Optimizing Galvanic Process: Wet Surface Estimation for Small Metal Parts to Avoid Material Waste

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Abstract. The optimization of a galvanic process is a crucial task for many manufacturers in the field of electro-deposition industry. This is true for companies operating in the high fashion field, in which expensive materials are used and reducing material waste is crucial. In this paper, the estimation of the wet surface of small metal parts is treated. In fact, considering a single piece, the amount of material required to guarantee a desired plate thickness is directly proportional to its outer surface. Starting with a rapid overview on other methods to come up with this task, the attention in principally oriented to surface estimation by means of optical scanning. A preliminary test session has been carried out and two main issues arose. The first one is related to resolution and accuracy: due to pieces small dimensions and details, high performances are required to achieve valid results. The second and principal issue is related to the high reflectivity of pieces, even before electroplating. With the aim of avoiding the use of matting paint (which is difficult to remove), the attention has been focused on commercial solution dedicated to jewellery and dentistry fields. Three devices (based on white and blue LED structured light) have been tested on high reflective and specular pieces. From the analyses, only the one based on blue LED technology was able to retrieve high reflective surfaces without matting. Minor issues arose in case of specular surface. The device has been considered suitable for the task.

Keywords: Reverse engineering · 3D reconstruction · Galvanic · Blue LED structured light · 3D optical scanners

1 Introduction

The optimization of a galvanic process is a crucial task for many manufacturers in the field of electro-deposition industry, leading to the deposition of the correct amount of material on a given item. This is particularly true for companies operating in the high fashion field, which are demanded to electroplate small metal parts like studs, clips and buckles using expensive materials, such as gold or platinum. To remain competitive on the market, it is strategical to deposit merely the exact quantity of material necessary to achieve the quality requirements imposed by clients, which are generally expressed in

S. Gerbino et al. (Eds.): JCM 2022, LNME, pp. 743–754, 2023.
https://doi.org/10.1007/978-3-031-15928-2_65

terms of plating thickness. On its turn, coating material's mass can be expressed in two different ways. Faraday's laws [1] on electrolysis set a dependency between the mass deposited (m) on an electrode and current intensity (I) and time (t):

$$m = \frac{M \cdot I \cdot t}{Z \cdot F} \tag{1}$$

where:

- m = mass deposited on electrode [g]
- M = molar mass of the material to be deposited [g/mol]
- I = current intensity [A]
- t = time [s]
- Z = valence of material's ions
- F = Faraday's constant (96485.33 C mol^{-1})

In this case, it is possible to set electroplating parameters to obtain a specific mass deposit, independently from electrode geometry.

Alternatively, considering the coating as a shell, it is possible to relate mass deposit and coating thickness as follows, without a significant loss of accuracy:

$$m = tws \cdot T \cdot \rho \tag{2}$$

where:

- tws = total wet surface [mm^2]
- T = coating thickness [mm]
- ρ = material mass density [g/mm^3]

Consequently, combining Eq. 1 and Eq. 2 it is possible to relate T to current intensity and time and, therefore, it is possible to set electroplating parameters to obtain a specific coating thickness. Unfortunately, *tws* remains an unknown variable and should be determined to address the problem of minimizing the amount of material to be deposited.

On an industrial scale, several identical pieces to be treated by the same galvanic process are arranged on a frame by means of hooks or, more frequently, wires. This means that the total wet surface corresponds to n-times the wet surface of the single item (Eq. 3).

$$tws = n \cdot ws \tag{3}$$

Therefore, the evaluation of the wet surface requires not only the single item wet surface (ws) but also the knowledge of the number of the pieces arranged on the frame (n). Both tasks are quite challenging, especially for complex geometries and for poorly user-controlled arrangement on the frame.

The number of pieces arranged on a galvanic frame can be highly variable and, even if the frame and the item's typology are unchanged, a $\pm 10\%$ deviation is normally expected. This is because only some item typologies can be placed on hooks (e.g., buttons), whose number (and position) in the frame are fixed and (generally) all positions are occupied. Conversely, almost all item typologies can be manually knotted to wires. In this case, pieces arrangement on the frame is far from constant and so is their number.

In a previous work [2], authors propose a counting machine capable of automatically estimate the number of parts already mounted on a frame, by means of an automatic machine-vision based procedure. The machine is based on rear projection and a light projector is used to project frame shadow on a canvas. A fish-eye lens is used to capture the image of the entire canvas, whose dimensions approximately coincide with the frame ones (approximately 700×500 mm). The obtained image is then processed by means of a specifically developed computer vision procedure, based on binary images editing and analysis. Starting from a unique shadow, in which frame, wires and parts are connected, it separates the silhouette of each part and estimates their number with a more than adequate accuracy and precision. During a first testing campaign, a maximum error of around 2% has been reported.

For what concerns *ws*, this could be easily measured on the CAD model of the item, if the variations from nominal geometry introduced by the manufacturing process are neglected. Unfortunately, only a limited number of items are digitally modeled in the high-fashion field. Mostly, buckles and studs are made by casting molding, where molds are obtained from a handmade prototype. In these cases, *ws* must be directly measured on the item. In this paper, the attention is focused on the analysis of most promising devices that can be adopted to provide a reliable estimation of *ws*.

2 Wet Surface Estimation

Focusing the attention on wet surface estimation of small metal parts, one possible approach is based on electrochemical analysis, according to scientific literature. In particular, Jean-Claude Puippe [3] patented a method to estimate the surface area of copper plates by applying constant voltage to two electrodes immersed in a specific solution.

By measuring current intensity, it is possible to derive the measurement of the surface of the electrodes. Despite being promising, this approach revealed some critical issues and further investigation is required before obtaining stable and satisfactory results. For this reason, authors propose a direct *ws* measurement by means of 3D optical scanning.

2.1 3D Optical Scanning Approach: Feasibility Analysis

Optical scanning approach is based on the measurements performed on a virtually reconstructed 3D model of the item, obtained by means of 3D scanners. To assess the feasibility of this approach, a preliminary investigation has been carried out in which a professional grade 3D scanner (*Romer Absolute ARM 7525* with *RS1* laser scanner) has been compared with a consumer one (*NextEngine HD*) for the 3D surface acquisition of a belt buckle, used as a first case study (see Fig. 1). The choice of the case study is motivated by the availability of the item's 3D CAD model, from which it has been possible to obtain a surface area measurement to be considered as ground-truth (equal to 1941 mm^2). The choice of neglecting possible errors introduced by manufacturing processes is justified by the high threshold of acceptability (±5%), which has been suggested by production managers of a company operating in the electroplating industry.

Fig. 1. Belt buckle used for preliminary tests.

Three main aspects have been considered to evaluate performances: surface measurement accuracy, scanning time and post processing time.

Both the devices, whose principal characteristics are reported in Table 1, are active optical scanners based on laser-camera triangulation technology [4]. As widely known, this scanning technology works well for the acquisition of diffusive (opaque) surfaces, while performances are poor in case of high reflectivity [5, 6].

Table 1. *Romer Absolute ARM + RS1* and *NextEngine HD* datasheet.

	Romer Abs. ARM + RS1	NextEngine HD
Technology	Laser-camera triangulation	
Typology	Anthropomorphic arm	Desktop
Accuracy [μm]	58	130
Resolution [DPI]	305	508
Scan. Speed [pts/s]	3×10^5	5×10^3
Scanning software	*Polyworks®*	*Scan Studio™*
Post-proc. Software	*Geomagic Design X®*	*RapidWorks®*

Unfortunately, pieces to be measured have mostly high reflective or even specular surface, also before electroplating, and the application of a matting agent is, therefore, required. This represents the main criticality related to laser-camera triangulation scanners and, more in general, to active optical scanners. In fact, the matting agent is difficult to remove from the surface of the items, and there is a real risk of leaving traces inside narrow incisions, small or threaded holes (generally M2 or smaller). In this preliminary phase, matting agent has been applied anyway, to achieve a useful result. As explained below, in the successive phases, matting will be avoided.

Preliminary test results are summarized in Table 2.

Fig. 2. Surfaces obtained by means of *Romer Absolute ARM* (left) and *NextEngine HD* (right) 3d scanners.

Table 2. Preliminary test results

	Romer Abs. ARM + RS1	*NextEngine HD*
Measured surface area [mm^2]	1926	2045
Accuracy [%]	−0.7%	+5.3%
Procedure	Interactive/manual	Automatic
Scanning time [s]	120	6420
Post-proc. Time [s]	600	Not required
Total time [s]	720	6420

As easily predictable, the reconstruction obtained by means of Romer scanner is valid and the relative surface measurement has an acceptable accuracy. Conversely, despite the higher resolution, the same can not be said about the one obtained by means of *NextEngine HD*. Even if the resulted accuracy is almost acceptable (+5.3%), the overestimation would have been significantly greater if the entire surface of the object had been successfully acquired by the scanner (several missing areas are visible in Fig. 2).

A second issue about *NextEngine HD* is the scanning time: 360° acquisition requires at least 8 different piece positioning and a single scan last about 10'. Even if there are not strict requirements, since pieces would not be measured in the production line, it is obvious that an exceeding time for a single item can have consequences on production planning.

On the other hand, it is also true that if the scanning and the post-processing procedures must be carried out manually, this requires the formation of a highly qualified personnel, with a further economic investment by a company willing to use the proposed system. In this point of view, it is preferable the adoption of a desktop solution, with automated scanning and post-processing operations.

All these considerations lead to the definition of a list of requirements to optimise the search for the best commercially available solutions. In the case in which the search does not cope with the requirements, the development of a specifically designed 3D scanner has been considered as an alternative option by the authors, thanks to the experience in the field of 3D scanning and surface reconstruction [7–9].

2.2 3D Optical Scanning Approach: Tests and Selection of Commercially Available Solutions

Among all the possible scanning technology available, the search has been focused on structured-light 3D scanners, which are considered as the best trade-off between scanning speed and accuracy. Based on authors experience, this technology is also less sensitive to reflectivity issues. According to a limited number of scientific papers, structured light technology with blue LED illumination seems to be the best solution to achieve good 3D reconstruction of high reflective surfaces without matting [10, 11]. For this reason, also this specific technology has been considered.

As previously mentioned, the search has been further limited to desktop solution, since these are more "user-oriented", generally offering automated scanning procedures and intuitive and easy-to-use dedicated software. In fact, this type of devices allows the acquisition of 3D geometry by framing the object from multiple viewpoints without the need to reposition the object and/or the scanner. Once the object is locked on a special plate, positioning is done automatically by the device according to predefined protocols. Since the objects, mainly buckles, studs, or inserts, are small, research has been further refined towards solutions specifically designed to scan small objects. These specifications are common to those required by the jewellery and dental industries, for which scanning systems have been developed for years.

Considering all the requirements expressed above, four potentially suitable scanners have been identified among the ones that were commercially available at the time of this analysis (see Table 3 [12, 13]).

Table 3. Selected 3D scanners.

Brand/Scanner Model	Scan vol. [mm]	Light source	Resolution [Mp]	DEMO
Solutionix/*Rexcan DS3 Silver*	Ø 70	Blue LED SL	2 × 1.3	✓
Solutionix/*Rexcan DS3 Gold*	Ø 70	Blue LED SL	2 × 5.0	✓
Open Technologies/*AuRum LT*	Ø 80 × 110	White LED SL	2 × 1.3	✓
Open Technologies/*AuRum 3D*	Ø 110	White LED SL	2 × 3.0	✓

Among these, *Rexcan DS3 Gold* was not tested since *Rexcan DS3 Silver* share the same technology, has almost the same specs (only resolution is higher) and is considerably lower priced (Table 4).

Tests performed during the demonstrations made it possible to assess the potential of each scanner and to highlight the main criticalities. In detail, scanning tests were carried out using samples buckles and studs with different levels of reflectivity and were performed mainly on untreated samples. Matting paint has been used only to see the different performance on highly reflective and opaque surfaces and only on those pieces for which it was possible to completely remove the paint. Three test typologies have been carried out, by using high reflective items (with and without matting) and specular items (without matting), summarized in Table 5.

Table 4. 3D scanners datasheet.

	Rexcan DS3 Silver	*Rexcan DS3 Gold*	*AuRum LT*	*Aurum 3D*
Accuracy [μm]	30	10	30	NA
Point spacing xy [μm]	≈75	>20	86	30
Point spacing z [μm]	NA	NA	NA	8
Fully automatic scanning	✓	✓	✓	NO
Price range [10^3 €]	15–20	25–30	<10	15–20

Unfortunately, in the last year all of them have become no longer commercially available. *Solutionix* scanners have been replaced by *D-series* (respectively *D500* and *D700*, which share the same technology of *Rexcan* series and the same architecture). For what concerns *Open Technologies*, the company has evolved into *Opentech3D*, but its products are not directly comparable to *AuRum* series. Consequently, the results obtained cannot be used to discriminate between specific products (i.e., individual scanners) but rather to discriminate which type of technology (blue structured light vs. white structured light) best addresses problems similar to the one presented in this paper.

Table 5. Tests typologies carried out during demos.

	Test #1	Test #2	Test #3
Example			
Feasibility	Evaluated	Evaluated	Evaluated
Accuracy*	Evaluated	No	No
Reflectivity	High	High	Specular
Matting	Yes	No	No

*: Evaluated only if CAD geometry is available.

3 Results

In this section results obtained by testing the *AuRum 3D*, the *AuRum LT* and the *Rexcan DS3 Silver* on the items listed in Table 5 are proposed together with their pros and cons.

3.1 AuRum 3D

AuRum 3D (Fig. 3) is composed by two separate units: a scanner unit and a workpiece table. This last is motorized and its encoded rotating movement allows a 360° scanning. Unfortunately, the workpiece table does not tilt. For this reason, at least two manual positioning are required to acquire the complete surface of a piece, with consequent manual alignment operations.

Fig. 3. *AuRum 3D* scanner

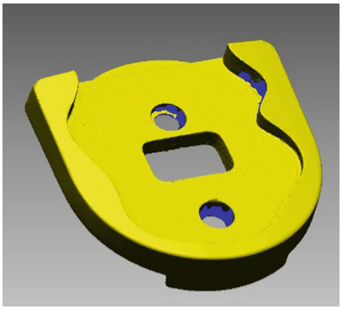

Fig. 4. Test #1 (*AuRum 3D*)

Due to white LED technology and to the open architecture, this type of scanner is very sensitive to ambient light for the acquisition of highly reflective surfaces without matting. Therefore, only test #1 has been carried out (Fig. 4). Without postprocessing, the measured surface revealed an accuracy error of –14% (see Table 6). The under-estimation is primarily due to the presence of several optical undercuts.

3.2 AuRum LT

Despite *AuRum LT* specifications, tests revealed that this scanner allows to obtain similar or even better results with respect to the previously tested scanner. The main advantages on *AuRum 3D* model are basically two: closed architecture and (limited) tilting and rotating workpiece table (see Fig. 5).

The first limits the influence of ambient light for the acquisition of highly reflective surfaces. The second allows a complete automatic piece positioning, thus limiting issues related to optical undercuts. Even if the tilt-movement is limited and the piece is not locked on the table, test #1 (with matting) showed a surface estimation accuracy error of around 5% (see Table 6 and Fig. 6).

Unfortunately, the drawbacks caused by white LED lights are still present. For this last reason, tests #2 and #3 (without matting) lead to incomplete surface retrievals, with no possibility of surface estimation (see Fig. 7 and Fig. 8).

Fig. 5. *AuRum LT* scanner.

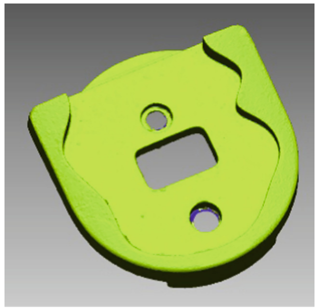

Fig. 6. Test #1 (*AuRum LT*).

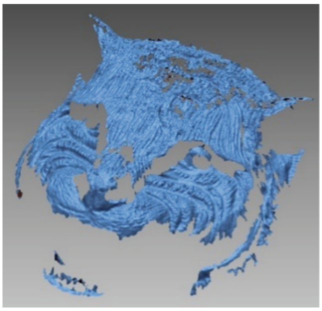

Fig. 7. Test #2 (*AuRum LT*).

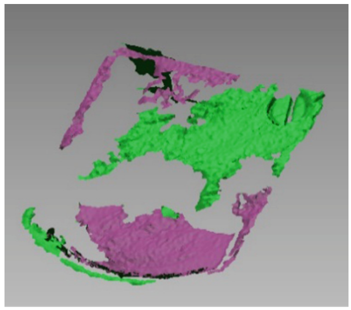

Fig. 8. Test #3 (*AuRum LT*).

3.3 Rexcan DS3 Silver

Among the others, *Solutionix* scanner is the only one based on blue LED technology. The architecture is like *AuRum LT*, but in this case the tilting table is improved with a locking system which prevents the piece to move. For this reason, the scanner allows a larger tilting movement (around ±90°) with respect to *AuRum LT* (see Fig. 9). This allows a complete automatic positioning, without any intervention by the user. In addition, alignment phases are fully automatic.

Test #1 (with matting) showed results comparable to *AuRum LT* (–5% accuracy error). The main advantage of this device emerged during tests #2 and #3. In particular, the retrieved surface in test #2 is almost complete, with few holes due to the presence of optical undercuts. As visible in Fig. 10, a surface estimation can be carried out even without post processing (in these pictures, one square on the horizontal plane is sized 10 mm × 10 mm).

Some criticalities arise in case of specular surfaces (test #3), as visible in Fig. 11. A large part of the curved surface is not retrieved, due to reflections. Moreover, the reconstructed surface appears rough, while it is actually very smooth. Probably, the main causes that compromise the surface retrieval are related to ambient light and interreflections.

Luckily, only a very limited number of small metal parts has specular surface before electroplating. Therefore, this issue has not been investigated further and the device has been considered suitable for the task.

Fig. 9. Solutionix Rexcan DS3 Silver.

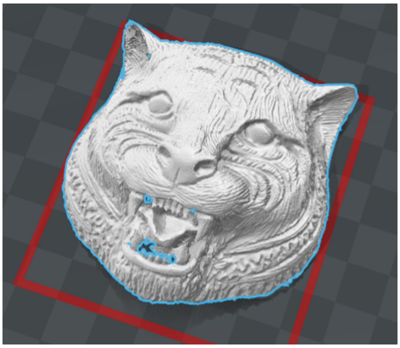

Fig. 10. Test #2 (*Rexcan DS3 Silver*).

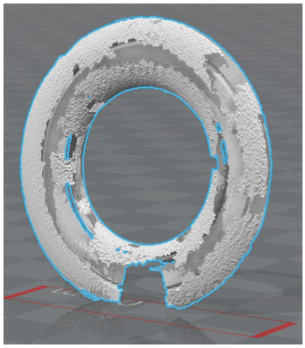

Fig. 11. Test #3 (*Rexcan DS3 Silver*).

In Table 6, the results obtained for all the scanners that have been tested are summarized.

Table 6. Test results.

	Rexcan DS3 Silver	AuRum LT	Aurum 3D
Test #1 Measured surface [mm^2] and accuracy [%]	2102 (–5%)	2090 (–5%)	1893 (–14%)
Test #2 feasibility	Yes	X	X
Test #3 feasibility	Yes	X	X

4 Conclusion

In this paper, the surface estimation of small metal parts in the field of electroplating is discussed. Preliminary tests, carried out by means of two optical scanners based on laser-camera triangulation technology, highlighted the limits of this technology in recovering highly reflective surfaces, without applying a matting paint. This is a real limit, since matting paint removal is not always possible and residual part may persist in holes and small wrinkles on the surfaces. Successively, an extensive research activity on commercially available scanners has been carried out, with a particular focus to devices dedicated to jewelry and dentistry fields. Among the ones based on the more recent structured light technologies (which adopt white or blue LED), it has been possible to select 7 products, 3 of which have been investigated further: *AuRum LT* (*Open Technologies*), *AuRum 3D* (*Open Technologies*) and *Rexcan DS3 Silver* (*Solutionix*). These have been tested during demonstrations, by scanning high reflective items (with and without matting paint). Both *AuRum LT* and *AuRum 3D*, based on white LED technologies, could not acquire high reflective surfaces without the application of matting. Conversely, *Rexcan DS3 Silver*, based on blue LED technology, did not show any issue in surface retrieval, except for objects with a fully specular surface. In this case, issues are supposed to be principally caused by the high sensitivity to ambient light and to interreflections. As the number of parts with a specular surface before being treated is very limited, the problem was not investigated further. On the light of the study reported in this paper, the scanner was deemed suitable for estimating the wet surface of the small metal parts.

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