INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY
IJARIIT

ISSN: 2454-132X
Impact Factor: 6.078
(Volume 9, Issue 6 - V9I6-1229)
Available online at: https://www.ijariit.com

A comprehensive literature survey on non-contact laser-based measurement systems

Shivkumar A.
shivkumar.10csk@gmail.com
Adhiyamaan College of Engineering, Hosur, Tamil Nadu

Dr. S.V. Suresh Babu
hod_mech@adhiyamaan.ac.in
Adhiyamaan College of Engineering, Hosur, Tamil Nadu

Jhanavi Trilok
jhanavi.trilok@gmail.com
Infion Advanced Laser Systems Pvt Ltd, Bangalore, Karnataka

ABSTRACT

Measurement is quantifying, evaluating, or accessing various physical quantities. Dimensional measurement is the most important factor determining a manufactured component's quality. There are 3 forms of measurement – manual, contact automated, and noncontact automated measurement. Manual measurement is when an operator performs a measurement using handheld instruments. Even if one person performs inaccurate measurements this leads to inaccuracy and hence the quality of the part is compromised. To overcome this human error, automated measurement systems were developed. In automated measurement, a part is placed within the system and the measurements are performed without human intervention. Hence improving the accuracy and reliability of the measurement process. Measurement systems have become the backbone of the manufacturing industry today. Various methods and technologies are used to develop these measurement systems. This comprehensive literature survey focuses on non-contact measurement systems. It also highlights the advances in these measurement systems, and how non-contact measurement systems have an upper hand over contact-based systems along with case studies on related research work presented for non-contact measurement in various fields.

Keywords: *Contact-based Measurement Systems, Dimensional measurement, Precision, Accuracy, Non -Contact Measurement Systems, Laser Scanning*

I. INTRODUCTION

Dimensional Measurement systems play a major role in countless industries to cross-verify the dimensional correctness of manufactured parts. Some of the most common parameters are length, width, height, circumference, depth, etc. From traditional methods such as rulers and calipers to more advanced methods such as CMM and laser scanners, these systems help to validate the quality of the part produced. The guarantee of the component's fitness to be used comes from how much deviation has been measured in each dimension from its reference value. These systems are widely used in the Automotive Industry, Medical, Healthcare, Aerospace, etc.

Some examples of the application of dimensional measurement systems are checking dimensional correctness and tolerance of engine parts, chassis components, etc. in automobile manufacturing; Precision is paramount in medical devices and implants. Dimensional measurement systems are used to verify the accuracy of implants and medical instruments to ensure they meet stringent standards; In the Aerospace industry Dimensional measurement systems are used extensively to check the dimensions of critical aircraft components, such as turbine blades and structural elements.

Dimensional Measurement Systems can be majorly divided into 2 Types: Contact- Based Measurement Systems and Non-Contact Measurement Systems.

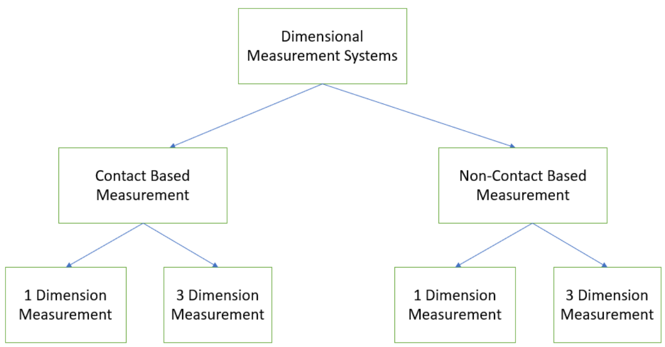

Fig 1.1 Division of Dimensional Measurement Systems

In contact measurement, the sensing part and the workpiece are both in contact. The most commonly used contact technique is a mechanical method in which the measuring tool is directly in contact with the workpiece. Caliper and friction roller-type instruments are some of their examples.[18]

In the non-contact measurement, the workpiece is not in contact with the sensing part. There are various methods for doing non-contact measures such as electromagnetic induction, laser imaging, optical method, electrical method, ultrasonic method, etc. Using any of these non-contact measurement methods, different features of the workpiece can be measured. The main advantage of using non-contact measurement is that it measures the workpiece without producing any deformation in it, which is caused by the contact forces using contact sensors when measurements are highly subtle to sub-micrometer accuracy resulting in lessening the disturbance in the manufacturing processes.[18]

The efficiency of the manufacturing process can be increased by incorporating a closed-loop manufacturing method (CLM). CLM mostly uses measurement technologies such as CMM and non-contact measurement systems to collect data on component dimensions and give continuous feedback to the system for automatic error correction.[18]

This survey delves into the details of the various technologies used to perform non-contact measurement processes. We will also throw light on measurement standards laid down by the manufacturing industry and discuss the recent developments and findings in the field of metrology.

II. MEASUREMENT STANDARDS OF THE MANUFACTURING INDUSTRY

In the manufacturing process, measurement uncertainties have a profound impact on high-quality production. For this, different standards are available for assuring quality production.[18]

III. TERMS AND DEFINITIONS

The organizations related to dimensional measurement standards are:

ISO

ISO (International Organization for Standardization) is an organization that promulgates international standards. It has formal procedures for developing and approving standards.[22]

ANSI

ANSI (American National Standards Institute) is an organization that promulgates United States national standards. It has formal procedures for developing and approving standards. ANSI approves a selected set of standards submitted by standards development organizations for approval and issuance as American National Standards. Many "national" standards do not go through this process.[22]

STEP

STEP (Standard for the Exchange of Product Model Data) is the common name for ISO standard 10303. This standard is composed of individual documents known as STEP "Parts". STEP Part 11 defines the EXPRESS data modeling language. STEP Part 21 defines an exchange file format for transmitting instances of data which has been modeled using EXPRESS. STEP also provides data models for various domains. The models fall into several classes. The class of model intended to be used is called an application protocol (AP). Part 11, Part 21, and Five STEP APs are described elsewhere in this analysis.[22]

CAM-I

CAM-I (Consortium for Advanced Manufacturing - International) is an international consortium of companies, consultancies, and academics who work collaboratively in a pre-competitive environment to solve problems that are common to the industry. CAM-I developed the Dimensional Measuring Interface Standard (DMIS) and maintains and extends DMIS through its DMIS National Standards Committee (DNSC).[22]

TERMS AND DEFINITIONS

ISO (International Organization for Standardization) standards cover a wide array of topics related to measurement. Here are some terms along with their definitions

I. **Accuracy:** The closeness of agreement between a measured quantity value and a true quantity value. [ISO/IEC Guide 99:2007]
II. **Precision:** The closeness of agreement between individual measurements when the measurement is repeated under the same conditions. [ISO/IEC Guide 99:2007]
III. **Traceability:** The property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties. [ISO/IEC 17000:2004]
IV. **Calibration:** The set of operations that establish, under specified conditions, the relationship between values indicated by a measuring instrument or measuring system, or values represented by a material measure, and the corresponding known values of a measurand. [ISO/IEC 17000:2004]
V. **Uncertainty:** A parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used. [ISO/IEC Guide 99:2007]

VI. **Measurand:** A particular quantity subject to measurement. [ISO/IEC Guide 99:2007]
VII. **Tolerance:** The permissible limit or limits of variation in a physical dimension, a measured value, or a physical property of a material or product.[ISO 14405-1:2016 - Geometrical Product Specifications (GPS) - Dimensional Tolerancing]
VIII. **Deviation:** The algebraic difference between a measured value or dimension and a reference value or dimension[ISO 286-1:2010 - Geometrical Product Specifications (GPS) - ISO code system for tolerances on linear sizes]
IX. **Upper Deviation:** The algebraic difference between the maximum limit of size and the actual size.[ISO 286-1:2010]
X. **Lower Deviation:** The algebraic difference between the minimum limit of size and the actual size.[ISO 286-1:2010]
XI. **Allowance:** The prescribed difference between the maximum material limits of mating parts.[ISO 286-1:2010]
XII. **Fit:** The relationship resulting from the difference between the sizes of two mating parts, where clearance or interference exists.[ISO 286-1:2010]
XIII. **Basic Size:** The nominal size of a part used for the purpose of general identification.[ISO 14405-1:2016]
XIV. **Limits of Size:** The maximum and minimum sizes established by the tolerance.[ISO 14405-1:2016]

TABLE OF STANDARDS

ISO 2768 and derivative geometrical tolerance standards are intended to simplify drawing specifications for mechanical tolerances. ISO 2768 is mainly for parts that are manufactured by way of machining or removal of materials.[24]

LINEAR DIMENSIONS

Permissible deviations in mm for ranges in nominal lengths	Tolerance class designation (description)			
	f (fine)	m (medium)	c (coarse)	v (very coarse)
0.5 up to 3	±0.05	±0.1	±0.2	-
over 3 up to 6	±0.05	±0.1	±0.3	±0.5
over 6 up to 30	±0.1	±0.2	±0.5	±1.0
over 30 up to 120	±0.15	±0.3	±0.8	±1.5
over 120 up to 400	±0.2	±0.5	±1.2	±2.5
over 400 up to 1000	±0.3	±0.8	±2.0	±4.0
over 1000 up to 2000	±0.5	±1.2	±3.0	±6.0
over 2000 up to 4000	-	±2.0	±4.0	±8.0

EXTERNAL RADIUS AND CHAMFER HEIGHTS

Permissible deviations in mm for ranges in nominal lengths	Tolerance class designation (description)			
	f (fine)	m (medium)	c (coarse)	v (very coarse)
0.5 up to 3	±0.2	±0.2	±0.4	±0.4
over 3 up to 6	±0.5	±0.5	±1.0	±1.0
over 6	±1.0	±1.0	±2.0	±2.0

ANGULAR DIMENSIONS

Permissible deviations in degrees and minutes for ranges in nominal lengths	Tolerance class designation (description)			
	f (fine)	m (medium)	c (coarse)	v (very coarse)
up to 10	±1º	±1º	±1º30'	±3º
over 10 up to 50	±0º30'	±0º30'	±1º	±2º
over 50 up to 120	±0º20'	±0º20'	±0º30'	±1º
over 120 up to 400	±0º10'	±0º10'	±0º15'	±0º30'
over 400	±0º5'	±0º5'	±0º10'	±0º20'

STRAIGHTNESS AND FLATNESS

Ranges in nominal lengths in mm	Tolerance class		
	H	K	L
up to 10	0.02	0.05	0.1
over 10 up to 30	0.05	0.1	0.2
over 30 up to 100	0.1	0.2	0.4
over 100 up to 300	0.2	0.4	0.8
over 300 up to 1000	0.3	0.6	1.2
over 1000 up to 3000	0.4	0.8	1.6

PERPENDICULARITY

Ranges in nominal lengths in mm	Tolerance class		
	H	K	L
up to 100	0.2	0.4	0.6
over 100 up to 300	0.3	0.6	1
over 300 up to 1000	0.4	0.8	1.5
over 1000 up to 3000	0.5	0.8	2

SYMMETRY (Position for ISO G&T Standard not-ASME or ANSI GD&T)

Ranges in nominal lengths in mm	Tolerance class		
	H	K	L
up to 100	0.5	0.6	0.6
over 100 up to 300	0.5	0.6	1
over 300 up to 1000	0.5	0.8	1.5
over 1000 up to 3000	0.5	1	2

RUN-OUT

H	K	L
0.1	0.2	0.5

IV. CASE STUDIES BASED ON NON-CONTACT MEASUREMENT SYSTEMS

In this section, we will briefly review fifteen research papers related to laser-based non-contact measurement systems in various fields.

Fu, S., Cheng, F., Tjahjowidodo, T., Zhou, Y., & Butler, D. (2018). A Non-Contact Measuring System for In-Situ Surface Characterization Based on Laser Confocal Microscopy. Sensors, 18(8), 2657. https://doi.org/10.3390/s18082657

Cheng, Tjahjowidodo, Zhou, and Butler (2018)[1] in their paper proposed a system for non-contact in-situ topography measurement. This system utilizes a laser confocal sensor in both lateral and vertical scanning modes for height measurement of the target features. Surface topography greatly affects the quality of a product. The traditional method of measuring surface roughness uses a physical stylus that is moved along the surface of the component in a raster motion form to capture the height deviations. These traditional systems have a very low speed and are highly affected by small variations in their working environment. Hence making in-situ measurement almost impossible or highly challenging.

In the first section of this paper, they briefly explain the various methods used for surface profile measurement – Stylus and confocal measurement and the comparison between the two methods. In Stylus Profilometry a stylus tip scans the surface to be measured and the displacement produced to the tip while scanning is then converted to either a digital or an analog signal based on the transducer used (optical or LVDT). The main drawback of this is the damage to the measured surface due to the force applied by the stylus tip during measurement. To avoid this, non-contact measurement systems are preferred. In contrast, confocal measurement works on the principle of confocal microscopy. The primary function of a confocal microscope is to produce a point source light and reject all the out-of-focus light. Laser light is used instead of white light since it has a smaller spot size. The detector will receive the highest intensity of light when the surface of the object to be measured is on the plane of focus of the confocal lens. Hence by capturing the values of varied light intensities along with a suitable encoder, a set of height values are generated. These height values when graphed give the surface profile of the object.

In the second section of this paper, they examine the system configuration and test its validity. The system configuration consists of a laser scanner (Keyence LT-9010M) mounted on an XY linear stage that has a 12.7mm travel range and a 30nm minimum incremental motion. An in-house Software was used to set the PID, speed, and acceleration of the linear XY axes. A precision roughness specimen is used to validate the measures of the laser confocal sensor (LCS). A misalignment between the LCS axis and the linear XY axes gave rise to jump errors. To overcome these errors a stitching algorithm was developed. To make this proposed system into an in-situ measurement system, the authors had to also take into consideration the vibrations generated by the scanning mechanism or the positioning system since these can give rise to errors at the time of measurement.

In the last section of this paper, the authors talk about their experimental results along with their conclusion and future scope of work. The Talysurf PGI profilometer was used as a reference instrument. It was observed that the measurement error increases linearly with increasing roughness Ra. This is because rough surfaces have sharper edges, defects, and other imperfections that can scatter light away from the sensor hence giving rise to larger errors. To overcome this linear correction algorithms were applied. Therefore, it was concluded that the proposed system was able to give correct results when the roughness factor Ra of the surface was in the range 0.2-7 micrometers.

Since this system is a non-contact measurement system it prevents damage and contamination of the surface. The 3-stage motion configuration of their design helps to reduce the vibrations and using linear compensation the relative errors can be minimized as well. The future scope of work was stated to make the system compatible for testing roughness greater than the stated range. (3-6 micrometer). Also, to study and check for uncertainties.

Thus, this paper gives us an idea of the working of confocal sensors and their use in non-contact measurement. It also gave us insights into the procedure to be followed and the likely errors that can occur during noncontact measurement.

Wu, T., Tang, L., Du, P., Liu, N., Zhou, Z., & Qi, X. (2021). Non-contact measurement method of beam vibration with laser stripe tracking based on tilt photography. *Measurement, 187,* 110314. https://doi.org/10.1016/j.measurement.2021.110314

Tang, Liu, Zhou, and Qi (2021) in this paper have proposed a system for analysis of bridge vibration measurement using lasers. In their system, they use a laser stripe and project the laser beam over the target object. When the object vibrates, there is a shift in the laser beam observed. This is done by capturing images continuously and then comparing them. The displacement measured can be converted into the time-history curve of the bridge vibrations. The proposed systems give rise to a non-contact technique of vibration measurement.

In the first section of this paper, the authors introduce us to structural vibration measurement systems and traditional methods of measuring the same. Structural vibration measurement in the past used contact sensors that were attached to the surface of the object to measure vibration responses such as displacement, velocity, and acceleration. From the data derived, modal parameters such as natural frequency, vibration mode, and damping ratio can be calculated. The main drawback of contact sensors is that they need to be wired for data transmission. Also, they can be used to measure displacement at discrete points. Therefore, maintenance of these sensors for continuous bridge health monitoring poses to be very difficult. This gave rise to the necessity of non-contact structural vibration measurement methods.

Further in the paper, the authors give an insight into photogrammetry which is a method based on photoelectric technology. It is said that photogrammetry is used in various fields in the industry because of its non-contact nature as well as its ability to perform measurements on a large scale. The working principle of this method is to capture images of the target using a CMOS or a CCD device that helps to extract the various features of the object such as 3D coordinate points, patterns, and boundaries. Hence any shift or deviation in these features can be easily detected. Based on the target being monitored, photogrammetry is divided into 3 types namely point tracking, digital image correlation, and target-free tracking methods. The authors give a brief introduction to the working principle of each of these methods.

In the second section of the paper, the authors delve into the methodology and the experimental setup used to validate the proposed system. The proposed system uses a laser light source that is projected onto the object being measured. This forms a laser stripe with a certain width on the object to be measured. A camera is then mounted at an angle theta to the laser stripe plane. When the surface vibrates, the laser stripe will also vibrate. Hence the vibration of the target object can be measured by measuring the displacement in the position of the laser stripe. The displacement was calculated at the pixel level which was then scaled to real-life values. It was observed that the scaling factor increases with an increase in tilt angle theta of the camera. For angles less than 30 degrees, the scaling factor was observed to be linear with the tilt angle. And when above 30 degrees the scaling factor displayed an exponential growth. It was concluded that to achieve high accuracy, a small tilt angle, large focal length, and small measurement distance must be maintained. A hammer test was done as an experimental setup. Using a hammer, vibrations were generated in a beam. These vibrations were captured using the above-proposed methodology. It was found that the displacement measurements almost matched the measurement of LVDT based contact measurement system with an error percentage of 5.47.

In the third section of this paper, the results of a field test are discussed. This test was mainly done to check the validity and reliability of the proposed system in a real-life environment. The system was installed on a beam of a railway track. The system was used to measure the dynamic response of the beam and the structural vibrations produced when a train passes on the track. Hence it can be concluded that this proposed system can be used as a low-cost alternative to the non-based measurement systems for structural vibration analysis. The main limitation of this system was that the measurable range was limited by the length of the laser light. The test distance was also a limitation since the increase in test distance increases the risk of noise and the effects of various environmental conditions that can generate unreliable readings.

Hsieh, Tung & Jywe, Wen & Huang, Hsueh & Chen, Shang. (2011). Development of a laser-based measurement system for evaluation of the scraping workpiece quality. Optics and Lasers in Engineering. 49. 1045-1053. 10.1016/j.optlaseng.2011.04.005.

Hsieh, Tung, Wen, and Hsueh (2011) in their paper have proposed a laser-based measurement system for the evaluation of the quality of scraping workpieces. Scraping is a process of removing small metal chips in their relaxed state to make the metal surface flat. According to them by scraping the contact-induced measurement errors can be eliminated. This system consists of a light-scattering type laser, and CNC machine, and an analog-to-digital converter. The triangulation laser is used to measure the depth of the uneven spots that require scraping and the CNC is used to capture the coordinate (x,y) point measurement points of the scraping points. The data generated from this system can be used to construct a 3D drawing of the metal surface along with the scraping points. The proposed system has a 100 mm/s scanning rate and a 10KHz sampling rate.

In the first section of this paper, the authors introduce us to the technique and need of scraping. Scraping is considered a basic and highly required procedure for high-precision machine tool manufacturing. It is said that scraping increases the oil content on the surface reduces friction, and lowers the thermal expansion of contact surfaces. Five parameters are evaluated for a scraping workpiece and they are as follows: - peak points per inch, percentage of points, distribution of heights of points or depth of surroundings, edge shape of the grooves, and flatness. The two most important parameters are the first two sated parameters i.e. PPI and POP. The proposed system can measure cast iron and Turcite workpieces. The traditional method of detecting the peak points in a workpiece involves using a standard plate painted with lead red. The workpiece is then brushed against the standard plate. The high points get the red color on them and the other points retain their original color. The colored points stand out and the peak points can be easily identified. The higher points are then removed using a scraping technique to give complete flatness to the surface.

In the second section of this paper, the authors discuss the design and methodology used to develop their proposed system. The CNC machine used in this system is used to control the x and y-axis motion. The laser triangulation sensor used obtains the z-axis measurement of the scraping parts. Labview was used to develop a user interface software. Some imperfections during the manufacturing process of the workpiece lead to the generation of tilt errors along the Z-axis. An algorithm is written to overcome these errors.

The paper delves deeper into the principles of evaluating the PPI and POP parameters using image processing. Once the 3D data of the workpiece is digitally processed the height of the points and the depth of the surrounding is calculated using various morphological methodologies such as dilation, erosion, opening, and closing. Each peak zone is shown in black and its central point is highlighted in green.

PPI= Marked Central/Measurements area (inch^2)
POP= Bearing area/measurement area (inch^2)

The flatness of the scraped surface can be obtained by calculating a least square plane passing through all the peak points. The flatness of the surface is defined as the difference between the maximum and minimum values of the regression plane. The edge shape of the grooves can be obtained by connecting the part between the grooves and the surroundings

In the last section of this paper, the experimental setup and the validation method used to check the accuracy of the system are described in detail. A roughness tool was used as a reference measurement instrument. A 90mm X 35mm cast iron was used as a scraping workpiece. The results obtained by both the proposed system and the reference instrument were 12 for PPI and 84% and 82% for POP respectively. Hence it was concluded that the proposed system achieved repeatability and consistency in its measurement methods.

Dong, & Xu, Zhimin & Sun, Zhongmin & Liu,. (2019). A Laser-Based On-Machine Measuring System for Profile Accuracy of Double-Headed Screw Rotor. Sensors. 19. 5059. 10.3390/s19235059.

Dong,Zhimin and Zhongmin(2019) in their paper have developed an On-machine-measuring system based on a laser displacement sensor(LDS) which uses a four-axis whirlwind milling machine as a carrier. It uses a combination of variable-structural-element morphological methods, a polynomial interpolation algorithm, and an ellipse-fitting method to increase the accuracy of the system. This hybrid method was experimentally verified. A smoothing algorithm based on the Lagrange multiplier is used to overcome piecewise curve fitting errors. This system was mainly developed for the measurement of Double heads screw rotors.

In the first section of this paper, the authors introduce us to complex spiraling mechanisms used in different industries across the world. The spiral dynamic mechanical screw pump and motor are the two most widely used mechanisms. There are two traditional methods for the measurement of the profile of double-headed screw rotor. Both these methods are contact-type measurement systems. The first method uses a micrometer to measure the profile manually. The second method uses a CMM as an automatic measurement system. Although this has higher accuracy and precision it consumes a lot of auxiliary time and increases the chances of positioning error. This gives rise to the necessity of a non-contact method for the same. LDS are the most common non-contact sensors used since they have a large working range, high accuracy, high speed, and good stability. The accuracy of data acquisition from an LDS depends on four major factors namely inherent characteristics of the measuring system, measuring environment, physical properties of the measured surface, and extraction method for spot centroids.

Inherent characteristics mainly deal with problems such as non-linearity of laser triangulation, disturbance of laser beam, and positional relation between the LDS elements. Changes in environmental lighting, ambient temperature, humidity, vibrations, and non-uniform refractive indexes in the environment give rise to errors due to measuring the environment. Various physical parameters of the measured surface can affect the measurement accuracy of the LDS systems such as color, luminance, shininess, texture, and curvature of the measured surface. Hence any of the above-stated factors can affect the measurement process and give rise to errors. The measurement can be affected by random noises generated within the system. Hence in this paper, the authors have designed and developed a reliable system to overcome these limitations. They have also developed a new type of centroid extraction algorithm which provides a noise-jamming technique.

The second section delves into the details of construction, working, and drawbacks of the proposed system. It mainly consists of an experimental setup and a Data acquisition (DAQ) system. The setup contains a fiber laser, collimating lens, coupling lens, optical filter, a nano servo micro meter displacement platform, and a DAQ connected to a CPU via an RS232 cable. The fiber laser system emits a beam of light of the wavelength 1550nm. This laser beam is turned into a parallel beam when it is passed through the collimating and shaping lens. The beam is then focused into a small spot using a coupling lens and is transmitted via an optical fiber cable. This beam spot is made to fall on a CCD-photosensitive surface. The CCD system is placed in a nanometer displacement system which will generate the coordinate position details of the specific point. The CCD This system had a drawback in that it could not perform global fitting operations which generated piecewise fitting errors. Hence a smoothing algorithm was developed to overcome this drawback.

In the final section of this paper, the actual machine measuring system is explained in detail. The on-machine measuring system consists of 3 main parts: measurement, data processing, and CNC unit. The LDS system used here is a KEYENCE LKH080. Before the measurement, the measuring parameters have to be set using the data processing systems software such as the encoder trigger frequencies, the principle axis speed, the Z-axis and C-axis speed, etc. A traditional CMM measurement system is used as a reference instrument to check the validity and accuracy of the proposed system. It was observed that the proposed on-machine measuring system can complete the profile accuracy measurement for a screw pitch within 39.7 s with measurement accuracy reaching ±8 μm, and the measurement uncertainties of the major axis, minor axis, and screw pitch are 0.72 μm, 0.69 μm, and 1.24 μm, respectively. Therefore, the measurement accuracy and efficiency are both verified.

Dong, Zhixu & Sun, Xingwei & Chen, Changzheng & Sun, Mengnan. (2018). A Fast and On-Machine Measuring System Using the Laser Displacement Sensor for the Contour Parameters of the Drill Pipe Thread. Sensors. 18. 1192. 10.3390/s18041192.

Dong, Zhixu, Xingwei, Changzheng, and Mengnan(2018) have proposed a fast and on-machine measuring system for the non-contact measurement of contour parameters of a drill pipe. This system uses a laser displacement sensor to acquire the contour parameter details of the drill pipe. They use a thread-repairing machine tool as a carrier in their proposed system. A wavelet threshold function was developed to suppress random error interference. An inclination error model was built to overcome the errors that can arise due to the laser sensor. After applying denoising and the aforementioned techniques a set of discrete values are generated. The discrete values are then separated according to the geometrical characteristics of the drill pipe thread.

In the first section of their paper, the authors give us an insight into the importance and uses of drill pipe thread. These threads are mainly used for connecting drill pipes in the oil and gas drilling industry. These taper threads are used to transmit high-torque, hence the dimensional accuracy of these threads' contours is the most important parameter that defines the quality of the thread. In the current scenario, the contour parameters of the drill pipe threads are divided into two categories. In the first category, the thread standoff is measured by wrenching the gauge thread. In the second category, a monomial parameter gauge is used to measure all the parameters of the thread except for the thread angle and pitch diameter. The authors further go on to tell why they chose laser displacement sensors for their proposed system. In non-contact measurement systems, LDS are largely used for reverse engineering and accuracy measurement systems. This is because they have high measurement accuracy, wide measurement range, and easy integration with computers to form intelligent testing algorithms. In this proposed system, the authors use an LDS to acquire data on the thread's axial section.

In the second section of their paper, the authors discuss the measuring principle and system configuration of their proposed system. The proposed on-machine system uses a drill pipe thread and repairing measuring tool along with an NCS as its carrier. The Numerical control system has four axes- X, Z, A, and B axes. The X-axis is for radial movement, Z-axis is for axial movement. A and B Axes are the rotating axes of the workpiece and rest tool respectively. The thread surface is placed in the middle range of measurement of the X-axis. The measurement takes place according to the thread taper degree. A drill thread's maximum diameter is 66.7mm but the laser sensor shell range is only 100mm. Hence a mirror setup is used to assist in the further measurement. The incident light from the light source is vertically reflected onto the thread. The light reflecting from the thread is captured by a CCD.

In the third section of this paper, Various data-processing algorithms are designed. The authors also describe the various challenges faced by them during the construction and testing of this system. The system is then tested for accuracy by using a reference instrument.

Bing Liang, Wei Liu, Kun Liu, Mengde Zhou, Yang Zhang, Zhenyuan Jia,A Portable Noncontact Profile Scanning System for Aircraft Assembly,Engineering, Volume 15,2022,ISSN 2095-8099, Pages 206-213,https://doi.org/10.1016/j.eng.2020.09.017.
(https://www.sciencedirect.com/science/article/pii/S2095809921001521)

Bing, Wei, Menge, Yang and Zhenyuan (2022) in their paper have developed a portable noncontact profiling scanning system for aircraft assembly parts. 3Dimensional profiling plays a crucial role in the inspection of aircraft parts. The aircraft parts are curved in nature and have a highly reflective surface. Owing to these drawbacks, the authors have developed a hybrid system for non-contact profiling of assembled aircraft. This 3D proposed system obtains 1D distances using proximity sensors and 3D data using a camera. This hybrid system helps to overcome the measurement errors that can be produced due to highly reflecting surfaces.

In the first section of their paper, the authors delve into the vastness of the aircraft building sector. They go on to explain the difficulties faced by the industry during the assembly of the aircraft due to the huge sizes of the panels and other automotive components. They discuss that periodic accuracy checks are a very important stage in the manufacturing process. It is said that the detection of key points and key profiles of the components is very important. The authors then talk about the various instruments that are being used in the industry for data acquisition and monitoring such as proximity sensors, photogrammetry, laser sensors, etc. Profile scanning is the most common research topic both as contact and non-contact techniques. Hence taking advantage of both contact and non-contact techniques this paper introduces us to a hybrid system that uses proximity sensors as tips and industrial photogrammetry for the non-contact measurement. Using this technique helps to overcome accuracy degradation caused by highly reflective interference. Moreover, a profile-driven scanning strategy is proposed to avoid tips scratching the measured surface and exceeding the measurement range when measuring profiles with compound curvatures, such as aircraft tailplanes, wings, and envelopes; therefore, the proposed method facilitates an efficient automatic scanning process.

The next section talks about the construction and configuration of the proposed hybrid system. The system uses proximity sensors to measure the distance between the sensors and the tail panel of the aircraft. These sensors have a high response, high resolution, and are compact. Three sensors are used for simultaneous measurement which ensures the efficiency of the scanning process. It works on an eddy current ranging principle and hence is not affected due to reflection. A scanning head holds the sensors together. Virtual Reference points are placed on the scanning head. This ensures that the distance between the sensors and the VRP is constant. The next part of the system consists of high-accuracy cameras that are used for the measurement of 3D coordinates of the VRPs. Calibration is done to find the structural relationship between the VRP and the sensors. Once the calibration is done, the profile reconstruction process begins. During the scanning process as many points are scanned and the coordinate details are captured. More the number of scanned points more the accuracy.

Thus, it can be concluded that the proposed system can be used to measure various components such as the aircraft tailplane. The results recorded are compared to a laser-based reference instrument and was found to have improved efficiency, accuracy and can achieve results in a shorter time span.

VI. CONCLUSION

From the aforementioned literature survey, we can conclude that non-contact measurement systems have a great scope for development in the future. Reviewing the previously done work of various authors on this topic gave us insights into various technologies used in developing non-contact measurement systems and their applications in various fields. Since our study was mostly focused on laser-based systems, we acquired in-depth knowledge about the laser sensors used and the reference measurement instruments to be used during testing. The main takeaway from conducting this literature survey was the fact that we understood the drawbacks of the systems proposed by various authors and the challenges they faced during the development of their intended systems. This creates a strong foundation for us and will help us through our journey of understanding and developing low-cost laser-based non-contact measurement systems.

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