THE INFLUENCE OF MICROSTRUCTURE OF 3D PRINTING ON TACTILE PERCEPTION OF HUMANS

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Abstract: *Braille script is one of the most important communication tools for visual disable people. This script is a group of six points, systematically composed into Braille cell representing each letter or number in alphabet. It has been used for marking medicine, entrances or exits and other items. The Braille script can be made from different materials, usually paper or metal desks applied to the required surfaces. In this work, Braille cells were applied by multi layered 3D printing directly to the textile surface taking into consideration the right preparation of substrates. 3D printing is created on basic cotton canvas in two variants: rough porous printing with micro roughness and smooth printing with minimal changes in roughness. A comparative evaluation for these two kinds of 3D printing was carried out to measure the micro roughness and the height using electron and confocal microscopy. Then, a qualitative study for the ability of blind people with different defects of visual impairment to recognize and read the printed Braille script was done. Blind people are using mechanoreceptors, especially Vater Pacini corpuscle, to provide information about the texture, pressure and vibration. Results of this study can define future modifications to examine influence of micro and nano structures on the tactile properties of 3D printed Braille scripts and other applications.*

Keywords: *3D printing, human perception, roughness component.*

1 INTRODUCTION

Tactile interactions are obviously ubiquitous and essential. A person could use the sense of touch to feel for the smoother fabric of his business clothes in his closet. On the other side one of the biggest problems of blind people is visually differentiating of clothes sizes, colors and clothing maintenance [1]. Visually impaired people generally need help with these activities, because manipulation with their textile garments becomes problematic. In the moment when color readers are expensive, these individuals need help of others. The human hand is a complex organ serving the functions of grip and touch. The mechanoreceptors of the hand can be categorised into those located within skin and subcutaneous tissues and those associated with joints and muscles providing the central nervous system with information about position of movement of hand and fingers. In addition to mechanoreceptors there are numerous free nerve endings reacting to thermal and painful stimuli generally referred to as polymodal nociceptors. They are found in the connective tissue of the locomotion apparatus as well as the skin and even enter the epidermis. Morphologically these are terminal branches of afferent nerve fibres without any specific structures around these 'free' nerve endings in marked contrast to the different types of mechanoreceptors [2].

Four types of mechanoreceptive afferents have similarly been identified by microneurography and tentatively matched to mechanoreceptors [3]. The afferents vary based on their rate of adaptation to stimuli, either slowly adapting (SA) or rapidly adapting (RA), as well as the size of their receptive field, small (I) or large (II). The slowly adapting receptors, Merkel receptors (SA I) and Ruffini cylinders (SA II), are respectively most sensitive to pressure (0.3-3 Hz) and stretching of the skin (15-400 Hz) [2]. The rapidly adapting receptors, Meissner corpuscles (RA I) and Pacinian corpuscles (PC or RA II), are on the other hand most responsive to taps on the skin (3-40 Hz) and vibrations (10-500 Hz) [2]. The neurophysiology of touch is however much less developed than vision or audition, with recent studies, for example, shedding doubt on the very existence of Ruffini cylinders in the human glabrous skin [3].

The objects which have been handled vary in shape and size. Cutaneous primary afferent responses are affected by the local shape of the object in contact with the skin. Afferent responses have been characterised for a range of shapes either scanned over the receptive field or indented into the receptive field. Local shape is conveniently expressed in terms of the local curvature of the object; the curvature at any point is the reciprocal of the radius of curvature at that point.

In Figure 1a, a wavy surface of increasing curvature scanned across the receptive field of an SA I afferent results in increasingly modulated responses of the afferent [4]. For a sphere of increasing curvature (decreasing radius) indented into the skin (Figure 1b).

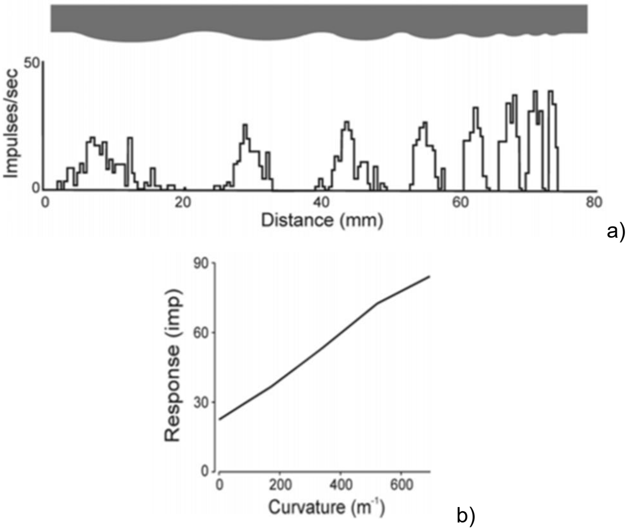


Figure 1 DAI afferent responses increase as the curvature of object increase: a) wavy surface of increasing curvature scanned over the fingerpad; b) spheres of increasing curvature (decreasing radius) indented into the fingerpad

Tactile roughness is a complex, multidimensional sensation that is dependent on the physical characteristics of multiple tactile elements (e.g. grains of sand for abrasive papers), including their size, shape, density (or spacing) and composition. To assess the underlying neuronal coding mechanisms, have been used the nature of the relation between perceived roughness and surface characteristics. For relatively coarsely textured surfaces, the dominant view at present is that the neural representation of tactile roughness can best be explained by a spatial variation code whereby differences in the firing rates of slowly adapting type I. Sutu et al. [5, 6] confirm hypothesis that dot height is the critical factor underlying the shape of the psychometric curve relating tactile roughness with dot spacing: monotonic increase versus inverted U-shape. This hypothesis has been tested and confirmed in this case study by controlled measurement of surface roughness of textile 3D print allows preparing not only readable characters of Braille symbols, but also association with pattern design as integral component of whole design [7].

2 EXPERIMENTAL

2.1 Materials and methods

Surface profile measurement is achieved by measuring a line across the surface and representing that line mathematically as a height function with lateral displacement, z(x). When measuring and characterizing surface texture, use is made of the rectangular coordinate of a right-handed Cartesian set, in which the x axis provides the direction of the line, the y axis lies nominally on the real surface and the z axis is the outward direction from the material to the surrounding medium.

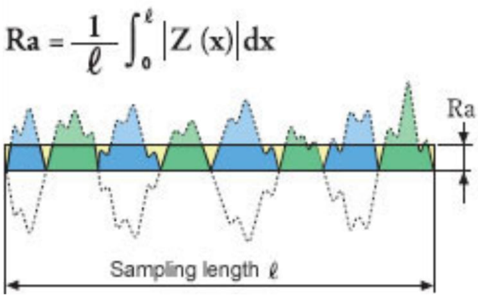
Samples were measured by three different systems of roughness measurement. First apparatus was laser scanning confocal microscope OLYMPUS LEXT OLS3000, second was Taylor Hobson stylus-based roughness meter TALYSURF and last method was based on 3D optical scanner ATOS 7 SR2 from GOM Company.

LSCM LEXT system 5x objective in bright field capturing mode and computer controlled moving xy stage have been used in the experiment. TALYSURF CLI 500 system was primarily equipped by Laser Triangulation gauge, which is a non-contact gauge capable of rapid 3D measurement and ATOS Compact Scan 2M optical scanner was equipped by fine optics.

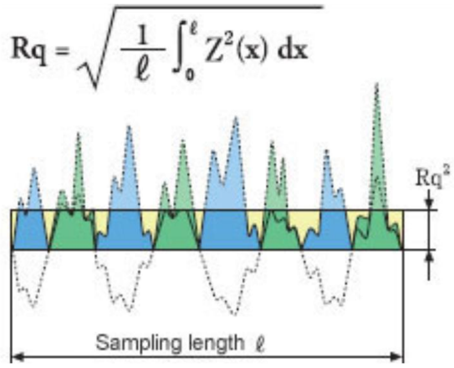
In order to evaluate the surface quality, this study pointing out the importance of evaluating a set of parameters and not only one. A roughness value can either be calculated on a profile (line) or on a surface (area). The profile roughness parameter (*Ra, Rq*,...) are more common. Figure 2 shows five profiles characterized by the parameter set (*Rq, Rsk, Rku*) [8].

But what happens when it's investigated the same set of parameters, but related to 3D measurements (*Sq, Ssk, Sku*). Most of the 2D parameters defined in ISO 4287 have a mathematical expression that can easily be extended to 3D. For example, *Sq* is simply an extension to a plane of the equation of *Rq* that is defined for a line:

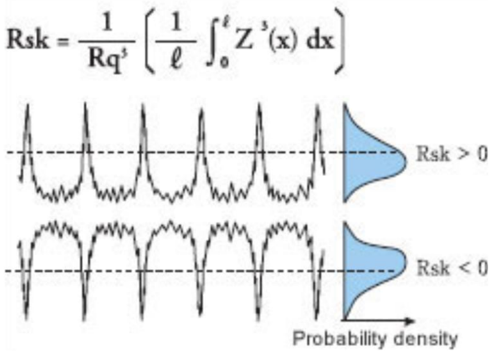
$$Rq=\sqrt{\frac{1}{lb}\int_{lb} Z^2(x)dx}$$
$$Sq=\sqrt{\frac{1}{A}\iint_{A} Z^2(x,y)dxdy} \tag{1}$$



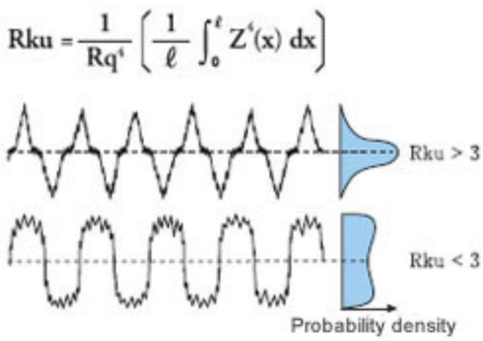
a) arithmetical mean deviation of the roughness profile



b) root mean square deviation of the roughness profile



c) skewness of the roughness profile



d) kurtosis of the roughness profile

Figure 2 The roughness profile

3D prints have been prepared on six different textile substrates with different roughness (twill, two canvas, knit, lining and satin) as shown on picture in Figure 3 by using of EXPANCEL microspheres.

Figure 3 Picture of several tested textile samples with Braille symbol of "Hand Washing" and detail of Braille symbol "Non-ironing" printed on twill

An unexpanded EXPANCEL microsphere consists of a thermoplastic shell encapsulating a hydrocarbon. When this thermoplastic shell is heated it softens and at the same time the pressure of the hydrocarbon increases. This causes the shell to stretch and expand in much the same way as a balloon and resulting patterns obtain 3D character.

3 RESULTS

Each tested sample has been measured by all above-mentioned methods three times. Each sample was firstly captured by mode of maximal resolution allowed by each method. In case of LSCM Olympus LEXT OLS3000 microscope has been plane resolution, which clearly resolves 0.12 µm line and space patterns of 0.01 µm height, for ultra-precise measurements of micro fabrication surfaces. TALYSURF CLI 500 system all axes can move at 30 mm/sec and data log at 0.5 µm, which allows for fast and accurate measurement and ATOS Compact Scan 2M optical scanner allows resolution range 21-615 µm (in our case 21 µm). Because resolution limit of all these systems is below tactile resolution of human touch, Gaussian filters of 0.8 mm filtered all captured data profiles. As you can see on picture in Figure 5 high resolution of confocal microscope caused number of artifact peaks in bottom part of scanned profile, which will be unrecognizable for human touch. Resulting roughness profile after Gaussian filtering appears much smoother in comparison to roughness presented on Figure 4 and it is near to probable human resolution [7].

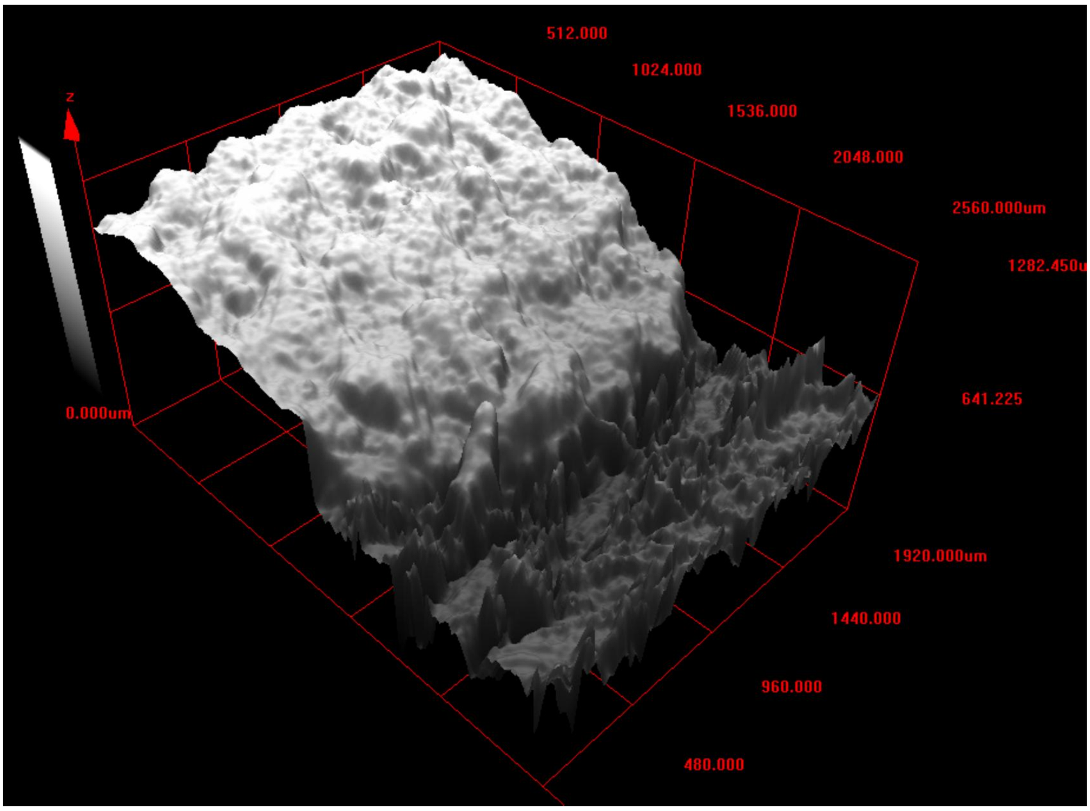


Figure 4 Scanned profile of knit – OLS LEXT

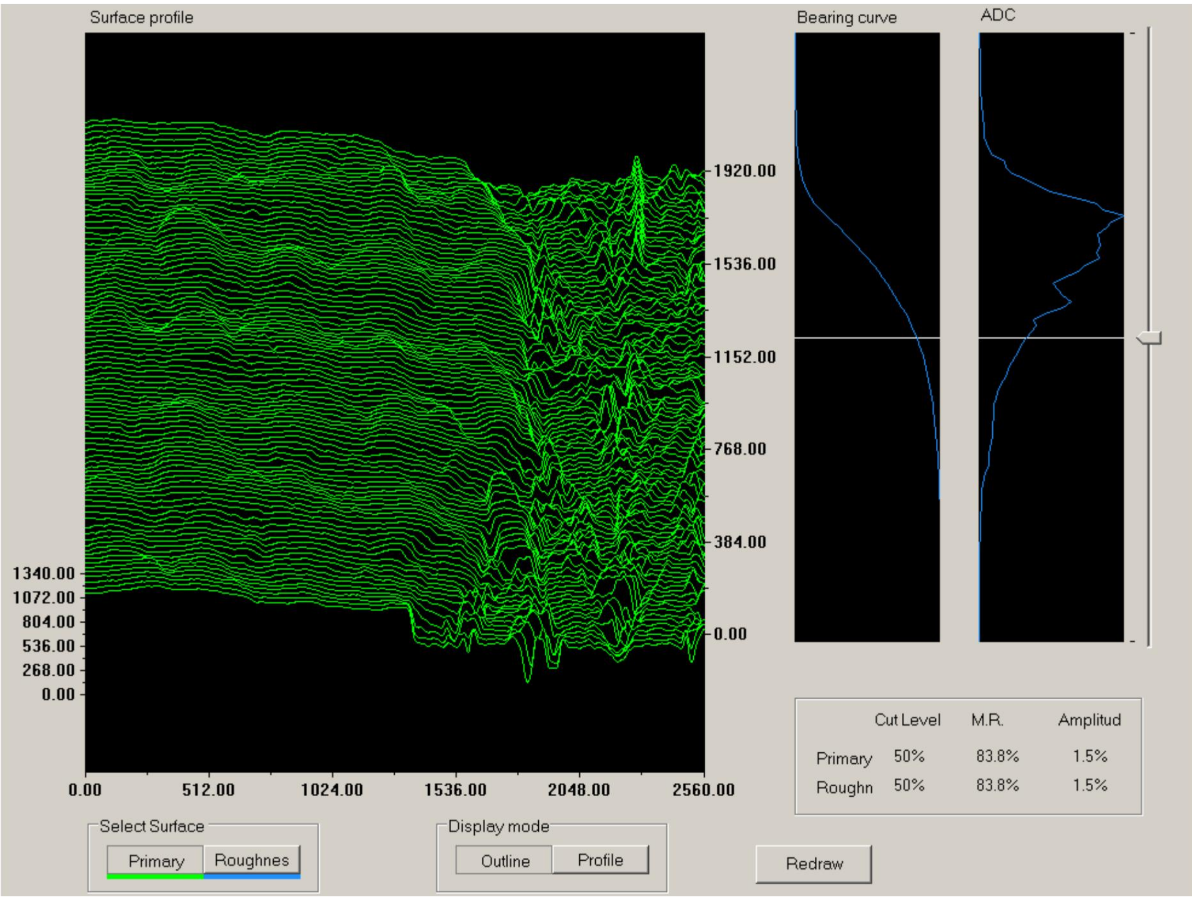


Figure 5 Plane roughness profile OLS LEXT - knit

In case of absolute resolution was TALYSURF system 5-times worse than used confocal microscope LEXT, nevertheless on picture in Figure 5 it is visible that used final resolution of this system is sufficient. Used Gaussian filtering, which is visible on bottom graph in Figure 6, shows less change in final profile of captured sample.

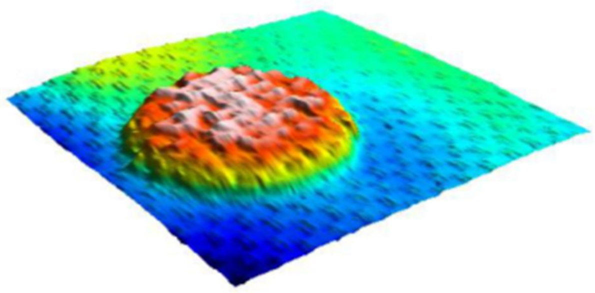


Figure 6 Scanned profile of satin – TALYSURF

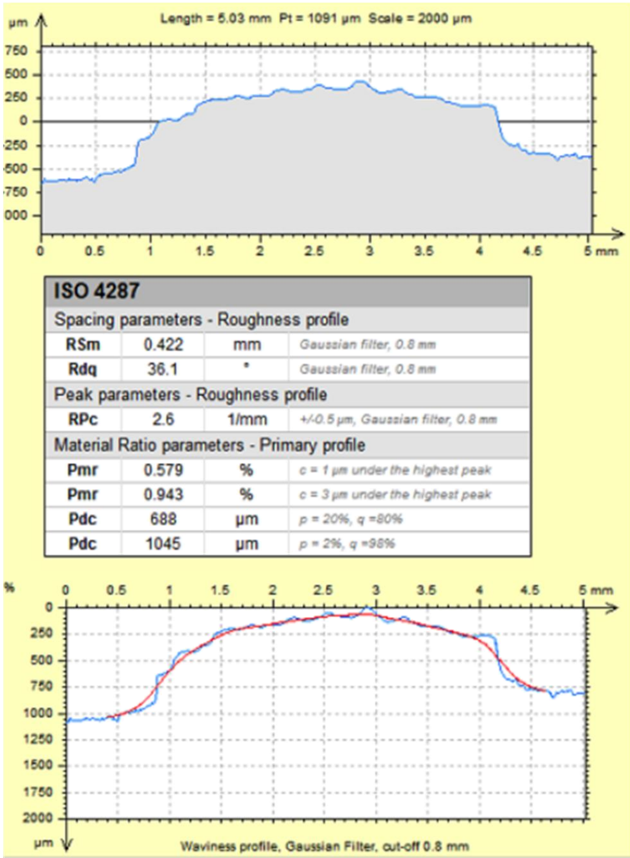


Figure 7 TALYSURF example of roughness analysis

Last method ATOS Compact Scan 2M optical scanner based on blue light technology allowing improvement of measuring system reliability independent of ambient light conditions is partially affected by necessity of special treatment of tested textiles. Because our samples have less reflectivity for blue light of this scanner, was necessary to cover surface of our samples by white chalk powder with high reflectivity. Resulting images were slightly smoothed by this powder as visible on picture in Figure 8, where typically pores of textile weave appear as coated by special finishing layer.

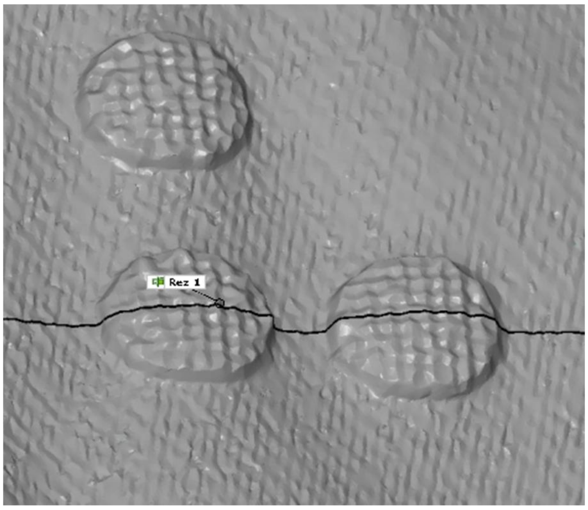


Figure 8 3D image of satin printed by Braille symbols captured ATOS Compact Scan 2M optical scanner

Powder treatment of surface tested textiles affects beside appearance of sample also measured roughness parameters as visible on graph in Figure 9, where is presented comparison of measured data of maximum peak height *Rp*.

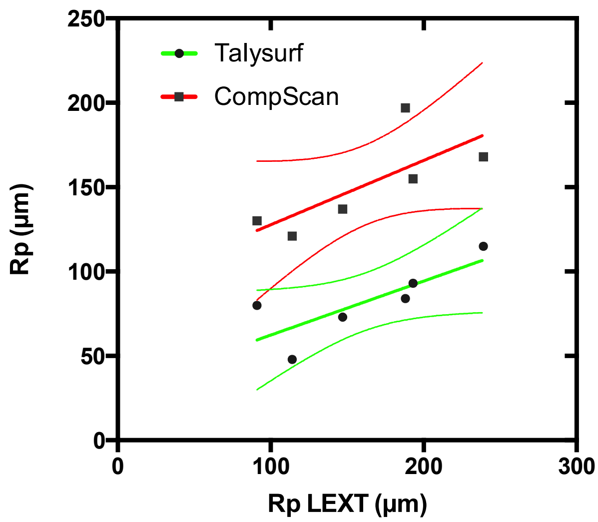


Figure 9 Relationship between maximum profile peak height (*Rp*) measured by tested profilometers

Table 1 Parameters of linear regression *y=a+b.x* in Figure 9

Device\Parameter	a	b	R^2
CompScan	90.427	0.3764	0.54
TALYSURF	28.911	0.3286	0.64

Regression budget shows that relationship between individual profilometers data is affected by flexibility of tested textiles. That means that presented measurements were influenced by insufficient flatness of tested textiles. Used method based on racks should be improved for next series of profile measurements. On the other side both compared methods show almost similar slope of trend.

4 CONCLUSION

Surface topography is of great importance in specifying the function of a surface. A significant proportion of component failure starts at the surface due to either an isolated manufacturing discontinuity or gradual deterioration of the surface quality. Typical of the former are the laps and folds which cause fatigue failures and of the latter is the grinding damage due to the use of a worn wheel resulting in stress corrosion and fatigue failure. The most important parameter describing surface integrity is surface roughness. In the manufacturing industry, surface must be within certain limits of roughness. This work shows, that most important factor beside above mentioned is sample preparation procedure. In case of optical method of surface topography are results affected by flexibility and less reflectance of textiles.

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