M. Z. Avramov, I. Ivanov,
V. Pavlov, K. Zaharieva

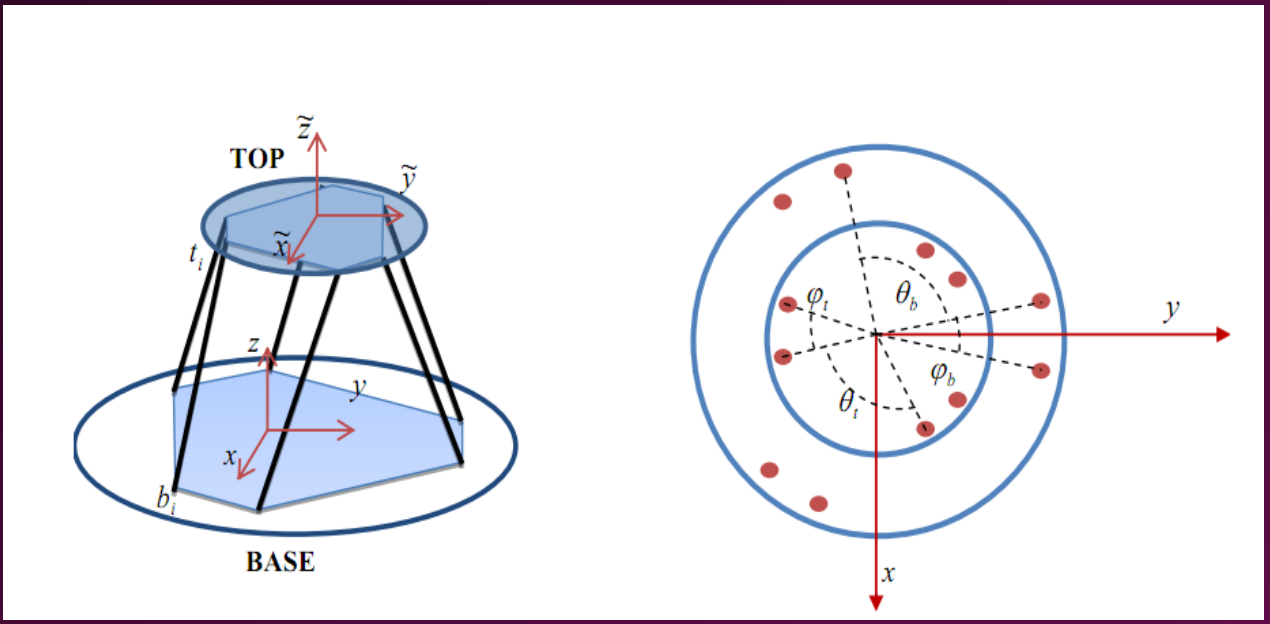
University of Sofia
Department of Physical Chemistry
mavramov@chem.uni-sofia.bg

Six Degree of Freedom Stage for optical Microscopy

Motivation

- Provide automation of different optical microscopy tasks with a single device
- Allow collection of data at known position and orientation to the optical axes of the microscope
- Allow object tracking in real time with the microscope
- Support precision adequate for reflective optical microscopy and this way avoid high price high precision hexapod solutions

Construction



Classic Stewart Platform[1] is chosen. For convenience presentation of the position of the Hexapod is presented in terms of translation of the motion plate and rotation between both coordinate systems $O(x, y, z)$ and $\tilde{O}(\tilde{x}, \tilde{y}, \tilde{z})$

b_i – mounting point of the *i*-th actuator on the base plate in $O(x, y, z)$
$\tilde{t}_i$ – mounting point of the *i*-th actuator on the base plate in $\tilde{O}(\tilde{x}, \tilde{y}, \tilde{z})$
t_i – mounting point of the *i*-th actuator on the base plate in $O(x, y, z)$
θ_t – large angle of mounting on top plate
θ_b – large angle of mounting on bottom plate
φ_t – small angle of mounting on top plate
φ_b – small angle of mounting on bottom plate

Mechanical Formulation

- Straight problem (translation and rotation to actuator lengths).

$$l_i = |\mathbf{T} + \mathbf{M}\widetilde{t}_i - bi|$$

$\mathbf{M}$ – rotation matrix ($\mathbf{M}$= $\mathbf{M}(\alpha,\beta,\gamma)$)

$\mathbf{T}$- translation vector

- Inverse problem (actuator lengths to translation vector $\mathbf{T}$ and rotation matrix $\mathbf{M}(\alpha,\beta,\gamma)$)[2].
  - The inverse problem is solved by minimizing the difference between straight function and the desired positions of the actuator using least squares.
  - The general inverse solution has multiple results but with reasonable constraints only one is qualified as physical.

Control of Kinematics

- PID controller implements the actuator motion with a PVM control on the actuator motor. A regular control function is used for correction of the expected value (in our case the velocity of expansion (compression) of the actuator.

$$u(t) = Kpe(t) + Ki\int_0^t e(\tau)d\tau + Kd\frac{de(t)}{dt}$$

$u(t)$ - PVM prediction value

$\mathrm{e}(t)$ - Error (deviation) from expected value of the velocity

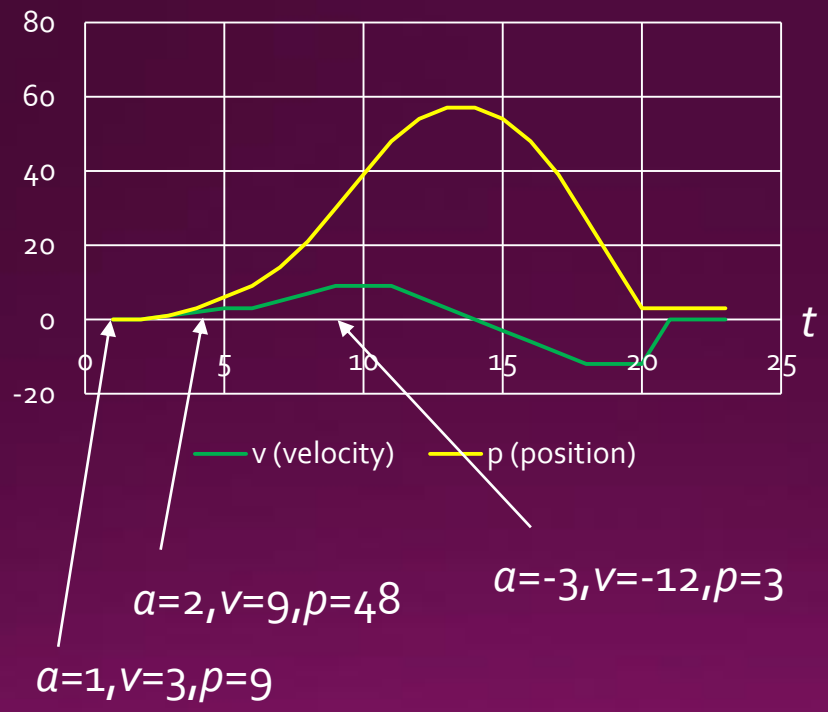
K_p, K_i, K_d – constants adjusted for best reaction of the hexapod

Low level control of the motion

- A triplet
  - a(acceleration),
  - v(velocity),
  - p(max position)

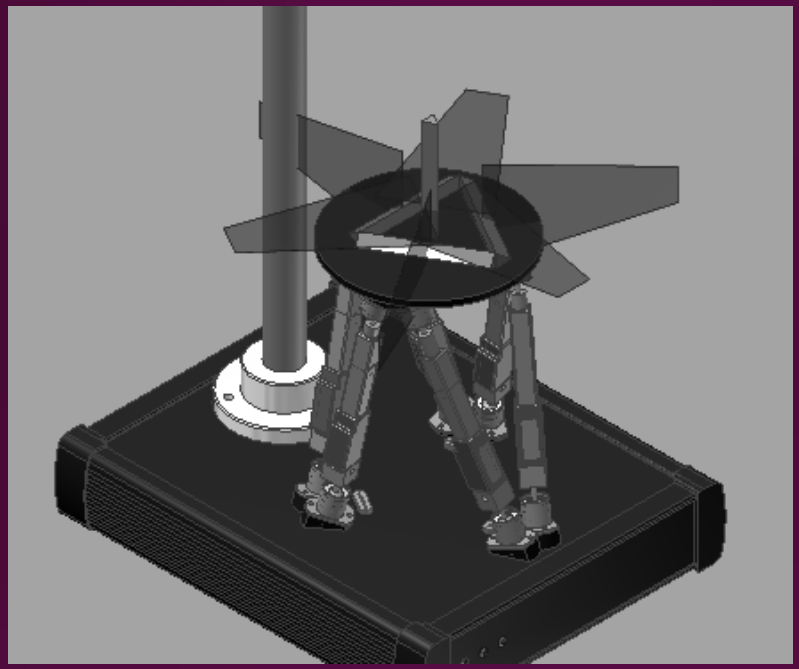
is sent to the controller of the hexapod for each actuator. The controller try to reach the requested velocity with the desired acceleration when the position is reached the next command is processed (if no more commands are available the actuator stops).

Command sequence and behaviour of one actuator



Calibration

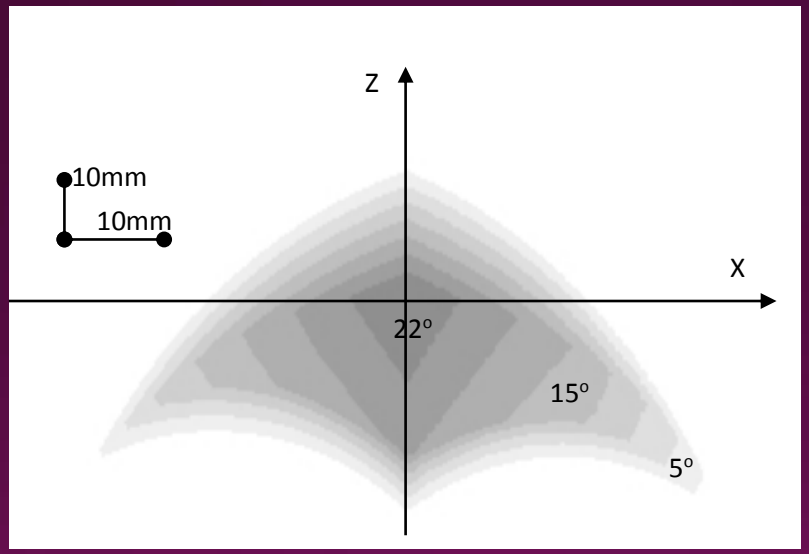
- Scanning Laser cameras are used for the measurements
- 3 cameras are used for parallel measurement in 120 deg position around the hexapod plate
- Another 3 cameras are oriented with the measurement plane perpendicular to the upper plate.



Moving the hexapod trough the range of all the 6 DOF a measurement of 12 coordinates (2 per beam) are collected. A least square optimization allow precise finding of the actual values of the parameters of the hexapod (Mounting points on both plates and lengths of the actuators)

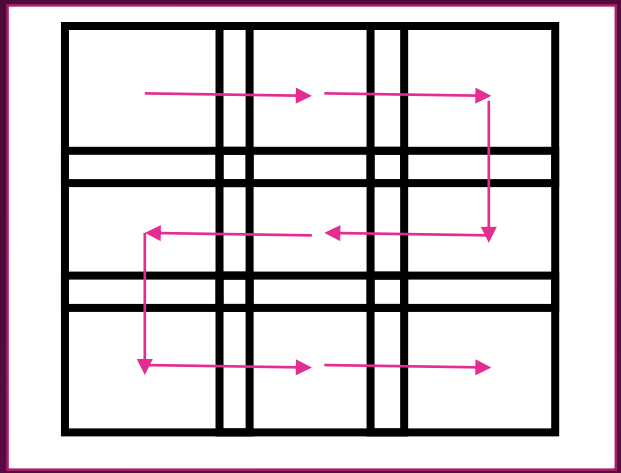
Motion ranges

- The construction of the Stewart platform does not allow full range of motion of every degree of freedom in all values of the other degrees. A presentation of the motion freedom can be visualized for 3 of the degree of freedom by the image on the right.



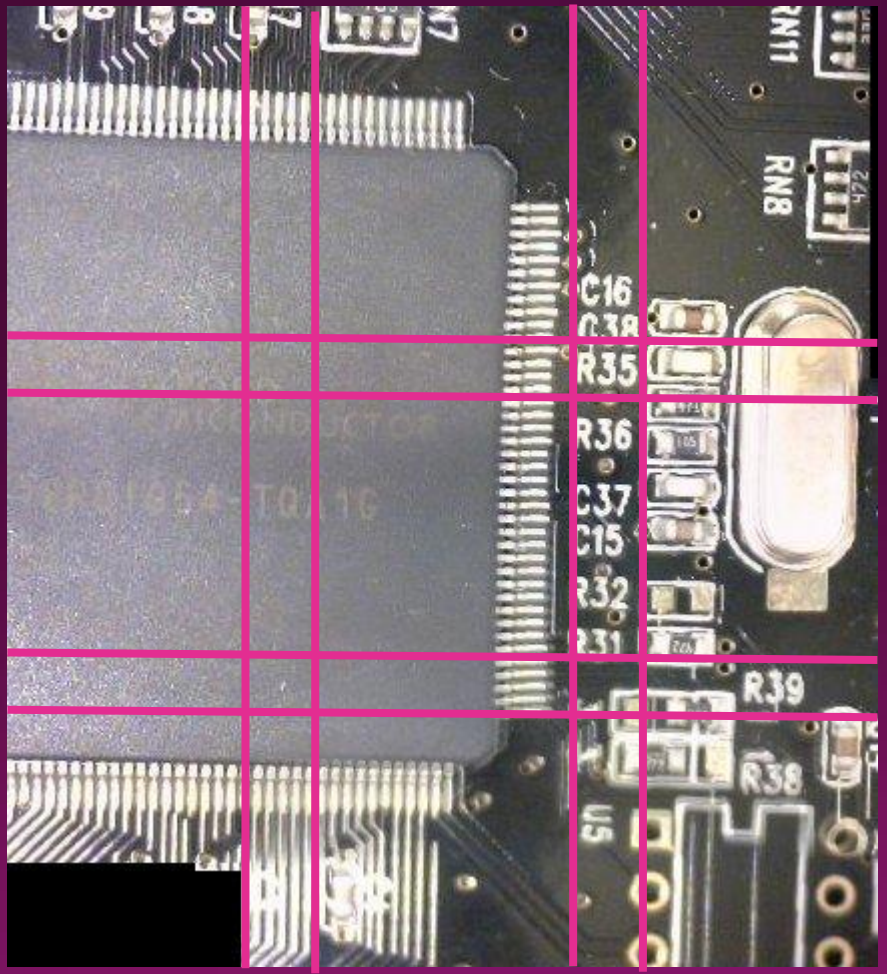
Applications – Panoramic Microscopy

- By moving the stage in a horizontal plane and keeping the field of view of the microscope partially overlapping one can obtain using a proper algorithm a combined image.
- A short range autofocus algorithm can be applied as well to improve the quality of the results.

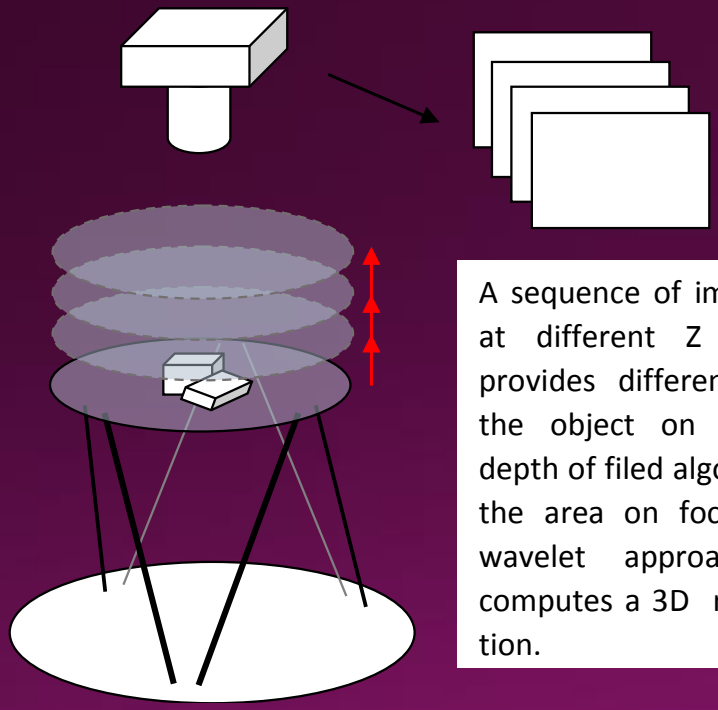


Applications – Panoramic Microscopy

- A sample stitched image using 3x3 scanning matrix
- In case of autofocus correction and scaling of the size of different images must be applied



Applications – Depth of Field

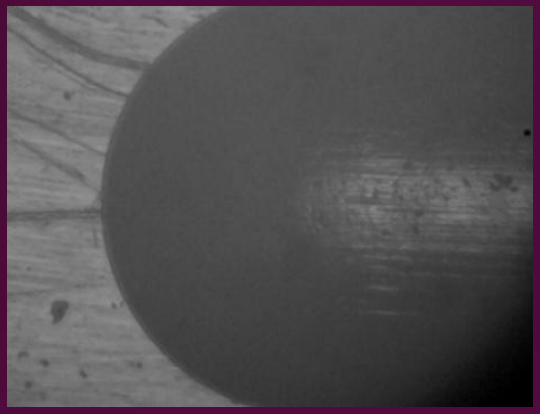


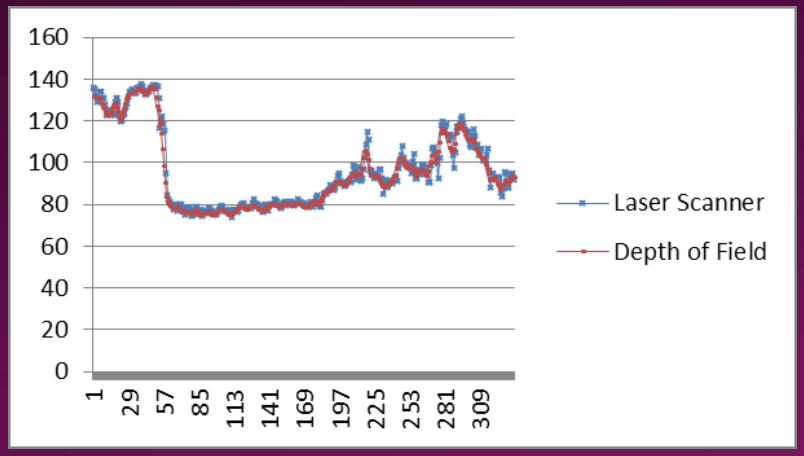
A sequence of images taken at different Z coordinate provides different parts of the object on focus. The depth of filed algorithm finds the area on focus using a wavelet approach[3] and computes a 3D reconstruct-tion.

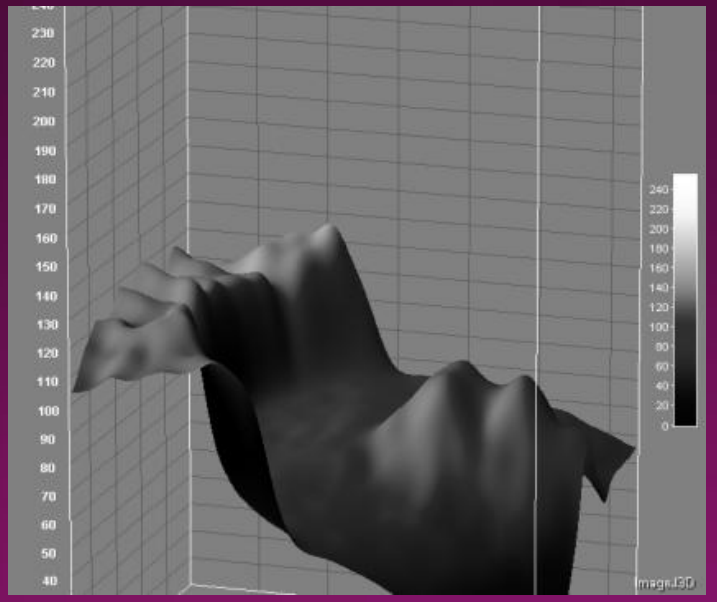
Applications – Depth of Field

Microscopy of a tooth processed for a seal – partial view due to high magnify-cation.

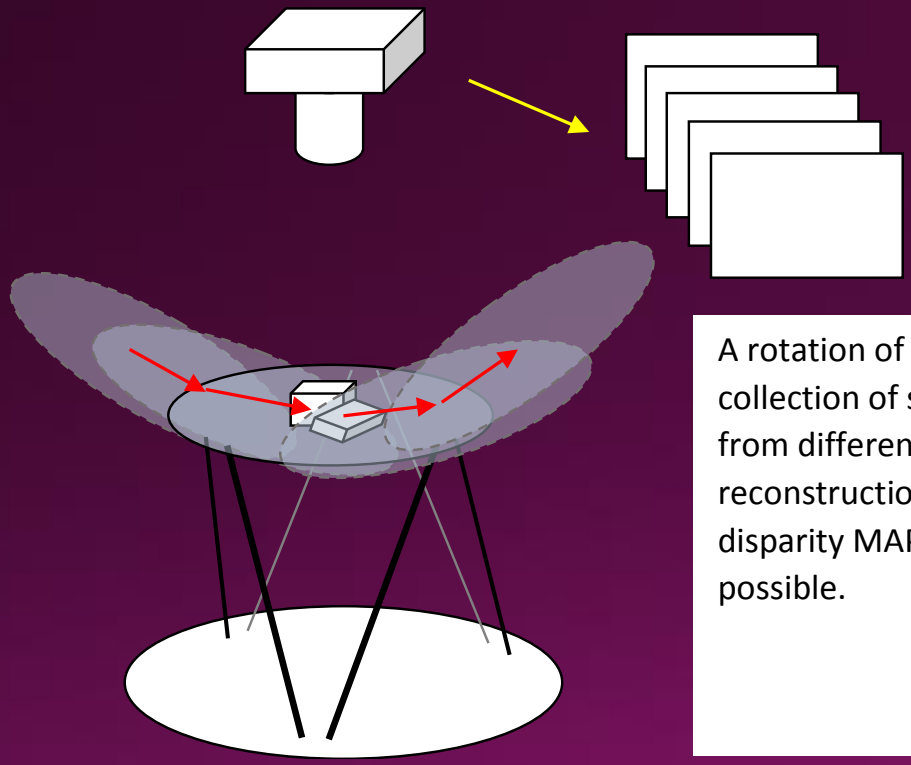
At a arbitrary chosen stripe a scan with laser beam scanner delivers similar results.







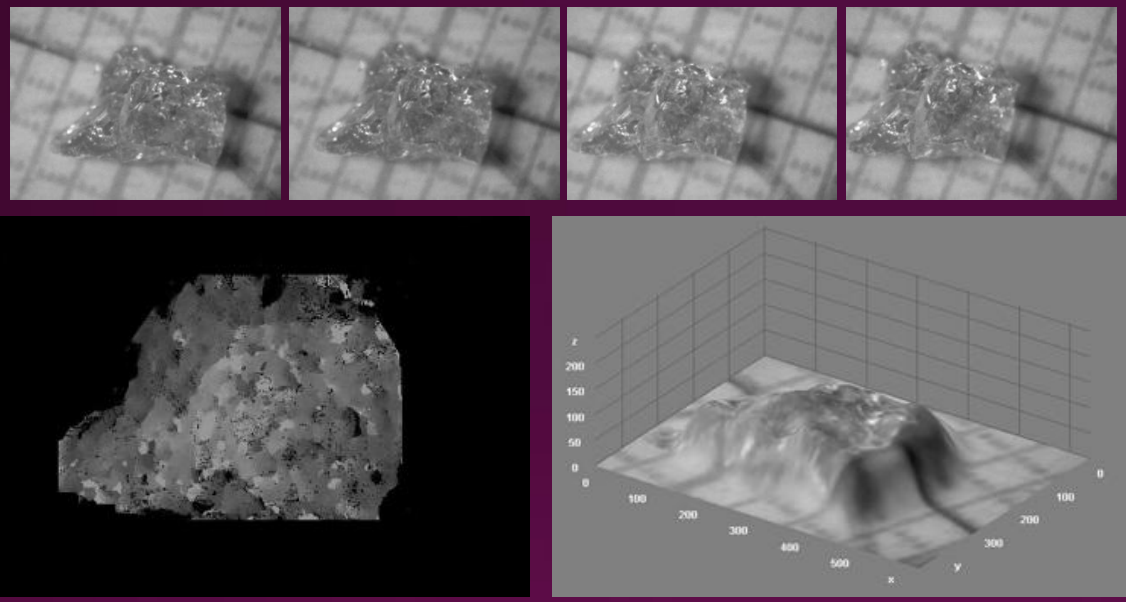
Applications – Multi viewpoint stereo



A rotation of the stage allow collection of specimen image from different angles. A 3D reconstruction after having a disparity MAP then is possible.

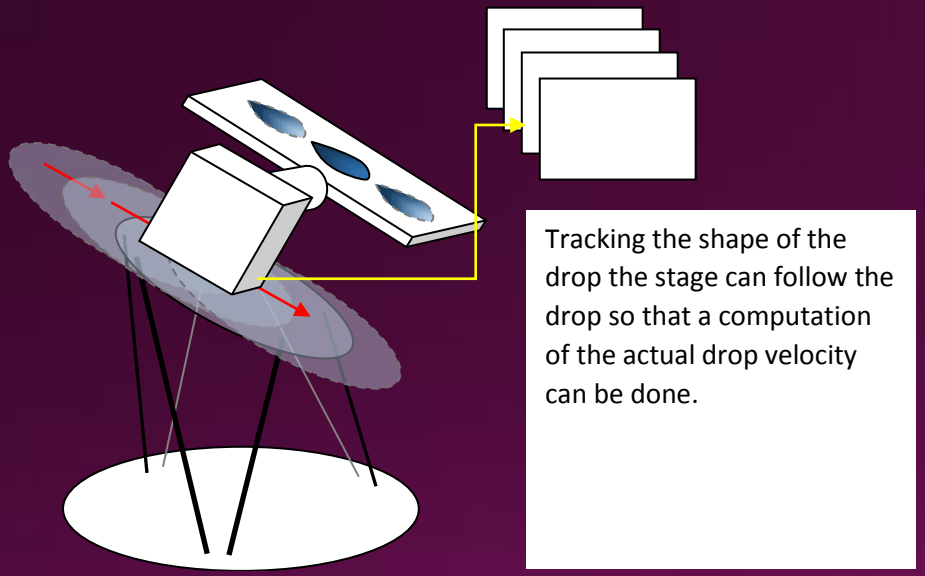
Applications – Multi viewpoint stereo

A multipoint view stereo-reconstruction can provide reasonable amount of data for optimizing the epipolar geometry in a way to reconstruct the real object.



Problems with occlusion and other issues related to 2 view point stereo can also be checked and cleared [4].

Applications – Specialized tracking

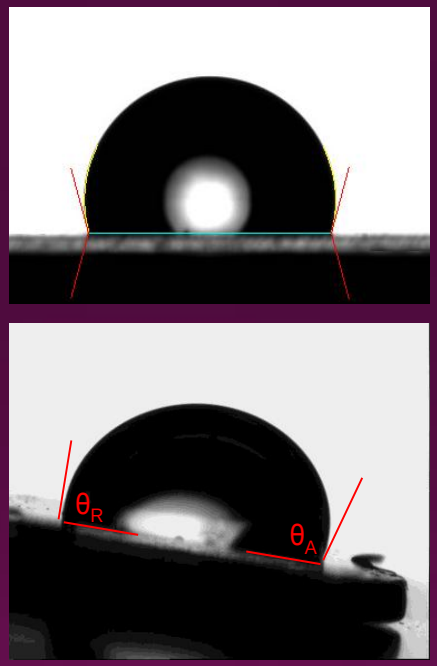


Tracking the shape of the drop the stage can follow the drop so that a computation of the actual drop velocity can be done.

An important interest in recent liquid surface science is the investigation of so called dynamic contact angles of liquid drops on a solid surface [5].

Applications – Specialized tracking

- For the investigation of liquid drops dynamic contact angles it is important to have relatively high resolution (e.g. having the drop in the field of view of the microscope).
- On the other site the goal of the experiment is to have the drop "leaking" on the surface.
- An automated tracking procedure with known trajectory is useful for this kind of investigations.



Conclusion

- The proposed robotized hexapod microscopy stage with 6 DOF can be used in several area of low resolution optical microscopy to provide positioning of the specimen during observation.
- Integrating the observed results and the motion control of the stage can provide significant improvement in optical microscopy automation.
- Bounding with high-performance image processing system allows the application of the system to metrological tasks and implementation of 3D reconstruction and measurement of objects.

Thank You for Your Attention

References:
[1] D. Stewart, "A Platform with Six Degrees of Freedom", UK Institution of Mechanical Engineers Proceedings 1965-66, Vol 180, Pt 1, No 15.
[2] Domagoj Jakobovic , Leonardo Jelenkovic THE FORWARD AND INVERSE KINEMATICS PROBLEMS FOR STEWART PARALLEL MECHANISMS,CIM2002, http://www.zemris.fer.hr/~yeti/download/cim2002.pdf
[3] M.Kraus and M. Strengert, Depth-of-Field Rendering by Pyramidal Image Processing, EUROGRAPHICS 2007 Volume 26 (2007), Number 3
[4] Hanqing Jiang at Al 3D Reconstruction of Dynamic Scenes with Multiple Handheld Cameras
[5] Avramov M., Soklev B. IECIS Berlin 2011

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