

## 2 Human hand

Since this work deals with *direct manipulation*, i.e. manipulation using hands, obviously human hands are of crucial importance for this exposition. In order to approach the research and development of a 3D user interface as the one proposed in this work, we must be familiar with the anatomy, biomechanical properties and biomechanical models of human hand to a sufficient degree.

### 2.1 Introduction

The human hand is a complex mechanical manipulator, able to perform both delicate manipulations (e.g. a clocksmith trying to repair a watch) and powerful manipulations (a gardener breaking and turning over earth with a spade). Besides being a tool to achieve a goal (for example, “move the teacup nearer”), hands are also a source of *tactile feedback*, obtained through the sense of *touch*. Each hand is controlled by the opposing brain hemisphere — for example, for right-handed people the right hand is controlled by the left side of the brain.

### 2.2 Human hand anatomy

The human hand (Figure 2.1, adopted from [4]) is a highly articulate object, consisting of 27 bones. (Note that the two bones at the bottom, *radius* and *ulna*, do not belong to the hand, but to the arm.) The bones of the human hand can be grouped as follows:

1. **Wrist bones (carpals, *carpus* in Latin)** — these bones include 8 bones called *carpal bones*, which are located between a) the two elbow bones (*radius* and *ulna*) and b) the palm (*metacarpus*).
2. **Palm bones (metacarpals, *metacarpus* in Latin)** — these bones include 5 bones called *metacarpal* bones (or simply *metacarpals*).

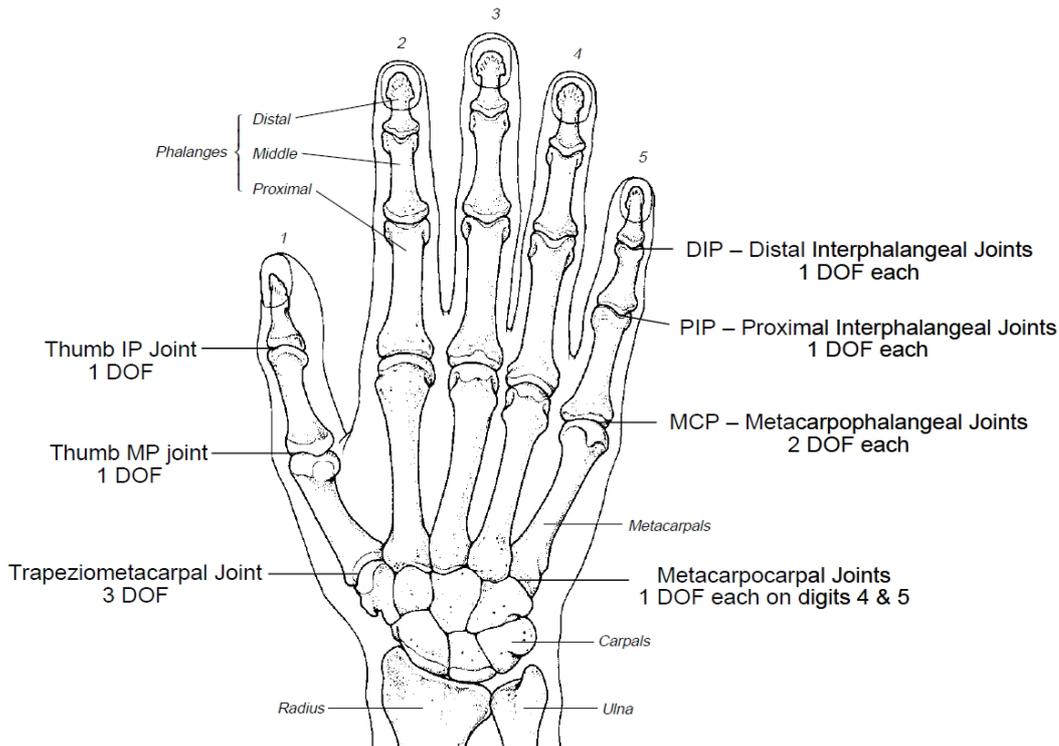


Figure 2.1: A drawing of a human hand, with joints and bones emphasized

3. **Finger bones (phalanges, also *phalanges* in Latin)** — these bones include 14 bones of all the fingers (thumb, index finger, middle finger, ring finger/annular and little finger). All fingers except the thumb have three phalanges:

- (a) *proximal* phalange,
- (b) *intermediate* phalange, and
- (c) *distal* phalange.

The **thumb** has just two phalanges (the intermediate phalange is missing):

- (a) *proximal*, and
- (b) *distal*.

For the illustration of muscles and tendons (cords or bands of inelastic tissue connecting a muscle with its bony attachment) of the human hand, refer to Figure 2.2, adopted from [4].

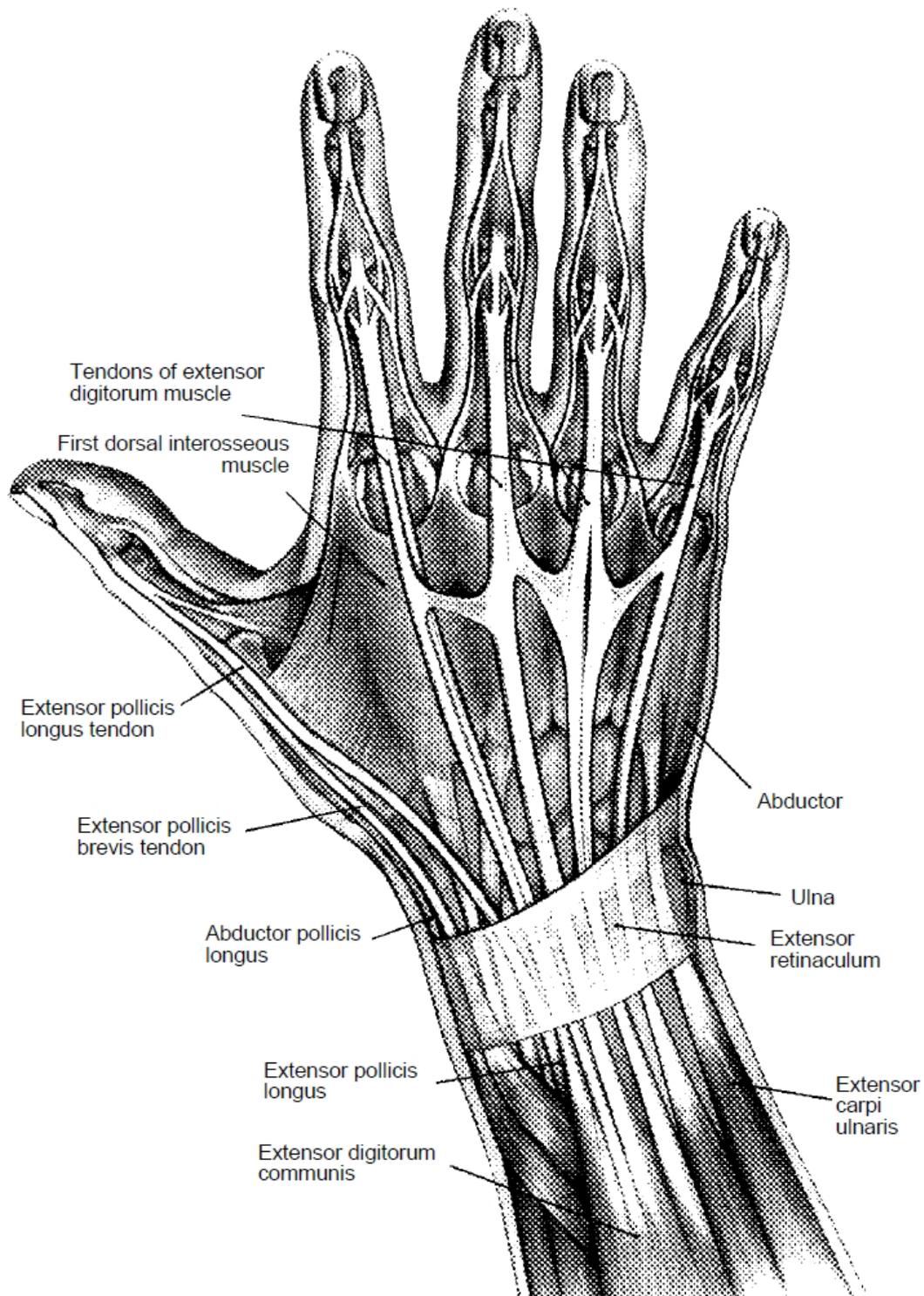


Figure 2.2: Muscles and tendons of the human hand

## 2.3

### Human hand modeling

Hand modeling can be defined in our context as the construction and use of a computer-based 3D biomechanical model of human hand. A hand model is

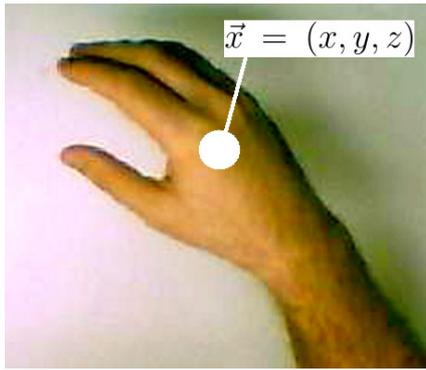


Figure 2.3: 3-d.o.f. hand model

therefore an approximation of the real human hand which, as has been shown in Section 2.2, has 27 bones, of which 19 belong to the palm (5 of 19) and fingers (14 of 19), and the remaining 8 belong to the wrist. The bones thus form a system with a certain total count of degrees of freedom (d.o.f.), and can be abstracted and modelled as such.

Various models, with various d.o.f. have been proposed in the literature. The simplest possible hand model must be the one with just three d.o.f. (i.e. one 3D position  $\vec{x} = (x, y, z)$ ). In this case, this 3D position then designates a characteristic 3D point for a hand, for example the hand's current mass center.

The highest number of d.o.f. for a hand model model is theoretically unlimited, however in practice the highest number of d.o.f. ranges from 27 to 33 d.o.f.

Of course, it depends on the application which hand model we will choose. For some applications, just 3 d.o.f. is sufficient, however for other application only models with high d.o.f. will suffice.

### 2.3.1

#### 3 d.o.f. hand model

This model (Figure 2.3) can be considered the simplest possible 3D hand model, because in this model the human hand is represented by one single 3D point  $\vec{x} = (x, y, z)$ , and has therefore just 3 degrees of freedom. The criteria for deriving  $\vec{x}$  is diverse, and can range from the mass centroid (barycentre) all the way to the mean of a number of “good features to track” (see Appendix C on page 116).

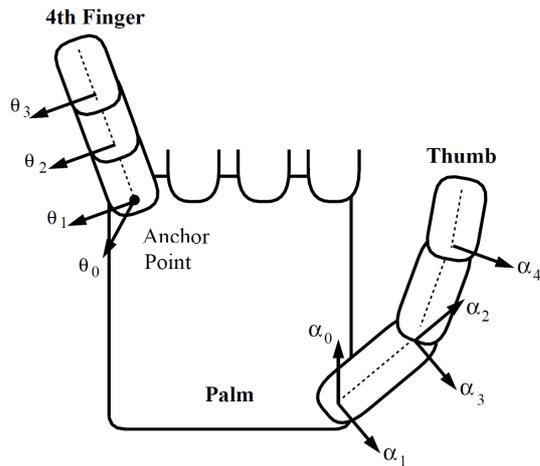


Figure 2.4: Rehg-Kanade 27 d.o.f. hand model

### 2.3.2 27 d.o.f. hand models

#### Rehg-Kanade model

Figure 2.4 depicts the Rehg-Kanade hand model, described in [5]. Here the hand is modelled as a collection of five kinematic chains (four fingers + thumb) attached to a base (the palm):

- the palm is modelled as a rigid block with 6 d.o.f. — 3 for position and 3 for orientation.
- each of the four fingers are planar mechanisms with 4 d.o.f. — 3 d.o.f. determine the finger’s configuration within the plane, while the 4th d.o.f. is reserved for abduction (i.e. finger movements away from the central axis).
- the thumb is modelled as a 5-d.o.f. mechanism, using the approach described in [6]

#### Wu-Huang model

The Wu-Huang model [7] (see Figure 2.5) is similar to the Rehg-Kanade model, with the same number of d.o.f. and the same distribution of d.o.f.

### 2.3.3 33 d.o.f. hand models

#### Model by Nirei et al

In [8] the hand is modelled as a collection of 21 segments and 20 joints, thus giving us a 33-d.o.f. hand model (see Figure 2.6):

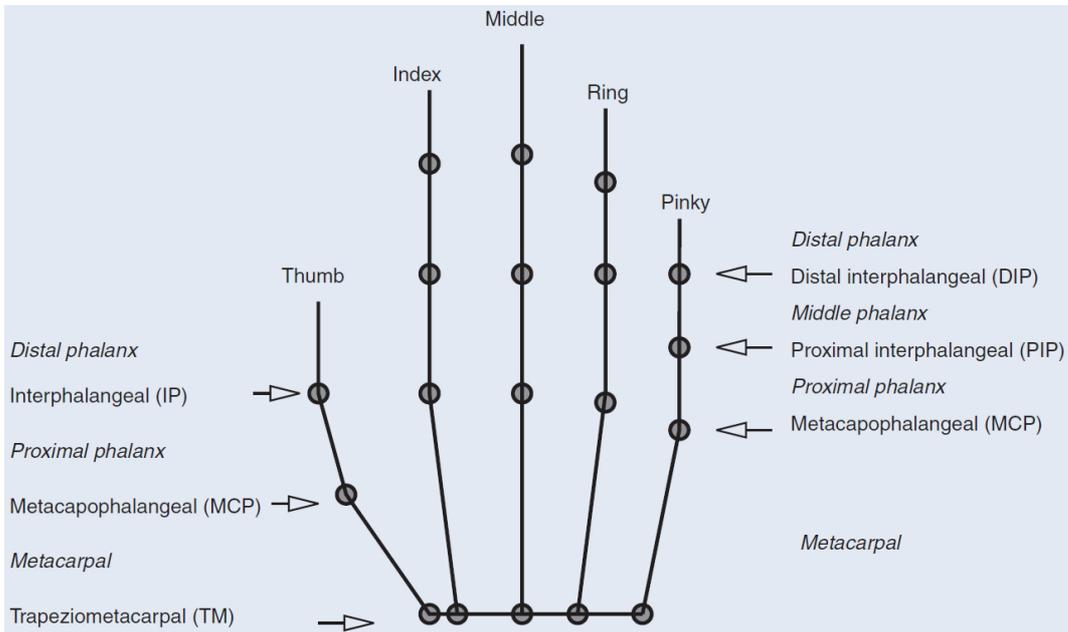


Figure 2.5: Wu-Huang 27 d.o.f. hand model

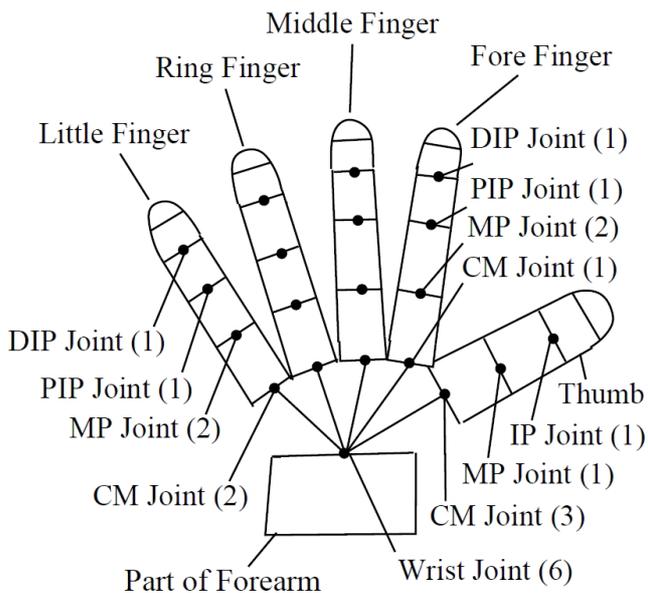


Figure 2.6: 33 d.o.f. hand model by Nirei et al