Surface Characterization of Stainless Steel Part by Optics

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Objective

Based on written requirements provided by the Savannah River Site (SRS), and discussions with Ms. Sproul of SRS, the objective for the proposed development is a turnkey, automated system for three-dimensional characterization of a metallic part, resulting in:

- x-y-z positions of a three-dimensional cloud of surface points which are sufficient for and will be used to generate as-built engineering drawings of the part
- detection of surface anomalies and their high precision spatial mapping to provide input into accept/reject decisions
- alarm capability comparing the surface anomaly data, based on client provided accept/reject criteria, and resulting in an alarm or flagging the part.

Technical Issues

Geometry: The parts are of the approximate shape shown in Figure 1, of stainless steel with a smooth, but not specular surface finish, and in the size range of approximately 5-in. to 15-in. long, and with a maximum cross-sectional dimension of roughly 3-in. to 5-in. depending on part length.

Precision: The required precision for surface anomalies (identified as scratches by Ms. Sproul) includes detection of anomalies down to 0.001-in. (25 µm) in size, and mapping at a precision on the order of 10 µm.

Throughput: Throughput was given as a maximum of one hour per part. Current inspection takes six hours per part.

Discussion: The three issues – geometry (size), precision (resolution) and throughput (speed) - are generally technical tradeoff issues. For example, if size increases and resolution remains
constant, speed decreases. In this case, the size and the precision for mapping the anomalies suggest at least separate, different sensors for implementing overall three-dimensional digitization for as-built drawings and anomaly mapping. Potentially, defect detection might coincide with overall digitization, but more likely will require a third sensor.

Concept

The proposed concept would achieve the objectives by integrating three different sensing/measuring technologies – two implemented by adapting commercially available off-the-shelf (COTS) subsystems and the third using either PNNL developed of COTS subsystems – plus a mechanical handling system most likely adapted from COTS components. Other than integrating and control software, it is anticipated that most software components would be COTS.

Handling: Part handling would be implemented using a PNNL adapted, COTS robotic positioning system, or possibly a COTS coordinate measuring machine (CMM). The vendor for one of the potentially applicable subsystems also sells a sensing head that can be used with a COTS CMM and is compatible with the following CMM manufacturers’ systems:

Table: Coordinate Measuring Machine Vendors

<table>
<thead>
<tr>
<th>Brown &amp; Sharpe</th>
<th>Helmen</th>
<th>Mora</th>
<th>RAM</th>
<th>Tanus</th>
</tr>
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<tbody>
<tr>
<td>CE Johansen</td>
<td>IMS</td>
<td>Myron</td>
<td>Resource Eng</td>
<td>Wenzel</td>
</tr>
<tr>
<td>Coordex</td>
<td>LK</td>
<td>Numerex</td>
<td>Rotoni</td>
<td>Werth</td>
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<tr>
<td>Cordax</td>
<td>Micro Vu</td>
<td>Poli</td>
<td>Sheffield</td>
<td>Zettmutex</td>
</tr>
<tr>
<td>DEA</td>
<td>Mitutoyo</td>
<td>Portage</td>
<td>Starrett</td>
<td>Zeiss</td>
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</table>

![Figure 2. Coordinate measuring machine vendors with systems compatible with 3D digitizing sensor available from Laser Designs, Inc.](image)

3D Digitizing for As-Built Drawings:

The 3D spatial data for as-built drawings could be acquired using the Laser Design, Inc. [http://www.laserdesign.com] DM-1620 (or equivalent) shown in Figure 3, or with other CMMs, the Laser Design CMM scanning probe shown in Figure 4, and converted to as-built drawings using Geomagic Studio software.

![Figure 3. Laser Design, Inc. DM-1620 3D digitizing instrumentation.](image)
Surface Anomaly Detection: Detection of surface anomalies (scratches) down to 0.001-in (25 µm) in size would probably be accomplished in a separate step. 3D digitizing at a resolution capable of detecting anomalies at this level would likely be too time consuming and require instrumentation of a much higher level of precision. However, it is possible that the sensor could scan the surface, detect and save the locations and extents of anomalies concurrent with the 3D digitization – depending on the mechanical handling and other potential incompatibilities. In either case, PNNL has successfully implemented technology for non-contact surface inspection using optical scattering and eddy current technologies. While the feasibility of implementing either method has not been evaluated in detail, past experience suggests no critical issues in a successful implementation.

Surface Anomaly Mapping: Once surface anomalies have been detected and their coordinates and extents recorded, an appropriate high precision 3D digitizing sensor will be returned to the location and a precision 3D map of the anomaly generated. A COTS instrumentation capable of doing this limited area (volume) measurement is available implementing different technologies over a range of spatial precision, and with different limiting characteristics. For example, Figure 6 shows one such instrument that is a laser profilometer having a height resolution of 1 µm over a height range of 10 mm, from a standoff distance of 30 mm. The same vendor, Solarius...
[http://www.solarius-inc.com/], offers systems that implement autofocus (similar height precision but much less range) and confocal microscopy (height precision to under 20 nm, but much less range) technologies. Costs for the system shown are in the $50,000 to $75,000 range.

Alternative

An alternate solution not investigated in detail would use a robot handling subsystem and a reference template of the part. The robot would follow the surface of the part at a nominal but known standoff distance based on the reference template. It would guide a high precision sensor over the surface recording the surface to high precision in a patchwork that would be computer stitched into a high precision surface map of the entire surface. This map would be evaluated and surface anomalies identified from the map, and used to trigger alarms of flags.

This approach has not been investigated and so represents not only an unknown cost and schedule, unknown degree to which the system would consist of COTS subsystems/components, but also the throughput is unknown until a sensor could be identified and the measurement method more specifically defined.

Conclusion
It is technically feasible to meet the requirements as understood. The combination of overall size, maximum resolution required, speed, cost, and the preference for a COTS turnkey, or at least integration of COTS subsystems/components is the challenge. In addition, the requirements that were discussed in the telephone conference exceeded those spelled out in the written requirement so as to leave some ambiguity as to the minimum acceptable specifications, adding some additional uncertainty in cost, availability of COTS subsystems/components and effort required to integrate a turnkey system. Given that two major subsystems and the handling system may be COTS systems, it is feasible that a prototype system can be delivered within one year from authorization of funding.