



## A 3D Virtual Sketching System Using NURBS Surfaces and Leap Motion Controller

Miri Weiss Cohen<sup>1</sup> , Daniele Regazzoni<sup>2</sup> , Chen Vrabel<sup>3</sup>

<sup>1</sup>Braude College of Engineering, [miri@braude.ac.il](mailto:miri@braude.ac.il)

<sup>2</sup>University of Bergamo, [daniele.regazzoni@unibg.it](mailto:daniele.regazzoni@unibg.it)

<sup>3</sup>Braude College of Engineering, [vrubelch@gmail.com](mailto:vrubelch@gmail.com)

Corresponding author: Miri Weiss Cohen, [miri@braude.ac.il](mailto:miri@braude.ac.il)

**Abstract.** A 3D sketching system is presented for transforming an ideation to an actual CAD model using Human Computer Interaction (HCI). The system uses a Leap motion controller to capture human gestures, and translated them by a recognition model. The pinch and pull gestures are used to represent actions for flexible manipulations on control points coordinates of NURBS surfaces. The continuous motion of the designers hands is converted to morphological/geometrical and mathematical values. Both cases of single and dual hands are developed, offering the designer a variety of resolution tools to convey their ideas and creativity.

**Keywords:** Human Computer Interaction Design, 3D sketching, Leap Motion controller, NURBS surfaces

**DOI:** <https://doi.org/10.14733/cadaps.2020.167-177>

### 1 INTRODUCTION

3D sketching and sculpting is the use of software which offers tools for shape modeling and manipulation of digital objects as if they were made of a real-life substance such as clay. Moreover, 3D sketching for product design from preliminary 3D sketches is a tool for creative design. Using CAD systems enables flexibility, leave plenty of room for exploring shapes, inventiveness and speed. Designers and engineers often desire to touch the surface in a CAD system to model and modify its' shape. The user intuitively uses his hands to express the intended changes and manipulations.

The basic stages from ideation to CAD models are twofold. First the visual and experience of creativity and the second is its applicability to definite mathematical forms which could can be handled through various optimization or manufacturing criteria. The combination of geometric and mathematical formulations using NURBS consist of fulfilling the goals of both stages.

The geometry used in 3D sculpting programs to represent the model can vary, and each offers different benefits

and has different limitations. Most of the 3D sculpting tools use mesh-based geometry, in which an object is represented by an interconnected surface mesh of polygons that can be manipulated in various ways. The limitation of mesh-based sculpting is the fixed topology of the mesh; the specific arrangement of the polygons can limit the way in which a detail can be added or manipulated.

In the past two decades, Human Computer Interaction (HCI), has been in great use to convey the idea of interpreting human gestures and intentions using a computer system. This work uses HCI with leap motion controller for shape modeling and modification of control points on NURBS surfaces to achieve the desired intended shape.

## 2 RELATED WORK

The concept of 3D sketching and sculpting using virtual environment and Motion Capture (MOCAP) systems is highly regarded by many [7, 8, 19, 21]. This allowing and providing an infrastructure and support for creative and elevation in the design process. Almost two decades ago Knoph et al. [10] presented a model of mesh with nodes, such that each node consists of mass connected graph of springs. Each node represents a material and its dynamic properties. [1] stated that the design process involves the translation of a creative idea into an accurate defined CAD output. This intensive manipulation process involves the generation of ideas transformed into graphical data which was in the past presented using pencil sketches.

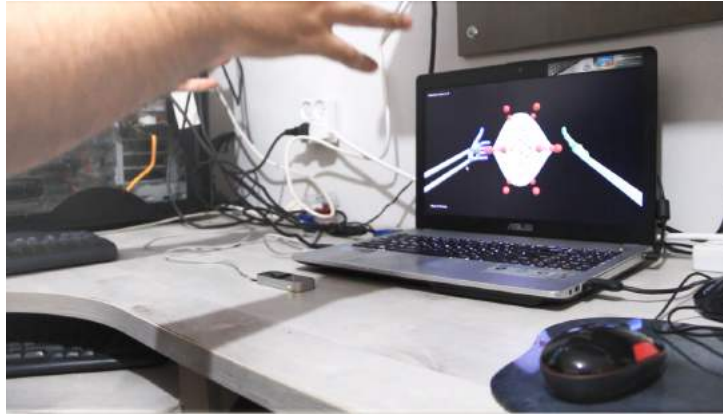
For the past two decades ideas are converted into CAD data and files as stated by [1] and [24]. Recent work by Vinayak et al. [20] includes expanding the ability of using CAD systems for 3D sketching and sculpting using MOCAP systems for bare-hand mid-air virtual pottery, using point clouds. In [21] they extended their work for clutching by proximal-attraction, shaping by proximal-attraction, and shaping by grasp and motion. The use of full body gestures to facilitate artistic expression was experienced by using a Kinect Sensor was done by [23] and [17]. Their research has indicated that this action is very enjoyable. Stnculescu et al. [18, 19], developed a system which incorporates free-form sculpting for self-adaptive meshes, where geometric and topology changes resulting from sculpting are created. In [15] Delaunay triangulation to reconstruct non parametric surfaces are used. Different approaches using Leap Motion Controller as a MOCAP device are detailed in [9, 2, 6, 4], portraying the advantages and accuracy in usage.

There is no doubt that the sketching process is essential for all stages of design, but comparing the usefulness of CAD systems design outcomes against those of manual sketching is still of interest and researched in [11]. The authors in their work, try to debate two separate issues, the benefit of using a CAD system over pencil sketching. And Second, how the creativity of the designer generates and performs using a sketch-3D modeling systems. In their case the examination was conducted by comparing tasks using Sketch Up and Silhouette Modeler. A different aspect of this creativity could be found in rehabilitation and for people with complex disabilities is detailed in [12].

While most of the 3D sculpting tools use mesh-based geometry, in which an object is represented by an interconnected surface mesh of polygons [24]. In this work the system implements the shape modeling, modifications and manipulations using NURBS surfaces, allowing the advantage of their representations[16].

## 3 PROPOSED APPROACH

For implementing HCI with 3D sketching and shape modeling the Leap Motion controller is used [4, 14]. The Leap Motion controller is a small USB peripheral device which is designed to be placed on a physical desktop, facing upward. It can also be mounted onto a virtual reality headset. Using two monochromatic IR cameras and three infrared LEDs, the device observes a roughly hemispherical area, to a distance of about 1 meter. The sensors have a field of view of about 150 degrees. The effective range of the Leap Motion Controller extends from approximately 3cm to 60cm above the device. The LEDs generate pattern-less infra-red light and the cameras generate almost 300 frames per second of reflected data, which is then analyzed by the Leap



**Figure 1:** Leap Motion Controller and Hand Movements in design environment.

software (SDK). The result provides a 3D position data of the joints of both hands by comparing the 2D frames generated by the two cameras. Acquiring the sensor data is done by analyzing the images using the feature recognition module. Each frame is the basic level of the data, [3] it contains lists of tracked entities, such as hands, fingers, bones and all the joints. The data obtained included position of the finger joints: distal phalanges, intermediate phalanges, metacarpals and proximal phalanges, in addition it provides direction and length between them.

These gestures recorded, are shaky and inconsistent resulting noise and inconsistency. We developed a method which integrates a moving average and the use the joints angles, not relative to actual space coordinates. A detailed method developed is found in [22]. It is considered 200 times more sensitive to movements compared with any touch-free technology available today. Its cost is very low, (70 USD) making it affordable for any business or private use.

Figure 1 is a snapshot of the working space. Using Leap Motion SDK and API to transform those hand movement frames into applicable input and Unity graphical engine is performed to provide rendering and transformation abilities needed by the designer.

## 4 SYSTEM DEVELOPMENT

In this stage all the processes are done simultaneously in real-time. Algorithm 1 details the full procedure of the systems' development approach, and is self explanatory, a detailed subsection follows.

### 4.1 Pre-Processing

The preprocessing stage is an initial stage made automatically by the system. It mimics the selection of 3D shape for further sketching/modeling.

- Load the selected object, defined by its control points, Knots and weights into the graphical engine.
- Calculate and represent the NURBS surface[16] defined by the loaded data.
- Display the 3D object and the defined number ( by the user, or use predefined) control points of the surface.

Figure 2 depicts one of NURBS surfaces that suffice the initial sketching process. The designer can use the predefined Surfaces, or define a surface from scratch.

**Algorithm 1:** BSplineSurfaceManipulationUsingLeapMotion()

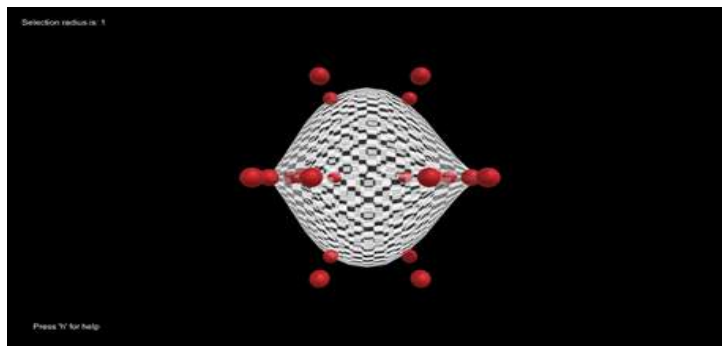
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1 Load control points from file to controlPoints[];
2 resultGrid = CalculateBSplineSurface(controlPoints[]);
3 triangles = TriangulateBSplineSurface(resultGrid[]);
4 DisplayBSplineSurface(triangles[]);
5 while True do
6   Acquire Leap Motion sensor data();
7   Map hand position to world coordinates();
8   if Pinch detected then
9     Find all control points in radius R => array;
10    repeat
11      update control points new position;
12    until release;
13  end
14  resultGrid = CalculateBSplineSurface(controlPoints[]);
15  triangles = TriangulateBSplineSurface(resultGrid[]);
16 end
17 DisplayBSplineSurface(triangles[])

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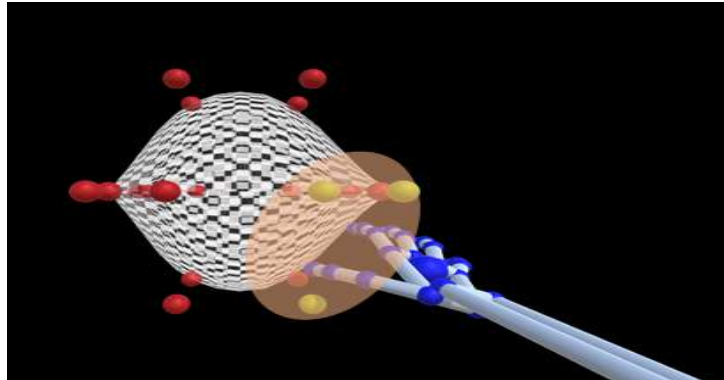
**Figure 2:** Initial sketching display of the 3D surface and some control points.

## 4.2 3D Sketching

The following steps detail the system processing in each movement made by the sketcher/designer.

- Acquire Leap Motion sensor data.
- The Leap Motion sensor provides coordinates in units of real world millimeters within the Leap Motion frame of reference. The hardware itself is the center of this frame of reference. The origin is located at the top, center of the hardware. To use information from the Leap Motion device, it is mandatory to interpret the data so it can be used by the sketcher.
- To map local coordinates to a 3D relevant coordinate system, the scale factors are adopted. Moreover, both hands positions are calculated, transformed and relatively considered.
- Nearest surface control point: For the NURBS surface to be modeled and modified in an intuitive and human design manner, closeness of the human gesture to the surface is evaluated. For creating 3D

sculpting modifications, the position of at least one of its control points must be initiated. The user is able to flexibly define the radius of nearest surface control point from the his hand/hands. A schematic Region of effectiveness is seen by the orange sphere in Figure 3.



**Figure 3:** A sphere used to find the ROI defined by the user.

- Changing surface control points positions: This is done by selecting control points within the chosen sphere, by a defined hand gesture. After selecting the relevant control points, the hand movement changes the coordinate positions causing changes in the surface simultaneously. These modification are done through two basic features: Pinch and Pull.
- Re-calculate the surface : The surface is recalculated after each frame when pinching or pulling effective on control points is conducted. The new 3D surface is re-triangulated and rendered in real-time.

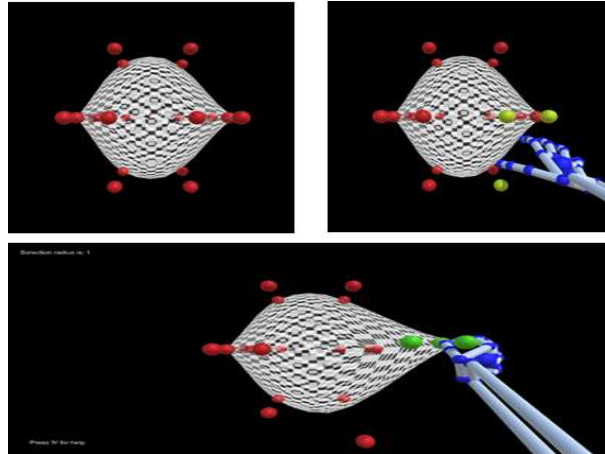
## 5 SYSTEM FEATURES

When a hand gesture is recognized, pre-defined action are activated, such as pinch / grab for pulling control points. The input of the Leap motion controller is not accurate enough for very small areas and dependant on the velocity of the movement. To overcome this fault There are multiple possible approaches for creating a feature vector based on a movements, the importance of a proper feature vector data selection is detailed in [5, 23]. Skeleton-Based features were mainly considered, as these features are based on wire frame models of the human body that contain angles and position data of joints. This representation is due to the output of the devise package [13].

In order to construct the vector representing the relevant data, three forms can be used: the spatial data of joints, the angles of the joints or a combination of both. In this system the angles of the joints were used, providing accurate data, not relative to actual 3D real space coordinates.

### 5.1 Pinching

Pinch detection is implemented in order to grab a control point and move it in 3D space, thus changing the surface, it is required to first pinch the object which represents the control point. Since hand movement is continuous, pinch detection must occur in each frame. The first stage to detect a pinch is determining the position of the thumb finger (joints) from the Leap Motion controller. A trigger distance needs to be set in the following stage. This distance is estimated from the thumb tip (joints) and the remaining finger tip joints. If the distance is smaller than the trigger distance - a Boolean flag that represents a pinch trigger is set to TRUE



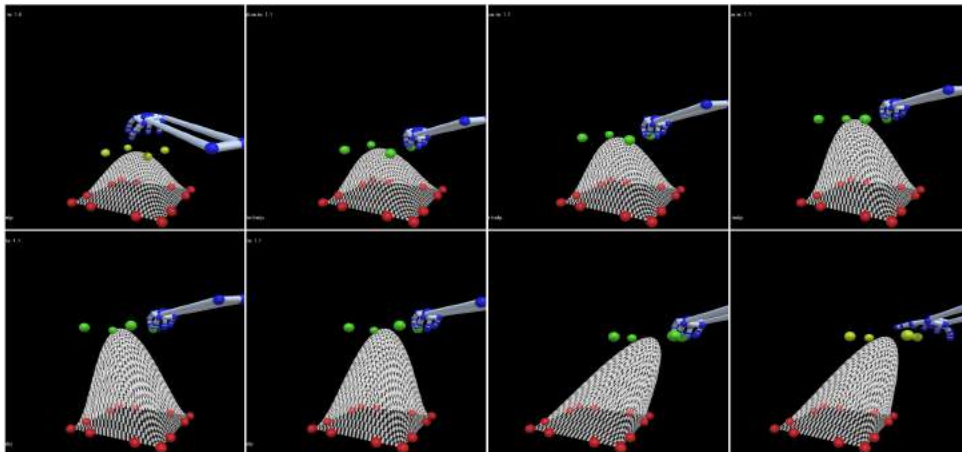
**Figure 4:** Basic surface (top left), control points selection (green)( top right), pulling (bottom).

The pinch position is the position of the thumb tip and it is sent as a parameter to the function which handles the actions performed during the pinch itself. Figure 4 depicts three stages of the sketching: the top left is the basic surface, the top right depicts the correspondence of the hand gesture and the control points. The the bottom depicts the pinch and pull features of the system. Pinch release is detected in a similar method, but with an opposite threshold. If any of the fingers is larger than the defined threshold, a release is detected.

## 5.2 Pulling one or more Control Points

This option is done by using the pinch gesture to choose and pull 1 control point resulting in a change of the surface visible to the user. Surface coordinates will be calculated according to the new mesh of control points.

Pulling a group of Control Points is done by using the pinch gesture to choose and pull a number of control

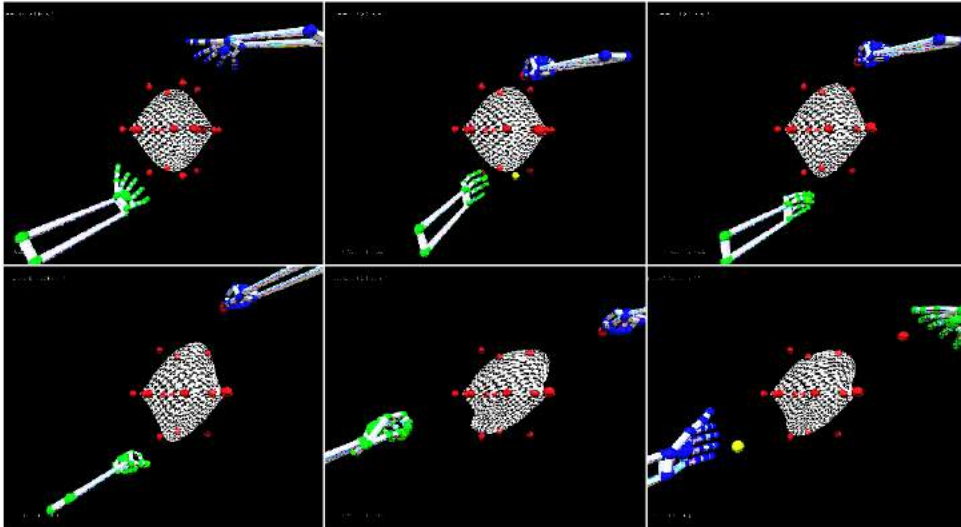


**Figure 5:** Changing the control points position using one hand.

points. This resulting a new surface with all the advantages and limitations of grouping a number of control points in the sketching process of design.

### 5.3 Pulling a group of Control Points with both hands

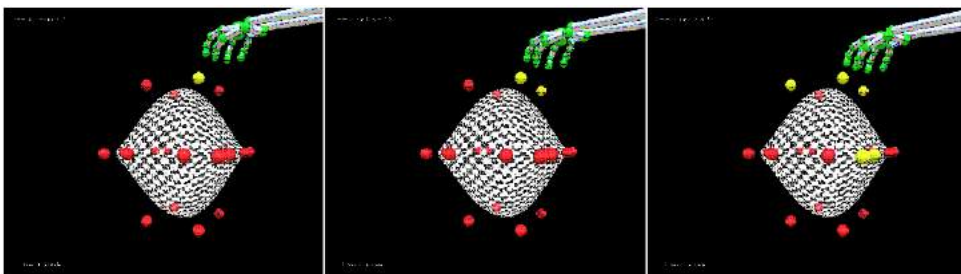
The scenario is using the pinch gesture to choose and pull a few control points with both hands resulting in a change of the surface visible to the user. The use of two hands mimics the human 3D sculpting process. In some cases this usage has the advantage of adopting the actual feeling as felt in reality, not offered by any other input devices. A group of snapshots depicting this process can be seen in as depicted in Figure 6.



**Figure 6:** Changing control points position using both hands.

### 5.4 Change pinch and grab sphere

Change pinch and grab sphere is done by using the keyboard. The defined radius of effected control points around the thumb according to its position on the screen at real time resulting in a change of the selected control points visible to the user.

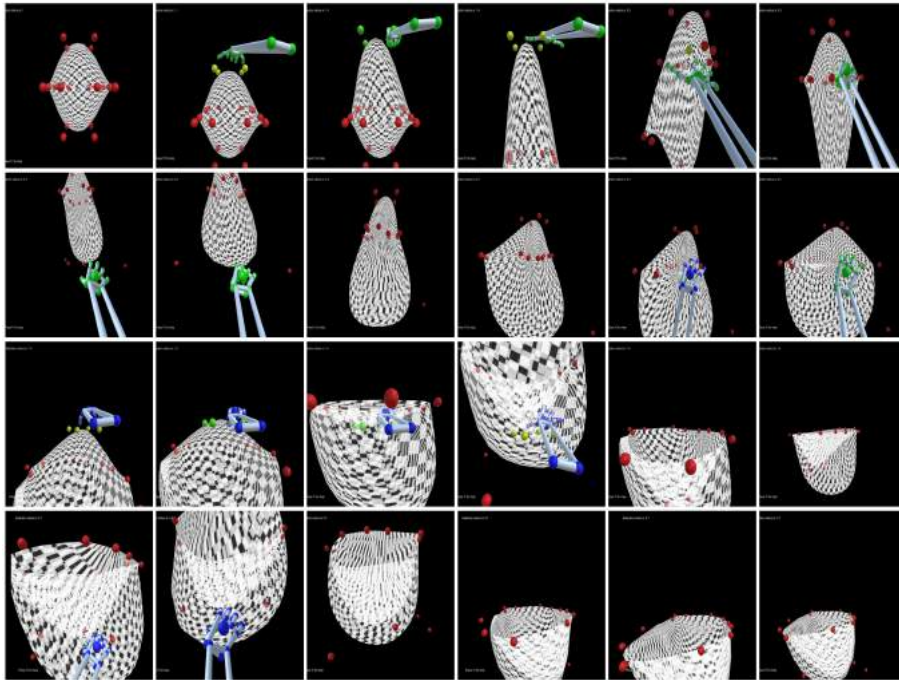


**Figure 7:** Changing selection sphere, and its implications.

The user interactively can see the change by the different color of the control points defined by him, as depicted in Figure 7. This could influence his decision making in the sketching process. scene the control points distance is calculated and compared to the radius chosen.

Figure 8 is a collection of snapshots of an example starting from a basic surface (in this case like a bulk of clay), and going through sketching and sculpting reaching a surface which resembles a bowl. All the process mimics the human hand gestures and features.

Although very intuitive in the design process, it can be seen that each stage represents not only the geometrical



**Figure 8:** Snapshots of a design process.

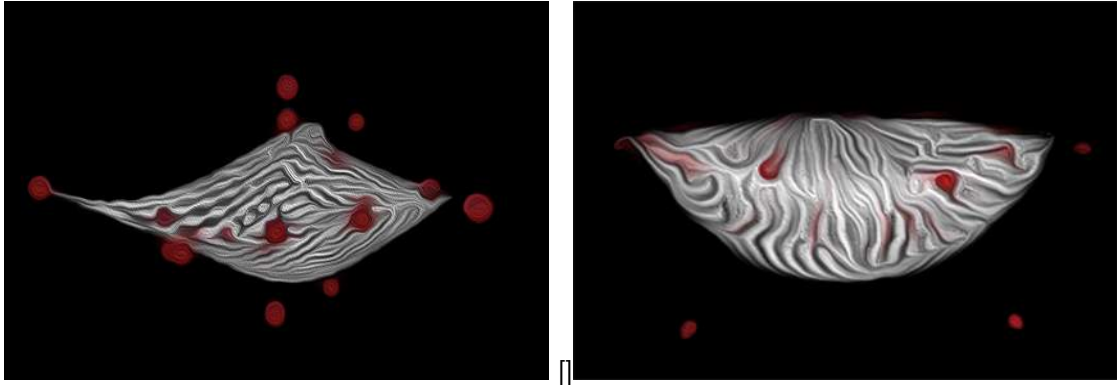
shape itself, but enables simulations and analysis. In addition basic camera control and scene management features are implemented such as rotating camera in all directions, moving camera in 3D space, depicted in the figure, zoom in and out as seen in the figure, load object from file, save object to file for future work, toggle control points off and on, and a help menu.

Figure 9 depicts two examples of 3D sketches. These are two simple examples, done by students using the system. The process is very enjoyable and enables inspiring ideas transformed into uniquely defined into 3D surface sketches.

## 6 CONCLUSIONS

This work presents a 3D sculpting/sketching system using a Leap motion modeling as MOCAP device and manipulating NURBS surfaces. The designers' intuitive process of iterative configuration of the initial 3D surface, to a desired resulting object, is done by gesture recognition of features. Pinch and pull actions for flexible influence on control points is defined. The use of single or both hands is developed, offering the designer a variety of resolution tools. 3D sculpting on NURBS surfaces, which are explicit mathematical expressions,





**Figure 9:** Two examples of sketches using the system.

provide excellent properties such as local control, continuity, fitting etc. This initial phase of sketching can be used for further analysis in advanced processing systems.

## ACKNOWLEDGEMENTS

The authors would like to thank the support given by the funding of Erasmus+ K-107 2017-18, and StaRs 2/2018 UniBg.)

## ORCID

*Miri weiss Cohen*, <http://orcid.org/0000-0001-5250-1016>

*Daniele Regazzoni*, <http://orcid.org/0000-0001-5533-7047>

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