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# Cost Effective Digitalization Solution for Sinumerik CNC System To Increase The Transparency and Utilization of The Machine

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***Abstract***: ***In this work, we fetch the current trends in industrial automation and data exchange technology adopted in Computer Numerical Control (CNC) machine and mitigate the features in in a cost-effective manner. The current trend is Industry 4.0, uses cloud-based systems for information and data exchanges in machine to machine communication. This methodology is reliable, but expensive and can be afforded only by large scale companies. In order to provide the data transparencies at low cost, we utilize a low-cost computing system using Python language for small scale industry. This technique was implemented in the existing CNC machine and the machine parameters such as Machine Operating Mode, Cycle Time, Part Count, Feed rate, Spindle Running Hours, Machine Running Hours, and Machine Utilization Hours are monitored. Graphical user interface (GUI) screens are developed to help human machine interface. Acquired real-time machine data will help boost transparency and help the operator/ user for smart decision making. The IIoT (Industrial Internet of Things) technology helps to connect more numbers of such machines, results in increased machine utilization and productivity through continuously monitoring and analyzes.***

***Index Terms***: ***, IoT, Automation, Computer Numerical Control (CNC), Data analysis, Industry 4.0, Industrial IoT.***

## I. INTRODUCTION

Industry 4.0 is the fourth industrial revolution. It focuses on cyber physical systems, the Internet of Things, cloud computing and cognitive computing. This brings forth smart factories to the industrial world. Industry 4.0 has four design principles which include: Interconnection, Information transparency, Technical assistance and Decentralized decisions. A cost-effective system has been designed to measure the temperature and vibration variables of a machining process in Hass Computer Numerical Control (CNC)[1]. Industry 4.0 is revolution in a new wave of cyber-physical systems in NC (Numerically control) machining process platform which realizes the real-time monitoring and 3D display of machine tools[2-4].

Increasing efficiency has always been a major factor in the manufacturing sector for better production. Improved efficiency leads to better profitability. With the IoT gaining importance, it has become one of the leading use cases for Industry 4.0[5], [6]. A combination of traditional condition monitoring enhanced with analytical algorithm forms the basis of Predictive maintenance strategies. Total Productive Maintenance (TPM) and 5S techniques minimize the breakdowns and improve the performance and efficiency of a machine [7]. This technology enables the prediction of machine failures before they occur. For many small business owners, the adoption of IoT may seem like a daunting challenge. Cloud computing based equipment monitoring systems help in monitoring the performance, statuses, equipment faults, production quality and precision of the machine [8]. These systems involve the use of expensive and complex software which are difficult to use. This bottleneck prevents many small scale industries from adopting these methods, and also their return on Investment takes a longer time. Monitoring machining processes have become a major factor for a manufacturer to improve the efficiency of the production line. Investigating the data of the CNC machine tool based on controller tuning operation help in increasing the productivity of industry 4.0[9-11]. It can also help in reducing the downtime of the machines. This work aims to help small manufacturing industries to use the current technology to improve functionality and identify the key areas for improvement and thereby increase the utilization by simplifying machine monitoring [12-13]. IoT technologies are the key factors in Industry 4.0 which help in increased product customization, productivity, and reliability of physical systems and are compared in real time [14]. Data extraction is made possible using industrial IoT in machines [15]. The proposed methodology will enhance small and medium enterprises to embrace IoT in a big way. These enterprises look for the following: cost should be affordable, the technology should be easy to use without any specialized knowledge or having to hire someone with special skills, it should be readily available, and the results should be accurate and must help them save or recover money faster. Our work is aimed to develop a solution that will help small and medium businesses achieve the above objectives.

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In our work, we will be monitoring the Sinumerik CNC with the help of a raspberry pi and thereby showing the machine's utilization patterns. The process of monitoring is initiated by selecting the list of parameters to be monitored [16]. The raspberry pi is programmed with the help of the programming language Python to meet the requirements.

Then the raspberry pi is hardwired to the Sinumerik CNC module to collect the required data over a specified period. The raspberry pi collects the data and collates for display. The various parameters that we require to be monitored are taken out from the CNC and given as input to the pi via the I/O card. The python program in the pi will run the proper algorithm to collect and store the data. The data is viewed on display screens in the form of graphical representations.

The organization of this paper is as follows: Section II reviews the concepts of Industry 4.0 and the design of cost-effective interface Module, Section III details the experimental setup functionality, Graphical User Interface design and the implementation results was discussed in Section IV followed with conclusion.

## II. BASIC CONCEPTS

The latest digital industrial technology is the Industry 4.0. This transformation makes it possible to analyze data of machines and thereby enabling faster and efficient production. Current market requirements and emerging autonomous technologies such as IoT are shifting the manufacturing companies' environment toward smart factories. Digitalization (Industry 4.0) is going to be a norm for all industries in the future. Most companies face challenges in adopting new technologies. In order to sustain a lead in the race, companies need to broaden in the field of digital technologies and implement digital manufacturing strategies. An Industry 4.0 solution will aid in overcoming the current challenges such as providing transparency, proper utilization of the machine, better production management, and thereby improving the efficiency of the manufacturing process.

### A. *Architecture*

If we consider the first parameter, Auto/Manual mode, the process is as follows. There is a selector switch on the CNC screen where we select whether it is the auto mode or manual mode. The information is transferred to the memory of the CNC and stored as an NC variable which will be a digital value (0 or 1). The NC variable is stored in the CNC memory. In the PLC logic we will write a small logical code to access the data. The data available in the CNC memory will be transferred to the raspberry pi via the PLC. Every company has its proprietary PLC logic software, and for Siemens, it is called the Simatic Manager. In the Simatic manager, we will write a small logic to access the NC variable and bring it as data to store in the PLC. Siemens will do this programming. Another code is required to transfer the data from the PLC through the I/O card to the raspberry pi. The value will be taken from the system and moved like 0 or 1 through the I/O module. The SINUMERIK I/O Module is PP 72/48D 2/2A PN. It has 72 digital inputs and 48 digital outputs. The digital output is then connected to a relay board. Relays are used to avoid the risk of the raspberry pi burning out. The raspberry pi can only handle up to 5V, and the GPIOs can tolerate only 3.3V without relays. Then, data is be stored in the raspberry pi. Similarly, it will be done for all the parameters. The CNC was monitored over two weeks for around seven to eight hours, and this was done using the methods below.

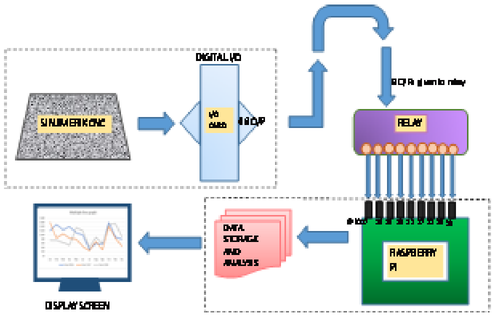



**Fig. 1. Design of Cost-Effective digitization Module.**

In the next section, we discuss the parameters selected. These parameters form the basis of our monitoring. More parameters can be added in the future with suitable additions to the programming.

### B. *Parameters*

***Machine Operating Mode: Auto/Manual***: When the machine is in manual mode, the operator can push buttons, turn wheels, and turn switches on or off. In Auto mode, we execute the program that is fed into it.

***Part Program Running: Yes/No:*** The set of instruction by which we can produce a part is known as a part program, and we can use to check the CNC program. This program gets executed when the cycle start button was pressed on the CNC.

***Cycle Time:*** The time taken to finish a production run by the amount of fine products produced.

***Part Count:*** The number of parts that have been produced during each production cycle is defined as the part count. It is monitored only when it runs in auto mode.

***Feedrate Override***: The feed-rate override is a multi-position switch which commonly ranges from 0 to 200 percent. It enables the setup person to slow (or stop) cutting motions on one end of the spectrum and double the programmed feed rate on the other.

***Spindle Running Time***: The spindle running hours is defined as the percentage of available time that the spindle of a machine is on.

***Breakdown Hours:*** The breakdown hour is the amount of time when a system is unavailable or of time that a system fails to perform its primary functions.

***Machine Running Hours***: The machine running hours is the working of a machine for an hour. This is used as a basis for cost finding and for determining operating effectiveness.

***Machine-Ready Time:*** Time taken after the part is produced until the next part is loaded onto the machine. It tells the operator that the machine is ready to start the process.

***Machine Utilization Hours***: It is the amount of time the machine is used successfully. Machine utilization compares the run time to the amount of time taken to setup the machine.

### C. *Software* Tools

**Tkinter tool:** *It is a toolkit for Python's GUI package. Tkinter is an inbuilt python module. It is an object-oriented layer [21].*

***Python 3:*** Python is a high-level object-oriented scripting language that it is easily readable. The interpreter processes Python at runtime. The program does not need to be compiled before executing it[22].
***Gnuplot:*** The Gnuplot is the tool used in our project to produce the graphs. Gnuplot programs help in generating two- and three-dimensional plots of functions [23].

## III. EXPERIMENTAL SETUP

The I/O card connected to the CNC has 72 inputs and 48 outputs. Nine outputs are selected and given to the raspberry pi via the relay. Pins 17, 18,23,16,25,12,22,27, 24, 13 are provided as input for manual mode, auto mode, the part program running, cycle start, rejected part count, federate override greater than 100, spindle output, machine output, alarm status, and machine ready respectively. The raspberry pi is programmed using python to collect and analyze the data. Graphical user interface screens are designed in the form of tables and graphs for easy interaction.

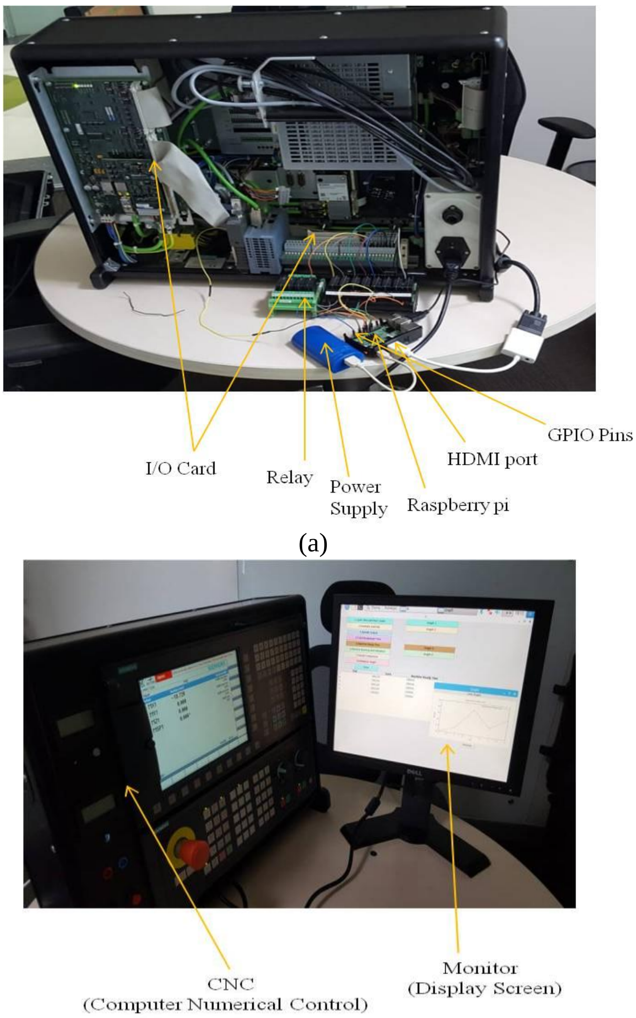



**Fig 2. (a)Experimental setup back view, (b) Experimental Setup front view**

### A. *Hardware Modules*

***Raspberry Pi 3:*** We have monitored the Sinumerik CNC with the help of raspberry pi. It is a mini computer that runs on the Linux platform and provides us with GPIO (General Purpose Input/Output) pins. It has 40 pins.
***Sinumerik CNC*:** A CNC (Computer Numerical Control) is a device used for material removal to get desired parts/components. The Sinumerik CNC 828D is basically the NC Kernel with a built-in PLC in the front which is connected to an I/O card. This can be used to control many complex types of machinery including mills, lathes, and grinders.
***I/O Module*:** The various parameters that have to be monitored are taken as an output from the CNC and given as input to the pi via the I/O card. The SINUMERIK I/O Module is PP 72/48D 2/2A PN. It has 72 digital inputs and 48 digital outputs. The digital output is connected to a relay board.
***Relay:*** In our work, we need to connect the pi to a module with a higher voltage. Relays are used to avoid the risk of the raspberry pi burning out. The raspberry pi can only handle up to 5V, and the GPIOs can tolerate only 3.3V without relays. Relays have two main contacts NO and NC.

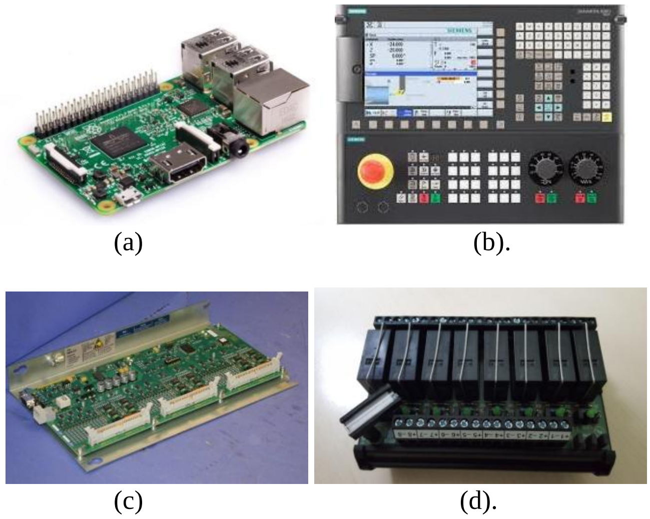
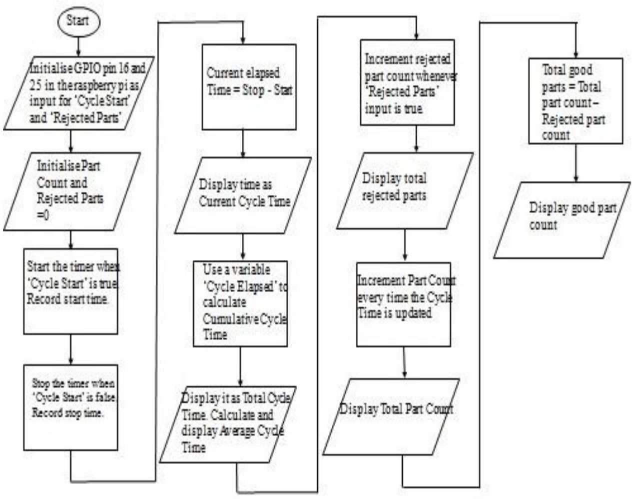



**Fig. 3. (a). Raspberry Pi 3 Model B V1.2 [17], (b). Sinumerik 828 D [18], (c). Sinumerik I/O Module is PP 72/48D 2/2A PN [19], (d) 8 Channel Relay [20].**

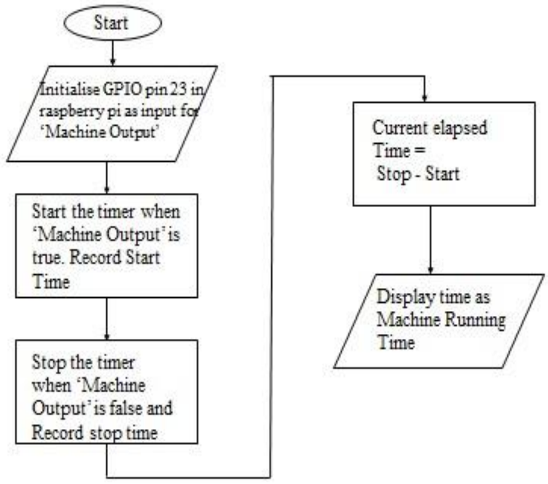
### B. *Software Design*

The flow diagram for the respective parameters program logic is as follows:

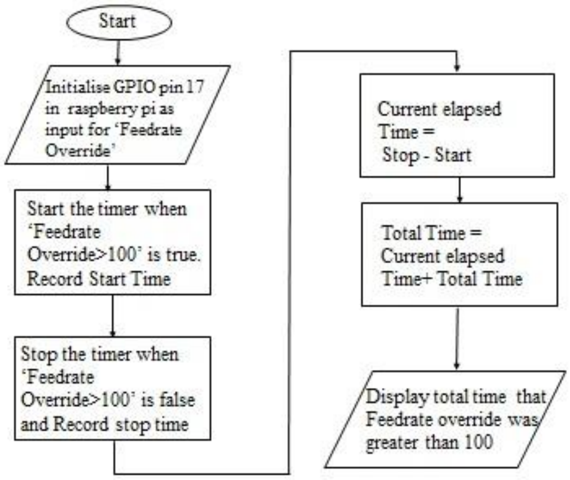
**Machine Operating Mode: AUTO/MANUAL and Part Program Running: YES/NO:** In the raspberry pi, GPIO pin 18 and 17 are initialized as 'Auto Mode' and 'Manual Mode' respectively. The selected mode will be displayed. GPIO pin 23 is initialized as 'Part Program Selected'. The display will show whether the part program is running or not.



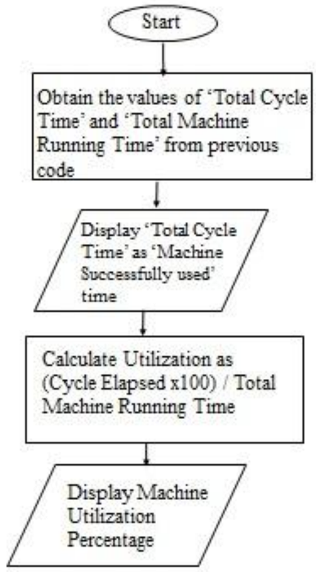

(a)



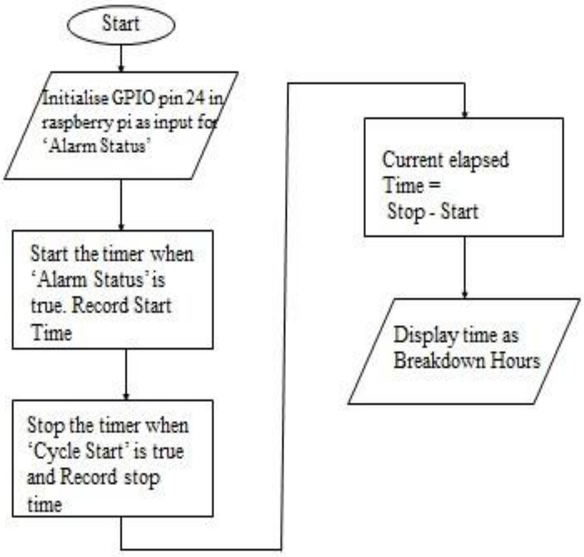

(d)




(b)




(e)




(c)

**Fig.4. (a) Cycle Time and Part Count, (b) Feed rate Override, (c) Breakdown Time,(d) Machine Running Hours, (e). Machine Utilization Hours.**

**Cycle Time and Part Count:** The calculation of current cycle time for every part manufactured the number of good parts and rejected parts, the average and total cycle time are outlined in Figure 4(a).

**Feed rate Override:** The time during which federate override are greater than 100 are recorded and displayed as shown in Figure 4(b).

**Spindle Running Hours:** In the raspberry pi, GPIO pin 22 is initialized as 'Spindle Output'. The total spindle running hours are calculated and displayed using the same algorithm as fig 4(b).

**Breakdown Time:** The total breakdown time was calculated as shown in Figure 4(c).

**Machine-Ready:** GPIO pin 23 was initialized as 'Machine Ready' and the total machine ready time is calculated using the same method as in fig 4(c).

**Machine Running Hours:** Figure 4(d) demonstrates how the total machine running time was calculated.

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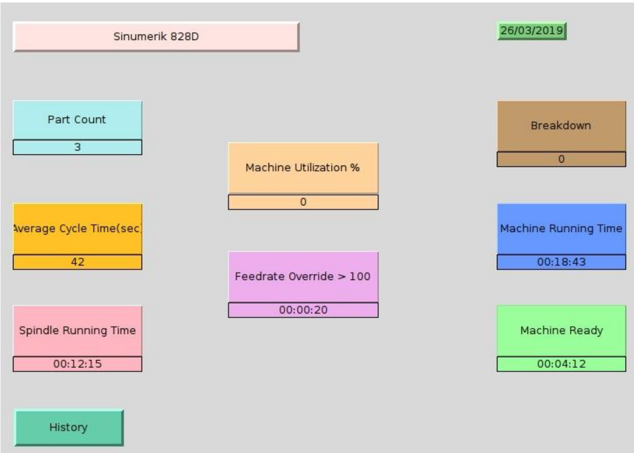
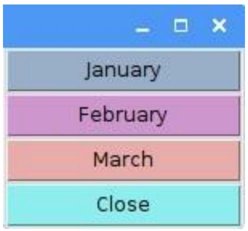
**Machine utilization hours:** The machine utilization percentage is calculated as shown in Figure 4(e).

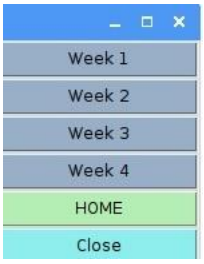
### C. *Graphical User Interface Module*

We have designed a Machine Utilization Dash Board which is displayed below. This is a system to help the operator to understand the production status of the machine at the current time. The information is given in the form of graphs, signals, numbers and lights to alert the user about the issues. This makes the state and condition of the processes easily accessible and clear to everyone. This helps the industry in monitoring and hence improving productivity.




(a)




(b) (c)

**Fig 5. (a) Machine Utilization Dashboard, (b).GUI of Months, (c) GUI of Weeks.**

When the history button in the dashboard is clicked, it shows screens that display the past data as required. The first screen displays the months. On selecting January, February, and March, the respective weeks are displayed.

## IV. RESULTS AND DISCUSSION

On selecting a week, the parameters will pop up. The same list of parameters will be displayed irrespective of which week is selected. On selecting each parameter, the corresponding table will be displayed along with the on monitoring the parameters over two weeks (eight hours daily), we have the following data as shown in the tables. The data recorded in the first week of January is shown below:

**Cycle time and Part Count**: It is inferred from Figure 7(a) that the average time for 1 part to be produced in a day is 48 sec. The total number of parts produced in a day is 425 parts and the total time for 425 parts to be produced is 5hrs 40mins 0sec.

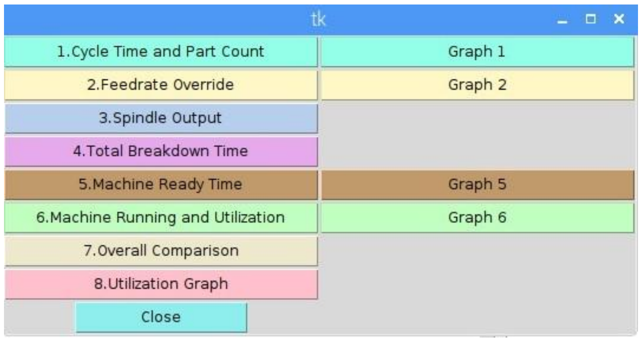



**Fig 6. GUI Screen of Parameters**

Cycle Time and Part Count

| Day | Date | Average Cycle Time | Total Cycle Time | Part Count |
|---|---|---|---|---|
| 1 | 1/01/19 | 48sec | 5hr 40min 0sec | 425 |
| 2 | 2/01/19 | 50sec | 5hr 45min 0sec | 414 |
| 3 | 3/01/19 | 48sec | 5hr 40min 48sec | 426 |
| 4 | 4/01/19 | 51sec | 5hr 48min 30sec | 410 |
| 5 | 7/01/19 | 49sec | 5hr 43min 49sec | 421 |

(a)

Feedrate Override

| Day | Date | Feedrate Override >100 |
|---|---|---|
| 1 | 1/01/19 | 25min |
| 2 | 2/01/19 | 55min |
| 3 | 3/01/19 | 50min |
| 4 | 4/01/19 | 45min |
| 5 | 7/01/19 | 20min |

(b)

Total Spindle Running Hours

| Day | Date | Total Spindle Running Hours |
|---|---|---|
| 1 | 1/01/19 | 6hr 20min 0sec |
| 2 | 2/01/19 | 6hr 25min 0sec |
| 3 | 3/01/19 | 6hr 20min 48sec |
| 4 | 4/01/19 | 6hr 28min 30sec |
| 5 | 7/01/19 | 6hr 23min 49sec |

(c)

Breakdown Hours

| Day | Date | Breakdown Hours |
|---|---|---|
| 1 | 1/01/19 | 1hr 15min 0sec |
| 2 | 2/01/19 | 0hr 35min 0sec |
| 3 | 3/01/19 | 1hr 20min 0sec |
| 4 | 4/01/19 | 0hr 48min 0sec |
| 5 | 7/01/19 | 0hr 40min 0sec |

(d)

Total Machine Ready Time

| Day | Date | Total Machine Ready Time |
|---|---|---|
| 1 | 1/01/19 | 10mins |
| 2 | 2/01/19 | 12mins |
| 3 | 3/01/19 | 18mins |
| 4 | 4/01/19 | 13mins |
| 5 | 7/01/19 | 16mins |

(e)

Machine Running time and Utilization Percentage

| Day | Date | Total Machine Running Time | Machine Utilization Percentage |
|---|---|---|---|
| 1 | 1/01/19 | 6hr 45min 10sec | 86.3 % |
| 2 | 2/01/19 | 6hr 46min 18sec | 85.4 % |
| 3 | 3/01/19 | 6hr 51min 23sec | 87.3 % |
| 4 | 4/01/19 | 6hr 47min 28sec | 82.6 % |
| 5 | 7/01/19 | 6hr 43min 16sec | 85.1 % |

(f)

**Fig 7. (a) Cycle time and Part Count, (b) Feed rate Override, (c) Spindle Running Time,(d) Breakdown Time, (e) Machine Ready Time, (f). Machine Running and Utilization Percentage.**

**Feed rate Override:** Figure 7(b) depicts that the feed rate override was greater than 100 for 25mins on 1st January 19. This shows that the operator has increased the programmed feed rate of over 100 for 25mins.

**Spindle Running Time:** Figure 7(c) shows the amount of time the spindle has functioned for each day in a week. The total spindle running hours for one day is 5hrs 80mins 0sec.

**Breakdown Time** It can be inferred from Figure 7(d) the amount of time in a day when the machine was unavailable or failed to perform its functions.

The total breakdown time in a day is 1hr 15min 0sec.

**Machine-Ready Time:** The above Figure 7(e) shows the time taken after a part is produced until the next part is loaded onto the machine. The total machine ready time for one day is 10mins.

**Machine Running and Utilization Percentage:** The total machine running time in a day was found to be 6hr 45min 10sec from Figure 7(f). The total machine utilization percentage for one day is 86.3%.

The first graph is a comparison of total cycle time, total spindle running hours, total machine ready time, breakdown time and total machine running (ON) time. The second graph is a comparison between successfully used time and total machine running time which gives us an understanding of the machine utilization. The graphical representation of the parameters data is depicted and shown in Figure 8:

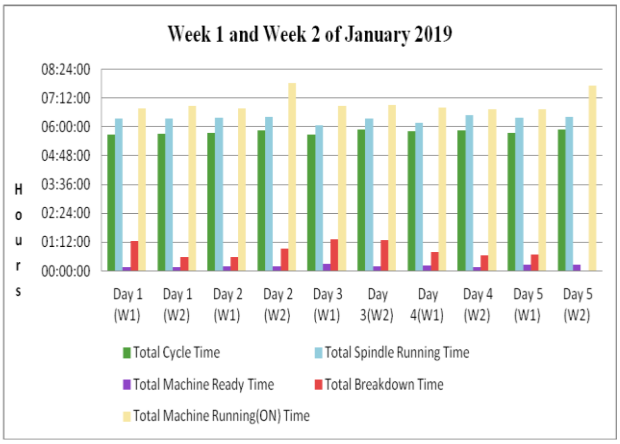
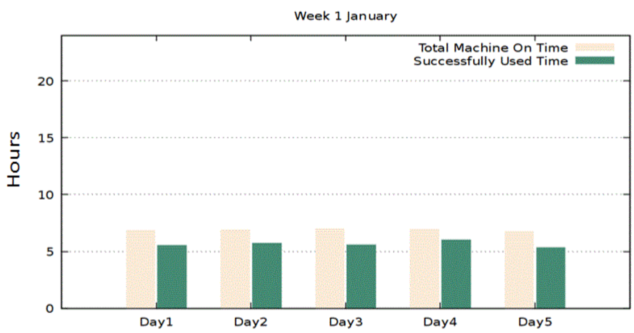
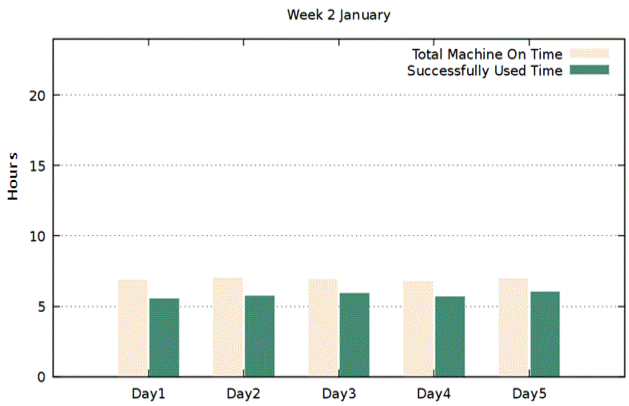



**Fig 8. Comparison of various parameters**




(a)




(b)

**Fig 9. (a) Machine Utilization Graph for Week 1, (b). Machine Utilization Graph for Week 2.**

Similarly, the graphical representation for the data recorded in the second week of January is depicted in Figure 9.

On analyzing the data, it is evident that breakdown time is significantly affecting the production. This graph shows how much percentage of the total time was wasted in the breakdown.

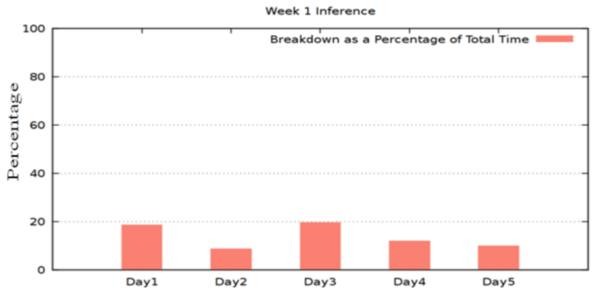



**Fig 10. Breakdown time in Percentage of Total Time.**

Proper maintenance is essential for extending the life of the machine and increasing productivity. Despite this, for small manufacturing enterprises, there are not much tools or equipment available to understand the impact of the machine breakdown or production loss, and rarely are these variables measured. We intend to provide the correlation between the actual machine running time and the successfully utilized time so that we will know to what extent there are losses and this will help in better planning of maintenance and future activities. The tables and graphs help us in visualizing the impact of various parameters. We aim to achieve maximum efficiency by improving utilization. One way to reduce breakdowns is to ensure proper alignment of all moving components and proper lubrication and cooling systems. When a product is getting machined, if at that point of time the machine breaks down, there are chances that we may not be able to reuse that particular piece.In some cases, we may have to start with a fresh piece, which results in a loss. In this particular instance, we were able to continue producing the part even after the breakdown, but in other cases, it may be required to restart the process. Minimization of breakdown time can be achieved by scheduling proper maintenance. We should also make sure that the ready time should be nominal and minimize defective part count. The design of CCEMS for the CNC machine tool and NWAIF gives many benefits [8] but, here in our work, we have focused on a solution independent of the cloud. The cycle time per piece has been monitored along with the spindle speed for Hass CNC and data is stored in the cloud with the focus mainly on maintenance [1]. In our work, we have monitored various parameters, analyzed and stored the data with the same accuracy and then display them in the form of tables and graphs without using the internet; hence our method is cost effective.

## V. CONCLUSION

Smart factories take the manufacturing industries a leap forward from traditional automation to a fully connected and flexible system, which compels the companies to take up the latest industrial mechanisms. We have provided a feasible, cost-effective solution using a raspberry pi to simulate an Industry 4.0 solution for CNC. This is a solution for small manufacturing companies to adopt new technologies for improving overall efficiency and become more competitive. We can capture the machine utilization parameters easily over a weekly period and simulate the acquired data in graphical form with the help of user interface screens. Data acquisition is done in real time so that the user can analyze the performance of the machine and the production rate at the current time. This method increases transparency, thereby giving insight on where the scope is available to improve machine utilization. This helps the user to get more profit, production, and higher efficiency. Adopting cost-effective technology for monitoring and managing the utilization and efficiency of machine tools will help in reducing waste and becoming more productive.

## VI. ACKNOWLEDGMENT

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