

COMPARISON OF SURFACE DATA

Exploring Real Samples Similarity for the Modelling of Engraving

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Abstract: The paper deals with the topic of real samples comparison. The whole research is processed as a part of the laser engraving modelling and simulation, for which real engraved and scanned samples are used as the input and which are further processed before their usage. All samples are represented as height maps, so we try to use MSE or PSNR computation for the comparison of samples. However, because of a special character of the samples, several problems have to be solved. Finally, the results for the whole set of data engraved into steel surface is presented and some interesting results are shown.

1 INTRODUCTION

This work is a part of larger project dealing with development of a special laser device with precise control and its modelling and simulation, which should assure exact results usable for physical research. All methods and results described in this paper solve only a small but very important part of the whole research of data pre-processing, more concretely, the mutual comparison of processed real samples.

Methods for sample comparison can be used for example for the verification of the modelling and simulation or, as shown in this paper, for exploring real data. Real data comparison is important for discovering the similarities among real samples and the interaction between the laser beam and the material surface. Because all the used methods are already described in detail in (Hájková, 2008), only some basics are outlined in Section 4, the main aim of the paper is to show similarities and divergences of real samples in dependence on the engraved experiment (described in Section 5).

2 LASER ABLATION

Because we want to explore real samples and compare them, we should first understand the process of laser engraving and especially the material ablation in detail. A laser beam is an

electromagnetic radiation. When this radiation strikes a surface of a material, some radiation is reflected, some absorbed and some transmitted. The irradiated material is most affected by the absorbed part of the radiation, which causes heating of the surface. The heat generated in the surface directly affected by the laser beam is conducted into the material. If the laser intensity is high enough, the material heats, melts, and if it reaches the boiling point, it starts to vaporize. A part of vaporized particles interacts with the laser beam and creates plasma, the other particles, which are not affected by the laser beam, approximately 18% of them as mentioned in (Anisimov, 1968), condense back to the surface of the material.

The previous description relates to the situation when the laser irradiates the sample continuously and the material is heated constantly during the whole engraving. If we engrave more laser beam pulses into one place on the surface, the temperature of the material increases during each laser pulse. Between each two consecutive pulses, the material surface cools down in part, but not fully. That is why the initial temperature is always higher and higher with each subsequent pulse. The evolution of temperature of such sample is shown in Figure 1.

To sum up the whole engraving process: if the surface of the material is exposed to an intense pulsed laser beam it creates a rapid rise in local temperature. The surface warms up and the material starts to ablate. The ablated material then redeposits around the irradiated area and together with various

local defects and original roughness of the material causes many problems in samples processing. Finally, at the exposure site, a pit with a transition ring around it is left behind (an example can be seen in Figure 2). The result of the engraving process depends on the used material, its roughness, and parameters of the laser. The whole process is described in detail in (Dahotre and Harimkar, 2008) or (Steen, 1991).

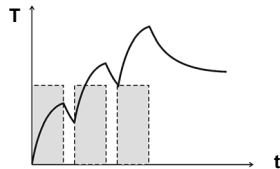


Figure 1: Evolution of surface temperature during engraving multiple laser beam pulses into the same point.

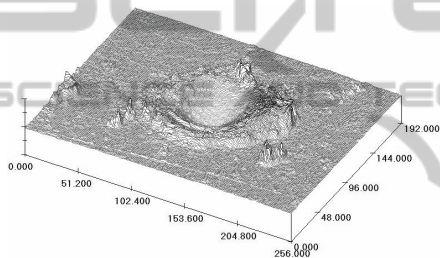


Figure 2: Sample 3D view from the conf. microscope.

3 REAL DATA DESCRIPTION

As already mentioned, we use real data as the input for the modelling of laser engraving. Samples originate from real samples engraved by a laser into a material surface. All samples are engraved into the specified material (we use steel) with the given laser (BLS-100 Nd:YAG solid-material, lamp-pumped laser with the wavelength of 1064nm), each sample is separately measured by a confocal microscope (Olympus LEXT OLS3100) and saved in the form of a height map. This height map is formed by a matrix of real numbers, which express the heights in a uniform rectangular grid. The dimensions of the samples reach approximately several hundreds of micrometers.

3.1 Experiment Description

We use the special testing data set consisting of samples engraved by the laser into a single point of the material. Such testing data should prevent potential faults caused by the external influences in a

maximum possible way. The number of pulses goes in sequence: 1, 2, 5, 10, 20, 30, ..., 100. Because each sample is unique, samples differ from each others even if the same experiment description has been engraved repeatedly under the same conditions and with the same laser settings. That is why each experiment is repeated five times in order to get sufficiently representative data set.

4 METHODS FOR COMPARISON

If we compare two height maps, we should make sure that both the surfaces are aligned properly. That is why it is very important to regularize all the samples before the comparison itself. Moreover, we need to compare only those areas which were modified by the laser beam. For this purpose, we use methods designed for the automatic detection of the heat-affected area described, e.g. in (Hájková, 2011).

As can be seen in Figure 3a, the size of both areas can differ and so we have to unify (enlarge) the detected areas so that they both have the same dimension and the heat-affected areas lie exactly in the middle (as shown in Figure 3b).

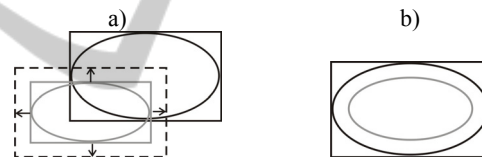


Figure 3: a) Two heat-affected areas of different sizes; b) unifying expansion of selection dimensions.

Finally, the level of material in both the samples is recomputed to have the same height. Then, we can compute the similarity of both samples. For our test, we have used two approaches: MSE and PSNR computation described in following sections.

4.1 MSE (Mean Square Error)

This method computes the mean square error (MSE) of two height maps. It is defined by the equation 1, where $W \times H$ represent the dimensions of the height maps and $A(i, j)$ and $B(i, j)$ indicate single points in the given position $[i, j]$ in the height map grid. The resulting value expresses the average error for each point.

$$MSE = \frac{1}{W \times H} \sum_{i=0}^{W-1} \sum_{j=0}^{H-1} (A(i, j) - B(i, j))^2 \quad (1)$$

It is not difficult to see that the more identical the samples are, the lower the MSE is computed. So, if

we want to find a pair of height maps that are the most similar, we look for the minimal value of MSE.

4.2 PSNR (Peak Signal-to-Noise Ratio)

The PSNR method uses MSE as a semi result. The PSNR value is computed according to the equation 2, where the MAX value represents the highest point in the height map.

$$PSNR = 10 \cdot \log_{10} \left(\frac{MAX^2}{MSE} \right) \quad (2)$$

PSNR works in an inverse way, so if we are looking for the most similar height maps, their PSNR has to be the highest one.

5 RESULTS

We have used the approaches and methods described above to explore a real data set to discover the similarities and differences of samples. For our testing, we have used an experiment described in Section 3.1 that is a sequence of 1 to 100 laser beam pulses engraved into a single point on a steel surface. This sequence was engraved five times, scanned and the heat-affected area was detected for each sample.

In the next step, all samples were mutually compared (each with each other) and the results of MSE and PSNR were collected in (Kotásek, 2010). Then we have selected different combinations of comparisons and we were searching for variations within them. Although there were some small differences, the global trend was the same for all of them and is discussed as follows. All values are summarized in Table 1 (MSE) and Table 2 (PSNR).

5.1 Measured Values

Let us have a look on Table 1 first, where MSE values are summarized. The more similar both tested samples are, the smaller the MSE is computed. That is why the smallest values are expected on the diagonal of the table, where samples with the same number of laser beam pulses are compared. In each column of the table, the smallest value is highlighted in bold. Although in some cases the minimal value does not lie exactly on the diagonal, it is always very close, most usually the neighbouring one. These imperfections are typically caused by the local defects that can be found in the samples. In Table 2 with PSNR results, the highest values are computed for the most similar samples and are also highlighted in bold. Also in this case similar problems with the position of the maximal values can be found.

Besides exploring the real samples discussed in

Table 1: Results of the MSE computation.

	1	2	5	10	20	30	40	50	60	70	80	90	100
1	0,69	2,00	1,55	11,89	12,51	10,90	9,66	27,27	29,13	41,58	44,87	23,80	44,38
2	2,00	1,35	3,26	10,81	11,55	10,37	8,98	24,55	26,41	37,52	40,83	21,41	40,33
5	1,55	3,26	0,81	10,73	11,59	9,91	9,70	27,24	29,40	42,41	45,73	24,91	45,27
10	11,89	10,81	10,73	1,16	2,10	2,50	2,34	7,04	9,41	16,04	18,69	8,04	17,67
20	12,51	11,55	11,59	2,10	2,37	3,01	2,56	7,27	9,53	16,43	18,82	8,37	18,40
30	10,90	10,37	9,91	2,50	3,01	2,83	2,75	8,65	10,80	18,30	20,68	9,19	20,34
40	9,66	8,98	9,70	2,34	2,34	2,75	1,15	6,99	8,78	16,00	18,22	6,70	19,15
50	27,27	24,55	27,24	7,04	7,27	8,65	6,99	2,40	4,23	6,23	8,04	3,79	7,70
60	29,13	26,41	29,40	9,41	9,53	10,80	8,78	4,23	5,07	7,06	8,69	4,33	8,73
70	41,58	37,52	42,41	16,04	16,43	18,30	16,00	6,23	7,06	5,04	6,85	6,12	6,23
80	44,87	40,83	45,73	18,69	18,82	20,68	18,22	8,04	8,69	6,85	7,19	7,67	7,85
90	23,80	21,41	24,91	8,04	8,37	9,19	6,70	3,79	4,33	6,12	7,67	1,03	7,72
100	44,38	40,33	45,27	17,67	18,40	20,34	19,15	7,70	8,73	6,23	7,85	7,72	3,45

Table 2: Results of the PSNR computation.

	1	2	5	10	20	30	40	50	60	70	80	90	100
1	39,58	35,25	36,62	25,85	23,75	26,39	25,55	22,05	21,40	20,87	19,33	20,88	18,66
2	35,25	37,91	31,37	26,60	24,2	26,55	26,05	23,01	22,20	21,83	20,18	21,83	19,53
5	36,62	31,37	41,25	26,66	24,42	27,09	25,27	21,93	21,30	20,60	19,04	20,37	18,43
10	25,85	26,60	26,66	44,97	41,76	41,01	40,03	34,14	31,27	29,78	27,35	30,49	26,92
20	23,75	24,20	24,42	41,76	38,59	39,96	38,64	34,46	31,64	29,90	27,46	30,21	26,92
30	26,39	26,55	27,09	41,01	39,96	40,07	39,75	32,53	30,45	28,74	26,71	29,76	25,95
40	25,55	26,05	25,27	40,03	38,64	39,75	43,19	34,37	31,97	30,04	28,22	32,10s	26,18
50	22,05	23,01	21,93	34,14	34,46	32,53	34,37	42,51	40,61	39,07	35,60	39,62	34,78
60	21,40	22,20	21,30	31,27	31,64	30,45	31,97	40,61	39,18	39,55	36,54	38,88	34,51
70	20,87	21,83	20,60	29,78	29,90	28,74	30,04	39,07	39,55	40,86	39,21	40,20	38,25
80	19,33	20,18	19,04	27,35	27,46	26,71	28,22	35,60	36,54	39,21	37,09	36,86	35,93
90	20,88	21,83	20,37	30,49	30,21	29,76	32,10	39,62	38,88	40,20	36,86	47,32	34,44
100	18,66	19,53	18,43	26,92	26,92	25,95	26,18	34,78	34,51	38,25	35,93	34,44	40,71

this paper, we also wanted to discover, which computational method is better to use for the automatic determining of the most similar samples. It is noticeable that the MSE and the PSNR give analogous results for determining the similarity (extremes in both tables are bold at the same positions), but the MSE seems to give better results for the automatic comparison, because the values representing the most similar samples can be well distinguished from the others (e.g. by thresholding). The most similar samples are in Table 1 highlighted with gray colour.

5.2 Results Visualization Discussion

Visualization of Table 1 brings some more interesting facts. The MSE results can be seen in Figure 4. In the plot, the horizontal axis shows the sequence of samples and the curves express the similarity of the individual samples. The distance between the samples determined as similar and not-similar is noticeable. An interesting characteristic can be seen in the plot the cumulating of the curves representing the similarity of a sample to each other.

If we take a look more closely, we can see that curves representing the samples with small number of pulses (1, 2 and 5) are placed close to each other in the plot. Also, the values in Table 1 do not differ a lot. The same situation can be discovered for samples with 10 to 40 pulses and then for samples with 50 to 100 pulses. So, samples can be divided into groups, in which they are similar to each other, but are very different from samples in the other groups. This is also the reason, why the curves are not labelled separately, but only in sets. The situation between two groups is more closely shown in Figure 5.

6 CONCLUSIONS

As can be seen from the described results and plots, the number of laser pulses engraved into one point of the material influences the ablation process a lot. What is the reason of the described relations? Accumulating temperature during the ablation process and so changing nature of the irradiated material. The heated material behaves differently if it is heated for a while or for a longer time.

So far, we have studied mainly samples engraved into steel, where all the laser pulses were engraved into a single point on the material surface. Our further plan is to explore the results when the laser is moving above the material surface with a constant or even a variable speed. In our future work, we would

also like to conduct more experiments with different laser settings and/or engraved into different materials and search for the next dependencies, how the engraved experiments influence the ablation process and the final shape of the material surface.

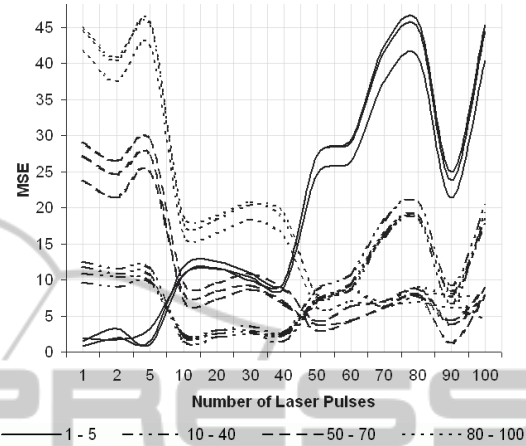


Figure 4: MSE results visualization.

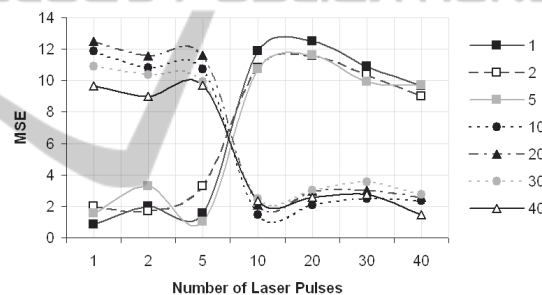


Figure 5: MSE computation results – detail of sweeping change of samples similarity.

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