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A CONCEPTUAL IOT FRAMEWORK FOR SUSTAINABILITY ASSESSMENT OF TURNING PROCESS WITH RESPECT TO QUALITY AND PRODUCTIVITY CONTROL

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ABSTRACT

Turning process is the most fundamental material removal process of any organization and the process on which determination of productivity level of the organization depends. Sustainability in the turning process can be attained by judicious selection of input parameters, keeping in mind the economic and environmental aspects simultaneously. This research work is an extension of the sustainability assessment of the turning process by utilizing Internet of Things (IoT) framework considering the relevant data and formulas from the previous study. It helps in analysing the performance of the tool and bringing in the required changes to improve it. The current manufacturing environment is very dynamic which makes the determination of the tool performance difficult to assess. Hence, employing the described method will help the company to consistently take in the data from the tool and analyse the performance at every instant.

KEYWORDS: ***Sustainable Turning, Internet of Things Framework, Piezo Vibration Sensor, Speed Sensor, Remote Sensing/Viewing, Authorized Personnel Access, Client Server Network.***

1. INTRODUCTION

Manufacturing industry has shifted their focus on developing products using sustainable manufacturing methods. This is because of the fact that the awareness among the manufacturers and the users is increasing rapidly. It has been made mandatory for all the countries to reduce their negative impact on the environment due to manufacturing processes. The interest of any individual, organization or country cannot influence the need for better methods to safeguard environment. There should be no compromise for a better and safe environment. Machining industry consumes the maximum energy and is the most waste generating industry. The major concern is, that in what way manufacturing processes can be used, so that the emissions can be minimized keeping the productivity high. Sustainability, in the present scenario, is a need rather than a choice.

The growth of any nation is largely influenced by the sustainability concept as it is aimed at the integration of environmental, economic and social aspects with their systems (Vinodh et al., 2015). Sustainable manufacturing (SM) transforms materials into finished products utilizing technologies that help in reducing “greenhouse emissions, waste generation, energy consumption, and use of non-renewable or toxic materials” (Madu, 2001). The increased consumption of non-renewable resources along with large scale generation of wastes and pollution has led to the need for implementation of SM initiatives (Amrina and Yusof, 2011). The primary indicator of the growth of any organization is the manufacturing performance. India is well course to increasing the share of manufacturing sector to 25 percent of GDP from existing 17 percent (THE HINDU), which instigates the manufacturing industries to consider sustainable manufacturing processes, in order to optimize the production cost. Since, a component is manufactured by incorporating a number of manufacturing processes as per consideration, thus, it becomes important to include all critical aspects of each processes to enhance the sustainability of manufacturing sector. Turning process being one of the fundamental metal cutting processes poses various sustainability concerns (Rao, 2010). There have been various approaches to address sustainability concerns posed by turning process; however, the possibility of digitization of the manufacturing (turning) process is the most ignored aspect of this sector. There have been a lot of frameworks dealing with real-time data gathering pertaining to different manufacturing processes, consequently leading to a responsive production management and maintenance. There have been frameworks to make process planning and to monitor feasible services for the Cloud manufacturing and frameworks to form a new possibility of solving that problem by integrating CAM systems with the diagnostic systems. But no such IOT framework has been yet included in the literature, which would have made it much easier for the organizations to ensure sustainable production throughout the organization, by gathering feedback from the employees and implementing the required corrective measures.

The above discussion thus arises the necessity for an Internet of Things (IOT) based framework that could assess the performance level of turning process simultaneously on various sustainability issues and could further digitize the process parameters. Some important indicators of SM considered in the study are tool-life, vibrations, turning cost, carbon emissions, etc. with respect to speed and vibration of the machine. The respective data for speed and vibrations is generated by velocity and piezoelectric vibration sensors. The data is further processed in the Arduino Module framework. The data is further sent to C++ programming framework where it is further employed into various calculations regarding carbons emissions and turning cost. This data is retrieved back in Arduino framework and sent over Wi-Fi module to the password protected online accounts over "Thingspeak" web server. The discussed framework is an extension of previous study focussing on sustainability assessment framework of turning process (Bhanot et al., 2016).

The structure of this paper is as follows: Section 1presents the background and context of the study. Section 2 presents the relevant literature for issues related to Turning process and IOT based application for the enhancement of turning/ manufacturing processes. Section 3 explains about various techniques/modules used in the data generation, data processing and data transmission for sustainability assessment and digitization along with illustration of the data flow in the "working" section. Section 5 further presents the results by taking a case study for the data generation, data processing and data transmission. Lastly, Section 6 highlights the utility of study with some concluding remarks.

2. LITERATURE REVIEW

The literature is reviewed focusing on the two basic requirements of the research. The need was to introduce IoT framework that can enhance the machining performance for turning process. Thus, literature focuses on turning process and IoT-based researches in manufacturing field.

2.1. Issues in Enhancing Machining Performance for Turning Process

Bhanot et al. (2016) considered the economic and environmental aspects of the manufactured product and presented a sustainability assessment framework based on equations developed after conducting the experiments at full tool wear criterion for turning process. Dambhare et al. (2015) also investigated sustainability problems related to turning process in an Indian machining industry. Sustainability factors were taken to be "surface roughness, material removal rate, and energy consumption". The effect of process parameters vis a vis "speed; feed and depth of cut, the type of cutting tool and the machining environment being dry/MQL/wet" were observed on the response variables utilizing "Analysis of Variance (ANOVA) and Response Surface Methodology (RSM)" techniques. The results of the study were very helpful in analyzing the effect of the cutting parameters on "material removal rate, energy consumption and surface finish".

Another study conducted by Wang et al. (2015) presented a method for evaluating the carbon emissions of a process plan by aggregating a unit process to form a combined model. The results of the study were very helpful in highlighting the detailed mapping of the impact between manufacturing process plan and corresponding carbon emissions along with decreasing the resource and energy consumption. Finally, the feasibility and validity check was done by applying the framework to a process plan of an axis.

Dzhudzhev et al. (2013) discussed about piezoelectric transducers and how they can be used for vibration measurement. The conversion functions were experimentally defined, and proper investigation was done. Here the vibrations limit is considered to be the sustainability parameter. This paper explains a practical method to measure vibrations induced in a machine. However, Tanaji et al. (2013) focused on achieving a higher rate of production along with a better surface finish. A CNC turning machine was engaged for the experimentation purpose considering various types of cutting tool inserts for different workpiece material. Further treatment of the recorded data was done using Minitab, followed by determination of optimal solution using Taguchi method.

Raju et al. (2016) estimated the machine performance by taking images along with the vibration signature from the accelerometer. The measured data during machining was used for monitoring the metal cutting process. Data from the image processing unit and the accelerometer was incorporated into a mixed variable estimation approach for evaluation of machining performance like "surface roughness and tool wear". Support Vector Machine (SVM) model was developed for estimation of machining performance. Aggarwal et al. (2005) reviewed the literature on the optimization of machining parameters in turning processes. "Geometric programming, geometric plus linear programming, goal programming, sequential unconstrained minimization technique, dynamic programming and many other conventional techniques" were employed for machining optimization. The latest optimization techniques included "fuzzy logic, scatter search technique, genetic algorithm, and Taguchi technique and response surface methodology".

2.2. Application of IoT Framework for Enhancing Machining Performance

Rymaszewska et al. (2017) focused on studying that how can servitization unlock the potential for innovative product-service systems by utilizing the third wave of Internet development. An attempt has also been made to address the question as in how organizations can reap the benefits by offering product-service systems as compared to what IoT is offering based on the analysis of servitization literature and technological breakthrough. Qiu et al. (2015) proposed a framework to enhance the effectiveness and efficiency while sharing physical assets and services based on an IoT-enabled SHIP, the overview of which has been highlighted by three key components: "Physical Asset Service System (PASS), Information Infrastructure, and Decision Support System". Research gaps depending upon the relevant literature were highlighted, and key research questions were presented which were found worthy of further exploration.

Brizzi et al. (2013) developed a responsive maintenance and production management system by gathering real-time data of manufacturing processes based on IoT exploitation. The presented work took advantage of the ebbits platform for analyzing the results. Adamczyk et al. (2004) realized that the need to search for new methods of "machining and its parameters selection" is generated when new materials are dynamically developed. Moreover, any change in the manufacturing environment calls for arranging preliminary cutting tests to fulfil customer requirements. Thus, the paper aimed at developing a tool diagnostic system and CAM system, integration of which could lead to the optimization of machining processes.

In all the papers discussed above, the possibility of digitization of the sustainability process has not been included, which would have made it much easier for the organizations to ensure sustainable production throughout the organization, to gather feedback from the employees and to implement the required corrective measures. Based on the above findings from the literature, the paper tends to focus on following objectives:

1. Integrating all the values received from corresponding sensors with the help of Arduino Uno module, which will be further, manipulated and exported.
2. Feeding these values in the C/C++ programming platform and wirelessly transmitting these values to the online accounts via IOT framework.

The current study has inculcated the use of both electronics and computers to ensure sustainability of the turning process in a much convenient way to provide a guiding framework to illustrate the implementation of Industry 4.0 framework. The study makes it easier for the employees and the workers to control the operations and to get the results remotely.

3. METHODOLOGY

The figure given below signifies the entire methodology adopted to integrate all the sensor values as well as manual entries with Arduino and further manipulate those using formulae in the C/C++ programming and wirelessly transmitting the outputs to the online accounts.

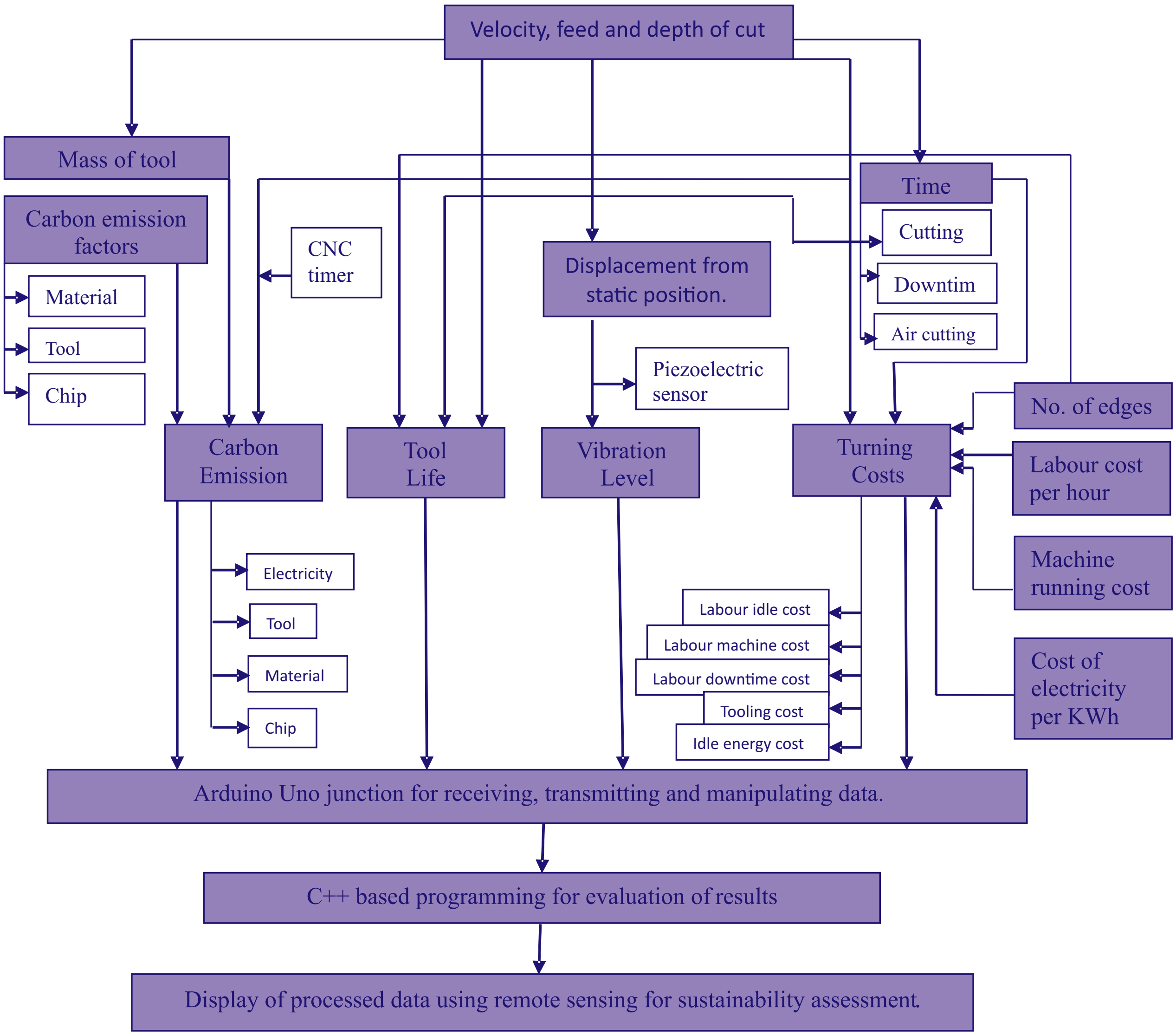

Fig. 1. IoT Approach for Turning Process

3.1 Techniques/Modules

3.1.1 Arduino Uno Module

Based on the ATmega328P (datasheet), Arduino Uno has fourteen input/output digital pins (6 PWM outputs), 6 analog inputs, a quartz crystal having a frequency of 16 MHz,a power jack,a USB connection, a reset button and an ICSP header. To operate; use USB cable to connect it to a computer or use an AC-to-DC adapter or a battery to power it.

3.1.2 Speed Sensors

Speed sensors are of great significant to know the speed of any kind of motors used while building any small robot or project. It works on the mechanism of blocking infrared beam with the help of a disc with holes(encoder disc), the total revolutions for a time period can be calculated by counting the number of times the sensors goes from high to low.

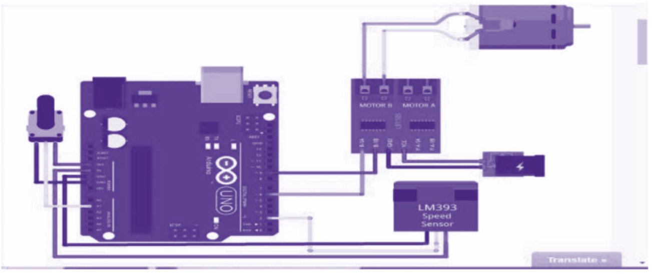

Fig. 2. Arduinoset-up with Speed Sensor and Motor

The above figure 2 gives an overview of the Arduino setup with speed sensors to be installed on the CNC machine. The speed sensor is connected via wires to the Arduino board using analog and digital input/output pins. On the other side, motor along with current controlling module is connected to the Arduino. The speed of this motor is to be calculated by the speed sensor.

3.1.3 PIEZO Vibration Sensors

To measure changes in pressure, vibration, acceleration, temperature, strain, or force; piezoelectric sensor is used. This sensor uses the piezoelectric effect by converting mechanical disturbances into electrical charge.

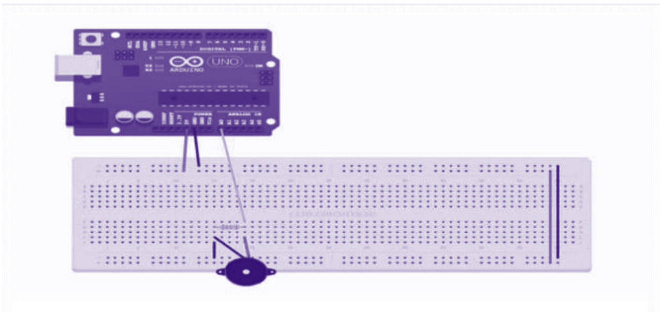

Fig. 3. Arduino set-up with Piezo Vibration Sensor

The above figure 3 shows the Arduino setup with Piezo Vibration sensor. The above circuit includes a 1Mohm resistor also. This resistor has one side grounded, and other side connected to an analog pin of Arduino and is in parallel connection with the piezo sensor.

3.1.4 WI-FI Module

ESP8266 Wi-Fi module is used to provide Wi-Fi access to any microcontroller. It is used to either host executable application or discharging all Wi-Fi functions from another microcontroller. It is controlled by AT commands which are pre-programmed. ESP8266 is cheaper, and its use into different genres is rapidly increasing in the community.

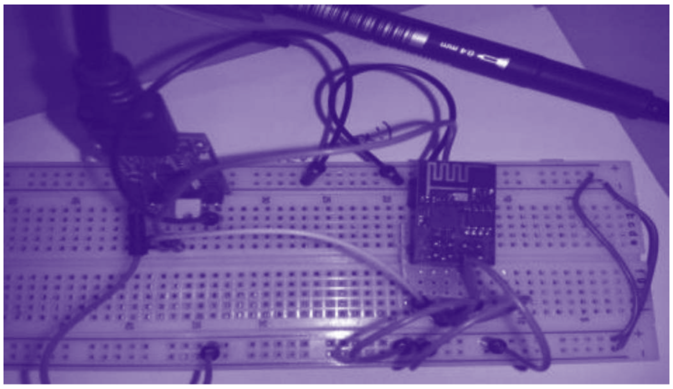

Fig. 4. Arduino set-up with Wi-Fi Module

The above figure 4 shows the Arduino setup with Wi-Fi module. The breadboard holds all the interconnects along with ESP8266 and Arduino module. The data from ESP8266 is sent and received with Arduino through input/output digital pins via male-to-male jack wires.

3.1.5 Code Blocks

We are using Code::Blocks (Version 16.01) to compile, edit, run and debug our code. It is a C/C++ along with Fortran IDE. We have used GCC compiler for compilation purpose in Code::Blocks. It is an IDE to perform cross-platform operations and provides a familiar and user-friendly interface and feel supporting multiple compilers, including GCC.

3.1.5.1 Code Editor

Code Block editor supports highlighting, class (private, public, protected) browser, hex editor and a wide variety of features. Tabs are used for organizing open files, and the code editor provides various fonts and size options along with different colors for highlighting.

3.1.5.2 Debugger

The Code Block debugger supports solution at the breakpoint. It also provides program debugging as it provides access to the local function and arguments, call stack, disassembly, switching of threads, CPU registers, and GNU debugger interface.

3.2 Working

3.2.1 Data Generation

Piezoelectric vibration sensor module along requisite circuitry converts the mechanical vibrations/disturbances to electrical impulses and transmits them to Arduino module. Velocity sensors are attached to spindles for transmitting data to Arduino module with the purpose of dynamic display of incoming data over the serial monitor or excel sheets or graphs. The values of velocity feed and depth which impact the mass of tool as well as the values of time (cutting, downtime, air cutting) are obtained from CNC machine. Also, the following data is collected manually: edges per insert, labour cost per hour, the machine running cost and cost of electricity per kWh.

3.2.2 Data Processing

Arduino Uno module which is configured via C based Arduino software provides the junction for receiving data from sensors and manipulating via codes available in APPENDIX A. As per required, this manipulated data is exported to C++ coding software where we are building a graphical user interface. The code for exporting data is again available in APPENDIX A. In this interface, various menus are laid out for choosing factors like type of power grid used, type of material of the workpiece, etc. which are used for determining the CEF Electricity and CEF Material. This is implemented using switch cases in C language. The software takes a few parameters externally for its computations. For the purpose of input scanf statements are used and for displaying the output printf statements are used. The data so obtained is then processed in our software and calculates various costs like labour idle cost, labour machining cost, labour downtime cost and downtime energy cost. The C code for the interface as mentioned above is given in APPENDIX B. Finally, the data generated from the C interface software is imported back to Arduino module and displayed on a serial monitor or further exported to excel sheets or Thingspeak Web Server.

3.2.3 Data Transmission

Wi-Fi module being ESP8266 is used for wireless transmission of data via Arduino module to the online web server "Thingspeak" utilising standard protocols.

A password protected online account is managed over "Thingspeak," and it receives data via API key given in the Arduino code available in the appendix so that the data can be displayed online dynamically in the graph format for the client. Various online accounts can be similarly maintained over Thingspeak web server corresponding to different data of various processes being executed in the manufacturing environment.

4. RESULTS &DISCUSSION

The following Assumptions have been made in order to explain the working of the proposed framework for IOT implementation to assess the sustainability of turning process. Initially, the data from all the sensors integrated with the Arduino module are received and exported to the C/C++ coding platform. The assumed values for the framework are as follows:

4.1Data Generation

4.1.1 Sensor Based Values

Following set of values can be directly incorporated by using sensors which in our case have been considered according to one specific case for illustration.

Velocity Sensor: 20 m/s

Piezo Electric Vibration Sensor: 10 mm/s

Time for air cutting/insert (in mins): 15

Total time for cutting/insert (in mins): 30

Down-time (in mins): 10

Figure 5 and 6 shows that how the software collects the values from the different sensors and finally utilizes them in the code to generate results.

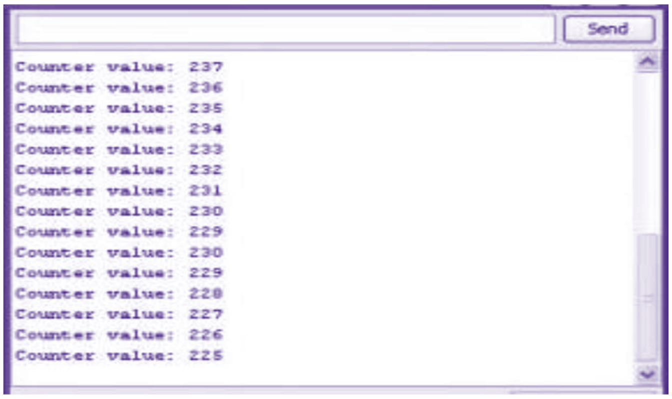

Fig. 5. Velocity Sensor Readings

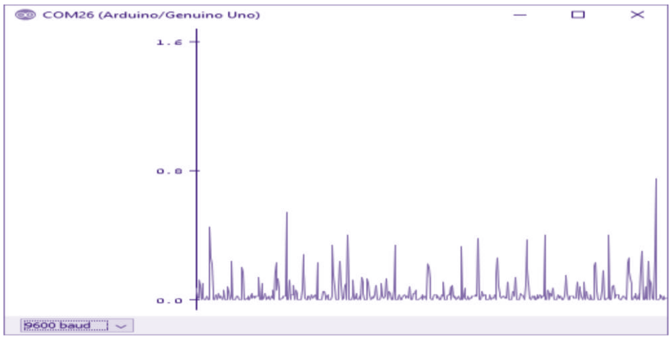

Fig. 6. Vibration Sensor Readings

4.1.2 Manual Entries

The code contains some predefined values related to the factors given below. The user needs to specify the type of factor required for the analysis.

1) Choice of Power Grid

On the basis of the option chosen, CEF for Electricity is obtained. As in this case the Power grid chosen was north india power grid. Hence,

CEF_Electricity =0.7802

2) No. of edges per Insert

Here, let the no. of edges per insert be 4.

3) Choice of Chip being Obtained

On the basis of the option chosen, CEF for Chip is obtained. As in this case the Chip chosen was waste iron scrap. Hence,

CEF_Chip =0.361

4) Type of material of work piece

On the basis of the option chosen, CEF for Material is obtained. As in this case the material of work piece chosen was steel. Hence,

CEF_Material =2.69

Now, a few fields are to be entered by the user while on the contrary a database can be generated in the system which can be later simply selected for analysing the machining environment. In current case, following values have been assumed as entered by the user for different indicators.

Labour charges/hour:100

Machine running charges: 500

Cost for insert: 500(Tooling Cost: 125)

Cost for KWH of electricity: 6

Basic power of turning utilised by the machine: 3

Power of Coolant applied: 0.33

Power of Spindle used: 0.25

Power of Axis Motor: 0.15

Tool Life (in mins): 150

Mass of tool (in gms): 100

Feedgiven (in mm/min): 4

Depth of cut (in mm): 5

Density of insert (in g/cm^3): 7.80

4.2 Data Processing

The software then uses the following set of formulas to compute the above mentioned indicators as referred to our previous study (Bhanot et al. 2016):

Labour Idle Cost= (labour charges + machine running charges)*(air cutting time per insert)

Labour machining cost= (labour charges + machine running charges)*(total cutting time per insert)

Labour Downtime Cost = (labour charges + machine running charges)* (downtime time)*60

Using the formulas given below the program calculates cutting energy cost, downtime energy and downtime energy cost, idle energy and idle energy cost.

Cutting Energy Cost= cost for KWH of electricity *cutting energy

Downtime Energy= basic power * downtime time

Down Time Energy Cost = cost for KWH of electricity * downtime energy

Idle energy= power of coolant +power of spindle +power of axis) * time of air cutting

Idle energy cost = cost for KWH of electricity * idle energy

Now, in order to find out the amount of carbon emissions due to various factors like tool, electricity, material and chip the program makes use of the following formulas.

By Electricity

Carbon Emission due to electricity = CEF_elec * (cutting energy + downtime energy + i dle energy);

By tool

CEF_tool = CEF_elec * (cutting energy/3.6) * (1000 / mass of tool);

Carbon Emission due to tool = (cutting time / Tool life) * CEF_tool * mass of tool;

By material

mass of chip = velocity of tool * feed * depth of cut* cutting time * density of insert / 1000;

Carbon Emission due to material = CEF_material * mass of chip;

By chip

Carbon Emission due to chip= CEF_chip * mass of chip;

4.2.1 Data Output

The following output values are obtained by using the above mentioned formulas

Labour Idle Cost: 9000

Labour machining Cost: 18000

Labour Downtime Cost: 360000

Downtime Energy: 30

Downtime Energy Cost: 180

Idle Energy: 10.95

Idle Energy Cost: 65.7

Carbon Emissions:

by Electricity : 31.949190

by Tool : 121.1547

by Material : 251.7840

4.3 Data Transmission

The values so generated are exported to Arduino from where they are further transmitted to the server at Thingspeak via Wi-Fi module and displayed in the form of graphs into several password protected online accounts. Figure 7 and 8 shows one of the ways in which, the considered indicators for productivity and quality control can be monitored in real-time basis.

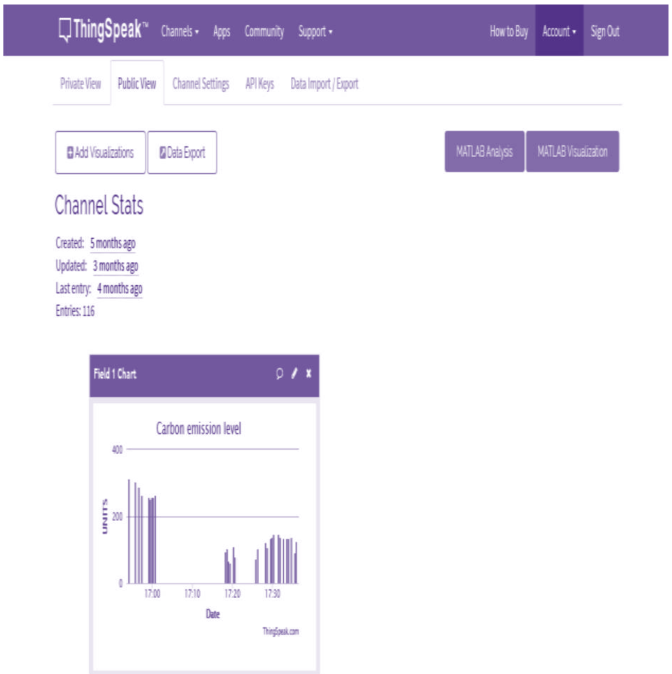

Fig. 7. IOT Framework for Monitoring Sustainability Aspects of Turning Process

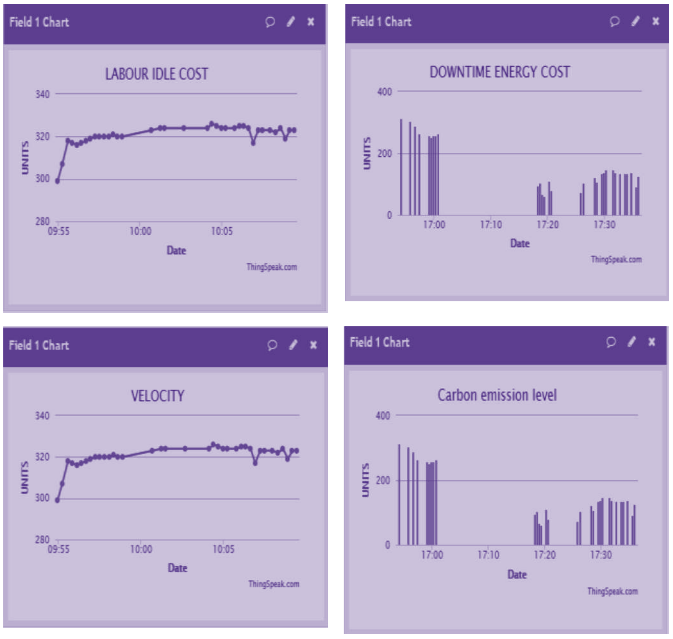

Fig. 8.Graphs for different indicators using IOT Framework

5. CONCLUSION

Digitization of various indicators can help ease the sustainability assessment of different machining processes in real time basis with the aid of IOT (INTERNET OF THINGS) framework along with Arduino and C/C++ programming. In this study, efforts have been made to present a framework to integrate the concept of Industry 4.0 for a machining environment considering few critical indicators. With real-time monitoring of machining process, it is expected to increase the efficiency of the process manifold by continuously keeping a check on productivity and quality issues and will help to devise suitable strategies for taking corrective measures the moment any lag is identified. The proposed framework will make it much easier for the organizations to ensure sustainable production throughout the course, by gathering the fed back digitized values from the process, as it is easy to comprehend and interpret as compared to analog values and further implementing the required corrective measures. It will also help the production managers to effectively monitor the status of various machining processes even from a remote location. Further efforts can also be made to incorporate preventive measures within the framework itself in the case of any alarming situation.

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APPENDIX A

1. SPEED SENSORS

```
#include <TimerOne.h>
int counter_speed=0;
int z1a = 6;
int z1b = 9;
void do_count()
{
 counter_speed++;
}
void timer_Isr()
{
 Timer1.detachInterrupt();  //stop the timer
 int rotation = (counter / 20);  // divide by number of holes in
Disc
Serial.print("Motor Speed:");
 Serial.print(rotations,DEC);
 Serial.println(" Rotation / seconds");
 Counter_speed=0;  //  reset counter to zero
 Timer1.attachInterrupt( timer_Isr );  //enable the timer
}
void setup()
{
 Serial.begin(9600);
 Timer1.initialize(1000000); // set timer for 1sec
 attachInterrupt(0, do_count, RISINGPIN);  // increase
counter when speed sensor pin goes
High
 Timer1.attachInterrupt( timer_Isr ); // enable the timer
}
void loop()
{
 int pot_value = analogRead(1);
 int motor_speed = map(pot_value, 0, 670, 258, 0);  // set
speed of motor (0-255)
}
```

2. PIEZO VIBRATION SENSOR CODE

```
int piezo_iot = A0;
int LED_iot=3;
int threshold_iot =120;
void setup()
{
Serial.begin(9600);
   }
void loop()
       {
          digitalWrite(led, LOW);
          int piezoVal_iot = analogRead(piezo_iot);
          byte velocity_iot = map(PiezoVal_iot, 0, 1036, 60,
157);
          Serial.write(velocity_iot);
          if (piezoVal_iot>threshold_iot)
          {
             digitalWrite(led, HIGH);
             delay(1000);
          }
       }
}
```

3. CODE FOR SENDING AND RECIEVING DATA TO AND FROM C CODE

```
#include <stdio.h>
#include <string.h>
#include <unistd.h>
#include <fcntl.h>
#include <errno.h>
#include <fcntl.h>
#include <errno.h>
#include <termios.h>
#include <sys/ioctl.h>
#include <getopt.h>
#include <stdlib.h>
#include <stdint.h>
#include <string.h>
#include <unistd.h>
#include <termios.h>
#include <time.h>
#include <sys/types.h>
int main(){
printf("Communicating with Arduino for IOT\n");
int portName_iot = open("/dev/ttyUSB0", O_RDWR |
O_NOCTTY | O_NDELAY);
struct termios options_iot;
tcgetattr(portName_iot, &options_iot);
cfsetispeed(&options_iot, B9600);
cfsetospeed(&options_iot, B9600);
options_iot.c_cflag |= (CLOCAL | CREAD);
tcsetattr(portName_iot, TCSANOW, &options_iot);
options_iot.c_cflag &= ~CSIZE;
options_iot.c_cflag |= CS8;
options_iot.c_cflag &= ~PARENB;
options_iot.c_cflag &= ~CSTOPB;
int velocity_iot;
read(portName_iot, velocity_iot, 1);
printf("%d\n",velocity_iot);
close(portName_iot);
return 0;
}
```

APPENDIX B

C++ EXECUTIBLE PROGRAM

```
#include<stdio.h>
void main()
{
double CEF_elec, CEF_tool, CEF_mat,CEF_chip;
int edges;
char pg;
char mat;
char chip;
```

```
double li_cost,
   lm_cost,
   ldt_cost,
   tg_cost,
   ce_cost,
   dte_cost,
   ie_cost;

double energy_dt,
   energy_ac,
   energy_cut;

double CE_elect,
   CE_tool,
   CE_mat,
   CE_chip,
   mass_chip,
   mass_tool;

double v,f,d,rho,cl,cmr,t_ac,t_c,t_dt, ins_cost,
elecKWH_cost,TL;

double p_basic,
   p_coolnt,
   p_spndl,
   p_axs;

printf("\nEnter the choice of Power Grid used: \n");
printf("a. North India Power Grid \nb. North East India Power
Grid \nc. East India Power Grid \nd. Middle India Power Grid
\ne. North-West India Power Grid \nf. South Power Grid \ng.
The national average\n\n");
scanf(" %c",&pg);
switch(pg)
{
   case 'a':
      CEF_elec=0.7802;
      break;
   case 'b':
      CEF_elec=0.7242;
      break;
   case 'c':
      CEF_elec=0.6826;
      break;
   case 'd':
      CEF_elec=0.5802;
      break;
   case 'e':
      CEF_elec=0.6433;
      break;
   case 'f':
      CEF_elec=0.5722;
      break;
   case 'g':
      CEF_elec=0.6747;
      break;
   default:
      CEF_elec=0.6747;
}
printf("\nCEF_elec: %lf",CEF_elec);

printf("\nEnter the number of edges per insert (value ranging
between 1 to 6): ");
scanf(" %d",&edges);
fflush(stdout);
printf("\n Enter the choice of chip being obtained\n");
printf("a. Waste Aluminium  Scrap \nb. Waste Iron Scrap \nc.
Waste Steel Scrap\n\n");
scanf(" %c",&chip);
printf("chip %c",chip);
switch(chip)
{
   case 'a':
      CEF_chip=0.256;
         break;
   case 'b':
      CEF_chip=0.361;
         break;
   case 'c':
      CEF_chip=0.361;
         break;
}
printf("\nCEF_chip: %lf",CEF_chip);
fflush(stdout);

printf("\nEnter the type of Material of Work piece : ");
printf("\na. Steel \nb. Iron \nc. Aluminium\n\n");
scanf(" %c",&mat);
switch(mat)
{
   case 'a':
      CEF_mat=2.69;
         break;
   case 'b':
      CEF_mat=2.22;
         break;
   case 'c':
      CEF_mat=16.13;
         break;
}
fflush(stdout);
printf("\nCEF_mat: %lf",CEF_mat);

printf("\nEnter the labour charges/hour : ");
scanf("%lf",&cl);
printf("\nEnter the machine running charges: ");
scanf("%lf",&cmr);
printf("\nEnter the time for air cutting/insert(in mins): ");
scanf("%lf",&t_ac);
printf("\nEnter the total time for cutting/insert(in mins): ");
scanf("%lf",&t_c);
printf("\nEnter the down-time(in mins): ");
```

```
scanf("%lf",&t_dt);

v = Comm();

// Labour Idle Cost
li_cost=(cl+cmr)*(t_ac);

// Labour machining cost
lm_cost=(cl+cmr)* (t_c);

// Labour Downtime Cost
ldt_cost=(cl+cmr)* (t_dt)*60;

printf("\nLabour Idle Cost: %lf",li_cost);
printf("\nLabour machining Cost: %lf",lm_cost);
printf("\nLabour Downtime Cost: %lf",ldt_cost);

printf("\nEnter the cost for insert: ");
scanf("%lf",&ins_cost);

// Tooling Cost
tg_cost= ins_cost / (edges);
printf("\nTooling Cost: %lf",tg_cost);
printf("\nEnter the cost for KWH of electricity: ");
scanf("%lf",&elecKWH_cost);
printf("\nEnter the basic power of turning utilised by the
machine: ");
scanf("%lf",&p_basic);
printf("\nEnter the power of Coolant applied: ");
scanf("%lf",&p_coolnt);
printf("\nEnter the power of Spindle used: ");
scanf("%lf",&p_spndl);
printf("\nEnter the power of Axis Motor: ");
scanf("%lf",&p_axs);

// Cutting Energy Cost
//ce_cost= elecKWH_cost * energy_cut;

// Downtime Energy
energy_dt= p_basic * t_dt;

// Down Time Energy Cost
dte_cost= elecKWH_cost * energy_dt;

// Idle energy
energy_ac= (p_coolnt +p_spndl +p_axs) * t_ac;

// Idle energy cost
ie_cost = elecKWH_cost * energy_ac;
printf("\nDowntime Energy: %lf",energy_dt);
printf("\nDownTime Energy Cost: %lf",dte_cost);
printf("\nIdle Energy: %lf",energy_ac);
printf("\nIdle Energy Cost: %lf",ie_cost);
//Carbon emissions
printf("\nEnter Tool Life(in mins): ");
scanf("%lf",&TL);
printf("\nEnter mass of tool(in gms): ");
scanf("%lf",&mass_tool);
printf("\nEnter the feed given(in mm/min): ");
scanf("%lf",&f);
printf("\nEnter the depth of cut (in mm): ");
scanf("%lf",&d);
printf("\nEnter the density of insert(in kg/m3): ");
scanf("%lf",&rho);

//by Electricity
CE_elect = CEF_elec *(energy_cut + energy_dt +
energy_ac);

//by tool
CEF_tool = CEF_elec * (energy_cut/3.6) * (1000 /
mass_tool);

CE_tool = (t_c / TL) * CEF_tool * mass_tool;

mass_chip =  (f * v * t_c * d * rho) / 1000;
//by material
CE_mat = CEF_mat * mass_chip;
//by chip
CE_chip= CEF_chip * mass_chip;
printf("\nCarbon Emissions: ");
printf("\nby Electricity : %lf",CE_elect);
printf("\nby Tool : %lf",CE_tool);
printf("\nby Material : %lf",CE_mat);
}
```

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