Image processing algorithms for characterization of MEMS type micro-tweezers aperture

TOPOR ALEXANDRU[1], VOICU RODICA CRISTINA[2], ULIERU DUMITRU[3], RAVARIU CRISTIAN[4,*], BABARADA FLORIN[4]

[1]SDETTI Doctoral School from Polytechnical University of Bucharest, Splaiul Independentei 313, Sect. 6, 060042, Bucharest Romania
[2]National Institute for Development and Research of Microtechnology, Str. Erou Iancu Nicolae 126A, 077190, Bucharest, Romania
[3]SC Sitex 45 SRL, Bulevardul Ghica Tei 114, Bucharest, Romania
[4]University "Politehnica" of Bucharest UPB, Faculty of Electronics ETTI, DCAE Department, Splaiul Independentei 313, Sect. 6, 060042, Bucharest, Romania

The goal of this work is to develop an accompanying software solution based on image processing techniques to characterize the microgripper’s behavior as a function of voltage. To achieve this kind of work, a series of micro-tweezers with electro-thermal actuation are developed, which fulfill different functions: positioning, push-pull, gripping, able to be integrated in the robotic micromanipulation system. The actual micro-gripper is simulated as a MEMS micro-tweezers, considering also the manufacturing technology and the component materials. A specific contribution is to demonstrate the feasibility of applying image processing techniques to obtain accurate measurements of the aperture, starting from images with the gripper arms as regions of interest. In this way, the demonstrator can be used in medical applications, where cell manipulation needs enhanced precision.

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1. Introduction

Microgrippers for cell manipulation were frequently implemented by MEMS technologies [1]. In order to perform precision measurements of the technical and functional characteristics of a microrobotic system or a microgripper, advanced real-time image processing techniques must be applied [2]. These innovative methods offer precision measurements through non-contact and non-invasive techniques. They are based on the analysis of images of the object of interest and by performing specific calculations on the pixel matrix obtained within each frame.

The knowledge needed to solve a certain problem through digital image processing is coded in the system in the form of a database. The block diagram emphasizes the communication between the processing modules. It is based on the previous knowledge of what should actually be obtained as a final result [2]. A request for feedback via the knowledge base to the segmentation module may require a new segmentation of the proposed image for analysis, possibly with other parameters. The visualization of the image resulting from the processing can be done after each stage of it.

A tracking algorithm that gives good results in many computer vision applications is the Lucas-Kanade algorithm [3]. The algorithm aims to identify and track "Harris" points that can be defined as inflection points, with a high response on both the vertical and horizontal gradients. The algorithm works under the assumption that these points maintain the same properties in one small movement from one frame to the next. This algorithm is a fast alternative for tracking large objects in real time where a certain degree of error is acceptable.

2. Image processing for MEMS type micro-tweezers

The description or the selection of characteristics represents a process which results in quantitative information or attributes that differentiate one class of objects from another. The last stage is the recognition and interpretation of data. Recognition is the process of classifying an object into a certain category based on the information (descriptors) resulting from the description of the segmented image. Interpretation involves finding a certain meaning for the set of recognized objects.

For measuring the micro-tweezers aperture in real time, a high resolution video camera is used. For describing the aperture characteristic depending on the applied current, real-time tracking techniques of some objects of interest, tracking method is used. The purpose is to demonstrate the feasibility of applying image processing techniques to obtain accurate measurements of the aperture, starting from images with the gripper arms as regions of interest, Fig. 1.

The two arms of the gripper produce an effect as a function of intensity and have a significant contrast to the background intensity. The shape and background ratio of each arm are thus unique. Within each frame, this distinctive effect will be sought in the image, i.e. the regions of interest (arms) will be identified in the image frame by frame.

Tracking works under the assumption that the optical flux is essentially constant in a local neighborhood of the pixels under consideration. In our case it refers to the distinctive shape of the arms and their contrast to the background.

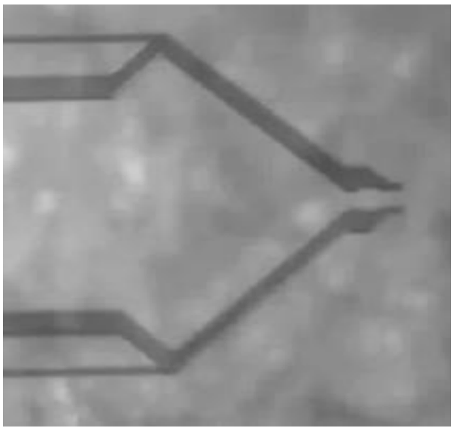


Fig. 1. A high resolution image of the gripper arms

This operation is in the direction of the idea of "tracking", i.e. estimating the trajectory of an object in a flat image, when moving within the observable area.

Under the circumstances of high precision that are required in the present application, a correlation-based algorithm that aims to track regions of interest (gripper arms) as distinctive elements in the image can be used. The algorithm consists of the following main steps:

1) Initialization: the video to be analyzed is loaded, certain parameters are set and the distinctive templates (gripper arms) are chosen to be followed from frame to frame.

2) Pre-filtering (optional): applying different filters to reduce noise and improve the signal-to-noise ratio, highlight certain elements in the image, etc., using convolutions with different specific kernels.

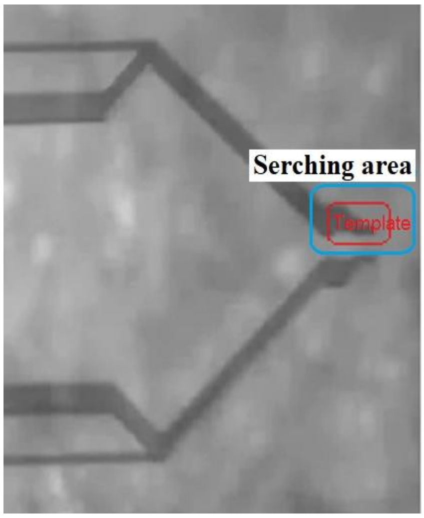
3) Frame-by-frame analysis: at each frame, the templates are correlated in a certain neighborhood (search area) of their last detected position, and the best identification (global minimum in correlation) is reported as the new position. Templates are updated accordingly.

In this context, the correlation between two images of arms, as template A and B, is defined by the Frobenius norm between frames A and B, [4].

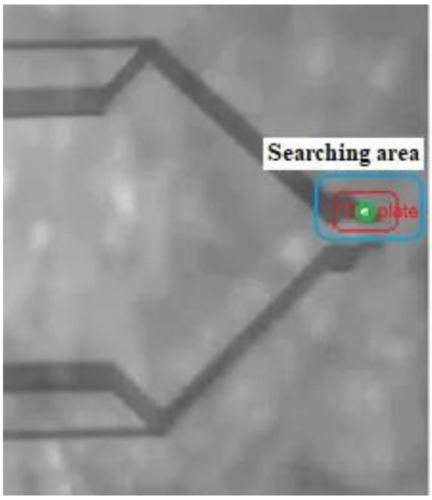
$$\|A - B\|_F$$

$$\sqrt{\sum_{i=1}^{m} \sum_{j=1}^{n} |c_{ij}|^2}$$

An example of tracking between frames A as template and B as searched area is presented in Fig. 2a.



(a)



(b)

Fig. 2. (a) A distinctive template and the search area around it; (b) Identifying the gripper arm (template) in frame B and marking it by green circle

Calculating the correlation between the template and the search area, the values from Fig. 3 are obtained.

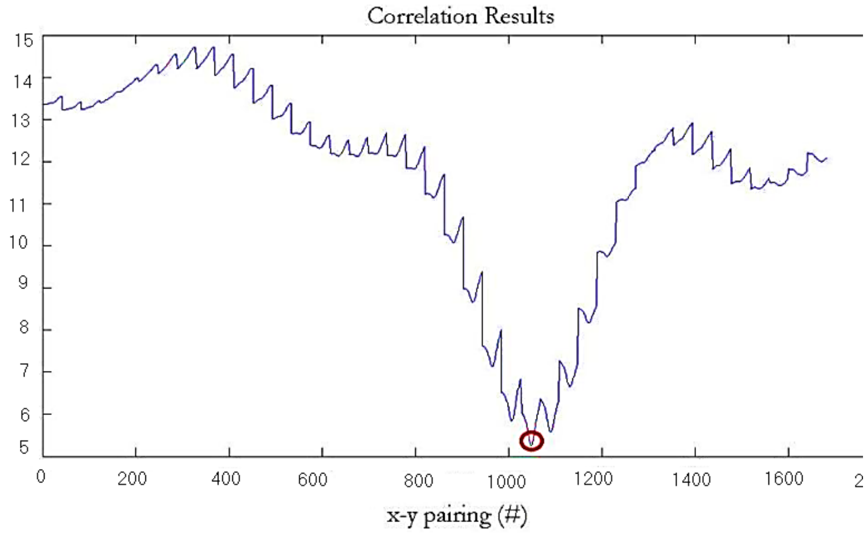
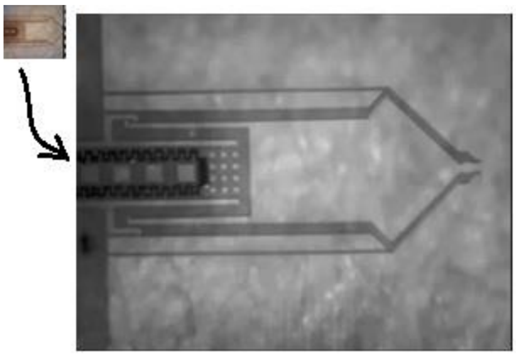


Fig. 3. Results of the correlation between the template and the search area for different x-y positions in the search area

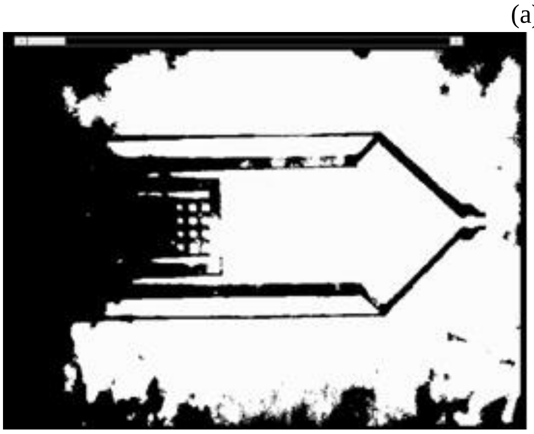
In this case, it is a unique x-y position that correlates perfectly (Frobenius norm = 0) with the template, being in fact exactly the position of the template chosen in frame A at initialization. In frame B the gripper arm will be searched again, being identified in Fig. 4b.

The local minimum of the correlation gives the result about the new x-y position of the template in the new frame. The algorithm gives good results for tracking along multiple video frames.

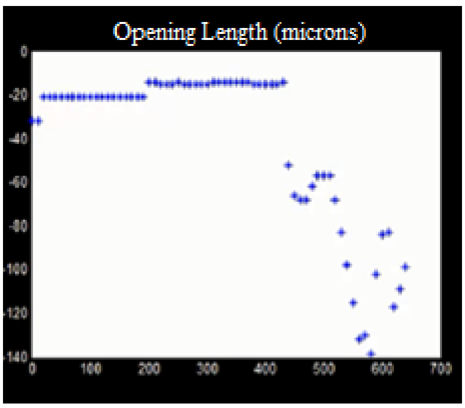
Better contrast and more pronounced minimum in the correlation function occur when the image is binary encoded. After uploading the color image, all RGB (color) frames are transformed into grayscale and filtered, Fig. 4a [5,6]. By using the previous algorithm steps in a MATLAB application and with a threshold of 140, a clear separation is obtained for the gripper arms. In Fig. 4b the gripper arms are highlighted with black with respect to the white color of the background.



(a)



(b)



(c)

Fig. 4. a) Actual photo of the gripper and the way it is captured by the optical system (CCD camera [5]) mounted and transformed into the filtered gray-scale image. b) The results of the noise filtering and threshold application steps. c) the gripper opening length with high precision in microns

The distance of the arms, marked by the red and green circles, is observed as higher values in the plot on the right (maximum 85 pixels up to the current frame), Fig. 4c. Continuing the processing on several frames, the additional separation of the arms is observed - registered as higher values in the plot on the right with maximum 140 pixels up to the current frame.

The knowledge needed to improve this problem indicates this digital image processing to be coded in the system as a form of database. In addition to directing the operations in each processing module, the knowledge base also has the role of controlling the interaction between different modules.

3. Image quality factors affecting accuracy

The elements that influence the accuracy of the measurement are: Signal-to-Noise Ratio, contract, optical effect in the CCD/image acquisition hardware.

The main noise sources in the system are:

- Scattering effects (diffuse reflection): assumed to be random and isotropically spread in all directions (from the different materials the background and the gripper is composed of, as a diffuse component of the reflection exists also for the gripper surfaces).
- System vibrations.
- Surface contamination with impurities.
- Photons from the ambient light being picked-up by the photodetectors.
- Electrical noise in the sampling system (e.g. shot noise), as well as electrical noise added from other subsystems due to imperfect electromagnetic shielding.

The noise sources can be modeled as random, meaning that their effect can be considered and modeled as Gaussian in the system. The SNR computed from the original image was 55 dB, with a contrast of 45%. As both these parameters have been estimated, a Wiener filter [6] was applied to the original image to obtain the image from Fig. 4a in grayscale.

Transforming the pixel level measurement to gripper arm displacement and positioning involves computation of the resolution, pixel size relative to the distance of the object from the camera.

To facilitate functional testing, we have implemented a software application that can be used in an interactive way, using Matlab, implementing the above steps and algorithms

The algorithm gives results for tracking along multiple frames in the video, being applicable and reproducible across multiple measurements and different recordings. The performance of the algorithm is close to real-time and can be integrated in the measuring component of the gripper system. The filtering applied and the correlation calculator can determine accurate positioning and aperture dimension of the gripper arms. Given that the acquisition rate is 50 fps the displacement is continuous with some noise in the measurement (coming from CCD recording is seen in Fig. 4c right. A simple-moving-average or exponential-moving-average could be applied to further improve the results of the tracking algorithm, but this was not in the scope of this work, as the gripper was observed to be indeed vibrating at constant voltage under certain circumstances.

4. Conclusions

The results of the imaging algorithm show that the micro-gripper model can be validated together with a faithful description of the arm aperture characteristic depending on the applied voltage. Fine adjustment elements allow the continuous improvement of the model and its physical and technical characteristics. The developed software was run on multiple recordings on the prototype and showed good reproducibility, enabling a characterization of the aperture size versus voltage to be specified for the developed microgripper.

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*Corresponding author: cristian.ravariu@upb.ro