Challenges in Measurement of Surface Topography beyond Micro-scale

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Abstract. Precision measuring machine manufacturers have been flooded with requests for more precise measurements. Not only high-accuracy and high-throughput, but also non-destructive and non-contact sensing are demanded for the latest precise measurement machines. It is well known that a variety of fine structures beyond micro-meter scale are formed on the surface of industrial products. Thus it is natural trend that the demand of 3D surface measurement with nano-scale will be drastically increased. Reflecting such a situation, Mitutoyo puts much effort into the development of a variety of measurement systems which satisfy such complex demands as a comprehensive manufacturer. In this report, some of the challenges related to industrial manufacturing will be introduced.

1. Introduction
The advancement of non-contact devices has grown dramatically over the last few years. Consequently there will be a general trend in the surface texture measurement of using non-contact optical sensor. A variety of optical sensors are provided in the market. As a matter of course, new types of sensors will be under development. Meanwhile the customers required high precision measurement system in their production line. The key words to satisfy these demands are high-accuracy, high-throughput and non-contact sensing. Yet, for the contact sensing there remains a lots of demands, like improving productivity of the traditional evaluation system and making possible to evaluate the complex contour that has not measured in the past. Reflecting such a situation, Mitutoyo puts much effort in the development of a variety of measurement systems satisfy such complex demands as a comprehensive manufacturer.

As our challenges contributing to the industrial manufacturing, Quick Vision with non-contact sensor head, Surftest probe which is a new sensing head for CMM and allows evaluating surface roughness and CV-4500/SV-C4500 enables the measurement of pitch diameter of screw thread with the dual-sided stylus. The photographs of these instruments are shown in figure 1.

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Two optical sensing techniques, white light interferometry (WLI) and point from focus (PFF) are equipped on Mitutoyo Quick Vision (QV) series that realises both non-contact measurement and minute 3D evaluation in single machine. The QV series can be mounted a non-contact sensing probe on its main three-dimensional coordinate measuring body with a vision probe. The hybrid measurement system with built in WLI head enables in sub-micro to nano scale surface measurement. With PFF head which uses the same optical system as the image sensor, the system provides micro to sub-micro scale measurement. WLI is well known technique which enables both of accuracy and wide-range measurement. That's why this technique is widely used in the industrial measurement instruments. The accuracy of PFF is lower than WLI in general, but it has a great advantage that no additional optical system is required for the customer who has already owned the typical vision measurement system. In the table 1, these two different sensing techniques are compared. As shown in the table 2 and 3, both for WLI and PFF, we provide self-developed objective lenses which maximize the machine ability. The accuracy of QVPFF is depends on the model as you can see in the table 4.

**Table 1. Comparison of characteristics of WLI and PFF**

|        | WLI          | PFF          |
|--------|--------------|--------------|
| Principle | White Light Interferometry | Focus Position Detection |
| Z resolution | 1\textasciitilde10nm | 50\textasciitilde100nm |
| Application example | IC package L&S, FPD photo spacer, Solar cell, MEMS | IC package, IC socket, Metallic parts, Plastic parts |

**Table 2. Objective lens for WLI**

| Magnification | 10× | 25× |
|--------------|-----|-----|
| Field of view | 0.32×0.24mm | 0.13×0.10mm |
| Z-axis measuring range | 170µm |
| Repeatability | 2σ\leq0.01µm |

**Table 3. Objective lens for PFF**

| Magnification | 2.5× | 5× | 10× | 25× |
|--------------|-----|----|-----|-----|
| Working distance | 40.6mm | 33.5mm | 20.0mm | 13.0mm |
| Field of view | PT 1× | 2.49×1.86mm | 1.24×0.93mm | 0.62×0.46mm | 0.25×0.19mm |
| Field of view | PT 2× | 1.24×0.93mm | 0.62×0.46mm | 0.31×0.23mm | — |
Table 4. Specification of QVPFF

| Model of QV   | QV ELF | QV Apex | Hyper QV | ULTRA QV |
|---------------|--------|---------|----------|----------|
| Default objective lens | 2.5×   | 5×      |          |          |
| Z-axis measuring range  | 21.0mm | 5.2mm   | 0.7µm    |          |
| Repeatability 2σ      | ≤2.0µm | ≤1.5µm  | ≤0.7µm   |          |
| E1 XY       | 2+3L/1000µm | 1.5+3L/1000µm | 0.8+2L/1000µm | 0.25+L/1000µm |

Some measurement examples of QVWLI and QVPFF are shown in figure 2 and 3. WLI does not depend on N.A., therefore it is possible to take high precision z-axis measurement on high aspect ratio work-piece.

Figure 2. Measurement examples of QVWLI
(left) nanoimprint mold  (right) micro lens array

Figure 3. Measurement examples of QVPFF
(left) ball grid array  (right) plastic molding component

3. Surftest Probe
To satisfy the demand of higher throughput evaluation in the production line needing both of dimension and surface texture, we enables the surface texture measurement with the traditional CMM by mounting roughness sensor as a CMM head. The customer can evaluate both of three-dimensional coordinates and surface roughness only with changing its measuring probe. Moreover the probe changing is automatically operated. This means that the new CMM head “Surftest probe” contributes to the drastic improvement of productivity. In table 5, the specification of roughness sensor Surftest probe is listed. In addition, various types of roughness detectors as illustrated in figure 4 are prepared, and allow performing wide-ranging measurement.

Table 5. Specification of Surftest probe

| Measuring range       | Auto, 40, 100, 360µm |
|-----------------------|----------------------|
| Traverse length       | 16mm                 |
| Measuring speed       | 0.25, 0.5mm/s        |
| Stylus tip radius     | 2µm                  |
| Measuring force       | 0.75mN               |
4. CV-4500/SV-C4500

CV-4500 is a high precision contour measuring instrument with the addition of a new function for continuously measuring top and bottom surfaces. The variable measuring force function has become more useful, enabling a wide variety of efficient, high precision measurements. When combined with the dual-sided stylus that is a new product with diametrically opposed contacting tips, the instrument can continuously measure in the upward and downward slopes without the need to change the arm orientation or reset the work-piece fixture. Eventually, the system expands the possibilities for the evaluation of precise work-pieces like a screw and thin metal sheet as shown in the figure 5. The specification of CV-4500 series is listed in table 6, and some measurement examples are shown in figure 6. SV-C4500 provides dual purpose measurement of surface roughness and contour combined with high accuracy by changing its stylus.

![Figure 4. Detector types](image)

![Figure 5. Top and bottom measurement on CV-4500 with the dual-sided stylus](image)

**Table 6. Specification of CV-4500 series**

| Model          | Measuring range X axis | Measuring range Z1 axis | Vertical travel | Linear displacement accuracy Z1 axis | Measuring force (software controlled) | X axis driving speed | Stylus tip radius | Inclining range |
|----------------|------------------------|-------------------------|-----------------|-------------------------------------|--------------------------------------|---------------------|------------------|-----------------|
| CV-4500S4      | 100mm                  |                         | 300mm           | 0.8 + |2H|/100µm                              | 10-50mN                | up to 80mm/s      | 25µm            | ±45°            |
| CV-4500H4      | 60mm                   |                         | 500mm           | H: Measurement height from the horizontal position |                                      |                     |                  |                 |
In the evaluation of a screw, which specification is strictly stated in the national standard, the angle of thread is about 60 degrees in general and for the implant placement it becomes 90 degrees. Our new system CV-4500 allows to get the pitch diameter of thread as same as the conventional three-wire method. The tip contacting angle to a thread is estimated about 63 degrees for upward slope, and 57 degrees for downward slope as shown in the figure 7. According to this simple consideration, the tip sphericity should be assured around 70 degrees for the precise measurement of a screw thread. If the poor tip was used, the measured profile would be strongly influenced by the deformed tip shape. However, if the proper calibration is performed to compensate the tip shape, it is possible to use any tip without sphericity assurance. For example, the two-dimensional outline shape of a tip was detected by tracing a very sharp edge. Once the tip shape is known, it is easy to compensate the error.

5. Conclusion
Several cutting-edge products of Mitutoyo are introduced briefly. As seen in these examples, the well-balanced measurement system should be provided to satisfy complex customers’ demands. As the world’s leading manufacturer of metrology equipment, systems and software, Mitutoyo understand the role that accuracy plays in customers’ efforts to manufacture better, faster and at lower cost. Mitutoyo continues to develop the most advanced and sophisticated metrology equipment available. If there come up with any problems in measurement and evaluation, please contact to our nearest branch offices.

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