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Robotics: For Physically Disabled & Handicapped People

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Abstract: In this paper, a task-oriented design (TOD) procedure is proposed by which a robotic arm can be designed to achieve predefined tasks of physically disable or handicapped person. To define the target tasks, we have observe everyday life of physically disabled & handicapped people. By using TOD procedure in a coherent and consistent manner, we can develop a working prototype of a care-providing robotic arm for physically disabled & handicapped people. Through this TOD procedure the robotic arm should plays important role in the life of physically disabled& handicapped people; we confirmed that the developed robotic arm is indeed able to carry out the predefined tasks just like a normal person.

Keywords: robot design, task-oriented design, care-providing robot, disabled people, task space, kinematic design, dynamic analysis

1. Introduction

This paper presents a design methodology named *task oriented design* and its application to a design of a care providing robotic arm. Provided below are the background And context associated with our endeavor. In engineering designs, one can never emphasize too much the importance of having *clear and well-defined goals* in mind from the beginning to the end. The design of a robot, of course, is no exception since the robot design usually has its goal tasks and specifications before the design.

Nevertheless, it is our observation that the majority of works when designing robots do not appear to be carried out in accordance with this principle. Instead, it appears that many designs attempt to make a robot *flexible enough* so that it can somehow achieve required tasks, only to realize that it never does. The reason for the failure is obvious and easy to see. It is well known that goal tasks involve motion position, velocity, acceleration and payload of the tip as well as the object and environment of the robot manipulation. Therefore, without clearly defined tasks, vague assumptions tend to dominate all the subsequent designs of kinematic parameters, joints, links, actuators, transmissions, power supplies, sensors, control schemes, etc. As the result, it is unlikely for the end products to guarantee goal tasks, and redesigns become inevitable. Of course, a design work is iterative in its nature (Caprari et al., 2000), and hence is subject to trial and error. But without *task oriented approach*, a robot design is very likely to demand an unnecessarily large amount of iteration, consuming substantial time, effort, and cost. The underlying philosophy of task-oriented design (TOD) is *to guarantee at least a set of tasks with high priority*. The TOD procedure we are going to present is essentially a top-down approach described in Fig. 1

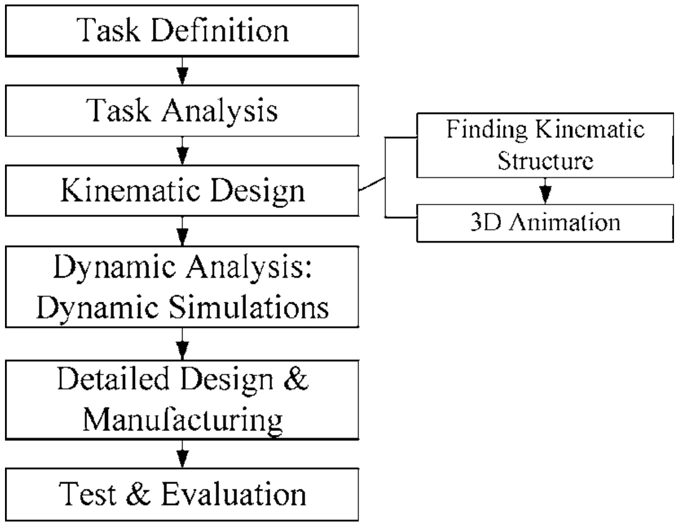

Figure1. Task-oriented design (TOD) procedure.

And there appear many application areas where such a guarantee is crucial, like helping handicapped people. For this reason, we feel it necessary to share our design experience long with detailed examples based on the TOD procedure with the robotics community.

In Japan, due to the effect of the aging society, seniors and disable persons (in particular, for lower limb) are becoming a big problem to be seriously considered. Therefore, it is required to develop more effective welfare apparatuses for the elderly and disabled. However, it is difficult to evaluate them by anthropometric because of the problems on the safety in experimental subjects and the measurement accuracy.

The TOD procedure we are going to present is essentially a top-down approach described in Fig. 1. Each Step in Fig. 1 is going to be detailed in the following sections.

2. Task Definition

As the first step of robot design, we have drawn a set of target tasks from the everyday life of physically disabled people. It is our conviction that this step, being the basis of all the subsequent steps, is the most important and deserves a very careful study.
Here we can observe the daily task of the physically handicapped person which is as follows. Shown in table no.1

Table 1. The 12 predefined tasks.

Task no.	***Name of task***	***Distance to user***
1	Serving a meal	Near
2	Serving a beverage	Near
3	Wiping & scratching face	Near
4	Shaving	Near
5	Picking up objects	Far
6	Turning on/off switches	Far
7	Opening/closing doors	Far
8	Making tea	Far
9	Pulling drawers	Far
10	Playing games	Near/Far
11	Changing CD/tapes	Near/Far
12	Removing papers from printer/fax	Near/Far

Task 1 and Task 2, eating and drinking, are common to most care-providing robots. Among Task 3 and Task 4, which are performed in contact with the faces of the disabled, Task 3 turned out to be much more needed than expected, because, according to their comments, itching is very difficult to endure, leading them to frequent frustrations. For some of them, Task 3 alone could justify the use of a robot.

Since the first four tasks are performed near or on the human user, safety was regarded as the most important factor, and collision detection was considered indispensable. Moreover, force control was required for satisfactory execution of Task 3 and Task 4 since these tasks involve contact with a face. Thus, force (torque) sensing was considered in the design procedure.
Among the 12 tasks, there are some that need to be carried out *remotely*, such as picking up objects, turning on or off switches, opening or closing doors, making tea, and pulling drawers. To accommodate these tasks, we have determined to provide a mobile base for the robotic arm. Summarizing the first step, we have endeavored to define the target tasks as clearly as possible at the very initial stage of the design. In a sense, through this task definition, we have attempted to embody the abstract target of '*providing care to a physically disabled person*' into a concrete and tangible form. The following design procedure is oriented to quantify the defined 12 tasks.

3. Task Analysis: Obtaining Quantitive Entities

In order to design a robotic arm for the 12 predefined tasks, it is necessary to describe the tasks quantitatively. To this end, we can analyze these tasks to obtain the following entities: via points, task execution time, and maximum payload. Of these, via points are used for kinematic design of the robotic arm, whereas the rest are required primarily for dynamic analysis. For development of robotic arm for above task as shown in fig 2.

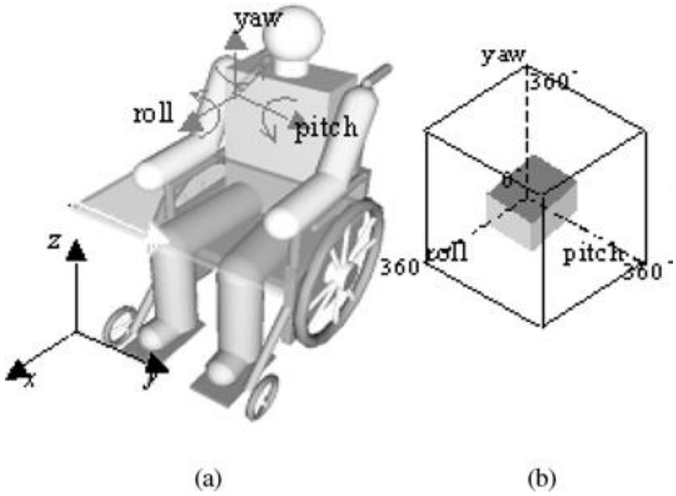

Figure 2 (a) Base frame for Cartesian coordinate and orientation
And (b) Graphical representation of orientation.

As is well known, a via point is defined as the point through which the end-effectors of the robotic arm is supposed to pass. In our case, a via point has six coordinates:
1) Three for the position and
2) Three for the orientation of the tool with respect to the base frame, which is fixed at the corner of the eating board as shown in Fig. 2(a). For remotely conducted tasks, the base frames are also remotely located and via points are represented in the base frames. In order to make a graphical database for via points, the six coordinates are represented in terms of regular hexahedrons in 3D space with a volume of $5 \times 5 \times 5$ cm3: the three position coordinates are represented by the center of the hexahedron; the three for orientation are expressed in terms of Z-Y-X.

After having obtained all the via point sets for the 12 predefined tasks in this manner, we have made the *union of all the sets* in order to define the *task space* or *workspace*, which was to be realized by the kinematic design.

4. Kinematic Design: Finding a Kinematic Structure

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In order to find a kinematic structure that realizes the task space obtained in the previous section, it was necessary to determine both the degree of freedom (DOF) and kinematic parameters of the robot to be designed. For the former, we have analyzed 12 tasks and concluded that 6 DOF are required; for the latter, we have adopted Denavit-Hartenberg (DH) parameters twist angle α, link length l and link Offset d, which were to be obtained by Grid Method.

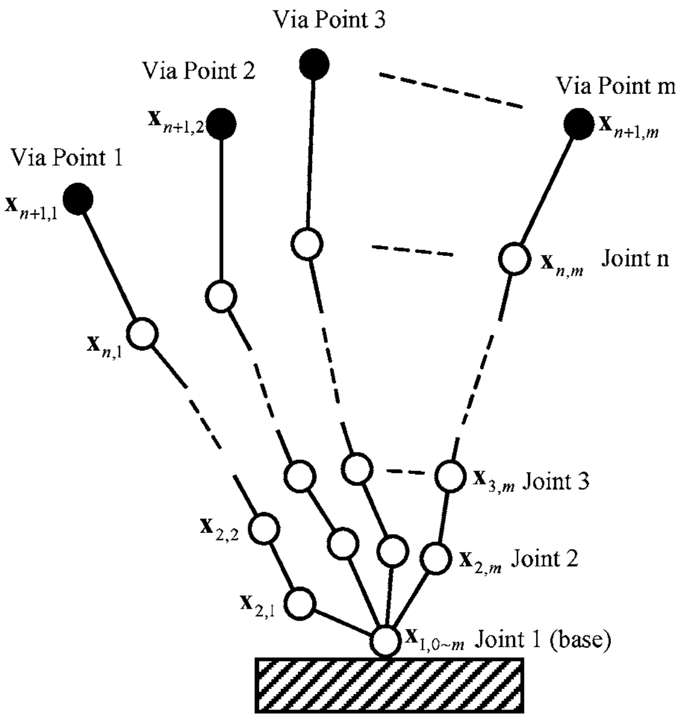


Figure 3. Initially given m sets of DH parameters for m via points.

The optimum design problem of Grid Method can be formulated as follows:

Find design variables $\mathbf{x}_{i,j}$, $\alpha_{i-1,j}$ to minimize a cost function

$f(\mathbf{x}_{i,j}, \alpha_{i-1,j}) = f(x_{i,j}, y_{i,j}, z_{i,j}, \alpha_{i-1,j})$;

$i = 2, 3, \ldots, n$; $j = 1, 2, \ldots, m$ ------------- (1)

subject to the p equality constraints

$h_s(\mathbf{x}_{i,j}, \alpha_{i-1,j}) = h_s(x_{i,j}, y_{i,j}, z_{i,j}, \alpha_{i-1,j}) = 0$;

$s = 1$ to p ---------------- (2)

and the q inequality constraints

$g_t(\mathbf{x}_{i,j}, \alpha_{i-1,j}) = g_t(x_{i,j}, y_{i,j}, z_{i,j}, \alpha_{i-1,j}) \le 0$;

$t = 1$ to q --------------- (3)

The cost function, $f(\mathbf{x}_{i,j})$ in (1), may include kinematic measures and constraints as follows:

$f(\mathbf{x}_{i,j}) = \sum_k w_k f_{k(i,j)}$ -------------- (4)

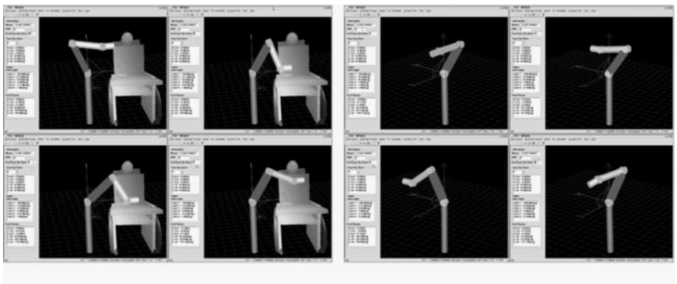
Where $f_{k(i,j)}$ denotes a kinematics measure such as dexterity measure, obstacle avoidance measure, and joint limit, and w_k denotes the weighting factor of $f_{k(i,j)}$.

5. Dynamic Analysis: Determining Maximum Torque

Dynamic simulations have been conducted to estimate the maximum torque at each joint when the robotic arm Performed the predefined tasks, for the sake of which we have used the followings:

1. The execution time and max. Payload for each task
2. Kinematic structure determined and the estimated values of mass, mass center, and moment of inertia of links and motors.

To elaborate, we use the execution time to generate task trajectories with a procedure as follows:



(a) Task 2: Serving a Beverage (b) Task 5: Picking Up a Book

Figure 4. Verification of the kinematic structure: 3D animation.

first, transform via points in Cartesian Space to those in joint Space through inverse kinematics; then generate a joint trajectory that passes the via points in joint space within the execution time. From the trajectory thus generated, one can obtain joint position, joint velocity, and joint acceleration; which in turn are used to obtain maximum torque at each joint through inverse dynamics.

In this section, we have made simulations by using task trajectory, payload, and kinematic structure obtained in the previous sections. As a result, the maximum torque of each joint has been computed and then used to select joint motors. Structure obtained in the previous sections. As a result, the maximum torque of each joint has been computed and then Used to select joint motors.

6. Detailed Design and Prototyping

Since some of the predefined tasks involve contact with humans, an *active compliance control* scheme has been implemented to prevent large contact force. For active Compliance control, joint torque should be measured and, thus, a joint torque sensor is required. It was our observation that adopting joint torque sensors, however, not only complicates the joint mechanism, but also increases the cost of the robot.

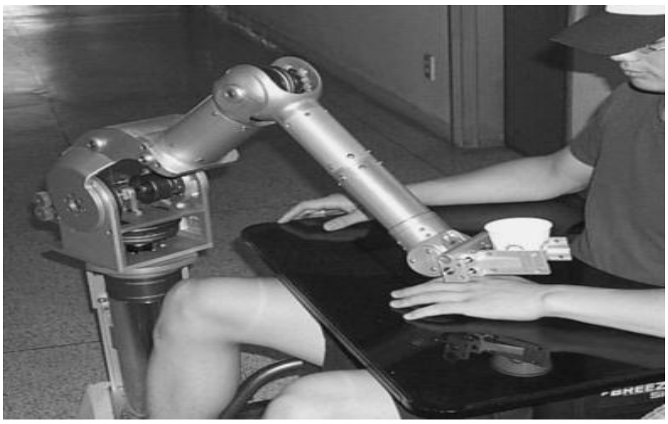


Figure 5 Prototyped robotic arm.

7. Test and Evaluation

In order to examine whether the prototype could carry out the predefined tasks, we have taken two procedures: making experiments in our laboratory and applying the arm to disabled people. The former was taken mainly to make experiment if the prototype met *technical specifications* derived from the 12 tasks; the latter to evaluate its comprehensive performance in reality including the feelings of users—hence, an ultimate test and evolution of robot must be need.

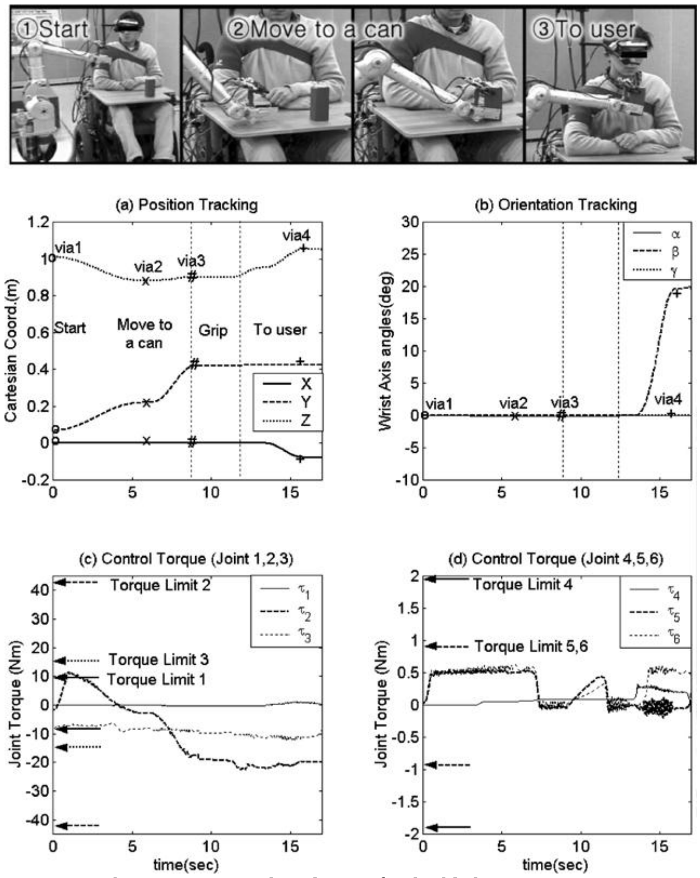


Figure 5. Robotic arm Test and Evaluation for disabled person.

8. Conclusion

Finally let us make a summary of the paper and discuss on task-oriented design (TOD) approach.

In this paper, we have proposed TOD, and applied it to a care-providing robot, step by step, describing each procedure in detail. In accordance with the method, we have defined 12 target tasks; translated them into task space, execution time and payloads; and realized them first on the kinematics level, and then on the dynamics level. Finally, we have constructed a prototype, experimented to examine if it could achieve the predefined tasks, and conducted a clinical test with disabled people in real situations. The result of the first trial was more positive than expected, and evidently it is owing to TOD approach.

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