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# Design and Implementation of a Lightweight, Large Workspace, Non-Anthropomorphic Dexterous Hand

*The design and implementation of a novel dexterous robotic hand is described. To provide flexibility of application the design features three fingers, each position or force controllable in X-Y-Z, and a large workspace (400 mm dia. × 75 mm deep). These requirements plus the need for adequate strength (i.e. force and stiffness) are in conflict with the need to keep the mass within the payload capacity of common robots. These contrary objectives are met by designing a novel hybrid parallel-serial finger mechanism, a lightweight frame and pneumatic servos for finger actuation. The implemented design is verified experimentally, and may be scaled for other applications.*

## 1 Introduction

For many years it has been recognized that a robotic hand with the workspace and dexterity to handle a wide range of objects would be an important development. Today, the trend towards manufacturing near one-of-a-kind products to meet customer demands is also driving the need for greater manufacturing flexibility.

While substantial progress has been made in the development of dextrous anthropomorphic robotic hands, these devices are not well suited to automated manufacturing. Wright and Bourne [1] observed that the manufacturing world is more demanding and narrower in scope than the everyday world from which our hands evolved. In 1997, Bekey [2] concluded that the robot hands which have been built are complex, expensive and unreliable. Few researchers have investigated non-anthropomorphic dexterous hands. For reviews of the relevant literature please see [1, 3].

In this paper the design and implementation of a novel lightweight, large workspace, non-anthropomorphic dexterous hand is described. The design process, completed design, and initial experimental results are summarized.

## 2 Design Specifications

**2.1 Finger Design, Number and Degrees of Freedom.** As in many previous hand designs, the decision was made to use three fingers with the current design. This limits complexity and will produce secure, precise grasps of generic 3D objects if the fingertip design provides either sufficient friction forces or a form closure type of constraint. The hand will also be designed to allow alternate fingertips to be interchanged easily.

It is readily apparent that increasing the number of DOF of each finger will increase the dexterity and flexibility of the hand at the cost of increasing its complexity. Since a high degree of flexibility is the overall goal, each finger will have three computer controlled DOF ($X$, $Y$ and $Z$). By actuating all three fingers in $X$-$Y$-$Z$, the hand will also allow the compliance of the held part to be actively controlled in 3D space (i.e. $X$, $Y$, $Z$, $\theta_X$, $\theta_Y$ and $\theta_Z$). As observed by many researchers ([1, 6] for example), control of compliance is important for the successful automation of many manufacturing tasks, and of the insertion process in assembly in particular.

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**2.2 Scalability and Workspace.** Although the hand will be designed to have a large workspace, realistically this workspace needs only to cover the range of part shapes and sizes encountered in the intended manufacturing task, i.e. the same hand would not be intended for use in electronics assembly and in aircraft assembly. At the same time it is intended that the design be scalable in terms of power and size to allow it to be used in many tasks.

The particularly challenging task for which the hand prototype will be built is automotive body-in-white assembly (BIWA). Since BIWA involves a large range of complex shaped parts (about 300–400 per car) and numerous dedicated tools, it is a good test case for the flexible hand design. Here the parts are typically less than 400 mm long and 75 mm deep, so a cylindrical workspace 400 mm dia. × 75 mm deep is ideal.

**2.3 Force, Stiffness and Mass.** The hand must produce sufficient internal grasping forces to secure the object without damaging it. For the BIWA application a force range of 10–150 N is expected to be adequate. In addition to resisting the grasping forces the hand's mechanical structure must withstand gravity, inertial and assembly forces. Taking the required accuracy of ±0.5 mm into account, and assuming the maximum externally applied force is ≤50 N, the required minimum stiffness is 100 N/mm.

A lower hand mass would allow a smaller, less expensive robot to be used. A tradeoff exists with this desirable characteristic and the stiffness, workspace and DOF requirements. Since the latter are greater contributors to the application flexibility of the hand, they will be given priority in the design process. The target for the hand's mass is 20 kg, which is within the typical payload capacity for a mid-size industrial robot. The design specifications for the hand are summarized in Table 1.

## 3 Mechanism Synthesis

**3.1 Type Synthesis.** Several mechanism types capable of providing the three DOF Cartesian motion required for each of the fingers were considered. The traditional serial designs used for robot manipulators were rejected since they tend to provide inferior stiffness and accuracy in comparison to parallel mechanism designs of the same mass. The chosen design consists of a "bipod" parallel mechanism (of type $R$-$P$-$R$-$P$-$R$, where $R$ = revolute joint and $P$ = prismatic actuator) to provide the $X$-$Y$ motion coupled serially to a single prismatic actuator for the $Z$ axis motion. Its kinematic diagram is shown in Fig. 1. This choice can be justified by considering the size of the required $X$-$Y$ motions (roughly 200 mm × 350 mm assuming the finger workspaces are

  