A Novel On-line Surface Roughness Measuring Method

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Abstract
Surface finish evaluation would help in the functional prediction of components. Many of the techniques used in the surface finish assessment are contact in nature. To do away with the limitations of contact techniques, non-contact techniques came in. These non-contact approaches used electro optical principles. Many of the non-contact approaches are not industry-friendly. Many of these techniques had limited applications in sampling inspection. Sampling inspection of components use statistical techniques and are not fool-proof. There are chances of defective components reaching the customer. This will not only make the customer un happy but also creates bad reputation of company in front of the customer. Nowadays, the thrust is towards 100% inspection. This is because, only 100% inspection will ensure quality products reaching the customer. This will make customer happy and will enhance the company's reputation. In this context, the present method assumes special significance. In the current research work, an effort has been made to develop a novel non-contact method for surface finish assessment. The method finds application in the automated, non-contact and on-line inspection of automobile and aircraft components.

Keywords
Surface Roughness Measurement, On-line inspection, Vision-based-inspection, non-contact inspection

1. Introduction
Many researchers from the last five decades have been working in the area of surface texture measurement. Surface texture consists of three components- roughness, waviness and error of form. Roughness constitutes one of the components of texture, are surface imperfections having shorter wavelength. These type of surface irregularities are mainly caused due to the cutting tool marks are may be due to the grit on the grinding wheel. Similarly, waviness is other type of surface imperfections having medium wave length. Waviness is mainly be either due to the machine tool vibrations or due to chatter in the equipment. Surface imperfections having large wavelength are called form-error. Form error may be due to the error in the machine tool guide ways or spindle of the machine tool. Thus, there is a need to filter out irregularities having medium and large wavelength, while measuring surface roughness of any given surface. Surface topography includes not only surface texture but also the flaws (e.g., cracks, scratches, etc.). Many surface roughness measuring methods were developed. The main reason behind their invention is that surface finish assessment would help in predicting the functionality of a component. That is, a component's success or failure can be assessed by measuring its surface finish. This would greatly help a manufacturing company in improving its reputation. This would prevent bad components produced by the company from reaching its customers. In this context, researchers have developed many techniques, including contact and non-contact types, for surface finish measurement.

Many of the existing methods of surface roughness measuring methods are good only for sampling inspection. They are basically post-process inspection techniques. That is, the surface inspection is done only after the manufacturing is done. Sampling inspection is not fool-proof, in that there are chances of good products being rejected at the same time, there is also a possibility of accepting a defective product. Thus, when a defective product reaches the customer, it would result in customer dissatisfaction. This is going to tarnish the company's image and its reputation. This necessitates, the need for 100% inspection. 100% inspection not only ensures quality product reaching customer but also the company may expect repeat orders from the customer. This will enhance the brand image of the company product. 100% inspection techniques are also known as on-line inspection methods, in this method, surface roughness measurements are performed, just after machining, that is measurements are made before unloading of the finished component from the machine tool. Whereas, post process inspection is performed after unloading of the component from the machine tool. Many of these post-process-based techniques would give precise results but many of these approaches cannot be used in industrial environments for 100% inspection. In this context, the current research work becomes significant.

2. Literature review

Surfaces are produced by different manufacturing processes. Manufacturing processes may be broadly classified into primary manufacturing processes and secondary manufacturing processes. Primary manufacturing processes include processes include forging, casting, etc. Whereas, secondary manufacturing processes include turning, milling, shaping, etc. With the advent of technology, closer tolerances can be achieved on components manufactured by these processes. This has not only caused a need to assess the surface finish but also to control the finish of the manufactured product. By measuring the surface finish on a manufactured component would help in predicting whether the component becomes successful or not, when it is put into service. Surface roughness (Figure 1) can be measured by contact and non-contact methods (Whitehouse 1994, Thomas 1982). The following paragraphs highlight other contact measuring methods.

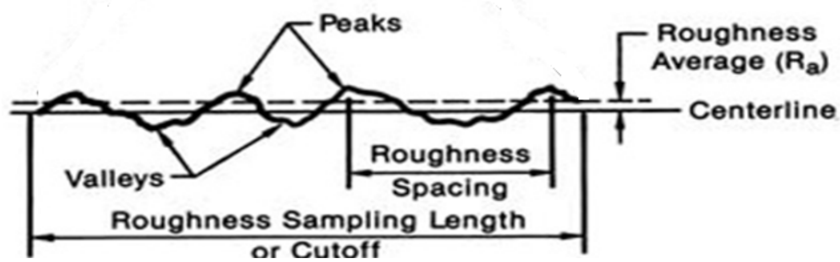

Figure 1 Surface roughness measurement parameters

Surface roughness parameters can be broadly classified into (i) amplitude parameters (ii) spatial parameters (iii) hybrid parameters.

2.1 Contact methods

i. Friction dynamometer: In this technique, a pendulum is used. The pendulum is made to swing against a surface under inspection. Retardation of the swing of the pendulum against the surface under inspection is measured which is proportional to the surface roughness. Both RMS roughness and mean slopes can be measured.
ii. Theta meter: The instrument makes use of a steel sphere. While measuring the surface finish of a surface, the steel sphere is pressed against the surface. The increase in load required for a given indentation is measured.
iii. The profilometer belongs to this category of contact measuring method. The instrument uses a diamond stylus for tracing the surface profile. The diamond stylus is traversed over the surface with the help of a motor. Using this instrument, it is possible to measure roughness and waviness. The stylus used in this instrument may be of different shapes such as pointed, conical and ball-end. While traversing the probe, during measuring the roughness, care is required for applying only enough force is applied on the probe. Which otherwise, is going to damage the work surface. In order to overcome this problem, soft probes are used. The advantage of soft probes is that they are fitted with the electronic circuits, which ensure enough pressure is applied while traversing the work surface during measurement.
One of the limitations of the contact way of assessing finish is that it requires physical contact with the object to be measured. This has made contact techniques slow. The surface finish readings obtained by these techniques are considered accurate for all practical purposes. They are considered as standard for surface finish measurement. To do away with the limitations of the contact method, researchers have proposed new methods.

2.2 Other methods.

2.2.1 Optical methods

2.2.1.1 Taper section method: Nelson (1969) proposed this technique. In this technique, the test surface is cut at angle θ then the test surface is examined by using a microscope. The method gives a very accurate result. The issue with this technique is that it is destructive. Peak to valley height can be measured by this technique.

2.2.1.2 Light section method: In this technique, a beam of light passing through a slit is made to illuminate the test surface at 45^0. The surface is viewed at 45^0 by a microscope. The image is then analyzed. If the image is straight, then the surface is smooth. Any deviation from the straight line is a measure of roughness (Kayser 1943, Way 1969, Shaw and Pecklenik 1963).

2.2.1.3 Gloss measurement: Elmendorf and Vaughan (1958) proposed a technique, which used a row of posts. The degree of reflectivity of posts is measured as a measure of roughness. Many people have worked on this method (Halling 1954, Westberg 1967, Vashist and Radhakrishnan 1974).

2.2.1.4 Diffraction measurement: Speckle is the result of diffraction of spatially coherent light reflected from a rough surface. Speckle is helpful for measuring surface finish (Dainty 1975, Asakura and Fuji 1974, Pari 1975, Leger 1975).

2.2.1.5 Direct Fourier Transformation (DFT): DFT technique was proposed by Ribbens and Lazik (1968). They used a replica of the test surface. A photographic film was illuminated by using this replica. The film is then developed. The PSD of the film is used for determining the roughness of the surface. Many researchers have studied this method (Anderson 1969, Nagata 1973, Thwaite, 1979).

2.2.2 Electrical methods

Sherwood and Cookall (1967) measured the capacitance between a smooth surface as well as inspecting surface and then determined the roughness of the rough surface. Radhakrishnan (1977) measured inductance between the magnetic reading head and rough surface and then compared the results with that of stylus instruments. The results showed a good correlation.

2.2.3 Fluid methods

Moore (1965) used an open bottom vessel for measurement. During measurement, the vessel is kept over the surface to be inspected. The vessel containing water. He has measured the time for the escape of water and then deduced roughness.

2.2.4 Light Scattering Methods

A rough surface, when illuminated by a ray of light at certain angle, the light will be reflected depending upon the heights of surface irregularities as well as the wavelength of light.

2.2.4.1 *Specular scatter*

Beckmann (1967) have measured the intensity of the reflected beam. Several researchers have shown that there exists a good correlation between the stylus and optical roughness parameters. The main limitation of the method is that the range of measured values is high.

2.2.4.2 *Diffuse scatter*

Griffiths et al. (1993) by using a single sensor studied the turning process and measured the diffuse angles up to 40^0. It was found that 30^0 was the best. He had noticed that the method could be used for online measurement of surface finish ($R_{max} > 5$ µms).

2.2.4.3 *Angular distribution*

Marx and Vorburger (1990) had conducted an experiment, where they had used eighty-seven individual detectors placed at 2^0 intervals. The demerit of the result is that the range is high. Also, the scatter of the result is also high.

These non-contact methods gave high measuring speeds. But, these techniques will not give sufficient information for the complete characterization of the surface. All these techniques described above cannot be used in the online inspection of components. Tomlinson (1919) proposed a new surface finish measurement method. The method is based on the optical principle. The method is a non-contact type. In this method, a galvanometer is used along with a mirror to provide a magnification of X30. These instruments are very sensitive and hence could not be used in industries.

In this context, the proposed system for measuring the surface finish accepts special significance. The method uses a low-cost vision system for grabbing speckle images. The images are then used for measuring surface roughness.

3. Theory

The speckle patterns obtained by the same surface, when illuminated at different angles $\theta+\delta\theta$ when superimposed produce a correlated speckle pattern. It has been proved theoretically that the degree of correlation between two fringes recorded on a photographic film depends upon the visibility of the fringe. Also, it has been proved (Leger 1975) that by measuring the visibility of the fringe, the surface finish can be measured. This was derived under the following assumptions.

1. Fresnel approximation
2. Gaussian approximation

$$Visibility = \frac{a-b}{a+b} \tag{1}$$

Where, a= maximum intensity in the fringe and b= minimum intensity in the fringe

The photographic process is not very useful as well as a reliable technique. Hence this film has been replaced by a vision system for recording speckle patterns. All the methods designed so far based on the speckle correlation are purely optical and are not fast enough to be used for automated and high-speed measurement of surface roughness. The proposed method is based on the speckle correlation patterns. In this method, a microcomputer-based vision system is used for registering and analyzing the speckle patterns.

4. Methodology

The steps followed in this research work are explained below.

4.1 Experimental set-up

Figure 1 depicts the set-up used for conducting experiment. The experiment uses specimens made out of different manufacturing processes (e.g., Grinding, Milling, shaping). The surface to be inspected is illuminated by laser light. The diffraction pattern (speckle) is captured by a charge coupled camera (CCD) connected to a Vision system. The Vision system made up of a CCD camera, an advanced Image processing board, a frame grabber, cables, and a high-end computer. The work station uses the Windows operating system. In-house software is developed using C++, for computing the roughness parameters.

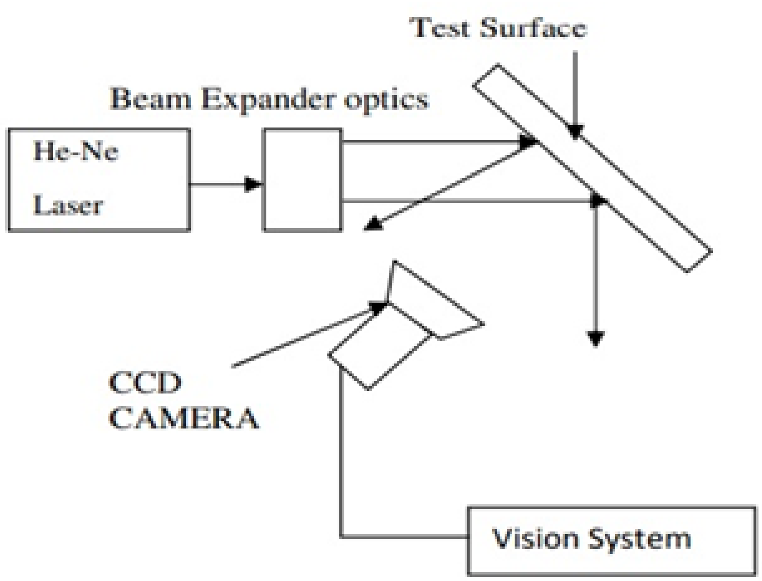

Figure 2 Experimental set-up.

Table 1 Milled Specimen Details

Speed (RPM)	**Depth of Cut (mm)**	**Feed (mm/min)**	**Stylus (Ra) Value in µms**
280	0.4	12.5	1.31
280	0.4	31.5	1.53
280	0.4	80.0	3.18
280	0.4	100.0	3.30
280	0.4	200.0	2.8
280	0.4	250.0	3.7

Table 2 Shaped Specimen Details

Speed (RPM)	**Depth of Cut (mm)**	**Feed (mm/min)**	**Stylus (Ra) Value in µms**
30	0.5	0.2	14
30	0.5	0.4	41
30	0.5	0.6	58
30	0.5	0.8	60
30	0.5	0.2	12
30	0.5	0.4	37

Table 3 Ground Specimen Details

Speed (RPM)	**Depth of Cut (mm)**	**Feed (mm/min)**	**Stylus (Ra) Value in µms**
593	30	--	0.8
684	30	--	1.06
813	30	--	1.01
500	20	--	1.09
500	40	--	1.17
500	60	--	1.29

4.2 Experimentation, Results and Analysis

For the experimental work, specimens are made out of milling, shaping, and grinding processes. Table 1, 2, and 3 shows the details of milled, shaped, and ground specimens. The specimen's roughness is measured using a stylus instrument. Stylus Ra values are tabulated as in Tables 1, 2, and 3. The readings obtained by stylus instrument is considered as a standard and are used for validating the measurements obtained from vision approach. During experimentation the specimen to be inspected is mounted on a rotating table as shown in Figure 1. The rotating table and hence the specimen is cable of rotating by small angle (e.g., 0.5 minutes). For illuminating the specimen, a Helium-Neon laser, having a wavelength of 633 nano-meter, is used.

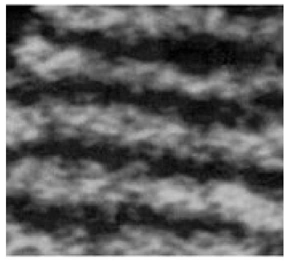

Figure 3 Correlated speckle pattern for a surface having roughness of 5 μms

Roughness measurement experiments were first conducted by using ground specimens. A ground specimen is mounted on a rotating table and is illuminated by a Helium Neon laser. The diffracted speckle pattern was captured by using a CCD camera connected to the vision system as shown in Figure 2. The specimen is then rotated by a small angle (e.g., 0.25 minutes) and again another speckle pattern was captured by the CCD camera connected to the vision system. The two speckle patterns thus obtained are superimposed one above the other to produce a correlated speckle pattern. Figure 3 shows the correlated speckle pattern obtained for a ground surface. In house developed software installed in the vision system is used for getting the correlated speckle patterns. The experiment is then repeated for all ground specimens. Every time two speckle patterns are registered in the vision system. Experiments were also conducted by using different grazing angles ($\delta\theta$) values (e.g., 0.25 minutes, 0.26 minutes, …etc.). It was noticed that the visibility of the corelation speckle pattern will be high for small grazing angle values. As the value of the grazing angle increased the visibility of the speckle pattern decreased.

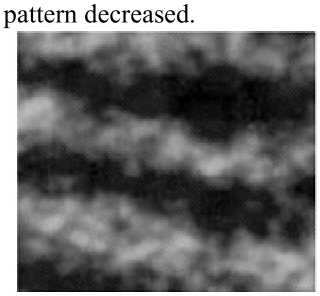

Figure 4 Correlated speckle pattern for a surface having roughness of 15 μms

The measurement experiments were then repeated by using milled specimens. A milled specimen is mounted on a rotating table is illuminated by a Helium Neon laser. The diffracted speckle pattern was captured by using a CCD camera connected to the vision system as shown in Figure 2. The specimen is then rotated by a small angle (0.25 minutes) and again another speckle pattern was captured by CCD camera connected to the vision system. The two speckle patterns thus obtained are superimposed one above the other to produce a correlated speckle pattern. Figure 4 shows the correlated speckle pattern obtained for a milled surface. The experiment is then repeated for all milled specimens. Every time two speckle patterns are registered in the vision system. These two patterns are used for getting a correlated speckle pattern by using software installed in the vision system. Experiments were also conducted by using different grazing angles ($\delta\theta$) values (e.g., 0.25 minutes, 0.26 minutes, …etc.). It was noticed that the visibility of the corelation speckle pattern will be high for small grazing angle values, even in case of milled specimens. As the value of the grazing angle increased the visibility of the speckle pattern decreased.

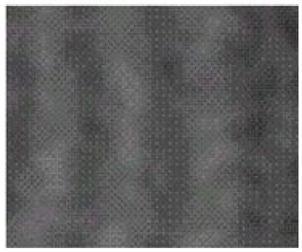

Figure 5 Correlated speckle pattern for a surface having roughness of 55 μms

The experiments were then repeated by using shaped specimens. A shaped specimen mounted on a rotating table, is first illuminated by a helium neon laser. The diffracted speckle pattern was captured by using a CCD camera connected to the vision system as shown in Figure 2. The specimen is then rotated by a small angle (0.25 minutes) and again another speckle pattern was captured by the CCD camera connected to the vision system. The two speckle patterns thus obtained are superimposed one above the other to produce a correlated speckle pattern. Figure 5 shows the correlated speckle pattern obtained for a shaped surface (Roughness: 55 μms). Software installed in the vision system is used for getting the correlated speckle patterns. The experiment is then repeated for all shaped specimens. Every time two speckle patterns are registered in the vision system. These two patterns are used for getting a correlated speckle pattern by using software installed in the vision system. Experiments were also conducted by using different grazing angles ($\delta\theta$) values (e.g., 0.25 minutes, 0.26 minutes, …etc.). It was noticed that the visibility of the corelation speckle pattern for ground surface image will be high for small grazing angle values. As the value of the grazing angle increased the visibility of the speckle pattern decreased.

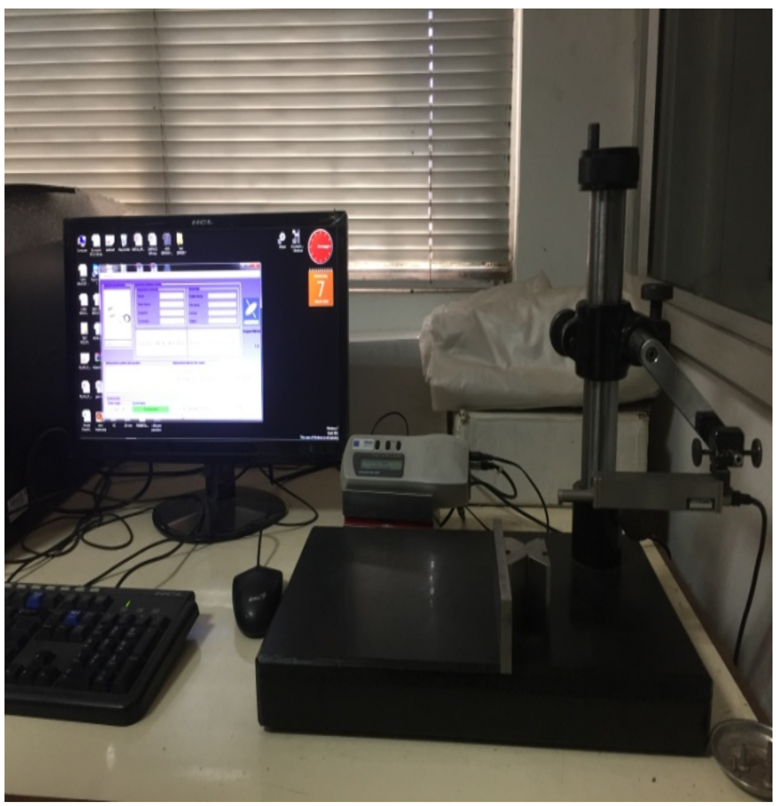

Figure 6. Stylus measurement of Surface roughness

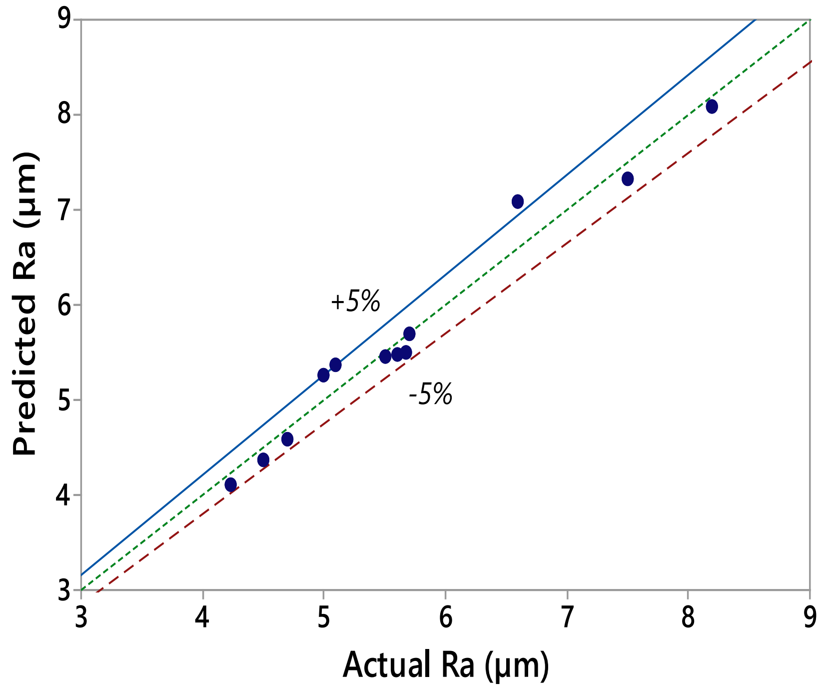

Figure 7 Correlation between Vision roughness and the stylus roughness (Ra)

Table 4 Comparison between Vision and Stylus roughness values

Component number	Ra value obtained from stylus instrument (µms)	Ra value obtained from Vision approach (µms)
1	1.31	1.2952
2	1.53	1.5035
3	3.18	3.1984
4	3.30	3.3030
5	2.80	2.7093
6	3.70	3.5930

Figure 2. 3 and 4 show the speckle images of ground, milled, and shaped surfaces. It can be seen from Figure 3 that the visibility of the fringe pattern is very good for medium rough surfaces. Fringe visibility improves as the roughness is decreased. For smooth surfaces of roughness (< 4 µms**)** the visibility becomes constant. Hence, the method cannot be used for roughness measurement of smooth surfaces (< 4 µms**)**.

Experiment also revealed, when the roughness of surfaces increases, the visibility of the fringe pattern decreases. Figure 4 shows the speckle pattern of shaped surface. It was noticed that the method cannot be used for roughness measurement of very rough (>30 µms) surfaces. This is because, the visibility of fringe pattern reduces and hence the method cannot be used for inspecting very rough surfaces.

5. Conclusion

In the current research work, specimens are produced by different manufacturing processes *viz*. shaping, milling and grinding, are used for surface roughness measurement. The roughness of these specimens were measured using the stylus instruments. As the roughness readings obtained by the stylus instruments are considered as standard for all practical purposes. In the current research work, stylus measured roughness readings are used for validating the roughness measurement readings obtained by vision method. The vision system used in this research work uses a CCD camera for acquiring the surface images. The experimental setup uses a frame grabber for getting a digital image. In the current research the test surface was illuminated by a Helium-Neon laser and a speckle pattern was grabbed. By rotating the table by a small angle another speckle pattern was captured for the same test surface. The software developed using C++ installed in the vision system, is used for getting the correlation speckle pattern. From the experimental results, it was observed that the visibility of correlation speckle patterns was improved with the decrease in surface roughness of the specimens. Experiments were conducted at different grazing angles of incidence. It was found that as the grazing angle increases, the visibility of the correlation speckle pattern decreases. This has led to the conclusion that for better accuracies of roughness measurements smaller grazing values will have to be used. This is true for shaped, milled and ground surfaces. A very good correlation between roughness readings was observed (Figure 7), between the vision method and the stylus method (Figure 6) for milling, shaping, and ground surfaces. The accuracy of measurement was good (Table 4). The proposed method of measurement cannot be used for inspecting very smooth or very rough surfaces. The proposed method has very good repeatability of measurements. The method presented in this research work can be used in the online inspection of medium to rough surfaces (4 µms to 30 µms). The method finds application in the automobile and aircraft industries. Surface roughness measurement range can be greatly improved by having very low grazing angles.

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Biography

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