3rd International Workshop

on

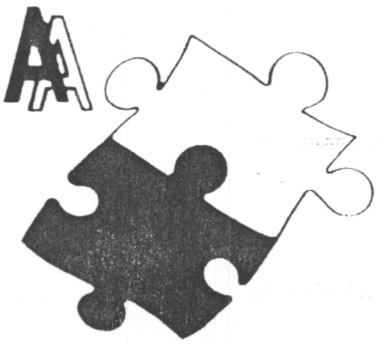
ROBOTICS IN ALPE–ADRIA REGION

(RAA '94)

as part of the

Central European Initiative

PROCEEDINGS



July 7–9, 1994, Bled, Slovenia

Computer vision tools for studing human arm motion

V. Filova[1]*, F. Solina[2], J. Lenarčič[3]

[1]IBL-Sistemi, Ljubljana, Slovenia
[2]Faculty of Electrical Engineering and Computer Science, Ljubljana, Slovenia
[3]The Jožef Stefan Institute, Ljubljana, Slovenia

Abstract – *In the paper, computer vision tools for studying human arm movements are presented. They are based on assumption that the image sequence is obtained under orthographic projection with a CCD camera and that the kinematic model is known. An algorithm for modelling and tracking the arm segment projections was developed. It was tested on selected movements of the upper arm parallel to the image plane. Supposing that the positions of the joint points of the kinematic model can be determined, an algorithm for reconstruction of 3D human arm movements from their 2D projections was introduced and verified with real data.*

Keywords: modelling data, tracking motion, human arm motion reconstruction

1. Introduction

Human body motion research, aimed at understanding motion mechanisms and estimating the kinematics and dynamics of motion, has received considerable attention over the past decades in areas such as robotics, surgery, rehabilitation and sports. A common method used to study the movement of various body segments is to attach markers at the selected anatomic points and then image them by using television cameras [6, 22]. The method is known as moving light display. The approach has the advantage of requiring little image processing as the marker classification problem is overcome either by sequential marker activation or by marker tracking using the a priori information of the arrangement of the markers. The disadvantages, however, are due to the difficulties of the calibration process and the deformation of the skin to which the markers are attached, both resulting in significant inaccuracies.

Recently, the research attempts have been directed to reconstructing the human motion from 2D and 3D synthetic and real image data [2, 3, 14, 17]. Several subtasks of this reconstruction task can be identified: (1) the problem of modelling the shape of the human body, (2) the problem of segmentation and mapping the image data into a body model, (3) the motion tracking problem, and (4) the problem of definition of the kinematics of a complex articulated mechanism, such as the human body in order to give consistent interpretation of the motion. The part that desireves a special attention is the human arm [10, 13].

The objective of our investigation is to overcome the disadvantages of the existing systems for studing the human motion and to utilise some new approaches in computer vision [18, 19] and robotics [1]. We developed a software package for modelling and tracking the motion of the arm segment projections and a package for simulation and reconstruction of the 3D human arm movements from a monocular image sequence. In this work we, first, define the problem of the human arm motion reconstruction. Then, we give the mathematical background of the modelling process and present some results of modelling the arm segment projections and tracking the motion of arm segments. Finally, we explain the reconstruction procedure and present an example of a reconstructed human arm motion from a series real images.

2. Reconstruction of the human arm motion

Once the sequence of orthographic projections of the arm movement is known (see Figure 1), the purpose is to reconstruct the 3D position of the arm in each frame. This requires to define the shape of the arm segments and divide the image data into the arm segment projections, to extract

---

*This work has been supported by the *Slovenian Ministry of Science and Technology*. The work is part of ongoing research at the *Robotics Laboratory* at the Jožef Stefan Institute (IJS), Ljubljana and the *Computer Vision Laboratory* at The Faculty of Electrical Engineering and Computer Science (FER), University of Ljubljana.

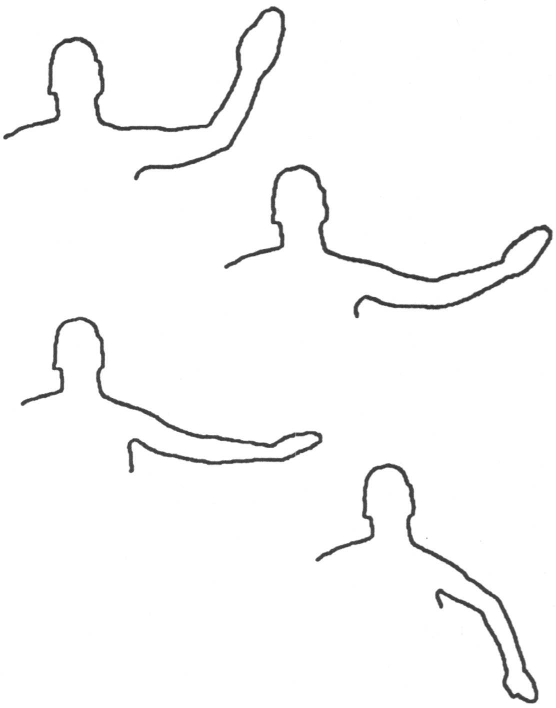


Figure 1: An orthographic projection of a 3D human arm motion.

relevant information from each image (segment axes and joint point locations), and to solve the inverse projection problem (the problem of determination the 3D location of the arm segments from its 2D projections) for each frame and connect the solutions into a smooth 3D motion.

In this investigation, we shoosed the second order curves to approximate the object form from the image data. The second order curves have the advantage to be symmetrical and described with a small number of parameters, they reveal the position and orientation of parts of the arm and thus enable the axes and joint points to be extracted, and by adding new parameters other forms can be obtained [16, 19, 20] that better fit the arm segments.

To solve the inverse projection problem up to an unique solution, we assume that the kinematic model is known, as well as the starting position of the arm motion sequence is known, and the motion is smooth.

3. Modelling 2D image data

The goal of the modelling process is to organise the 2D data in terms of common characteristics and features and obtain a concise and description useful for further processing. After selecting an appropriate model for the data, a widely used approach to estimate the model parameters is the least squares method. This is based on the assumption that the errors in data have a normal distribution. In computer vision, however, this assumption is frequently inappropriate. The image data, rarely belong to a single object. Therefore, large deviations in the data, indicating that all data points do not belong to the same distribution, are treated as outliers. We identified the outliers by using methods from robust statistics. For this purpose, we developed robust M-estimator based on the *iteratively reweighted least squares* algorithm [4].

3.1. Robust M-estimation

A robust M-estimate for the parameter vector $\vec{p} = \{a, b, c, d, e\}$ of the model $\hat{f}(\vec{p}, x, y)$ (1), defined as

$$f(\vec{p}, x, y) = p_1\phi_1+p_2\phi_2+p_3\phi_3+p_4\phi_4+p_5\phi_5+1 = 0. \tag{1}$$

where $\{\phi_1, \phi_2, \phi_3, \phi_4, \phi_5\} = \{x^2, xy, y^2, x, y\}$, minimizes the error function $\epsilon(\vec{p})$ that sums the deviations $e(x_i, y_i)$ of the observations from the fitted curve (2).

$$\epsilon(\vec{p}) = \sum_{i=1}^{N} \rho(\frac{e(x_i, y_i)}{s}). \tag{2}$$

The parameter s is a known or previously computed scale parameter and ρ is a robust loss function. This is more general than the sum of squared deviations (for the L2 regression problem, we have $\rho(x) = x^2$), or the sum of absolute deviations (L1 regression problem, where we have $\rho(x) = |x|$).

If $\psi(\vec{p}, x, y) = \frac{\partial(\rho(\vec{p}, x, y)}{\partial(\vec{p})}$, then a necessary condition for a minimum of the function $\epsilon(\vec{p})$ is that $\vec{p}$ satisfies

$$\sum_{i=1}^{N} \psi(\frac{e(x_i, y_i)}{s}) \quad \phi_m(x_i, y_i) = 0, \qquad m = 1, 2, .., 5. \tag{3}$$

Equation (3) is a system of five nonlinear equations where ψ plays the role of a weighting function. It can be solved iteratively via several different methods, one is *iteratively reweighted least squares* [4, 5]. Before the iteratively reweighted least squares scheme is applied we have to select an appropriate ψ function (see for example [15]). We choosed the *Hampel redescending* function [7]. It has the property that $\psi(x) = 0$ for $|x| > c$ where c is a preselected cutoff value, also known as the finite rejection point. This allows to reject outlier points.

The Hampel M-estimator has been implemented in Mathematica programming language. It is a part of the MoDaRS *Software Package for modelling Image Data by Robust Statistics* [7] we developed.

3.2. Experimental results

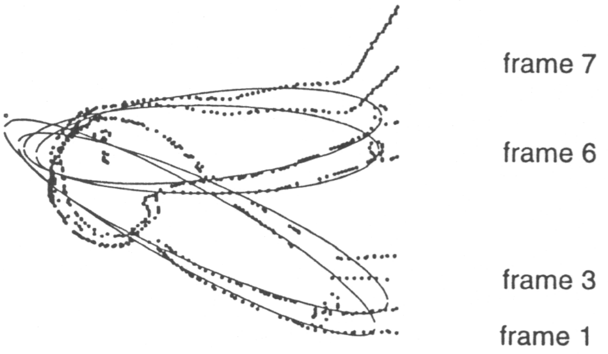


Figure 2: Hampel(0.7,1,2) used to model the upper arm projections.

The *Hampel(0.7,1,2)* M-estimator was applied to model the upper arm projections during the arm movements in the frontal plane and to track the motion. The model parameters $\{A, B, X_0, Y_0, \varphi\}$ were estimated in two ways:

1. *Frame by frame*
   Obtain the inital angle estimate by L2 regression independently for each frame. Then, apply iteratively reweighted least squares sheme to obtain the final estimate for each frame.

2. *tracking*
   For the first frame, obtain the inital angle estimate by L2 regression. Then, use IRLS algorithm to obtain the final angle estimate for the first frame. For all other frames, use the final estimate of the previous frame as an inital estimate for the current frame. Then apply IRLS.

The values of the estimated parameters $\{A, B, X_0, Y_0, \varphi\}$ are presented graphically in Figure 3. The parameter φ gives the orientation of the upperarm. It is difficult to decide which of the two ways gives better results. The values of the scale parameter s are smaller and the values of the parameters are changing smoother in the tracking mode. This is due to a better initial estimate that is taken from the previous fit and the outliers are already rejected.

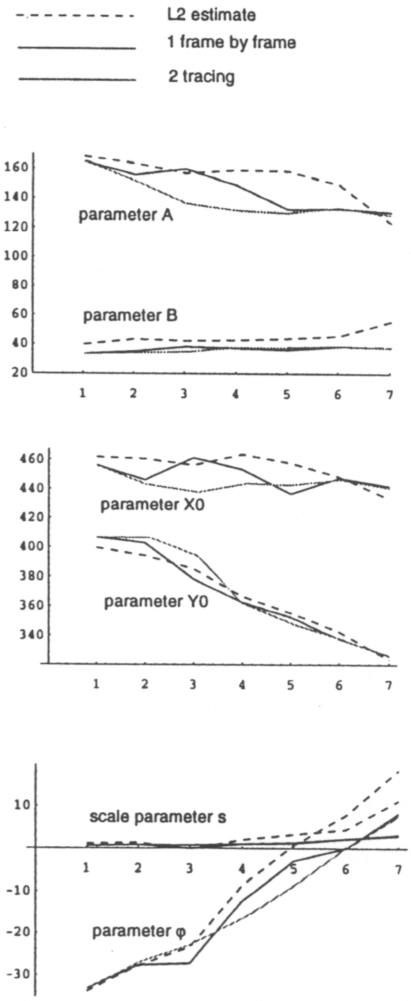


Figure 3: Graphical presentation of the results obtained frame by frame and by tracking.

4. Motion analysis of human arm stick figure

Assuming that the human arm consists of rigid segments, instead of studying the motion of the whole segments, we can concentrate on its stick figure. First, we introduce the kinematic model of the arm, then, we give a solution to the inverse projection problem. At the end, we present some results with real data.

4.1. Kinematic model

The **kinematic model of the human arm** defines the segment lengths, the ranges of angle values and the dependencies between the joint angles δ_i (see Figure 4). According to this model [12, 21] the arm (without the palm) has six revolute degrees of freedom (DOF), two in the sternoclavicular joint, three in the glenohumeral joint and one in the elbow joint. The reference coordinate frame

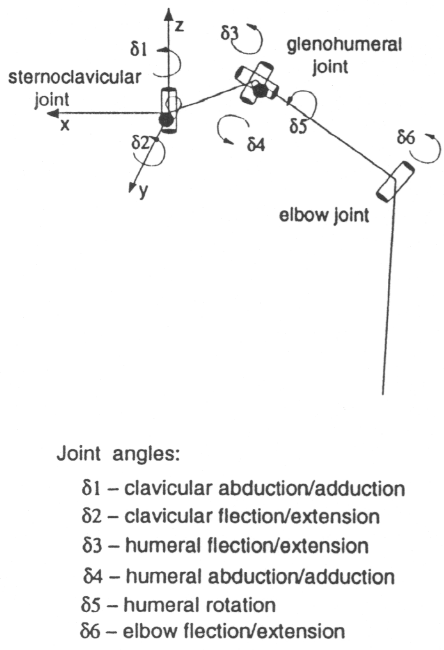


Figure 4: Kinematic model of the left arm.

is placed in the sternoclavicular joint.

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

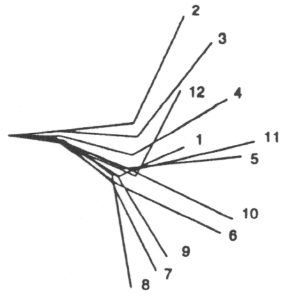
The mathematics of the image projection depends on the camera model that is used. When the projection is orthographic, a pair of points in the image plane, for which the 3D distance is known, can be backprojected to two diferent positions.

Since the arm consists of three segments, there are eight possible solutions. However, as the previous position of the arm in 3D is known δ_1 to δ_4 are uniquely determined troughout. For δ_5 and δ_6 there are two possible solutions.

We apply the kinematic model in the following order [9]:

1. For each image in the sequence:
   (a) **given** the previous position of the arm and relations of the arm segment lengths in 2D and 3D **solve for** the current positions of the shoulder and elbow joint points and the values of the angles $\delta_1, \delta_2, \delta_3, \delta_4$,
   (b) calculate the two posible positions of the wrist joint point and the values of the angles δ_5 and δ_6 for these positions.

(a) 2D projection of the joint points on the image plane



(b) Reconstructed 3D motion of the human arm

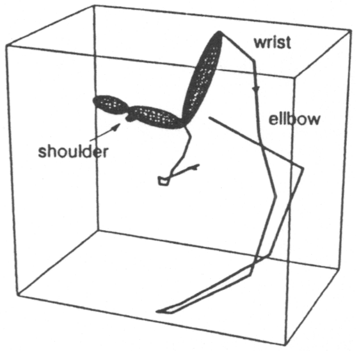


Figure 5: 3D motion of the stick figured human arm presented with: (a) its othographic projections, (b) trajectories of the joint points.

2. Reconstruct the whole motion using the time varying joint angles and choose the solution that satisfies the ranges of motion for the joint angle δ_5, specified by the kinematic model (see Fig. 4).

4.3. Experimental results

This section presents an example of a reconstruction of the 3D motion of the human arm from a sequence of real images (see Fig. 1). The image sequence was taken under orthographic 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 [11]. **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. 5a. **Output** of the procedure are the reconstructed trajectories of the shoulder, elbow and wrist joint points (see Fig. 5c) and the time-varying sequences of the joint angles of the kine-

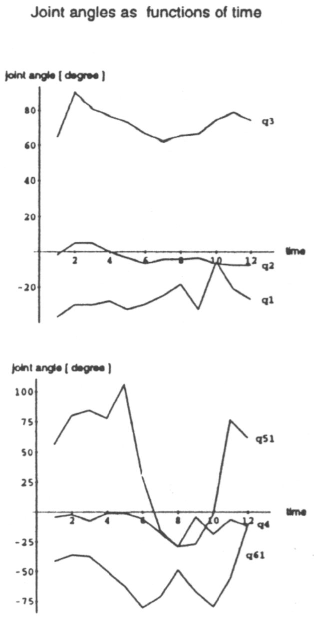


Figure 6: 3D motion described with time-varying joint angles.

matic model (see Fig. 6).

The reconstruction procedure is a part of the SPRham *Software package for Simulation, Presentation, and Reconstruction of the human arm movements* [8], we developed. The package is written in the Mathematica programming language and is limited to reconstruction of movements of the left arm from an image sequences taken with the camera in front of the body.

5. Conclusions

Two software packages for studing the 3D human arm movements were developed. The MoDaRS *Software Package for modelling Image Data* is based on robust statistics techniques. A robust M-estimator is built on iterativelly reweighted least squares algorithm. We used the estimator to perform the outlier rejection while modelling arm segment projections with second order curves. We showed that the estimator can also be used to track motion.

The SPRham *Software package for Simulation, Presentation, and Reconstruction of the human arm movements* is based on the assumptions that the kinematic model of the arm is known and that the positions of the joint points of the kinematic model can be determined in each frame in the image sequence. We tested the software on many real sequences, one is presented in this paper. An advantage of the approach is that the whole motion in coded using few parameters of the kinematic model. The experiments show that even with the help of an operator it is difficult to determine the position of the shoulder joint point.

References

[1] E. I. Agba. T. L. Wong, M. Z. Huang, "Solid modeling of kinematic chains", In *Proc. of 5th International Conference on Advanced Robotics*, Pisa, Italy, pp. 959-964, 1991

[2] C. I. Attwood, G. D. Sullivan, K. D. Baker, "Model-based recognition of human posture using single synthetic images", In *Proc. of the 5th Alvey Vision Conference*, pp. 25-30, 1989

[3] N.I. Badler, B.B. Hunter, Jr. and C. Philips, "Slice display for human models construction with spheres", *Research Report MS-CIS-88-84*, Graphics Lab., Dept. of Computer and Information Science, School of Engineering and Applied Science, University of Philadelphia

[4] P. J. Besl, J. B. Birch, L. T. Watson, "Robust window operators", *Proc. of the 2nd International Conference on Computer Vision*, Tampa, Florida, pp. 591-600, IEEE Computer Society Press, Washington.D.C, 1988

[5] J. B. Birch, "Some convergence properties of iteratively reweighted least squares in the location model, *Commun. Stat.* , pp. 359-369, 1980

[6] G. Ferrigno, A. Pedotti, "ELITE: A digital dedicated hardware system for movement analysis via real-time TV signal processing", *IEEE Transaction on Biomedical Engineering*, 32: 943-949, 1985

[7] V. Filova, "Software package for modeling 2D image data", Technical report IJS DP-6735, Jožef Stefan Institute, Ljubljana, Slovenia, 1992

[8] V. Filova, "Software package for simulation, presentation, and reconstruction of human arm movements", Technical report LRV-93-5, Computer Vision Laboratory, Faculty of Electrical Engineering and Computer Science, Ljubljana, Slovenia, 1993

[9] V. Filova, "Analysis of 3D human arm motion from a monocular image sequence", Master Thesis, Faculty of Electrical Engineering and Computer Science, University of Ljubljana, Slovenia, 1994

[10] T. Flash, N. Hogan, "The coordination of arm movements: an experimentally confirmed mathematical model", *Research Report A.I.Memo 786*, Artificial Intelligence Lab., Center for Biological Information Processing, Whitaker Colledge, MIT, 1984

[11] M. Leonardi, Installation of ANVAM image processing system, IJS Technical report, Jožef Stefan Institute, Ljubljana, Slovenia, 1993

[12] J. Lenarčič, A. Umek, "Experimental evaluation of human arm kinematics", In R. Chatila and G. Hirzinger editors *Experimental Robotics II*, Springer-Verlag, London, 1993

[13] J. Lenarčič, A. Umek, V. Filova, M. Leonardi, F. Solina, "Upper Extremity kinematics for studying FES induced movements", In *Proc. The Ljubljana FES Conference*, Ljubljana, 1993

[14] W. Long, Y. Yang, "Log-tracker: An attribute-based approach to tracking human body motion", *Research Report 88-19*, University of Saskatchewan, Saskatchewan, Canada, 1988.

[15] M. J. Mirza, K. L. Boyer, "Performance evaluation of a class of M-estimators for surface parameter estimation in noisy range data", *IEEE Transactions on Robotics and Automation*, Vol. 9, No. 1, pp. 75-85, 1993

[16] A. Pentland, B. Horowitz, "Recovery of nonrigid motion and structure", *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 13 (7): 730-742, 1991.

[17] K. Shiraishi, M. Terauuchi, K. Onaga, "Recognition of human motion based on interpretation of 2D pattern deformation", In *Proc. of IAPR Workshop on Machine Vision Applications*, pp. 185-188, Tokyo, Japan, 1990

[18] F. Solina, A. Leonardis, A. Macerl, "A direct part-level segmentation of range images using volumetric models", In *Proc. of International Conference on Robotics and Automation*, San Diego, CA, 1994

[19] A. Vidmar, F. Solina, "Recovery of superquadric models from occluding contours", In Reinhard Klette and Walter Kropatsch editors *Theoretical Foundations of Computer Vision*, Mathematical Research, Vol. 69, pp. 227-240, Berlin, 1992. Akademie Verlag

[20] D. Terzopoulos, D. Metaxas, "Dynamic 3D models with local and global deformations: Deformable superquadrics", *IEEE Transaction on Pattern Analysis and Machine Intelligence*, 13 (7): 703-714, 1991

[21] A. Umek, "Kinematic analysis of the human arm and evaluation of the workspace using computer graphics", M.Sc Thesis, University of Ljubljana, Slovenia, 1992

[22] VICON System: User Guide, Oxford Metrics Ltd, 1985