CZECH PATTERN RECOGNITION WORKSHOP '93

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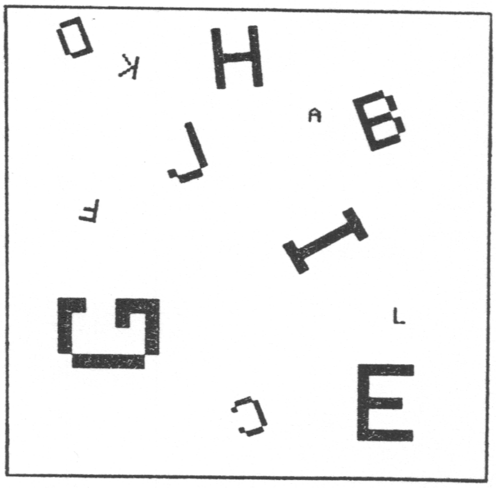

Czechoslovak Pattern Recognition Society

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Model-based reconstruction of 3D human arm motion from a monocular image sequence

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Abstract

In this paper we propose a model-based approach to human arm motion reconstruction from a monocular image sequence. The approach is based on the assumption that the human arm can be considered an articulated object with a known kinematic structure and that the 2D positions of joint points in the kinematic model can be extracted from the image sequence. We define the problem, explain the reconstruction process and present some preliminary results.

1 Introduction

A traditional approach to reconstructing human body motion in 3D is to reconstruct the movement of markers attached to the human body [1,4,8]. The 3D coordinates of the markers are computed by triangulation, using two or three cameras. The disadvantages of the approach result from the difficulty of the calibration process and the deformation of the skin to which the markers are attached, both resulting in significant inaccuracies. Another approach to measuring human body motion is to track the movement and deformations of the body surface [7,9]. However, the approach involves sophisticated body shape modeling, which is time consuming.

The human arm, as a part of the human body, can be modeled as an articulated object consisting of three segments connected by joints. In this paper, we will try to show that when the lengths of the arm segments and the mechanism of joint-joint displacement are known, the human arm motion in 3D space can be reconstructed from the orthographic projection of the joint points on the image plane. To address the multiple solution problem we assume that the starting position of the arm motion sequence is known and that the motion is smooth.

In the next section we introduce a kinematic model of the human arm and define the inverse projection problem. In Section 3, we explain the reconstruction procedure. In Section 4, we give an example of a reconstructed human arm motion from real images. We conclude with some directions for further work.

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2 Problem definition

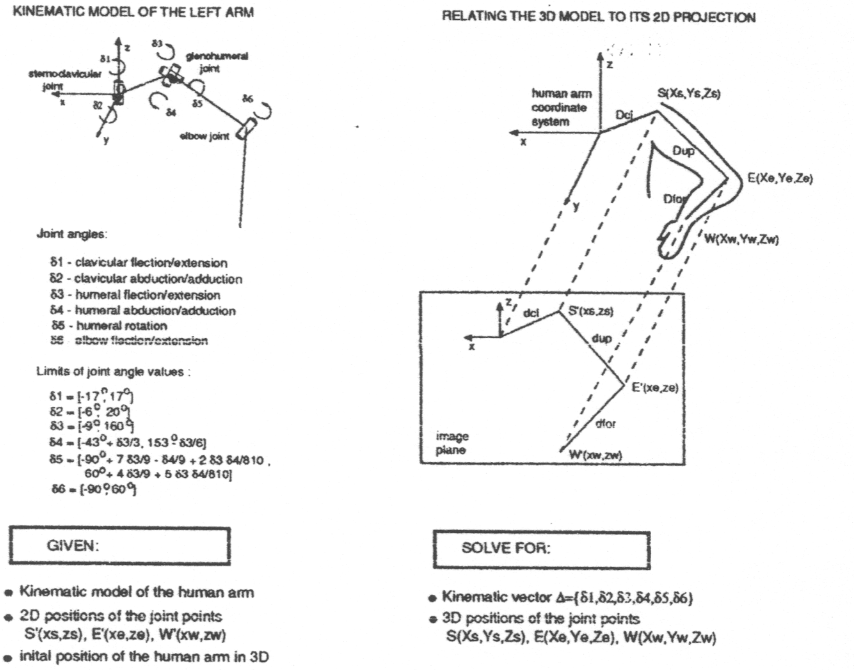

Figure 1: Inverse projection problem.

In order to reconstruct and understand 3D motion of the human arm from sequential 2D images, it is necessary to (1) define the shape of the arm segments, (2) extract valid features from each image, and (3) reconstruct 3D postures from each image and connect them in smooth 3D motion. In this study, we only consider phase 3 of the process. Phases 1 and 2 have been considered elsewhere [2].

Our study is based on the following assumptions:

1. in each image frame, the 2D positions of joint points can be extracted [2],
2. the motion can be explained with the simplified kinematic model of the human arm developed by Lenarčič [5] and Umek [10], and
3. the starting position of the arm motion sequence is known and the motion is smooth.

The **kinematic**[1] **model of the human arm** [5,10] includes knowledge about segment lengths, ranges of angle values and dependencies among joint angles δ_i (see Fig. 1). According to this model, the arm (without the palm) has six revolute degrees of freedom (DOF). The root coordinate system is placed in the sternoclavicular joint. We will use the kinematic model to solve the inverse projection problem up to unique solution.

[1]**Kinematics** deals with the geometry of motion with respect to a fixed coordinate frame as a function of time, regardless of the forces and moments that cause the motion.

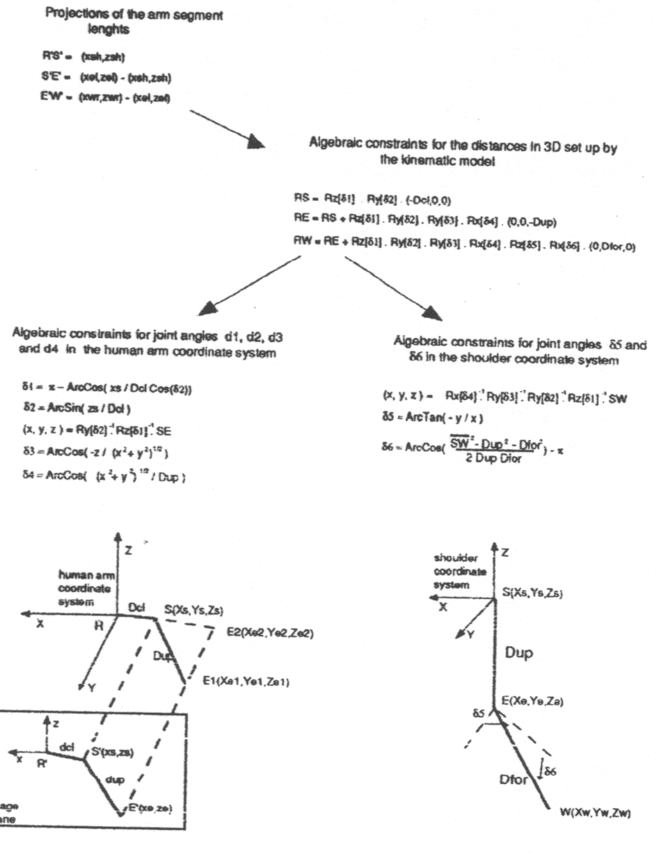

Figure 2: Algebraic constraints used in the reconstruction procedure.

Using the kinematic model the inverse projection problem can be defined as follows: **given** the kinematic model of the human arm, 2D positions of the joint points and the previous position of the arm in 3D **solve for** the values of the kinematic vector $\Delta = \{\delta_1, \delta_2, \delta_3, \delta_4, \delta_5, \delta_6\}$ and the 3D positions of the joint points. The problem of 3D human arm motion reconstruction can be now defined as follows: **from a monocular image sequence of the arm motion find a unique solution for the position of the arm in space as a function of time and describe it by the time-varying kinematic vector** $\Delta = \{\delta_1, \delta_2, \delta_3, \delta_4, \delta_5, \delta_6\}$. This involves several instances of the inverse projection problem, i.e., one per image.

3 Extracting 3D structure from 2D joint point positions using the kinematic model

The mathematics of image projection depends on the camera model that is used. When the projection is orthographic, a pair of points in the image plane, for which the 3D distance is

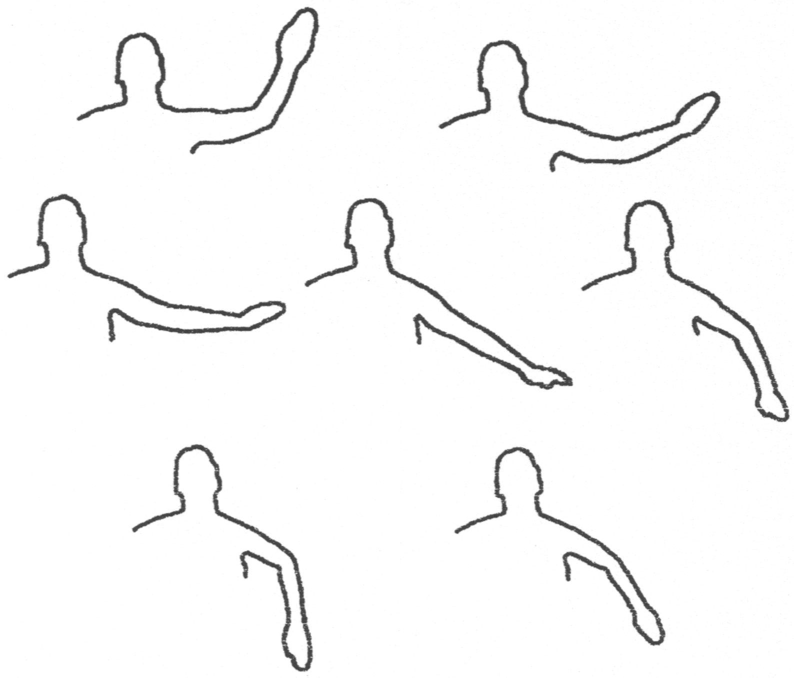

Figure 3: Several orthographic projections of a 3D human arm movement.

known, can be backprojected to two diferent positions.

Assuming that the arm consists of three segments, there are eight possible solutions for the structure of the arm kinematic link in space. However, as the previous position of the arm in 3D is known δ_1 to δ_4 are uniqualy determined troughout. For δ_5 and δ_6 there are two possible solutions.

The **reconstruction procedure** is as following:

1. For each image in the sequence:
   (a) **given** the previous position of the arm and relations of arm segment lengths in 2D and 3D **solve for** the current positions of the shoulder and elbow joint points and the values of angles $\delta_1, \delta_2, \delta_3, \delta_4$ (see Fig. 2),
   (b) calculate the two posible positions of the wrist joint point and the values of angles δ_5 and δ_6 for these positions (see Fig. 2).
2. Reconstruct the whole motion using the time varying joint angles and choose the solution which satisfies the ranges of motion for joint angle δ_5, specified by the kinematic model (see Fig. 1).

4 Experimental results

This section presents an example of a reconstruction of 3D motion of the human arm from a sequence of real images (see Fig. 3). The image sequence was taken under orthographic

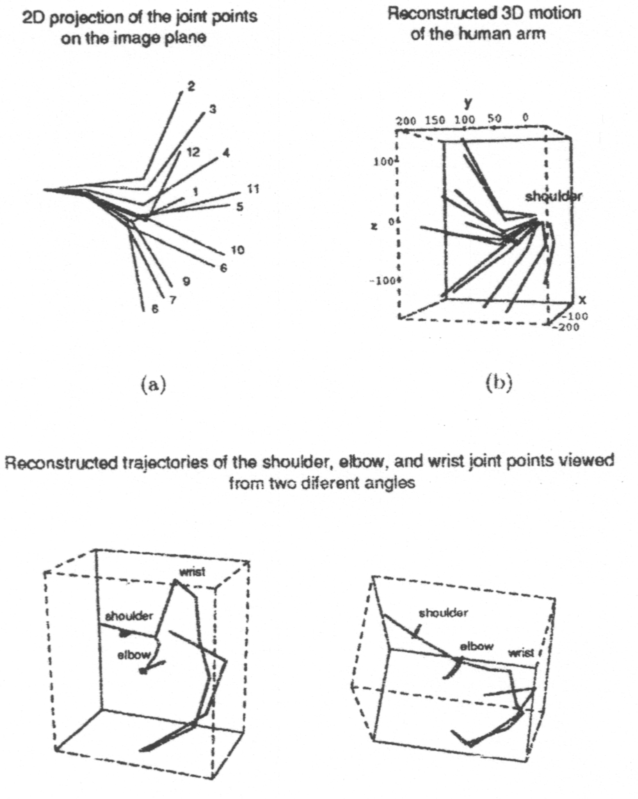

Figure 4: 3D motion of the stick figured human arm presented with: (a) its othographic projections, (b) positions of the upper and lower arm in space, (c) trajectories of the joint points.

projection with the CCD camera placed in front of the human body. The image frames were processed and the locations of joint points in each frame were indicated manually using the ANVAM PC-based image processing system [6]. **Input** to the reconstruction procedure are the inital 3D position of the arm and the 2D locations of the joint points, connected in stick figures of the arm on Fig. 4a. **Output** of the procedure are the reconstructed trajectories of the shoulder, elbow and wrist joint points (see Fig. 4c) and the time-varying sequences of the joint angles of the kinematic model (see Fig. 5).

The reconstruction procedure is a part of the *Software package for simulation, presentation, and reconstruction of the human arm movements* [3]. The package is written in the *Mathematica 1.2* programming language and is limited to reconstruction of movements of the left arm from image sequences taken with the camera in front of the body.

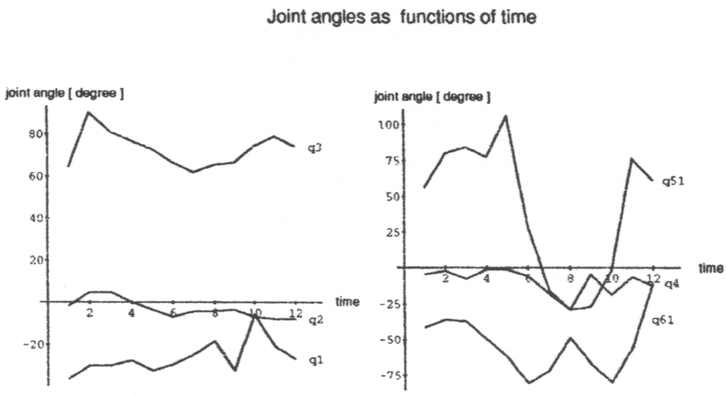

Figure 5: 3D motion described with time-varying joint angles.

5 Conclusion and further work

A model-based approach to reconstructing 3D human arm motion from a monocular image sequence was presented. The kinematic model was used to solve the inverse projection problem up to a unique solution. The reconstruction procedure is a part of ***Software package for simulation, presentation, and reconstruction of the human arm movements.*** We tested the software on many real sequences, one of which is presented in this paper. The 2D joint point positions in this stage of research are indicated manually. The experiments have shown that even with the help of an operator it is difficult to find the exact position of the shoulder joint point. Therefore, we are currently studing how to use the kinematic model to reconstruct the motion without using the shoulder joint point. Integration of existing software with software for automatic extraction of the valid features from arm segment projections is under way.

The advantage of our approach is that it doesn't use markers. The whole motion can be very concisely described with the time-varying kinematic vector $\Delta = \{\delta_1, \delta_2, \delta_3, \delta_4, \delta_5, \delta_6\}$. Such description is directly applicable in robot control, computer graphics or to the study of the human arm motion, including improvements of the existing kinematic model.

Acknowledgement

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