

Capturing Revolute Motion and Revolute Joint Parameters with Optical Tracking

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Abstract. Optical tracking of users and various technical systems are becoming more and more popular. It consists of analysing sequence of recorded images using video capturing devices and image processing algorithms. The returned data contains mainly point-clouds, coordinates of markers or coordinates of point of interest. These data can be used for retrieving information related to the geometry of the objects, but also to extract parameters for the analytical model of the system useful in a variety of computer aided engineering simulations. The parameter identification of joints deals with extraction of physical parameters (mainly geometric parameters) for the purpose of constructing accurate kinematic and dynamic models. The input data are the time-series of the marker's position. The least square method was used for fitting the data into different geometrical shapes (ellipse, circle, plane) and for obtaining the position and orientation of revolute joints.

1. Introduction

The model identification process of a mechanical or biomechanical system can be a tedious process when different kinds of parameters are required to be computed. In order to develop a computer model, the required parameters are related to the physical properties of each of the component (geometry, size, mass, inertia, stiffness) and the connection with neighbouring elements which will impose relative displacement and motion constraint.

Tracking and motion capturing is the process of recording the movement (position) of objects or people [1,2,3]. These systems can be optical, magnetic, acoustic, gyroscopic or mechanical. Commercial systems with optical tracking and reflective markers works mainly in a constrained space and the tracked system or person has to wear markers. These 3D motion capture systems are fast and accurate, but are costly and not available in outdoor environment. Inertial sensors (like gyroscopes and accelerometers) are also common for motion capturing, these electromagnetic tracking systems are fast, but they behave poorly in the presence of metallic objects.

The major two components of a mechanical or biomechanical system are the links (bodies with certain geometry, of rigid or elastic nature) and joints. The joints are imposing restrictions on the relative motion of bodies of the system. The revolute joint has one degree of freedom, if an anchor point is defined on the connected link, the bodies can move so that these points are always in the same place and the relative rotation of the bodies is not restricted. Revolute motion and revolute joint are present in a large number of technical systems and biomechanical models (e.g. robot arms, human knee joint, journal-bearing joint, car suspension mechanism). The parameter identification of joints



deals with extraction of physical parameters (mainly geometric parameters) for the purpose of construction of accurate kinematic and dynamic model. Having a precise 3D kinematic (shape and joint) model of a mechanical system is very useful in a variety of computer aided engineering simulations. The measured data contains noise due to the tracking imperfections. To reason about the uncertainty of the belief multiple techniques exist, like Bayes rule [4], divide and conquer strategy, maximum-likelihood estimate or least square regression. In this paper the linear least square algorithm was chosen, because it is fast and accurate for this kind of applications.

2. Optical tracking

Optical motion tracking are used in a wide range of applications [1,2,5], which require accurate and robust measurement of the 3D position and orientation of one or more objects in a user-defined coordinate system.

Marker-based tracking is a popular method in virtual reality applications, performance evaluation for athletes, rehabilitation, training, films and video games to create realistic movements and special effects. However, it requires physical markers to be placed on the subjects. Markerless and vision-based motion capture techniques have gained an increasing interest recently and become available thanks to increasing computational power of mobile devices. Markerless tracking has some limitations in the way that data is recorded and collected, due to the settings, environment and number of cameras. Two-dimensional (2D) video cameras with image processing and analyzing software are more affordable, but they are less accurate and are light sensitive. In [1] the motion capture data combined with contact forces measurements allowed the estimation of inertial parameters of the human body. Combined with various anthropometric biometrics, the captured full-body motion is used for person identification [6], joint angle measurement [7,8], capturing and identification of a wide range of human movements [3,9] and shape feature extraction for motion pattern [10].

2.1. Optical tracking with markers and image processing

Optical tracking consist of obtaining geometric information by analysing sequence of recorded images using video capturing devices and image processing algorithms. The tracking system is providing the temporal position of the marker(s), but even if the motion capture system is calibrated and the tracking data is recorded with high frequency, the uncertainty remains, especially due to the image processing methods, deformations or other tracking deficiencies [4].

2.2. Optical tracking with reflective markers

The most efficient and fast motion capturing systems are using retro-reflective markers (usually small balls). The cameras are equipped with an infrared pass filter in front of the lens and infrared LEDs around the lens illuminate the space. The markers reflect the incoming light back to the camera and the image is internally processed by the tracking system. This system calculates the 2D markers position in image coordinates with high precision. Using multiple cameras, the 3D position of each marker can be derived. The degree of accuracy of this system can be under 0.1 mm [2]. The optical tracking has been used in measurements of 3D displacements in various fields, from body parts (head, arms, fingers) [5] to buildings and other types of civil structures [2].

3. Least square method for retrieving the revolute motion and revolute joint parameters

The input data for the least square method is the time-series of the marker's position. The markers are attached to a link with revolute joint, so their path is circular and the position and orientation of the revolute joint can be found from this circle's geometrical parameters. Depending of the optical tracking method, the markers' coordinates are expressed in the camera plane (in case the position is obtained from the image of one camera) or in the user-defined 3D reference frame, if more cameras and reflective markers are used.

In case the coordinates of the markers (x_M , y_M) are obtained in the camera's reference frame, the path of circular motion of the marker is seen as an ellipse in the image plane. The revolute joint parameters can be obtained by fitting the coordinates of the markers on an ellipse.

If the markers' coordinates are in the user-defined reference frame, first these positions have to be fitted on a plane, then (with the new coordinates in the plane) on a circle.

The equations for fitting the data to an ellipse (1), plane (2) and circle (3) can be written as:

$$F(x, y) = x^2 + \omega_1 y^2 + \omega_2 xy + \omega_3 x + \omega_4 y + \omega_5 = 0, \quad (1)$$

$$F(x, y, z) = x + \omega_1 y + \omega_2 z + \omega_3 = 0, \quad (2)$$

$$F(x, y) = x^2 + \omega_1 y^2 + \omega_2 x + \omega_3 y + \omega_4 = 0. \quad (3)$$

The unknown are (4):

$$\boldsymbol{\omega} = [\omega_1 \quad \omega_2 \quad \dots \quad \omega_i]^T \quad (4)$$

with $i=5$ for the ellipse, $i=3$ for the plane and $i=4$ for the circle.

The recursive least square requires a training set of N samples [11,12]. The following two matrices can be defined for the circle and ellipse (5), and for the plane (6):

$$\mathbf{X}_N = [x_i^2], \quad (5)$$

$$\mathbf{X}_N = [x_i], \quad i = 1 \dots N \quad (6)$$

respectively for the ellipse (7), circle (8) and plane (9):

$$\mathbf{Z}_N = [y_i^2 \quad x_i y_i \quad x_i \quad y_i \quad 1] \quad i = 1 \dots N \quad (7)$$

$$\mathbf{Z}_N = [y_i \quad z_i \quad 1] \quad i = 1 \dots N \quad (8)$$

$$\mathbf{Z}_N = [y_i^2 \quad x_i \quad y_i \quad 1] \quad i = 1 \dots N \quad (9)$$

The unknown, which will describe the required parameters will be:

$$\boldsymbol{\omega} = (\mathbf{Z}_N^T \mathbf{Z}_N)^{-1} \mathbf{Z}_N^T \mathbf{X}_N \quad (10)$$

In case a new measurement is acquired (x_{N+1} , y_{N+1}) or (x_{N+1} , y_{N+1} , z_{N+1}), the unknowns will be updated with:

$$\boldsymbol{\omega}_{N+1} = \left(\begin{bmatrix} \mathbf{Z}_N \\ \mathbf{Z}_{N+1} \end{bmatrix}^T \begin{bmatrix} \mathbf{Z}_N \\ \mathbf{Z}_{N+1} \end{bmatrix} \right)^{-1} \begin{bmatrix} \mathbf{Z}_N \\ \mathbf{Z}_{N+1} \end{bmatrix}^T \begin{bmatrix} \mathbf{X}_N \\ x_{N+1} \end{bmatrix}. \quad (11)$$

Using the matrix inversion rules for avoiding the computation of the inverse of big matrices, the recursive algorithm will correct the unknowns:

$$\boldsymbol{\omega}_{N+1} = \boldsymbol{\omega}_N - [\mathbf{K}_{N+1} [\mathbf{Z}_N] \{error : x_{N+1}^2 (or \ x_{N+1}) + z_{N+1}^T \boldsymbol{\omega}_N\}], \text{ where:} \quad (12)$$

$$\mathbf{K}_{N+1} = \mathbf{K}_N - \frac{\mathbf{K}_N \mathbf{Z}_{N+1} \mathbf{Z}_{N+1}^T \mathbf{K}_N}{1 + \mathbf{Z}_{N+1}^T \mathbf{K}_N \mathbf{Z}_{N+1}}, \quad (13)$$

$$\text{with } \mathbf{K}_N = \mathbf{Z}_N^T \mathbf{Z}_N.$$

The obtained vector ω is describing in parametric form the position of the ellipse and its major axis (which will be the diameter of the circular path of the marker), and the centre point of circle and its radius.

4. Obtaining the revolute motion of the link of a four bar mechanism

To one link of a four-bar mechanism a coloured marker is attached (figure 1). The path of this marker is circular, and the proposed algorithm's aim is to obtain the centre point and radius of this circle. In the camera plane, this circle will have elliptical shape, so its centre point and its major axis will have to be found.



Figure 1. The four-bar mechanism with the marker.

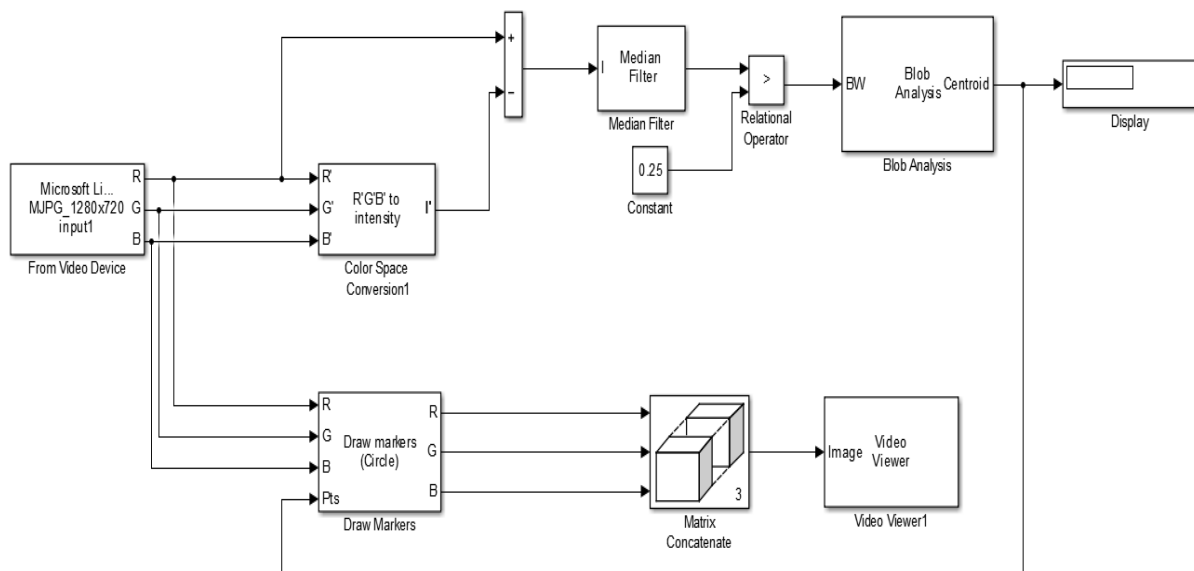


Figure 2. Image processing for the centre point of the marker.

A high-definition camera is recording the movement, and the image processing algorithm is retrieving the x and y coordinates of the centre of the round shaped coloured marker, defined in the image plane (figure 2). The algorithm is transforming the captured image in grey-scale, followed by median filtering and blob analysis of the round shape. In figure 3 are presented two ellipses identified

in different positions of the camera, together with their centre and major axis, corresponding to a revolute motion of the crank of the four-bar mechanism.

5. Conclusions

Information regarding the parameters of the analytical model of a mechanical device can be obtained by measuring coordinates of markers in a sequence of recorded images using video capturing devices and image processing algorithms. Using the least square method for fitting the data into different geometrical shapes (ellipse, circle, plane), the parameters of the revolute joint can be obtained. A precise 3D kinematic (shape and joint) model of a mechanical system is very useful in a variety of computer aided engineering simulations.

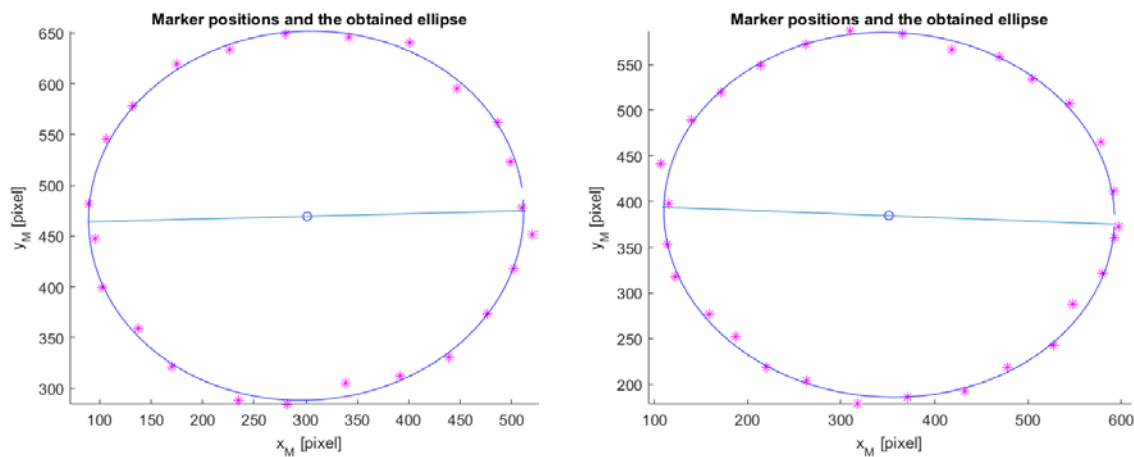


Figure 3. The obtained ellipses and their major axis.

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