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Pacific Northwest National Laboratory
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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.

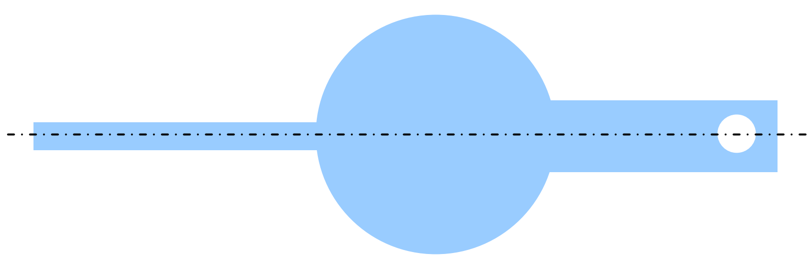


Figure 1. Approximate geometry (side view), rotationally symmetric about the axis, except for the hole at the right.

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.

<u>Handling:</u> 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:

Brown & Sharpe	Helmel	Mora	RAM	Tarus
CE Johansson	IMS	Mycrona	Resource Eng	Wenzel
Coord3	LK	Numerex	Rotondi	Werth
Cordax	Micro Vu	Poli	Sheffield	Zettmess
DEA	Mitutoyo	Portage	Starrett	Zeiss

Figure 2. Coordinate measuring machine vendors with systems compatible with 3D digitizing sensor available from Laser Designs, Inc.

<u>3D Digitizing for As-Built Drawings</u>:

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

DM-1620 SPECIFICATIONS

Laser probe options	A complete line of RPS laser line-sensor probes is available. Refer to separate laser specification sheet for additional information.
Software - Laser Scanning	Advanced Surveyor Scan Control software. Supports point-to-point and continuous scanning. Refer to separate software specification sheet for details.
Software – CMM (Optional)	Geomet Jr. for classic CMM geometry with touch probe.
Touch Probes - CMM (Optional)	Renishaw TP-ES and other CMM probing products
Computer	High-end, PC with Open GL video
Environmental requirements	Temperature: 68° F ± 3° F / 20° C ± 1.8° C Humidity: 50% ± 15%
Axes	X,Y,Z Optional DCC rotary stage.
Measuring table	Granite or Stainless Steel
CMM Measuring system (optional)	Electronic touch probe TP-ES with styli
Warranty	One-year parts and labor. Technician's travel expenses not included.
Miscellaneous	Ways, bearings and scales fully covered or enclosed. Installation provided by supplier. Assistance provided by customer as needed
Travel (X,Y,Z) – in.	16 x 20 x 14
Travel (X,Y,Z) – mm	400 x 500 x 350
Overall Size – in / mm	29 x 36 x 42 / 725 x 900 x 1050
Machine weight	225 lbs (102 kg)
3D Volumetric Accuracy	.00038 "
Linear Accuracy	.00018" + .000006" / inch, Bandwidth (4.5 + L / 150 µm, L in mm)
Resolution	.000020" (.5 µm)
Repeatability	.00016 " (4 µm)

Figure 3. Laser Design, Inc. DM-1620 3D digitizing instrumentation.

[http://www.geomagic.com/] (or equivalent) shown in Figure 5. The DM-1620 is a manual system and costs approximately $65,000. A computer controlled system costs around $107,000. The software shown is $22,000.

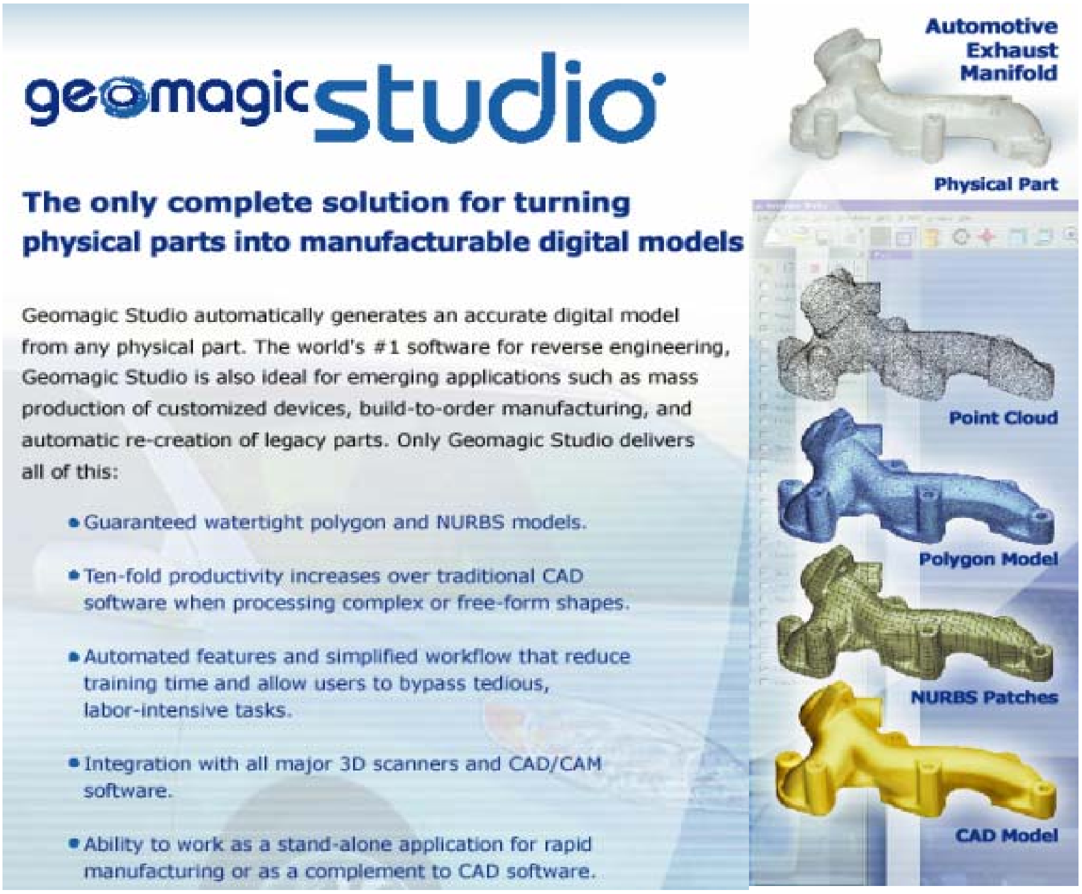
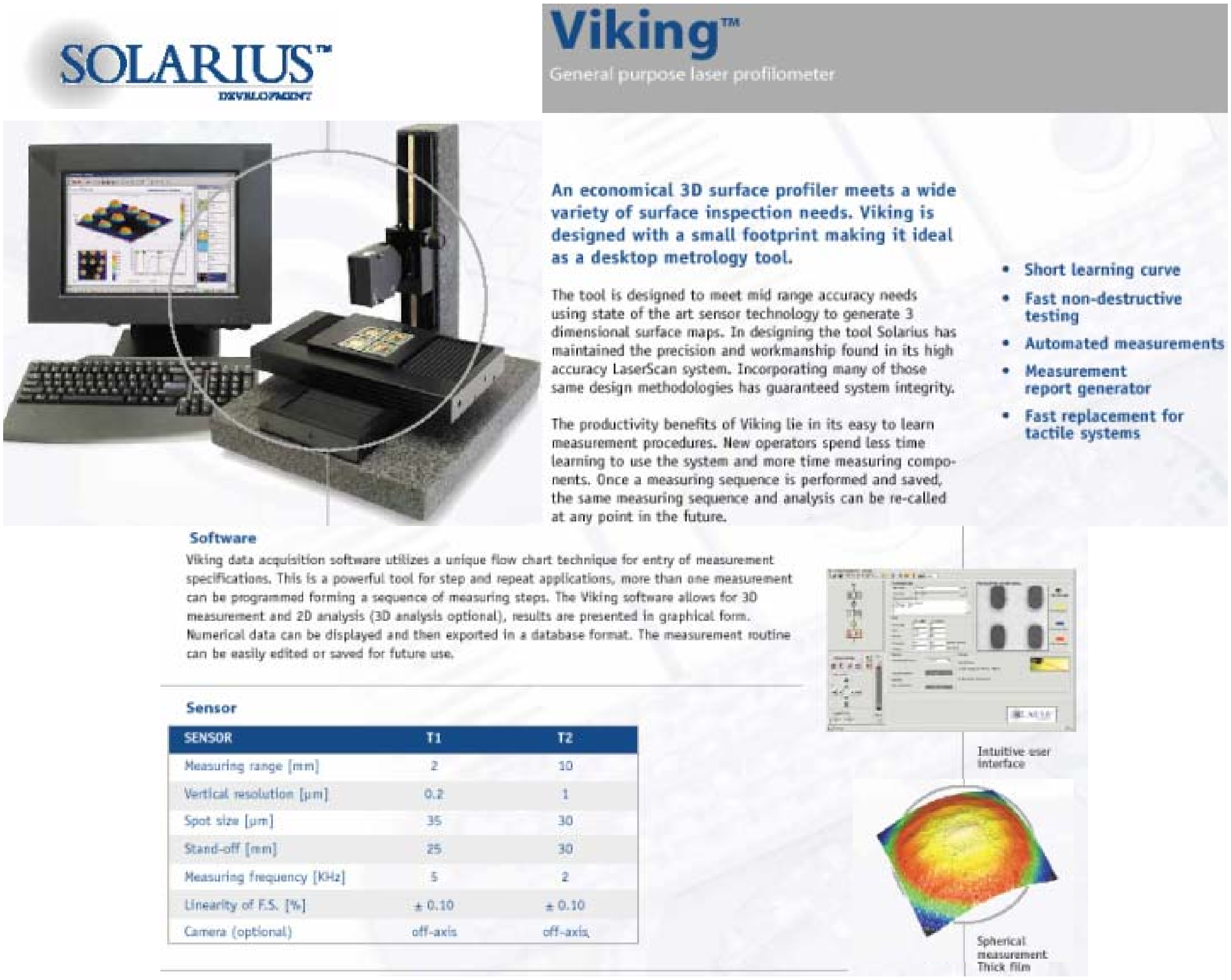


Figure 5. Geomagic Studio software for converting 3D spatial data into CAD drawings.

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.



SENSOR	T1	T2
Measuring range [mm]	2	10
Vertical resolution [µm]	0.2	1
Spot size [µm]	35	30
Stand-off [mm]	25	30
Measuring frequency [KHz]	5	2
Linearity of F.S. [%]	± 0.10	± 0.10
Camera (optional)	off-axis	off-axis

Figure 6. Solarius Viking high precision surface profiler.

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.