SIMULATION OF SURFACES MICROROUGHNESS BY MEANS OF POLYGONAL REPRESENTATION

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ABSTRACT

The paper presents a method of visualisation of surface microroughness acquired by hydroabrasive division (AWJ – abrasive water jet), by means of polygon representation. The method stems from theoretical and practical possibilities of so-called global illumination mapping of unevenness using suitable image maps. Based on data interpretation stemming from measurement of the surface roughness, an original method is proposed and realised, which also enables to visualise light interactions in the visualised microsurfaces.

INTRODUCTION

So far, the most used tool to measure surface quality has been a contact profilometer, whose disadvantage is the possibility of only a 2D surface evaluation (i.e. along the selected line), contact with the measured surface (which can lead to destruction of the surface or distortion of the measured data), and finally, to a certain degree, a significant time-shift between the measurement itself and its evaluation. The above-mentioned drawbacks of 2D surface evaluation lead to the necessity of devices of new generation enabling 3D surface evaluation (i.e. on the selected surface) in real time without its possible destruction. Neither of the procedures solves problems of light interaction visualisation on given surfaces (Arola and Ramulu 1997) Current methods of surface evaluation, either 2D (along lines) or 3D (in points on a raster), are limited to monochromatic representation of microroughness without a possibility to compare interaction of various light sources under various angles of incidence and various intensity and wavelength of the used luminous flux, and without an ability to visualise diffusive and reflexive qualities of the examined surface. However, a necessity arises for repeated time-consuming and costly measurements without knowing at least an approximate result. Another disadvantage is the fact that in the case of 3D surface evaluation by non-contact devices, we dispose of a record which does not contain all profile qualities of the examined surface. In the case of optical methods, it depends on the resolution of the used raster where we examine light reflections in the selected network of points. It appears that more demonstrative surface evaluation is still achieved by 2D evaluation methods. Our presented method of visualisation of the observed surfaces, which uses the most modern findings from computer graphics, leads to possibilities of simulation of luminous flux distribution on the examined surfaces and to significantly better possibilities of a subsequent comparative analysis.
Therefore we have created the presented method, which enables to visualise light interactions with microsurfaces from the point of view of reflexive and diffusive qualities using a suitable image mapping combined with selected physical methods of global illumination, their mutual interconnection with consequent visualisation implications.

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STATE OF THE ART - SURFACE CREATION

Knowledge of the topography of surfaces created by AWJ and their classification is very important for "machining" techniques (Botak 2009). In the reports published by authors optical methods was used for the investigation of the surface structure cutting of areas (Hloch 2008). Optical methods are based on illuminating by defocused laser beam and white light beams. Measurement of surfaces generated by water jets and abrasive water jets, according to technological conditions is quite difficult (Valíček 2010). It is caused by specific surface structure. In contrast to classical methods, the surface created by water jets and abrasive water jets is rather diffuse (Hlaváček 2009). After testing a few optical methods to study the surface characteristics of several samples prepared by abrasive water jet machining authors (Hloch 2009) decided to apply a newly developed method. It is specially dedicated to measurements on surfaces with a relatively rough surface structure. The method is based on the visualisation of the roughness by oblique angle illumination - shadow method (Valíček 2007). The optical effect caused by light impinging on the surface at an oblique angle is used to visualise the geometrical shapes present at the sample surface. The shapes can thus be displayed in a simulated optical plane. The intensity of the light scattered by the surface treated in this manner contains the information about the frequency and height of the geometrical shapes present on the surface.

Nevertheless, a lot of problems occurred during the investigation of surface structure created by water jet and abrasive water jet machining that is reported in (Hloch, Valíček and Simkuet 2009).

For example scratches made by abrasive particles form small planes with random inclination to the plane tangential to the local surface profile, thus generating micro-mirrors randomly reflecting the incident light. This phenomenon increases the signal noise and it makes proper evaluation of the surface unevenness more difficult. In order to render surfaces acquired by AWJ using image maps, we stem from a consideration. Provided we use a heightmap to create a corresponding relief of the examined surface, a physically exact interpretation needs a corresponding number of reference surfaces (see the reference polygon network). Provided we stem only from the fundamental of displacement mapping, we get to the level of interaction surfaces, whose number is limited by the current visualising tools, particularly concerning rendering speed.

Thus it is necessary to find a solution enabling physically plausible as well as performable visualisation. From physical point of view we presume that those are surface peaks with the highest amplitude that are the most active in light distribution across the visualised surface.

Based on information stored in the corresponding heightmap, we can declare that unevennesses which will be participating most actively in the interaction with luminous fluxes in the scene are surfaces with the highest brightness representing the most significant roughness of the given surface. (Fig.1)

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HeaderLines=10
ScanMode=3D
XSize=3000
YSize=1000
Depth=32
XRange=0.029999
YRange=0.0100005
ZScale=1.00708e-008


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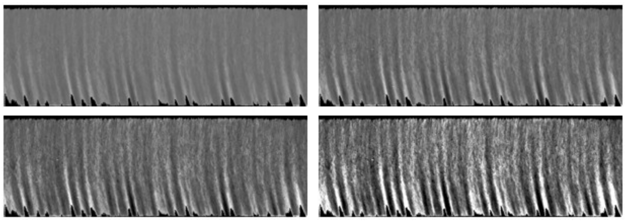

Figure 1: Visualisation of the original heightmap based on the measured unevenness matrix. Contrast marks unevenness of the visualised surface

The number of polygons, and related accuracy of rendering of the visualised surface, is regulated by defining the darkest value of the heightmap for which the given surface will be generated. From implementation point of view, it will concern allocation of the alpha channel to all colour shades which will be below this minimal boundary. The required visualisation accuracy will be then defined by setting the value of the darkest shade (i.e. a concrete value from the data matrix where the values below this boundary will equal 1. Subsequent allocation of a normal map to such created surfaces will define direction normal (Fig.2)

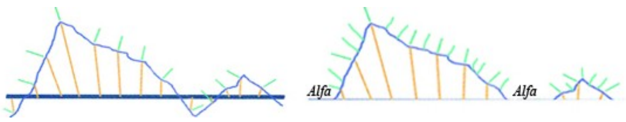

Figure 2: Designated area for primary displacement map

For such a created image map, we introduce a term primary displacement map. Having applied the primary displacement map, the observed relief is segmented while keeping accurate topology of the observed surface. This is the way to physically create a polygon network where the peak of individual polygons are shifted in the direction of the heightmap and reflective qualities of the surfaces defined by those peaks are influenced on the basis of the corresponding normal map. Polygons which have the alpha channel dedicated on the basis of the heightmap are not influenced by this map, therefore we can apply a residual heightmap on them. For this map, we introduce a term secondary displacement map. Despite the fact that the map is more segmented (from the polygon size point of view), there is no conversion of the secondary displacement map into a polygon surface, which will result in a significant reduction of the needed polygons while keeping a physically corresponding value of the given visualisation. In order to specify light simulations more exactly in the secondary displacement map, we will use a virtual displacement mapping with an assigned normal map. A normal map contains information on the angle of incident of the reflected light on the surface of the visualised sample. (Fig 3).

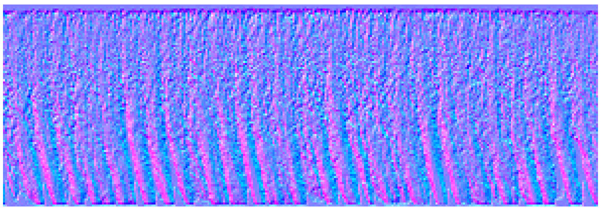

Figure 3: Visualisation of normal map

In fact, it concerns a combination of displacement mapping with normal bump mapping using alpha channel in the displacement map. With respect to the above -described, we have used a term double displacement for this kind of visualisation of a large number of surfaces concentrated into a small area. The network must be chosen in a way that the corresponding visualisation would conform to the information contained in the corresponding image maps. At best, it is necessary to choose such dimensions which would correspond to the dimensions of the visualised surface. The density of such a polygon network is given by the corresponding primary displacement map. (Fig. 4). Depending on the required speed and accuracy of rendering, it is possible to influence this density by changing the relevant attributes with respect to the visualisation software itself. These attributes relate to conversion of the rendered object into triangles designed for subsequent rendering (tessallation).

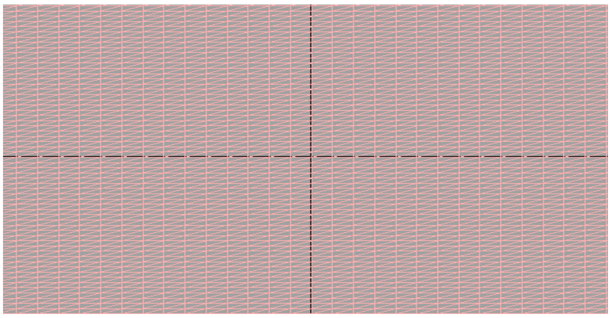

Figure 4: Reference polygon network (zoomed 20x)

It appears that it is not relevant whether the reference polygon network has been created by polygon modelling because in the case of any modelling, rendering itself of any object in the scene is given by this conversion. A reference polygon network thus creates a virtual space (which is possible to be visualised) containing information on the shift of polygon peaks with respect to the primary displacement map. In a reference polygon network, we define only dimensions along axis x and y. the dimension in direction of the x axis is defined by the corresponding primary displacement map on the basis of information contained in the height map. Having applied the primary displacement map on this polygon network, we will use the information contained in this map to generate own polygon surface, where the peaks of individual vertices will be moved (Fig 5).

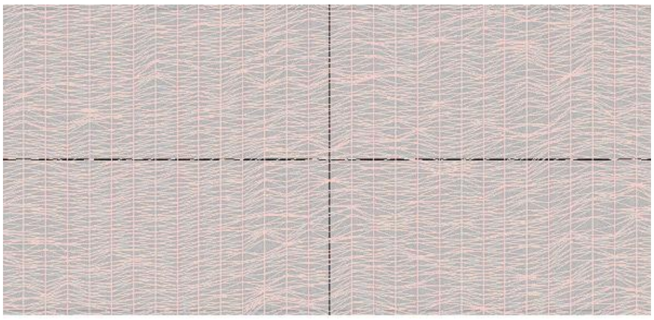

Figure 5: Polygon surface (zoomed 20x)

The places that we define the primary displacement map by alpha channel will keep the original topology of the reference polygon network, which will result in zero change of orientation of the individual polygon peaks with respect to the axis z. We then map in a normal map on such a created object and we assign it corresponding material-optical qualities of the visualised surface of the particular material. It primarily concerns attributes defining reflexive refractive, and diffusive qualities which are related to the distribution of luminous fluxes on given surfaces and which are traceable in material tables. It is then possible to proceed to incorporation of information contained in the secondary displacement map. As this map fills in places which are invisible from the point of view of the primary displacement map it will result in polygon rendering on this part of the surface on the basis of the reference polygon network. Rendering of the secondary displacement map proceeds on the principle of virtual displacement mapping taking into consideration that, with respect to the normal map, there will be a change of orientation of individual normals within the secondary displacement map without changing the typology type of the generated polygon surface. In our proposed conception of visualisation of surfaces by abrasive waterjet, the final visualisation is composed of the primary and secondary displacement map and normal map hand in hand with the corresponding material allocated to the generated polygon surface. The scheme of double displacement applied on aluminium is indicated by a so-called shading network diagram (Fig 6)

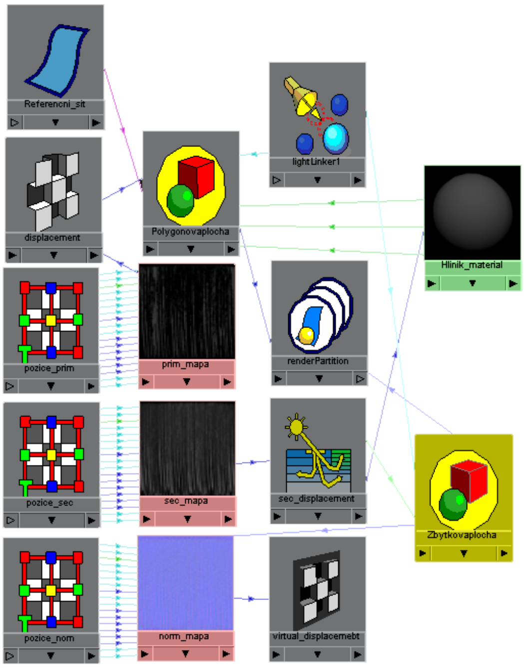

Figure 6: Schematic demonstration of double displacement

To simulate light interactions on surfaces acquired by AWJ, we stem from possibilities of global illumination algorithms, Final Gathering and the method of photon maps, applied on a surface generated by double displacement. Optimal setting of attributes related to rendering algorithms has a crucial influence on the speed of rendering, quality, and usability of the final synthetic image of the simulated surface. We assume that, with respect to theoretical combination presumptions of the photon map method with algorithm Final Gathering, there will be a rapid decrease in the rendering time.

EXPERIMENTAL SET UP

The initial material for experimental purposes was unalloyed titanium with the specification ASTM B265-99, supplied in the annealed condition.
Testing of the rendering speed and image qualities of the visualised surface has been carried out only on the surface generated by the primary displacement.
Table 1 shows that the change of value Global illum radius has a key influence on the speed of rendering, unlike attribute Global illum accuracy, whose influence on the speed of rendering can be neglected. The energy value does not influence the speed of rendering, the same for the exponent expressing attenuation of the light intensity. The energy correspond to energy balance of the emitted photons inside the visualised scene. Value 2 corresponds to a physical model of spreading light in space.

Table 1: Effects of photon map method attributes to the speed of the visualised scene

Photon map method				
Accuracy	Energy	Exponent	Radius	Time(min:sec)
1	8000	2	0	13:34
50	8000	2	0	13:32
100	8000	2	0	13:31
200	8000	2	0	13:32
300	8000	2	0	13:34
100	8000	2	0.1	22:54
200	8000	2	0.2	25:26
300	8000	2	0.5	40:02

The basic disadvantage of using photon maps is a relatively high time-exigency to process synthetic image. Incorporation of algorithm Final Gathering into this process results in reduction in calculation of emitted photons into the scene, which will finally lead to reduction in the rendering time while keeping quantitatively corresponding visualisation. It is given by the algorithm itself, which uses information acquired by the method of photon maps on distribution of photons focused into the visual field of the observer. In the case of visualisation of surfaces acquired by AWJ, the surfaces are rendered in two phases. The first phase sets attributes of the method of photon maps. The next phase carries out implementation of algorithm Final Gathering and testing of influences of corresponding parameters on the speed of rendering. Table 2 shows optimal value setting.

Table 2: Impacts of attributes of method Final Gathering on the speed of rendering of the visualised scene

Final Gathering			
Final gather rays	Min radius	Max radius	Time(min:sec)
100	0	1	15:30
200	0	1	22:12
300	0	1	27:46
400	0	1	30:06
100	0.01	1	12:17
100	0.05	1	05:33
100	0.1	1	04:22
100	0.5	1	02:03
100	0.1	0.1	12:16
100	0.1	0.2	06:38
100	0.1	0.5	04:27
100	0.1	1	04:16

On the basis of the presented data, we can declare that in the case of visualisation of surfaces acquired by AWJ using our introduced method of double displacement, the interconnection of the method of photon maps with method Final Gathering leads to time-acceptable requirements in the visual device. Implementation of Final Gathering into the algorithm of the method of photon maps leads to a significant reduction of the rendering time while keeping the corresponding information of the synthetic image. Fig. 7 shows realised simulation of an aluminium surface using the method of double displacement.

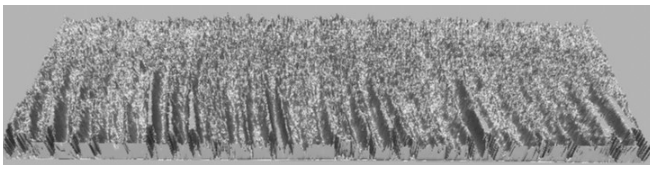

Figure 7: Final visualisation of a titanium microuroughness on the surface acquired by AWJ, using double displacement method.

Another advantage of our introduced method of double displacement for visualising surfaces acquired by AWJ using global illuminating algorithms Final Gathering and the method of photon maps is visualisation of photon maps on relevant surfaces. Classical methods of rendering techniques, stemming from bump mapping, cannot principally simulate distribution of photons on individual parts of the visualised surface. Thanks to creation of a polygon surface on the basis of double displacement, we have at our disposal relevant reference polygon surfaces where photon distribution takes place within the observed scene, which is not possible in the case of rendering bump mapping techniques. Existence of a diffusive surface is a condition for creation of a corresponding photon map. For visualisation of photon maps, we stem from the consequences of creation of photon maps on diffusive surfaces, which participate in the spread of light distribution on the visualised surface and in visualisation of photons participating in caustics phenomenon, which is related to light reflections.

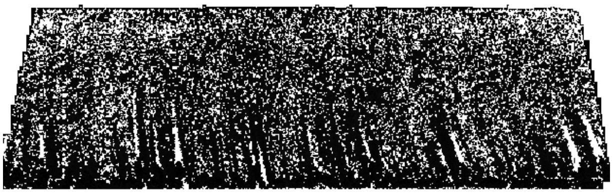

Figure 8: Visualisation of a photon map

According to Fig. 8, white areas correspond to photons participating in caustics phenomenon, which in physical interpretation refers to those surface parts whose division was primarily done by the used abrasive. The other surface parts, rendered in a dark colour, correspond to surfaces which were divided by waterjet almost instantly without a direct influence of the contained abrasive. This visualisation consequence leads to relevant technological conclusions in the choice of a suitable dividing cut. In the case of hard materials, the division itself is rather done by the selected abrasive which leads to creation of surfaces with a high level of reflexive surfaces, which will lead to area visualisation with a high ratio of photons participating in caustics phenomenon. The distribution of photons which simulates diffusive or reflexive reflections in individual areas of the examined surfaces is influences by material-optical qualities stemming from the concrete shading network of the applied material on the object surface and from the corresponding primary displacement map. The size of the area, where is it decided if it concerns a reflexively or diffusively reflecting surface, is done by changing the values stemming from the setting of illuminating algorithms. In the case of the method of photon maps, the value corresponds to the value of Global illum radius.

RESULTS AND DISCUSION

The paper has introduced a method of 3D visualisation of microsurfaces acquired by dividing abrasive waterjet. Based on information stored in image maps using the pre-set method of double displacement, we optimised the combination of global illumination methods of Final gathering and photon maps, which has led to a high level of lifelikeness of the visualised surface in time-acceptable sequences. Such a surface, visualised by distributed luminous fluxes on the surfaces defined by material-optical qualities of particular materials, can be further processed for definition of surface qualities, both from the point of view related to geometric surface qualities of the observed sample and comparison of optical qualities of the light source with respect to wavelength, intensity, or angle of incidence of the light beam. The presented procedures, related to the proposed conception of visualisation solution of unevennesses on surfaces acquired by AWJ, also enable to categorise areas of the visualised surface which are created by primary activity of the used abrasive or primary activity of the waterjet.

Our proposed and realised solution significantly improves the possibilities of comparative analysis against the possibilities of conventional bump mapping techniques, which are dependent on the position of the observer (in certain angles the bump mapping effect fades out) and which do not enable to visualise such phenomena, such as shades, reflections and refractions on the visualised surfaces, related to the change of orientation of the light source in the scene. Moreover, conventional methods of displacement mapping leading to generation of corresponding surfaces on the basis of information stored in height and normal maps fail with respect to unbearable amount of polygon planes necessary to visualise a great number of polygons concentrated in small areas. The presented conception of the solution removes these disadvantages.

APROACH TO THE SOLVED PROBLEMS

The presented method of 3D visualisation of microsurfaces acquired by technological division by abrasive waterjet enables to:

- Render the relief of the visualised sample surface.
- Generate a polygon plane representing significant surface unevennesses.
- Take into consideration material-optical qualities of the observed sample.
- Visualise distribution of luminous fluxes on the visualised surface.
- Take into consideration qualities of the light source with respect to the visualised surface

CONCLUSION

For the following period, we can set tasks related to practical optimisation of our proposed methodology of double displacement in the area of comparative analyses, or selection and implementation of this methodology into various programming tools when using a wide range of global illumination methods in 3D scenes, particularly in cooperation with the staff of the Institute of Geonics, AS CR in Ostrava, company AQUACLEAN in Bratislava, and company REZMAT in Dubnica nad Váhom. Another part of further work is application of the achieved results and pedagogical knowledge when familiarising students with possibilities of 3D graphical visualisation hand in hand with theoretical and practical impacts of the solution in the problem area.

Questions of further research in the following period are formulated in the following lines. It concerns definition of a suitable threshold value for creation of primary displacement maps, stemming from heightmaps, with subsequent definition of nominal parameters. Definition of suitable density of the corresponding reference polygon plane in dependence on the map of unevennesses acquired by optical measuring technological processes defined by requirements on the final visualisation. In addition, possibilities of comparative analyses on the basis of the corresponding photon maps or energy light maps stemming from the possibilities of analysis and image processing. Last but not least, research on impacts of usage of various visualisation algorithms on visualisation of analysed surfaces.

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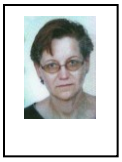

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