An Optimised Design of an Active Orthosis for the Shoulder - an Iterative Approach

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Abstract

This paper deals with the design of the shoulder joint mechanism of a powered orthosis for the upper limb developed in the MULOS Project under the EU TIDE Programme. Because of the large range of motion at the shoulder, its complex kinematics and the constraints imposed by the body, there is a need for a mechanism which, while occupying the minimum space, allows the arm to achieve the maximum possible workspace. The problem is to design a kinematic chain, possessing the same workspace as the shoulder joint in such a way as to allow the two mechanisms to move freely in concert. Moreover, the major constraint is not only that represented by the volume occupied by the body but also the structure of the wheelchair to which the orthosis must be attached. The solution has been achieved using an iterative approach in which an adjustable structure, having a fixed centre of rotation approximating to that of the shoulder, can be configured to minimise the problems of singularities and collisions with adjacent structures.

Introduction - the design problem

This paper is concerned with the design of the shoulder mechanism of a five degree of freedom powered orthosis to be attached to a powered wheelchair for use by people with severe physical disability. When designing such a device, the kinematics and the drive design are intimately connected. In particular, because of the relatively high torque required to elevate the arm, there is a requirement for a design which can accommodate the required drive system, while at the same time, permitting the shoulder to move through the required workspace. Therefore, the problem is to design a kinematic chain intimately connected to the humerus, which can move with the shoulder through the required workspace.

This requirement has led to the investigation of possible designs assuming that the shoulder joint could be considered as a spherical joint. This led to a conceptual design having a spherical joint with its centre of rotation coincident with that of the shoulder, resulting in two linked kinematic chains (the manipulator and the shoulder) which are equivalent and possess the same workspace. However, since such a spherical joint cannot be achieved in practice, it becomes necessary to design a sequence of three revolute joints, having intersecting axes, which approximate to a spherical joint. Furthermore, since the shoulder complex does not move as a pure spherical joint, and, in addition, the user's position is not fixed, the rotation centre of the manipulator must always be, to some extent, different from that of the shoulder. The consequence of this inevitable misalignment is shown in Figure 1.

In conclusion, if *z* is small, then the two kinematic chains are nearly coincident and, assuming that they are not rigidly connected (because of the presence of soft tissues) they can move together as a mechanism. A further compensation is provided by scapulothoracic movements. Furthermore, in order to allow a greater *z* it is possible to insert passive degrees of freedom located between the two structures. The above considerations strongly suggest the design of a shoulder mechanism whose centre of rotation is as close as possible to that of the human shoulder.

Having decided to use a system of three joints with intersecting axes, it is next necessary to determine its spatial position and order of the joints of the structure. However, even in this reduced form, the problem presents a high degree of complexity because in order to maximise the workspace of the two kinematic chains linked together it is necessary to find the optimum relationship between the significant variables of the system (e.g. orientation of axes with respect to a fixed frame, link lengths and geometry) leading to the maximum workspace. It was decided that this problem was too complex for analytical solution and an experimental approach was chosen.

Experimental Development of Passive Three DOF Linkage

This problem has been addressed experimentally using a passive three DOF linkage having ten available adjustments of link lengths and orientation of all axes of rotation. Initially this was assembled in such a way as to avoid collision with user body segments. For a number of configurations, the compatibility of the workspace of the two kinematic chains has been experimentally evaluated according to the flow diagram (Figure 2) below.

It can be seen from Figure 2 that optimisation was performed in two stages. First, the kinematic chain of the shoulder mechanism was adjusted and deemed to be satisfactory when it allowed access to the required workspace without problems of singularities or of collision, with either a part of the structure or with the user. When this stage of kinematic optimisation had been achieved, then it was possible to proceed to more detail design of the powered structure. However, the integration of the main mechanical components (e.g. motors, power transmission, sensors) unavoidably changed the volumes occupied by the system and positions at which collision occurred, making it necessary to perform a further series of iterative adjustments of the design configuration. Finally, experimental studies have shown that the user is able to access all of the workspace required for identified tasks.

Conclusions

In this paper it has been shown that it is possible to design a powered orthotic structure capable of moving the shoulder through a large workspace. This has been achieved by designing a spatial linkage, having a fixed centre of rotation, which is approximately coincident with that of the human shoulder. Experimental studies have allowed optimisation of this design from the point of view of link lengths and orientations. Further experimental studies with the final design have established that the resulting manipulator can move the arm through all of the required workspace.

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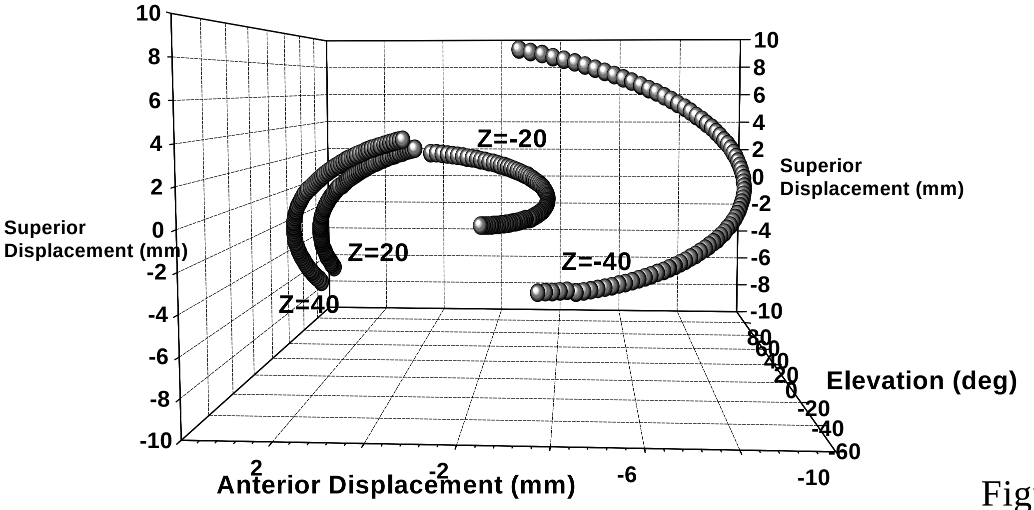

Figure 1 The translations of the shoulder which occur during elevation of the arm as a result of misalignments of the shoulder and manipulator axes (z = amount of original misalignment (mm))

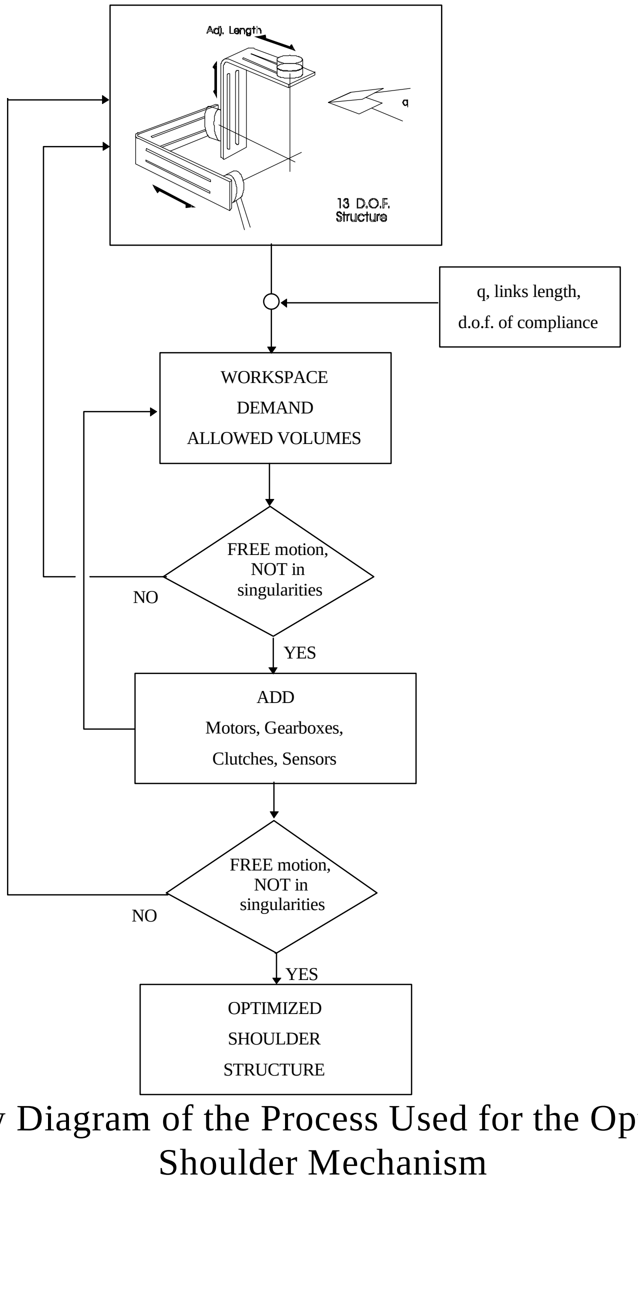

Figure2 Flow Diagram of the Process Used for the Optimisation of the Shoulder Mechanism