Journal of Manufacturing Engineering, September 2024, Vol. 19, Issue. 3, pp 089-100
DOI: https://doi.org/10.37255/jme.v19i3pp089-100

LIVE DIMENSION DETECTION DURING MACHINING OF WORKPIECE USING SMART DETECTION SET UP ON GENERAL-PURPOSE LATHE

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Abstract

In a manufacturing setting, the profile dimensions of the workpiece are key quality factors. Various automatic inspection approaches currently assess dimensions based on characteristics and variables, tool paths as OK or Not OK in CNC, and online inspection methods for other machines after manufacturing. However, continuous on-machine profile dimensions and simultaneous manufacturing were left to focus. An intelligent recognition system based on a laser lines sensor using a smart profile dimension detection algorithm (SPDA) communicates real-time measurement information to the operator. It plots the current status of the Workpiece, mapping linear distance by accurate laser reflection of the exact mid-surface line of the workpiece as profile data of a symmetric shaft. It compares the length-diameter obtained from longitudinal and lateral sensors with the master data provided. The algorithm implements Python libraries for displaying panels and organizing workpieces. The standard image changes color from red to green as it is relevant to the status. The predetermined order of manufacturing parts and gradient descent optimization feature sets benchmarks to display the status of the workpiece. The real-time live measurement is facilitated with an error of less than 10%, i.e., 0.1 mm, saving manufacturing time by 30%. It also eliminates the inspection stage, and no reduced job rejection is found.

Keywords: *Stepped Shaft, Real-Time Profile Dimension Detection, Laser Line Sensor, Algorithm, Inspection Stage, Manufacturing time*

1. Introduction

Currently, manufacturing processes have become extremely complex owing to technological advances. Using new materials and more complex operations at increasing production rates and higher quality levels, the current world of manufacturing companies is caught between the growing needs for safety, reduced time-to-market that implies short manufacturing time, and minimal manufacturing costs through the efficient use of resources [1]. To meet these demands, manufacturing companies must operate their machines using a quick response and self-driven approach. Industries have developed CNC machines and automats to fulfill these objectives, reducing workforce requirements. However, general-purpose machines still exist, and they are operator-based. Along with automation, the accumulation of labor must be focused. The quality obtained from CNC and general-purpose machine outcome comparison leads to the nonuse of machines. Several attempts were made through experimental work to increase production rates and minimize manufacturing defects by enhancing the operator's skills. Real-time feedback systems are used as a measurement support system, and their results are displayed. Some methods have already been used for measurement in the manufacturing process to accurately achieve the current status of the workpiece while getting feedback. However, all attempts found online on other machines were implemented after manufacturing the workpiece piece and discarded during live manufacturing. The setup should be in the machine and simultaneously work with the operator, workpiece, cutting parameter, tool, parameter, tool, and sensor. A self-efficient solution for the following concerns can be proposed, which needs to catch up with current manufacturing methods.

i. The real-time monitoring of profile dimensions during manufacture.
ii. Simultaneous manufacturing and inspection: An integrated approach for effective quality control.

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iii. Intelligent recognition: Detecting precise profile dimensions
iv. Real-time visualization should be able to provide a clear and valuable display of workpiece status.
v. Error reduction: Achieve high accuracy
vi. Time savings decrease in production time.
vii. Defect prevention: Improved quality control leads to fewer work rejections.

2. Literature Review

Thai M. Orak et al. Measuring the dimensions of metal profiles by acquiring photographs to spot variations in dimensions is applied. A platform was established to imitate the real-time environment, and pictures of the metal profile were captured utilizing four laser light sources. The form of the substance is created by merging photos from many cameras. The findings were obtained with tiny differences from the actual values [2]. This technique is virtually prepared as an animated method. No real-time practice was applied to the machine. Also, no real-time continuous challenges are not countered in the process. In addition, it is image-dependent. Xuebing Li proposes a vision-based fusion method for measuring workpiece piece dimensions. The FCN deep learning model is used to identify interference zones in pieces. The directional texture repair approach deals with interference zones. A method for detecting rough edges using the deep-learning model is proposed. The proposed approach has a measurement accuracy of up to 0.02 mm [3]. The above method is for image-based and indirect measurement of the later completion of the process on modern machines. Yongmeng Liu et al. introduce a cylindrical profile measurement model with seven systematic errors, including eccentricity error, tilt error, sensor probe radius error, probe offset error, probe support rod tilt error, and horizontal and vertical rail tilt error. Additionally, it is based on the seven systematic errors in the cylindrical profile measurement model. First, the autocollimator and image processing are utilized to properly extract the verification parameters, followed by the stepwise estimation technique and equalization optimizer (EO) to acquire the sectional and spatial parameters. The measurement experiment is based on the large-scale stepped shaft profile measuring apparatus. The approach above provides a theoretical basis for implementing high-precision, large-scale shafts after manufacturing them. It is yet to be implemented for the actual and live production process [4].

E.S. Gadelmawla, A vision system that automatically measures and inspects the majority of typical screw thread characteristics (18 in total). The system has been calibrated for both imperial and metric units, and its accuracy was tested by measuring a standard ISO metric thread plug gauge and comparing the results to the standard values. The findings indicated a maximum discrepancy between the standard and measured values of ±5.4 μm, indicating high measurement accuracy. This system is vision-based and applied after manufacturing and offline line setup. Operators cannot judge status as a must rely on skill and gut feeling [5].

Zhixu Dong et al. A modified triangle laser displacement sensor with 1.0 μm resolution was utilized to measure the diameter of a turned workpiece with curvatures. The sensor was connected to a custom stage set on a precise slide unit powered by three motors. The laser sensor was regulated by a θ motor based on workpiece curvatures, ensuring the illuminating laser beam is always expected on the component surface and allowing for online measurement of workpiece diameter [6]. This is applied after manufacturing, and judgment is conveyed later to the raptor for further application. J.K. Che et al. state that a high-resolution webcam was utilized as the picture-securing gadget to capture live pictures of the Workpiece being turned with a driven light source as light-field backlighting. The images were pre-processed to expel clamor and subjected to a sub-pixel edge area to distinguish the Workpiece using MATLAB calculation. After each pass, the distance across the workpiece was decided by subtracting the after within the edge area from the first breadth after applying the rectification scale figure. The vision strategy was viable in measuring the breadth in real-time amid turning inside a precision of 0.6% [7]. It gives the idea of entitled work, but as this method is vision, the presence of light leads to inaccuracy. Peng Hu et al. propose a novel strategy for inward profile estimation and geometric parameter assessment, such as the foot sweep, steepness, and straightness of the soak sidewall of a tall viewpoint proportion aspheric workpiece. It uses a two-probe measuring framework, incorporating a sidelong relocation gauge for the inward soak sidewall profile estimation and a pivotal uprooting gauge for the inward profound underside profile estimation. For accuracy, the orderly mistakes related to the estimation method, counting the miscalibration, misalignment, and the roundness blunder of the gauge tests, as well as the slide movement blunder of the four-axis movement stage, are all assessed and isolated from the estimation comes about [8]. For general-purpose methods, two probes will interfere in the operator's working zone, which may lead to further errors during live production.

2.1. Problem Definition

The use of general-purpose machines and the accumulation of operator skills are becoming increasingly complex due to technological advancement. In this regard, operator fatigue from manufacturing and constant, intermittent measuring of workpiece dimensions rise during mass production, resulting in poor quality and rejection. A quality brilliant set is necessary to serve as a continuous guide to the operator for quality production, closely related to CNC quality. Today, in general-purpose machine operation, the operator must rely on the offline output results of measurement of the workpiece and take subsequent action.

2.2. Objectives

CNC machines are used to produce quality products. More or less, this can be achieved if the worker is trained and guided with particular tools from general-purpose machines with continual feedback support systems. The parameters viz. cutting, Process, Tool, Feed, Speed, and Depth of cut can be set for particular work [9]. Most facilities for automatic measurements and subsequent support systems for workpiece measurement analysis are available in CNC machines or special-purpose machines. This newly introduced method Viz. On machine Profile Dimension Detection, the intelligent setup using the Smart Profile Detection Algorithm is kept because it is implemented for the following objectives.

i. An on-machine mechanism measures real-time profiles, i.e., length and diameter dimensions section-wise.
ii. Adopting method for changing workpiece profile.
iii. Continual feedback and simultaneous communication with the operator to ensure quality manufacturing.
iv. Eliminate the in-process inspection stage and the in-between inspection.

3. Experimentation

3.1. Material used

Considering the objective of real-time measurement profile dimension of the workpiece section, the smart Setup is prepared. The experimental setup comprises a Workpiece-sensor alignment unit in which lateral and longitudinal laser line distance sensors [9-10], mechanical attachments for both sensor's movement, attachment for lathe carriage and longitudinal sensor movement and sensor, and workpiece to be machined are included.

3.2. Setup for Profile Detection

The lateral sensor [11] captures the diameter dimension and that of the longitudinal sensor [12] for length measurement. The data conversion unit carries SMPS attachments and an A to D conversion kit using Raspberry Pi 4.3 [13]. Coding is used to encode digital data in an algorithm. The display communication unit comprises SPDA for hand-to-hand communication with the operator. The Smart profile dimension detection Algorithm's SPDA Al principal duty is to continually monitor and analyze the profile dimensions of a workpiece in real-time during the production process, ensuring that dimensions are within set tolerances by comparing them to master data. It shows a display window in two parts. Part 1 contains a display of dimensions Box of Standard dimensions and real-time dimensions. Part 2 contains a Workpiece image with section-wise names and changes in the color system. Five types of stepped shafts with different application features are used for turning on general-purpose lathes. The following table shows components used in SMART Setup with the SPDA algorithm

4. Method for Flow of work

4.1. Workpiece position and sensor initial setting

Initially, the workpiece is set on a chuck so that its axis and longitudinal sensor line are precisely, perfectly, and virtually intersect. The laser line sensor detects the exact mid-surface line of the workpiece by reflecting accurate laser measurements as linear distance. This helps precisely map the profile data, ensuring high accuracy in measuring length and diameter. The Workpiece is co-axial with longitudinal sensors and a lateral virtually intersecting work axis exactly mid-horizontally [14]. The different workpieces with changes in their profile shapes are turned against the change accumulation in feature aspects. The work materials are EN 353 and bright metal. From the operator side, the tool points on the workpiece, and from the opposite side, the sensor point and workpiece coincide and travel simultaneously. Both sensors can easily map the turning workpiece along the length and diameter since they correlate the movement of the sensor and workpiece simultaneously.

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Table 1 Showing components used in SMART Setup with the SPDA algorithm

S. No	Component	Function	Position	Range / Dimension
1	General purpose Machine	Carry out machining operation	SSI	Manual-operated six-speed
2	Bed Strip attachment	for connecting the Lathe Bed to the sliding attachment	On lathe Bed	L 300 mm, t = 6 mm
3	Inverted T-strip attachment	Attaching bed strip attachment to lateral sensor attachment	Stand attached to bed strip before Lateral sensor attachment	250 mm horizontal strip, 250 mm vertical strip
4	Lateral sensor Slider holder (with threaded rod)	Holding and allowing to & fro horizontal motion of the Sensor	The upper side of the Inverted T-strip attached to the sensor holder	250 mm threaded rod, Single simple holder
5	Lateral and longitudinal Sensor Holders (02)	Holding Lateral and longitudinal Sensors during measurement of length and diameter, surface finish	On horizontal attachment of respective sensor slider	M.S holder with rolling cushion (Push fit)
6	Lateral laser distance sensor	Measuring the Diameter of W/P	On Tail Stock inline to the center of W/P	Measuring range – 50 to 250 Resolution - 2µm to 120µm Linearity ±15µm to 350µm Response time < 900µs
7	Longitudinal laser distance sensor	Measuring of Length of W/P	On the Sensor holder, exactlylaterally intersecting W/P axis	Measuring range – 50 to 300 Resolution - 2µm to 120µm Linearity ±15µm to 350µm Response time < 900µs
8	Sliding attachment Lateral sensors.	Supporting Forward-reverse, Up-Down Movement of lateral Sensors.	The lateral side opposite theoperator	Sliding – 300 mm to & Fro Vertical – Up & Down 100 mm
9	Sliding attachment for longitudinal sensors.	Supporting To-fro, Up-Down Movement of longitudinal Sensors.	On Tailstock	Traveling L 200 mm H 50 mm H 30 mm
10	Stand for lateral sensor.	Stand to support sliding attachment and allow to move sensor Horizontally and vertically.	On the table at a distance near the chuck	BASE 150 mm X 150 mm Vertical standpipe – 250 mm
11	Raspberry Pi 64-bit via	Analog to Digital converter	Outside PC nearby Sensor	64-bit, RS485 connectordisplay compatible
12	SPDA loaded into Raspberry memory card	Algorithm for evaluation and guidance	On laptop	Java script, Use of Pillow, Open CV, Tkinter, GUI Python Libraries
13	A TO D Converter	Converts analog signal to digital signal for providing it to Sensor	Near the Raspberry Pi kit	0 to 10 v out conversion

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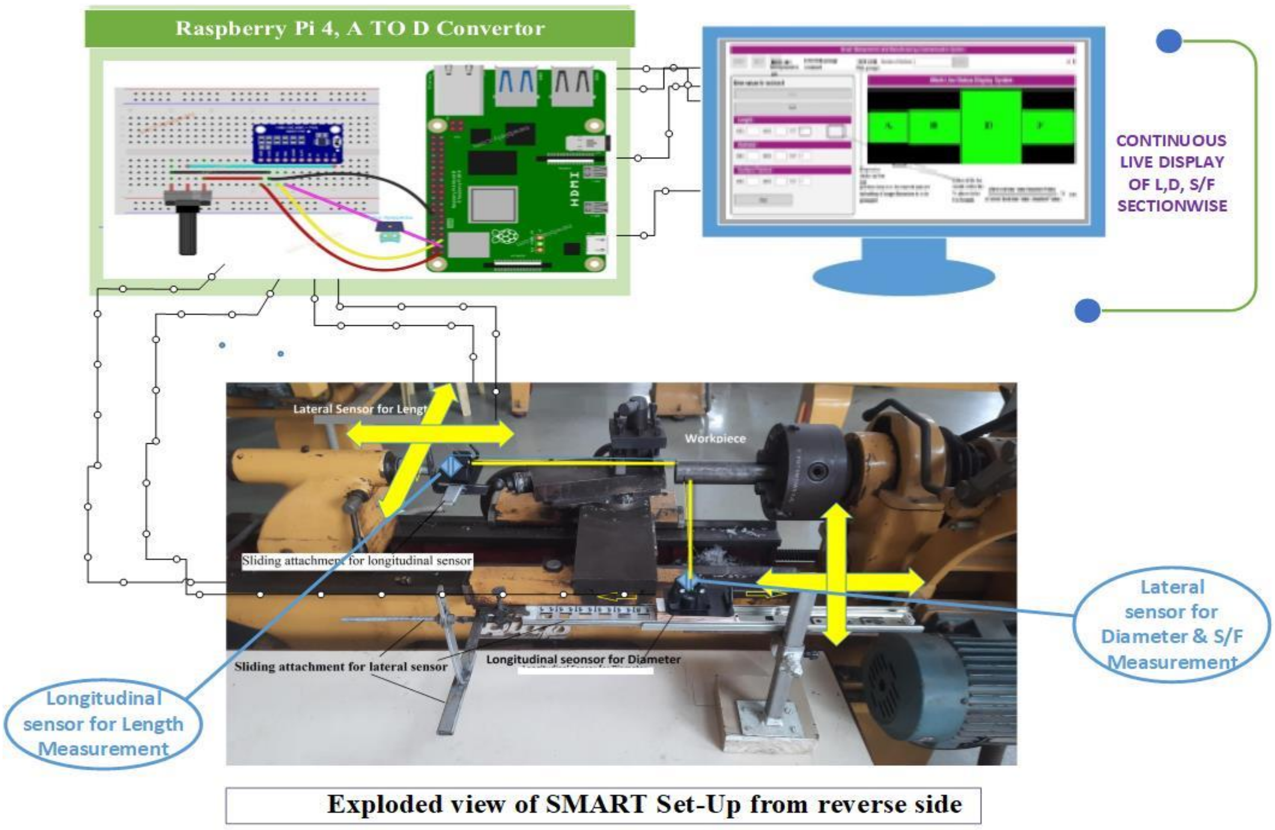

Fig. 1 Mechanical Configuration for SMART Set-U

4.2. Setting workpiece manufacturing conditions

With reference to the standard drawing, the operator decides the sequence of the Workpiece. The operator studies the drawing of the Workpiece and enters the sequence, such as sequential parts SP1, SP2, and SP3, etc., for the algorithm display window. The operator decides the cut's feed, speed, and depth for maximum and minimum material removal.

4.3. Data Acquisition and Transformation

The distance sensors are employed to measure both the length and diameter of real-time live dimensions continuously according to action taken by the operator for machining operation. The sensor generates a signal of an electrical signal varying from 0 to 10 volts as a measure of distance over the given length. This output interfaces with an electronic circuit - a Raspberry Pi 64-bit equipped with an RS485 connector and an integrated A/D converter facilitating data visualization [15-16]. A tailored code crafted on the Raspberry Pi platform captures the sensor's electrical output, transforming it into a digital readout. This conversion enables the algorithm's subsequent utilization, harnessing an inherent correlation between electrical signals and distance measurements. Another code is generated to accumulate the digital sensor value and display the system to transfer the data to the algorithm developed.

4.4. Processing through Algorithm

The manufacturing process followed by the component's drawing was studied, and self-learning tools were applied to obtain data for optimization. With some previous references [16, 17, 18], the newly developed Algorithm SPDA is used for processing and decision-making. Lase line triangulation sensor technology is linked with this self-learning module while processing the holding stepped shaft.

The Python image analysis algorithm considers the sensor length and diameter output as a real-time profile dimension. It compares with the standard drawing dimension section-wise sequentially. The several features of Python libraries, such as Pillow Open CV, are used for optimization and benchmarks to assess the job's status. The Python-based algorithm interprets data from laser sensors, compares it to master data, and delivers real-time feedback to the operator. It also organizes and shows the workpiece's condition, altering the picture's color according to whether the measurements are correct or require adjustment by its libraries. Gradient descent is a machine-learning approach that optimizes the algorithm's parameters. It iteratively modifies these parameters to reduce the difference between the projected workpiece status (Accurate, Precise, Not OK, Rejected, or about to Reject) and the actual status. This optimization method improves the model's capacity to categorize Workpieces accurately. [19]

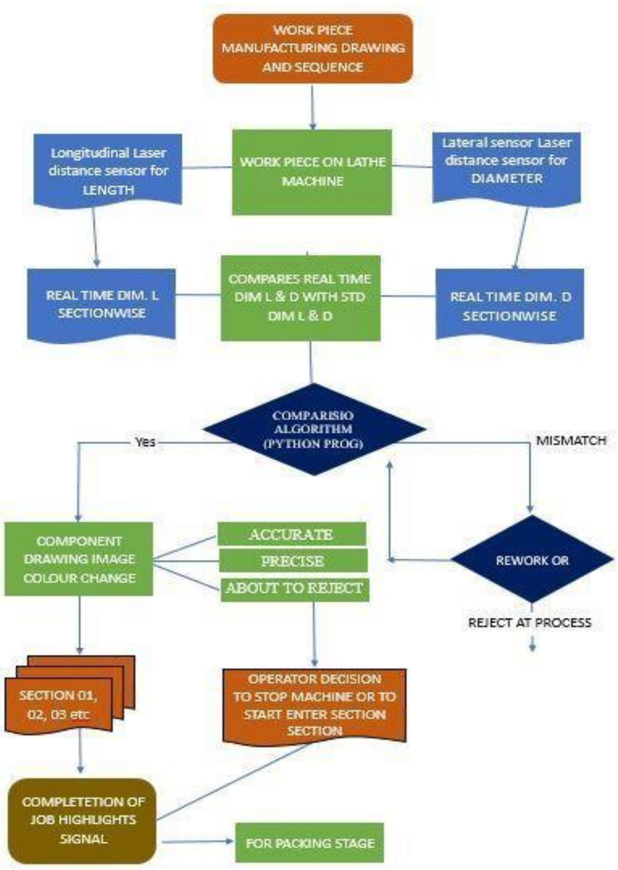

Fig. 2 Showing Workflow chart for Smart setup

4.5. An algorithm

The operator is given the flexibility to insert the target dimension and relate the particular dimension set of the section to the component drawing. Once the operator gives naming as section S1 on the dimension set and S1 on the component drawing image, both dimensions set (Length, diameter) and component image section get correlated by this procedure. Initially, the workpiece image is fragmented into sequential parts like SP1, SP2, SP3, etc. [20]

Once a particular section's standard and real-time dimensions match, the corresponding section 3D CAD drawing image will change from red to green. This indicates the completion of that specific section and moving towards the next step, the section for manufacturing. Likewise, the standard and real-time dimensions are sequentially compared section-wise, and the corresponding AD drawing image is green—simultaneously, decisions like OK.

4.6. Action to be taken by the operator

After receiving information like part okay, not okay, completed, Incomplete, rejected, or about to reject, an Operator takes appropriate action against the same. If the Workpiece complies with the given standard dimensions, then the operator starts to manufacture the next segment of the Workpiece. The machine will be stopped if the operator fails to comply with the given dimension. There is a display of dimensions phase-wise and continuously. An operator can take high cuts during initial material removal. Completed, Not OK, About to reject, and rejected will be displayed. The algorithm supports decision-making and Communication with an operator. The display system facilitates the continuous real-time operation of the Workpiece in terms of dimension and guides for a precision, accuracy, or rejection scenario for the Workpiece. Objective 1, on machine pro-file dimension detection, is needed for continual feedback to the operator to ensure quality manufacturing can be achieved. By providing continuous, on-machine measurement of the workpiece dimensions during manufacturing, the SPDA system eliminates the need for a separate inspection stage, thereby streamlining the production process.

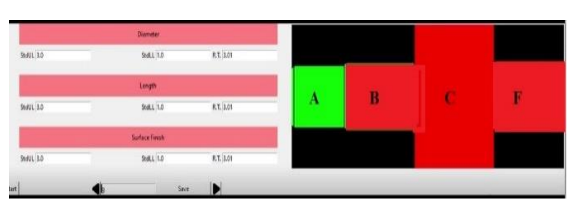

Fig. 3 (a) Sequence Section (A) green Completed, and Red B, C, D indicate yet to complete

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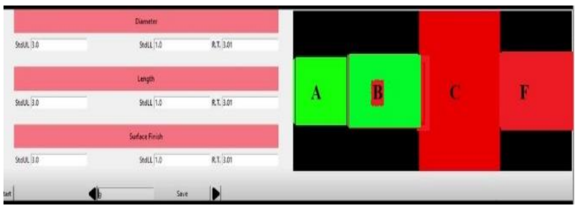

Fig. 3 (b) Sequence Section (A, B, C) green Completed, and Red D indicates yet to complete

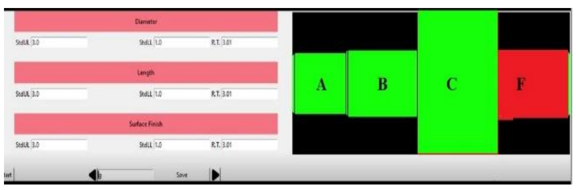

Fig. 3 (c) Sequence Section (A, B) green Completed, and Red C, D indicate yet to complete

Fig. 4 Sequence Section (A, B, C, D) green completed

the operator will be informed to consider appropriate feed and DOC to achieve closer dimensions. It guides the following action after completion and also discusses the consideration of feed doc for manufacturing [18]. Respective deviations are mapped and reflected in corrective action simultaneously.

4.7. Part of the complete algorithm

It is mentioned here to give an idea about the algorithm: import cv2, driver code, class and function definitions, for handling the GUI for the data widget class data widget, return self. Start. get(), self. endul.get(), self—the end. Get () to handle the data of each section, capture img and defcapture_image(), place the widgets using the Tkinter grid layout, and configure the window's rows and columns to fit the window on resize. [21-22]

5. Observation and Data Collection

In the context of experimentation, five different component drawings are considered, with each of the five types of components and ten pieces per batch manufactured using an intelligent setup. Considerations.

1. The laser line distance sensor is set precisely in the middle of a workpiece from the lateral side and at the starting point of a workpiece.
2. The laser line distance sensor travels over the Workpiece along the travel of the lathe carriage.
3. The conversion of electrical output to distance in mm depends on the correlation.
4. Travel of the lateral sensor along the axis of the Workpiece is a measure of diameter.
5. Variation of the Workpiece along the longitudinal sensor is the measure of length.
6. The operator will slightly adjust the longitudinal sensor for a change in length. There is no change in any factor

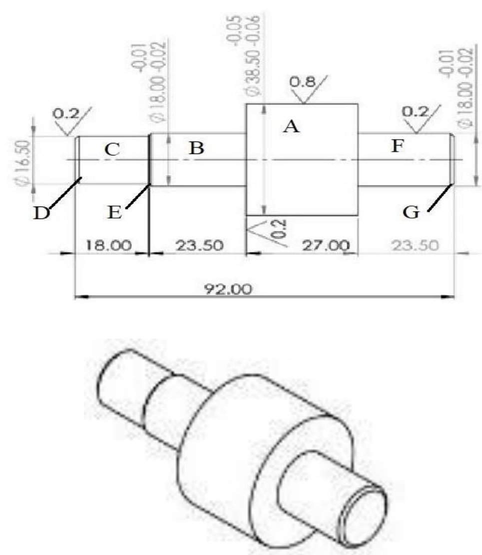

Fig. 5 Drawing of Type A Workpiece for manufacturing

Table 2 shows values of diameter and length section-wise sequentially. It reflects the sequence-wise initial standard and real-time live diameter and length dimensions shown on the display system. Standard dimensions are the target dimensions. Table 3 shows values of diameter and length section-wise sequentially for change in the workpiece profile. Another workpiece with different dimensions and sections is considered for turning and measurement purposes. The sequence to be decided by the operator will be changed. With standard cutting parameters, the operator can continue to use an intelligent setup as a feedback reference.

A sample size of 5 workpieces of each type is considered. All these workpieces are manufactured using the initial and intelligent setup. Table 4 shows the average error between automatic measurement by smart setup and physical inspection done on the same component using a Vernier caliper. The average error during each section of W/P is calculated and considered error found during that Workpiece measurement. Likewise, error for all workpieces is mapped in the table. Along with error, other factors inlined to production are observed.

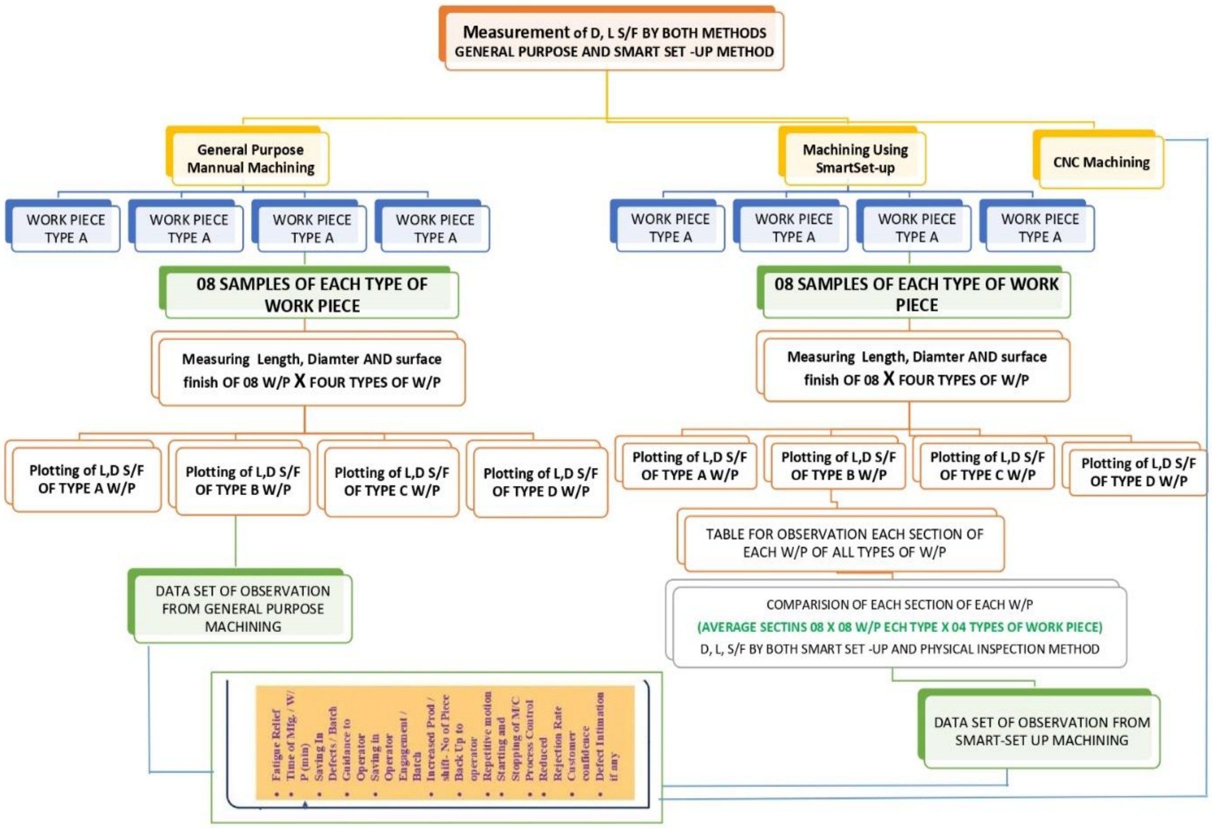

Fig. 6 Methodology to Conduct experiential and observation

Table 2 Profile dimensions of Type A Workpiece No 01 Sample size: 10 by intelligent setup.

S No	Component Part Sequence	Length mm					Diameter mm				
		Initial	Standard	Real-Time	Phy. Insp	Error in mm	Initial	Standard	Real-Time	Phy. Inspect	Error in mm
1	Section A	94	68.50	68.54	68.49	0.05	40	- 0.05 38.50 - 0.06	38.47	38.51	0.04
2	Section B	41.50	41.50	40.47	40.53	0.06	38.48	- 0.01 18.00 - 0.02	17.98	18.03	0.05
3	Section C	18.00	18.00	18.00	18.05	0.05	17.98	16.50	16.51	16.45	0.06
4	Section D	1	1	1	1	0	1 X 45º	1 X 45º	1 X 45º	1	0
5	Section E	1	1	1	1	0	1 X 45º	1 X 45º	1 X 45º	1	0
6	Section F	50.5	23.50	23.50	22.47	0.03	40	- 0.01 18.00 - 0.02	17.98	18.03	0.05
7	Section G	1	1	1	1	1	1 X 45º	1 X 45º	1 X 45º	1	0

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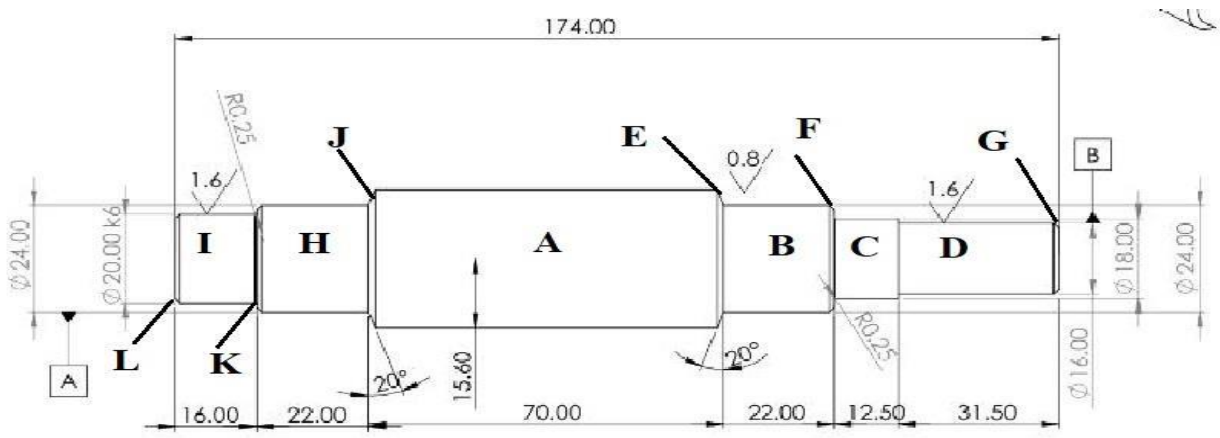

Fig. 7 Type B Workpiece drawing for manufacturing

Table 3 Type B Workpiece Profile dimensions detection by smart set up section-wise

S. No	Component Part Sequence	Length mm					Diameter mm				
		Initial	Standard	Real-Time A	Phy. Inspect B	Error A-B	Initial	Standard	Real-Time A	Phy. Inspect B	Error A-B
1	Section A	178	136	136.01	135.95	0.04	34.00	31.20	31.20	31.17	0.03
2	Section B	136.1	66	65.99	65.94	0.05	31.20	24.00	24.02	24.05	0.03
3	Section C	65.99	43.99	43.98	44.04	0.06	24.02	18.00	17.99	17.94	0.05
4	Section D	43.99	31.49	31.49	31.48	0.01	17.99	16.00	15.98	16.02	0.04
5	Section E	1	1	1	1	0	1 X 20	1 X 20	1 X 20	1	0
6	Section F	1	1	1	1	0	1 X 20	1 X 20	1 X 20	1	0
7	Section G	1	1	1	1	0	1 X 20	1 X 20	1 X 20	1	0
8	Section H	38.00	22.00	21.98	21.95	0.03	34.00	24.00	24.02	23.96	0.06
9	Section I	22.00	16.00	16.02	15.98	0.04	24.02	20.00	20.01	20.05	0.04
10	Section J	1	1	1	1	0	1 X 20°	1 X 20°	1 X 20°	1	0
11	Section K	1	1	1	1	0	1 X 20°	1 X 20°	1 X 20°	1	0
12	Section L	1	1	1	1	0	1 X 20°	1 X 20°	1 X 20°	1	0

Table 4 The observation of % error of measurement and various factors by both methods of manufacturing

S. No	Type of Workpiece	Average Error in Measurement		Manufacturing Time min / Piece		No of Piece Rejected /Per Lot		Guidance to Operator	
		mm	%	General Method	SMART Set-Up	General Method	SMART Set -Up	General Method	SMART Set-Up
1	TYPE A	0.05	5	15	6.6	0	0	0	100%
2	TYPE B	0.06	6	20	8.5	1	0*	0	100%
3	TYPE C	0.03	3	8.5	4.6	2	0*	0	100%
4	TYPE D	0.04	4	8.5	5	1	0	0	100%
5	TYPE E	0.05	5	10	6	1	0*	0	100%

*Error occurred, but encountered due to live communication system error rectified before and no rework required

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Table 5 Effectiveness of SMART Setup regarding measurement as well as manufacturing point of view

Type of Workpiece	Average Error in Measurement %	Manufacturing Time min / Piece	No of Piece Rejected /Per Lot	Continuous Guidance to Operator %	In-Process Inspection %	Accumulation Labor skill %
Avg. Factors	5	6.14	0	100	0	100

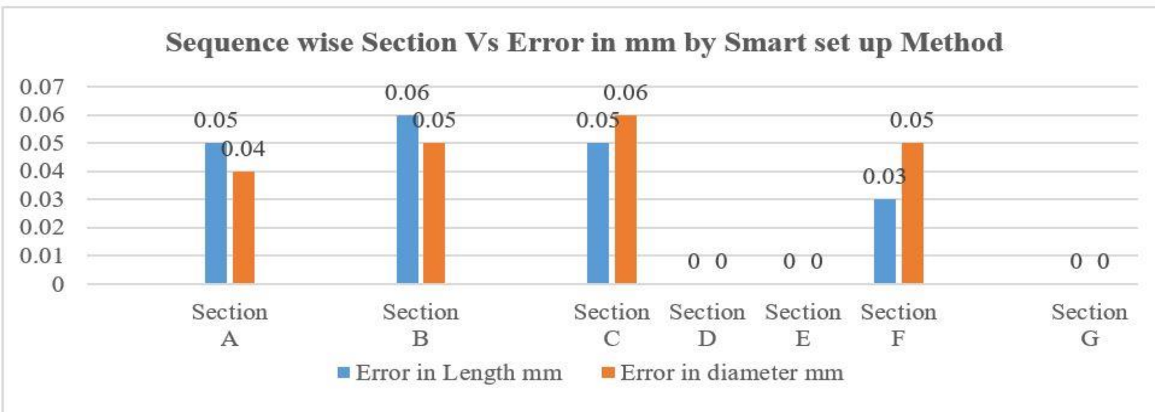

Fig. 8 % Error found in Physical inspection and Smart set up Profile dimensions measurement

Table 6 Performance indicators for manufacturing and quality scenario by both methods of manufacturing

S. No	Workpiece Number	Time / W/P of Mfg. in min		Defects / Batch in number		Operator Engaged in no of operation / Workpiece		Increased Prod. / shift hr in number	
		General Method	SMART Set-Up	General Method	SMART Set -Up	General Method	SMART Set-Up	General Method	SMART Set-Up
1	WP 01	25	18	01	00	9	4	2.1	3
2	WP 02	26	17	00	00	9	4	2.4	3
3	WP 03	24	19	01	00	9	4	2.3	3
4	WP 04	25	17	00	00	9	4	2.1	3
5	WP 05	26	19	00	00	9	4	2.3	3
6	WP 06	26	18	00	00	9	4	2.1	3.1
7	WP 07	26	20	00	00	9	4	2.4	3.2
8	WP 08	28	19	00	01	9	4	2.3	3
9	WP 09	25	19	01	00	9	4	2.2	3.1
10	WP 10	27	20	01	00	9	4	2.2	3
Average Result		25.8	18.6	0.4	0.1	9	4	2.24	3.04
Converted into Average %		100	73.90896	40	10	100	40	100	126

6. Results and Discussion

The graphic shows a table comparing two production processes, "General" and "SMART Set-Up," on various performance parameters. The table contains data on five types of workpieces (A, B, C, D, and E). The chart for each workpiece displays the average measurement error in millimeters (mm), production time in minutes per piece, number of rejected pieces per lot, and a statistic known as "Guidance to Operator."

One important finding is that the "SMART Set-Up" approach consistently decreases production time compared to the "General" method for all work-piece types. However, the effect on measurement in-accuracy and the number of rejected pieces is not constant. The "SMART Set-Up" approach decreases rejected parts for some workpieces (B, D, E), but it either raises or keeps the same amount of rejected. The discussion can be reopened for the potential limitations and suggestions for improvement, like using better sensors to reduce errors. The above error result of up to 5-6% can be improved using the high-resolution sensor and updated laser line triangulation sensor technology. Still, its cost will be higher than current sensors. As the general purpose operations are carried out with limited tolerances, they can be easily handled using the current and updated sensors. The operator must take the utmost care of machine vibration. The error lies in operation and gets magnified by the operator's ignorance. However, the intelligent system helps reduce the operation load by lowering the operator's engagement to no productive operations and relieving the operator from timely and intermittent inspection and allied target stress by providing a continuous display system.

Additional Workpiece manufacturing data from both methods shows that retrofitting it to an intelligent Method can significantly enhance the general process. Especially the data regarding removing the need for mid-process inspection, the claims about time savings, and reduced job rejections. Mid-Process Inspection: While the data does not explicitly reference mid-process inspection, a comparison of "General" and "SMART" procedures shows that the SMART system may include built-in quality control mechanisms that eliminate the need for manual inspections. This might be extrapolated from the decreased failure rates (0.4 vs. 0.1) and the possibility of real-time monitoring and modification. Time Savings: According to the statistics, the SMART system decreases production time per workpiece by 25.8 minutes compared to 18.6 minutes. This shows that the system is more efficient regarding resource utilization and process optimization. Reduced Job Rejections: The SMART system's reduced defect rate (0.4 vs. 0.1) indicates that it is more successful at creating quality Workpieces, lowering the risk of job rejection. The data gives compelling evidence to support the promises of time savings and decreased job rejections.

7. Conclusion

Considering the manufacturing scenario, quality norms, existing general-purpose machine set-ups, and accumulation of labor, the SAMRT Setup with SPDA is a simple, effective solution. It plays a vital role in eliminating the In-between W/P inspection stage by providing continual feedback to the operator to ensure quality manufacturing. As the commencement of tool & sensor movement is inline, only linear dimensions are sufficient to give profile dimensions. Ease of manufacturing leads to an average saving of manufacturing time of 6.13 min per piece. The average real-time measurement error encountered is about 4-5%, which can later be eliminated by the use of high-quality sensors in the future. However, even though the error is within the limit, it can be judged and waived before rework. The support system may act as a road map to quality manufacturing.

8. Acknowledgement

As the research has no conflicting financial interests and is not funded by any agency or institute, we acknowledge the earlier researcher stated in the reference section for their guidance and promising road map for building this newly developed setup.

9. Conflict of interest

The authors state that they have no known conflicting financial interests or personal ties that might have influenced the work presented in this study.

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