Six DV cameras were installed around the subject. Thus it was ensured that each marker was recognized by at least two cameras to enable the transformation from coordinates of frame markers into 3D space coordinates.[6] Because DV cameras do not provide an option for an electronic synchronization of frame switch, the time offset of each camera related to a master camera is determined by LED bars shown in all camera views (see Fig. 1). The LEDs on the bars switch simultaneously with a frequency of 500 Hz. In this way, the time slice of the shutter of each camera relating to the master camera could be calculated with a resolution of 0.002 s. The exposure time (shutter) of each camera was 1/150 s. The video frames of all cameras were recorded via an IEEE 1394-interface by PC.

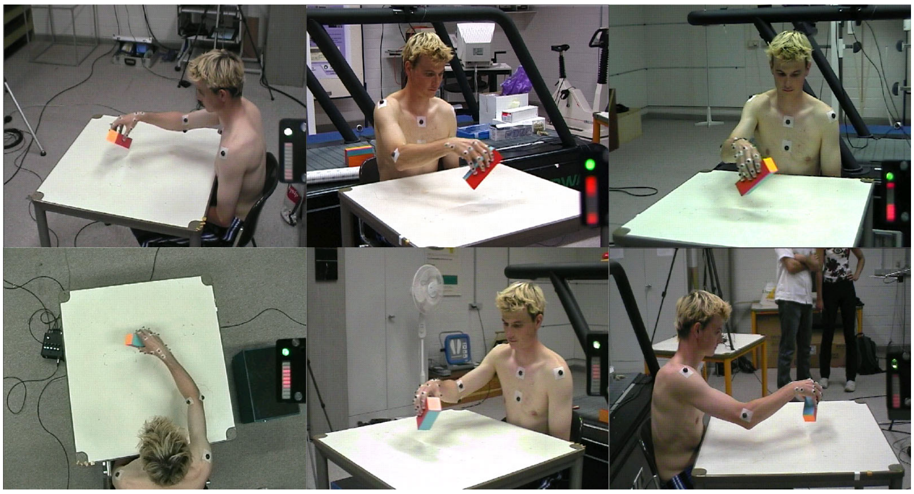

Fig. 1. Views from six cameras used for motion capturing during object manipulation.

To determine image coordinates and to transform them into spatial coordinates a video-coordinate tracking software (SIMI Motion, see Fig. 2) was used. The direct linear transform (DLT) of 3D spatial coordinates is based on a calibration cube of 0.6 m × 0.6 m × 0.6 m according to the algorithm of Abdel-Aziz & Karara.[7] After the export of transformed 3D coordinates into a specific software for kinematic analysis the trajectories were smoothed using cubic spline approximation.[8] Based on the spatial coordinates of a 26 point model of right arm, hand, and fingers the motion could be animated as stick figure and user defined kinematic parameters could be calculated (see Fig. 3).

For the comparison of movement patterns (marker and object trajectories, arm and finger joint angles) from repeated execution of predefined motion tasks of one subject or from motion data of different subjects the time series of trajectories and joint angles had to be normalized in time. After time normalization, the mean trajectories and joint angles with standard deviations were calculated.

3. Results and discussion

The evaluation of kinematic data was focused on intra-individual and inter-individual comparison of movement patterns at standardized object manipulation. Results are presented predominantly for one motion task: grasping at a cuboid on

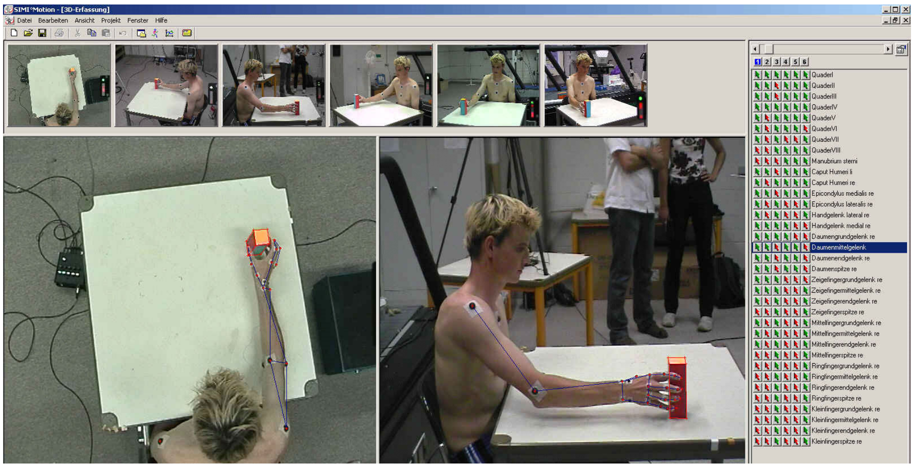

Fig. 2. User interface of the SIMI Motion software for manual registration of marker coordinates in six camera views.

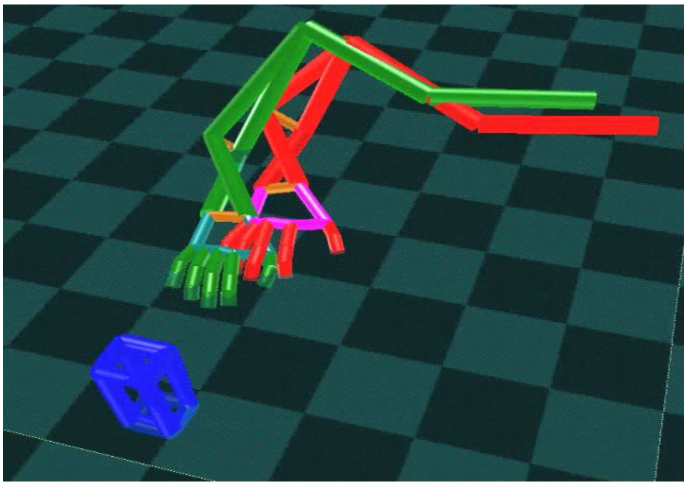

Fig. 3. Stick figures of two subjects at starting position for a predefined object manipulation.

the table and putting it to a heightened rack (see Fig. 4).

The trajectories of the manipulating hand showed permanent curved paths in the sagittal plane of the subject (side view). Figure 5 shows that the object was not directly (not on a linear path) put from the starting position to the target. In some cases, the subjects first moved the manipulation cuboid towards their body before directing the object to the target (y-direction at lifting in Fig. 5).

Fig. 4. Four subjects immediate before putting the cuboid on the 0.4 m heightened target position.

A displacement of objects in the horizontal plane was accomplished more directly and on nearly straight lines. This was observed even if objects had to be rotated during their shifting on the table plane (see Fig. 6). In most cases the horizontal component of the movement is characterized by the principle of minimization of trajectory length.

The subjects were urged to manipulate the objects normally like in their daily life. There were subject specific differences in the time used for the movement cycles. Almost constant manipulation durations were measured for each subject except one. The duration of movement cycles is a characteristic feature of each subject. The mean manipulation speed is largely an expression of the mentality of the test person. It was observed that the time used for entire manipulation was reflected in the time intervals used for parts of the motion. In this context, it would be interesting how time pressure effects the time relations of different parts a complex motion.

The body length of the subjects reached from 1.60 m to 1.93 m. In spite of large differences in arm length the chosen hand and object trajectories of the subjects were similar. Differences of limb length were compensated by corresponding joint angle positions of shoulder, elbow, and wrist. As expected, intra-individual differences of movement trajectories and limb joint angles in cyclic movement tasks were

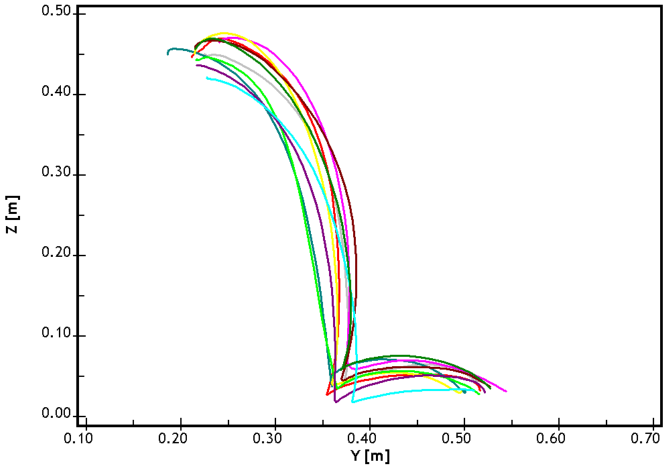

Fig. 5. Side view of hand trajectories of 10 subjects putting a cuboid on a heightened position. Note that the hand moves from the starting position at y=0.50 m to the cuboid at y=0.35 m and than after grasping the object to the target (z=0.40 m).

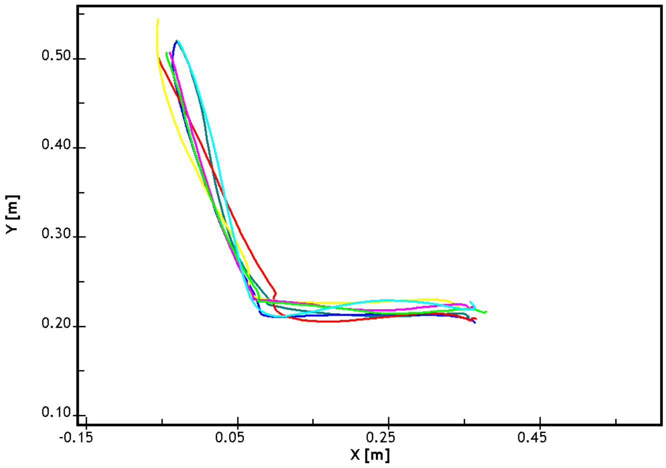

Fig. 6. Hand trajectories of 7 subjects during grasping a cuboid at (x=0.10 m, y=0.20 m) and putting it with rotation to (x=0.40 m, y=0.20 m). Starting position of the hand was at (x=-0.05 m, y=0.50 m).

much smaller than respective inter-individual differences. This was predominantly caused by varying limb length. The inter-individual similarity of hand and object trajectories point to the hypothesis that the entire movement is mainly controlled by the trajectories of the periphery (hand and object) and not by joint positions.

The eyes of the subjects moved immediately after grasping the object from the object to the target position. A permanent visual tracking of the object was never observed in our tests. These phenomena are also discribed by P. van Vliet.[9]

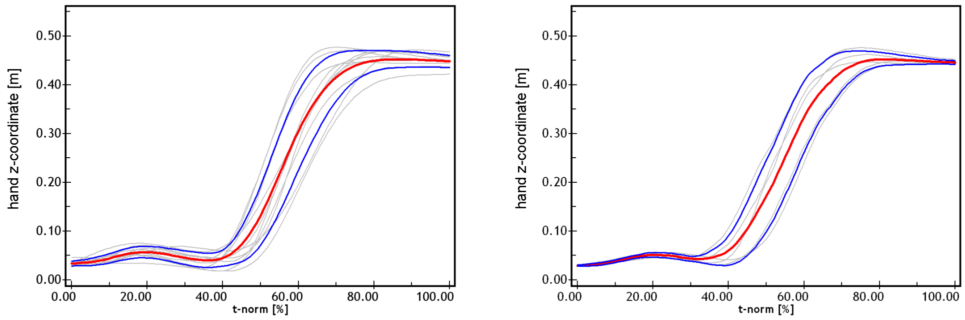

Fig. 7. Putting a cuboid to a heightened position: Mean, standard deviation, and individual time series of the vertical coordinate $z(t)$ of 10 subjects (left) and of 5 trials of one and the same subject (right).

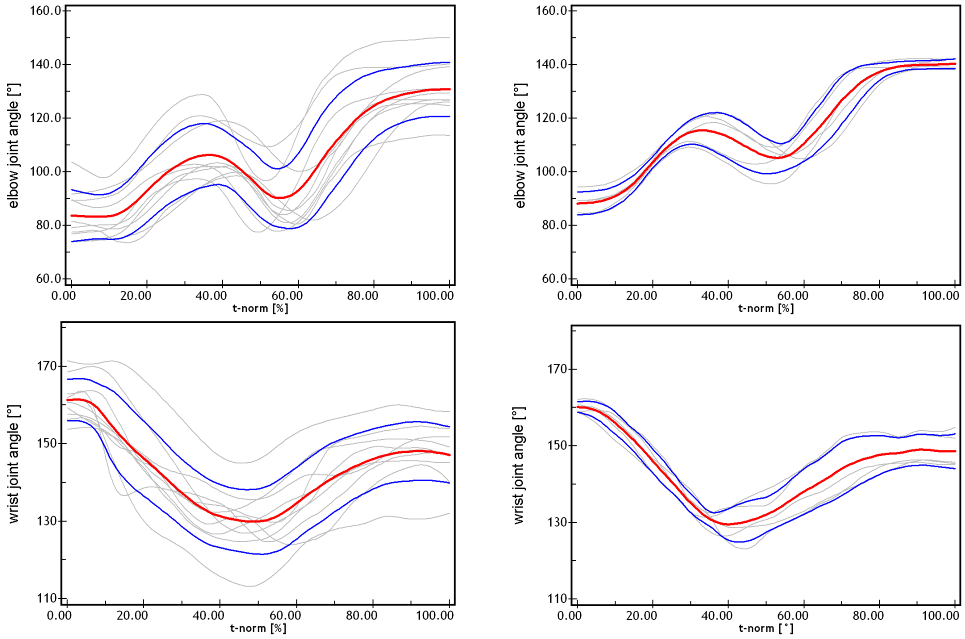

Fig. 8. Putting a cuboid to a heightened position: Mean, standard deviation, and individual time series of the vertical coordinate $z(t)$ of 10 subjects (left) and of 5 trials of one subject (right).

For the control of humanoid robots the timing of grasping is significant. Because of subject specific differences in finger mobility, the joint angles of the fingers show large individual divergence. This is the reason why the grasping state is described as the distance between the index finger tip and the thumb tip. Thus the kinematics of grasping movements can be graphically illustrated in a more useful manner than by plotting the joint angles of the fingers.

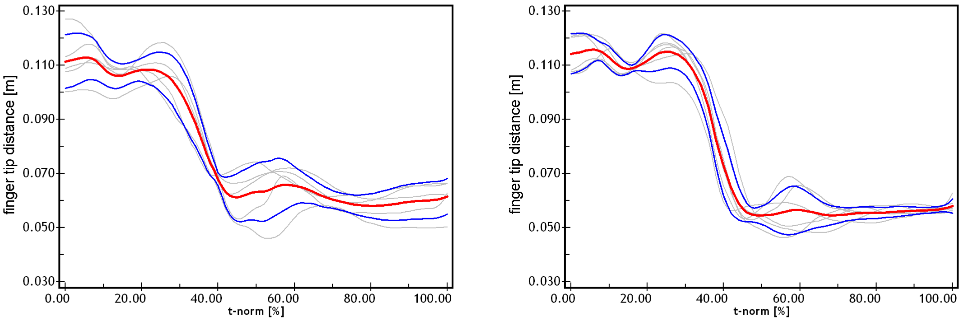

Fig. 9. Putting a cuboid to a heightened position: Mean, standard deviation, and individual time series of the vertical coordinate $z(t)$ of 10 subjects (left) and of 5 trials of one and the same subject (right).

The subjects sat in a normal position at a table. This was the start position of all movement tasks investigated in this study. In this situation, the position of the hand could be influenced by the joint angles of shoulder, elbow, and wrist. Additionally, the translation of the right shoulder induced by rotation of the shoulder axis or inclination of the upper body can affect the position of the hand. Subjects with low body height showed more rotation of the shoulder axis compared to test persons with longer arms (see Fig. 10).

The redundancy of joint angles in shoulder and elbow for a given hand position is a well known problem in trajectory planning of humanoid robots. One option is the minimization of elbow height. Our observations show that this assumption is not true for a majority of the manipulations examined in this study. Particularly, if the right hand of a right hander moves from a position in front of the right shoulder to the right, the elbow was often even higher than the hand. During manipulations in front of the left shoulder (right hander) a deep elbow of the right arm was frequently observed.

Caused by functional anatomical reasons, object displacement to the right side is less often realized by a rotation in the shoulder joint in transversal plane but more often by an abduction of the upper arm combined with an elbow extension. Especially, persons with short arms use this strategy that leads inevitably to a high elbow position (see Fig. 11).

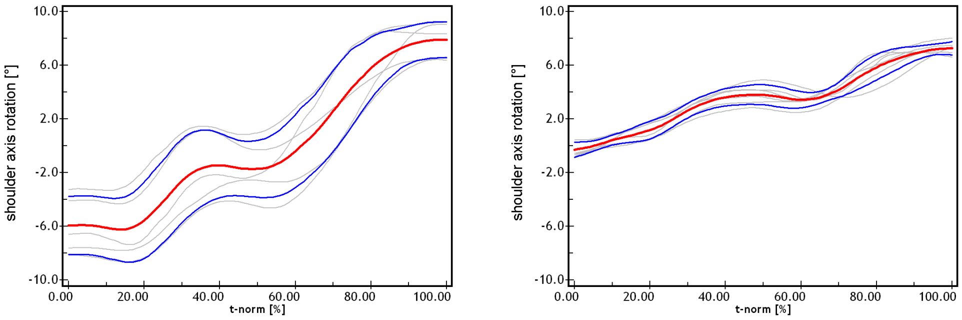

Fig. 10. Putting a cuboid to a heightened position: Mean, standard deviation, and individual time series of the shoulder axis rotation in horizontal plane (from top view) of 5 trials each of a subject with 1.78 m body height (left) and a subject with 1.93 m body height (right).

The presented results of selected human motions display the abundance of solutions (combinations of joint angle postions) for a given starting and target position of a manipulation object. The mentality of the individual subject affects speed and accuracy of motion. The manner of grasping and the run of movement trajectories over the whole motion depends on the length of the segments (arm, hand, and finger) and the position of the object relating to the subject. Despite of the above mentioned individual and situtation dependent constraints, the trajectories of subjects performing a specific motion task show a remarkable similarity. Based on a kinamatic analysis of a diversity of movements the differences between human motion and motion of humanoid robots will be scaled down continuously.

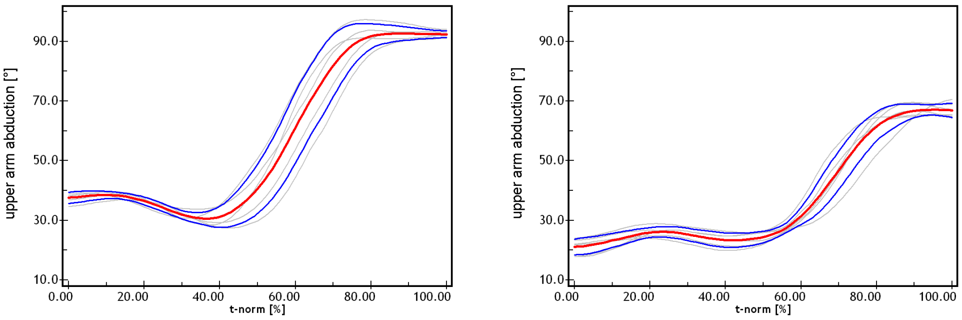

Fig. 11. Putting a cuboid to a heightened position: Mean, standard deviation, and individual time series of the shoulder axis rotation in horizontal plane (from top view) of 5 trials each of a subject with 1.78 m body height (left) and a subject with 1.93 m body height (right).

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