Preprints of the 21st IFAC World Congress (Virtual)
Berlin, Germany, July 12-17, 2020

Low Cost Monitoring on a Shoestring: Solutions for Digital Manufacturing

Yedige Tlegenov, Gregory Hawkridge, Duncan McFarlane, Ajith K. Parlikad, Nicholas J. Reyner, Alan Thorne

Institute for Manufacturing, University of Cambridge, Cambridge, United Kingdom
(e-mails: [yt361, gth24, dm114, aknp2, nr413, ajt28]@cam.ac.uk)

Abstract: Digital manufacturing is focussed on leveraging the availability of digital information to improve the effectiveness of manufacturing activities. One of the digitalisation pathways for manufacturing is monitoring, which can be challenging due to the high costs of industrial monitoring solutions and the difficulty in justifying their return on investment. This study examines whether the introduction of low cost technologies can address the monitoring needs of digital manufacturing. In particular, we consider the role non-industrial, "off-the-shelf" technologies can play. The main aim of this paper is to present blueprints for low cost monitoring of industrial operations and identify candidate low cost technologies which can contribute effectively to the implementation of these systems. Related work on low cost monitoring and commercially available technologies are analysed and evaluated. Low-cost monitoring blueprints and candidate technologies are proposed based on the results of the analysis. An example implementation of a presented blueprint indicates the potential of integrating non-industrial, off-the-shelf technologies into low cost monitoring solutions.

Keywords: Industry 4.0; Cyber-Physical Systems; Device integration technologies; Intelligent manufacturing systems; Internet-of-Things and Sensing Enterprise; Information and sensor fusion.

1. INTRODUCTION

In the past decades the manufacturing sector has been rapidly advancing through the development of modern digital technology. The digital manufacturing paradigm seeks to leverage digital information to improve the effectiveness of manufacturing operations. A key aspect of digital manufacturing is monitoring equipment and/or processes. Monitoring has become increasingly essential as a key component for cost and quality control in manufacturing. Advanced monitoring systems have been developed that capture and process large amount of data to accurately characterise the condition of manufacturing operations. However, the cost of these systems is often only justifiable for large manufacturing operations.

In response, the *Digital Manufacturing on a Shoestring* project (https://www.digitalshoestring.net/) was launched in 2018 to address a common concern that recent developments in digital manufacturing are unlikely to be accessible by SMEs (McFarlane et al., 2019; Schönfuß et al., 2019; Hawkridge et al., 2019, de Silva et al., 2020). The project proposes a different approach to the digital evolution of a manufacturing operation by focussing on low cost, non-industrial solutions to industrial automation and information challenges. One of the key developments in this projects is to develop reusable "building blocks" for key elements of low cost solutions (McFarlane et al., 2019). The aim of this paper is to present preliminary blueprints for low cost monitoring in industrial operations and identify candidate low cost technologies which can contribute effectively to digital manufacturing. The intent is that these technologies form building blocks for low cost digital solutions.

This paper begins with a review of related work and relevant commercial technologies. Section 3 presents blueprints for a low-cost monitoring solution. Candidate technologies for delivering low cost monitoring are presented in Section 4, followed by an example implementation in section 5. Finally, the presented work is concluded with a discussion.

2. BACKGROUND

2.1 Related work on monitoring in manufacturing

The literature on monitoring in manufacturing is very broad. Here authors simply refer to some developments relevant to this paper. The use of appropriate monitoring methods can enhance the profitability of manufacturing. Manufacturing systems tend to fail at some period during their operational life. Some of the most common techniques used in the manufacturing sector are monitoring temperature, vibration, and acoustic emission (Rao, 1996). These three monitoring techniques have been used for various applications, equipment, and processes in manufacturing, such as additive manufacturing (Tlegenov et al., 2018), automated machinery (Engeler et al., 2017), conveyors (Liu et al., 2018), forging and casting (Behrens, 2016), electric motors (Nandi et al., 2005), injection moulding (Ogorodnyk and Martinsen, 2018), machine tools (Zhang et al., 2018). However, these systems have high component and installation costs. Because of this, common industrial monitoring solutions are not yet accessible for a wide range of manufacturing companies. There is therefore benefit in examining low cost monitoring technologies and evaluating the possibility of their implementation within the manufacturing environment.

2.2 Low cost monitoring technologies

Table 1 presents a review of low-cost monitoring technologies in various applications from literature. The abbreviations in Table 1 are RPi – Raspberry Pi, MCont – microcontroller, MComp – microcomputer, A – analogue, D – digital, ADC – analogue to digital converter.

Table 1. Review of low cost monitoring systems

#	Paper title	Computation	Communication	Sensing
1	Abraham & Li (2014)	MCont: Arduino Uno	Wireless: IEEE 802.15.4	*D* / Temp: RTH03
2	Fuentes et al. (2014)	MCont: Arduino Uno	Wired: Serial	*D* / Temp: DS18B20
3	Oberloier & Pearce (2018)	MCont: Arduino Uno	Wired: Serial	*A* / Current: CQ2334
4	Karami et al. (2018)	MCont: Arduino Uno	Wireless: IEEE 802.15.4	*A* / Temp: Type K
5	Basto et al. (2017)	MCont: Arduino Uno	Wireless: IEEE 802.15.4	*A* / Temp: LM35
6	Perumal et al. (2017)	MComp: RPi + ADC	Wireless: IEEE 802.15.4	*A* / Temp: RTD PT100
7	Garbhapu & Gopalan (2017)	MCont:MSP430 MComp: RPi	Wireless: IEEE 802.15.4	*A* / Temp: LM35
8	Pereira et al. (2018)	MCont: PIC18F2550 MComp: RPi	Wired: Serial	*A* / Temp: LM35
9	Lewis et al. (2016)	MComp: RPi	Wired: Ethernet	*D* / Temp: DS18B20

Monitoring technologies were analysed in terms of their computation, communication, and sensing technologies. Microcontrollers, such as Arduino Uno, were used to obtain high sampling rates from analogue or digital sensing devices, but not performing the visualisation or analysis. On the other hand, microcomputers such as Raspberry Pi were used to obtain the signals from sensors, and then analyse, and visualise the data. Communication technologies varied depending on the application: wired for near board sensor locations, wireless for sensor locations on distance. Sensor output interfaces in literature were mainly of two types: analogue and digital. In summary, previous works suggest that microcontrollers are suitable for analogue sensing interfaces and for high sampling rates, and microcomputers are suitable for digital sensing interfaces with lower sampling rates but with the possibility of data analysis and visualisation on the board.

3. BLUEPRINT FOR A LOW COST MONITORING SOLUTION

3.1 Scope of a monitoring solution

In this section we propose a blueprint describing the key elements of a low cost manufacturing monitoring solution. Monitoring systems range from those that simply obtain and present the latest data values to an operator, to those that store historic data and use it to perform complex analysis for defect traceability, predictive maintenance or bottleneck identification. A generalised monitoring system can be decomposed into four stages: collect data, analyse, manage and store data, present information. The data acquisition stage is responsible for capturing raw data, either directly from the asset via an application programming interface (API) or from auxiliary sensors attached to the asset. The interpretation stage provides context and meaning to the data. This can include segregating data streams based on the asset to which they correspond and converting raw data into the values that they represent.

The data management stage stores the contextualised data. This may be in a latest value table, a sliding window cache or a time series database. The analysis stage extracts useful information from the acquired data. This may incorporate threshold analysis, control chart generation or machine learning. The alerting stage notifies the relevant authorities of any past, present or predicted future alarm conditions detected by the analysis stage. This may include notifying an operator/supervisor or triggering a maintenance request. The presentation stage provides access to generated data and information. This can include visualisation, either directly via an attached display or via a web application; or provision of a network API for data use/aggregation by other tools.

3.2 What does low cost mean in terms of manufacturing?

The term “low cost” is relative; it depends on the application and user. For example, the U.S. government’s monitoring roadmap defined a range from US$2000 to US$5000 as low cost for a governmental authority, but that is not affordable for most monitoring end users (Watkins, 2013). Low cost in monitoring can be identified as the sum of all monitoring solution components costs, plus development, installation, and maintenance costs. In addition, sometimes the term low cost has only been applied to the measurement device (or sensor) costs only. Since the sensor alone has little use without the whole monitoring system components, in this work, the low cost term is applied to the whole monitoring solution, consisting of not only a sensor, but also communication tools, computational devices, data management, visualisation and analysis technologies. Based on the authors’ discussion with several SMEs in the UK, a monitoring system is considered low-cost if each component is less than £100 and the total system cost is less than £1,000.

3.3 Simple blueprints for low cost monitoring

This section proposes simple blueprints for low cost monitoring based on the commonalities found in literature. The most basic and lowest cost blueprint of a monitoring system is one that is centralised and stand-alone, as shown in Figure 1. The primary computational device is a microcomputer. Microcomputers typically have multicore CPUs which allow multiple computational tasks to be done in parallel. As such a microcomputer can simultaneously perform data acquisition, analysis and visualisation. Furthermore, microcomputers generally allow for visualisation of data and information to be done directly through an attached display or through a network interface. An optional microcontroller can be connected using a serial interface over USB.

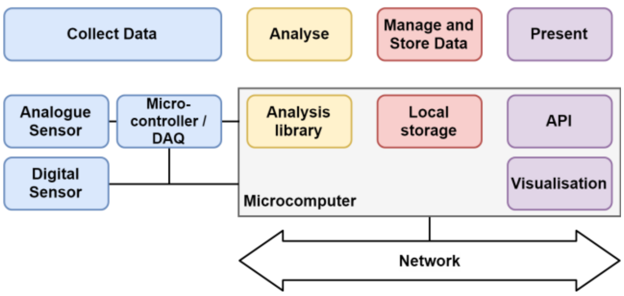

Fig. 1. Blueprint for a centralised, stand-alone monitoring system

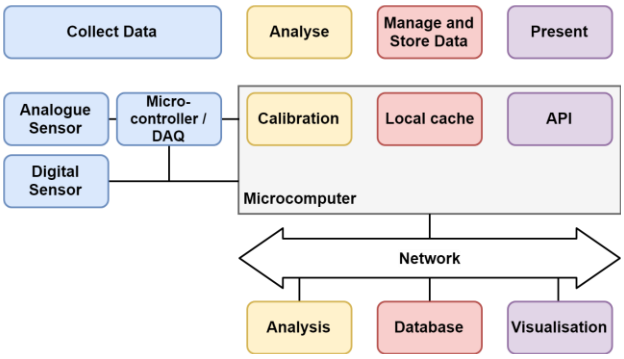

Fig. 2. Blueprint for a decentralised monitoring system

The optional microcontroller can be used to provide determinism, which is important when samples need to be taken with regularity at high sample rates (i.e. every 1ms +/- 10us). The software aspects of the monitoring system can be implemented/developed using open source software/libraries; however, they typically require some degree of customisation/configuration.

A decentralised monitoring system should be considered when the cost of microcomputers with sufficient capabilities to perform all the monitoring functions locally is prohibitive, or when many assets are going to be monitored. In the decentralised monitoring blueprint (Figure 2), the analysis, alerting, visualisation and long-term data management are removed from the microcomputer and performed on dedicated hardware. This means that these services can be shared by multiple microcomputers in larger systems and that they can be scaled according to varying requirements of a system.

The rationale for presenting a decentralised monitoring system is that it is more compatible with the building blocks approach being proposed in the Digital Manufacturing on a Shoestring project (McFarlane et al., 2019). This system decomposition lends itself to the identification of low cost technologies as components, which we access next.

4. TECHNOLOGIES FOR DELIVERING LOW COST MONITORING

4.1 Low cost data collection

There are number of sensor types that monitoring can utilise in manufacturing such as: temperature, for monitoring heat generation; vibration, for detecting out of balance vibration; and acoustic emission, for material failure sound detection and regulation compliance.

Table 2. Review of low cost sensing technologies

Variable	**Sensor type**	**Range** (Fraden 2016)	**Sensitivity** (Fraden 2016)	**Price range**
Temperature	Thermo-couple	-200 to 1,750°C	1 to 5°C	£1.8 to £80
	NTC Thermistor	-50 to 250°C	0.05 to 1.5°C	£0.02 to £40
	RTD	-200 to 600°C	0.1 to 1°C	£0.8 to £100
Vibration	MEMS	0 to 32kHz	400 to 2.2mV/g	£0.7 to £90
Acoustic	Electret condenser	0 to 20kHz	-24 to -47dB	£0.4 to £60
	MEMS	0 to 100kHz	-18 to -58dB	£0.2 to £80

Table 2 summarises some popular low-cost sensing technologies. It shows that temperature monitoring can potentially be achieved using thermocouples and thermistors, vibration monitoring using MEMS accelerometers, and acoustic emission monitoring using electret condenser or MEMS acoustic sensors.

When considering low cost sensors, there is usually a compromise between range and sensitivity. However, the range and sensitivity offered by many non-industrial, off-the-shelf sensors is sufficient for most applications.

4.2 Low cost computation

The presented blueprints use both microcomputers and microcontrollers to perform computation. Microcomputers are used as the primary edge devices and will therefore be the focus of this section. Since the objective of this paper is low cost, commercially available monitoring technologies, only single board microcomputers are evaluated.

Figure 3 summarises a market analysis of the popular single board microcomputers available at the time of writing. These microcomputers were evaluated based on computing performance and connectivity, as these factors are core to their function within a monitoring system. Each microcomputer was given a computing performance score from 1-3 and a connectivity score from 1-3. The sum of these scores are presented as the combined score in the figure. The scores are determined as follows:

Computing performance:

1. Low: < 4 CPU cores; < 1.2 GHz; < 1 GB RAM
2. Medium: 4 CPU cores; 1.2 to 1.4 GHz; 1 to 2 GB RAM
3. High: > 4 CPU cores; > 1.4 GHz; > 2 GB RAM

Connectivity performance: (All had Ethernet connectivity)

1. Low: has no Wi-Fi, Bluetooth or BLE
2. Medium: has either Wi-Fi, Bluetooth or BLE
3. High: has Wi-Fi, Bluetooth and BLE

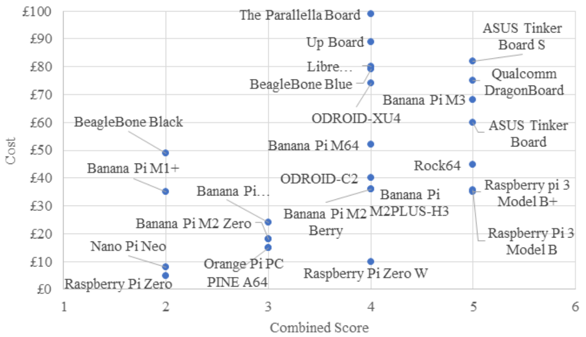

Fig. 3. Review of low cost single board microcomputers

As can be seen from Figure 3, the Raspberry Pi 3 Model B+ is the lowest cost board of the boards with the top combined score. With its mid-range computing performance and excellent built in connectivity options at a low price.

The cost of a monitoring system is not only linked to the hardware cost of the system and for this reason it is recommended that Raspberry Pi or Raspberry Pi compatible microcomputers so that it is possible to benefit from the large communities surrounding these platforms and the wealth of libraries and tutorials that they provide.

4.3 Low cost communication

There are wide range of communications networks to choose from when designing a connected digital manufacturing solution. These networks are based on a stack of protocols: sets of rules that allow electronic devices to communicate with one another. Portability is an important factor for many digital manufacturing applications, and could easily be the primary reason to choose one communication over another. In Internet-of-Things (IoT) applications, for example, the hardware that is compact and portable is more beneficial. Using wireless communication is another good option for portability because the data acquisition can be portable while computing devices can remain stationary. As can be seen from Figure 4, Bluetooth Low Energy (BLE) and Wi-Fi wireless networks have the highest data transmission rates as well as are in the cheapest category as the Raspberry Pi microcomputer comes with those technologies already built-in, hence no additional hardware is required. External communication networks such as USB and Ethernet are also widely adopted for portable systems because of quick installation and compatibility with many devices.

Industrial applications often require real-time communications and high levels of robustness that are not easily achieved through wireless communications, rather wired communications are more suited to these needs. Popular industrial wired communications protocols includes: EtherNet/IP, PROFINET IRT, EtherCAT, Powerlink, SERCOS III. EtherCAT stands apart in terms of offering superior performance/price, as EtherCAT delivers determinism in a solution at the lowest cost, compared to the other protocols. EtherCAT data rates are over 100MBps and the shields for both Raspberry Pi and Arduino are available for £35 and £44 respectively, meaning this industrial grade technology can be implemented in a low-cost solution of comparable price to some of the low-cost wireless networks.

4.4 Low cost analysis, data storage and visualisation

Data management can either be performed locally or in the cloud. Local data management can be performed using a variety of open source software such as MySQL, CouchDB, Redis, etc. Cloud based data storage is also an option and can be achieved using any of the major Database-as-a-service (DBaaS) providers such as Amazon DynamoDB, Microsoft Azure SQL Database, etc. However, the economics of cloud storage may be hard to justify as "low cost" unless large amounts of data need to be stored. Analysis of sensor data can be performed using a variety of open source analysis software such as Pandas, PyBrain, Tensor Flow, etc. Alerting would typically require some form of integration into an existing management system. However, a simple for could be achieved using an SMTP library to send an alert email when the analysis software observes a particular condition. Visualisation is best performed using a web interface as it can be used to displayed data locally as well as over the network. Several packages are available for web-based visualisation such as Bokeh, Dash, etc.

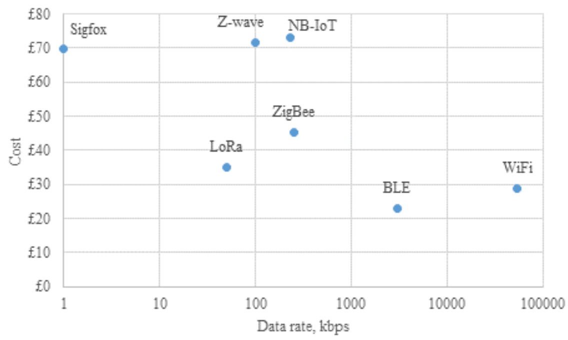

Fig. 4. Review of low cost wireless communication technologies

4.5 Discussion

The development of low-cost monitoring solutions is constrained by the limited performance of inexpensive hardware and software, poor robustness of non-industrial components, potential integration issues with existing systems, and increased development effort. However, as technology advances, once expensive hardware and software becomes accessible and affordable to a wider range of users. To ease development effort and integration issues, it is necessary to leverage the large communities surrounding many low-cost platforms and the wealth of libraries and tutorials they provide. In this section we have proposed preliminary findings on technologies that can contribute to low cost industrial monitoring solutions. These results are part of ongoing work in developing integrable solution that will support SMEs increasing digital capabilities.

5. CASE STUDY

The aim of the case study is to show that the blueprints proposed in Section 3.3 can be effectively used to develop low cost monitoring solutions which can contribute to digital manufacturing. Candidate low cost technologies have been identified for this case study and reusable “building blocks” have been used for the key low cost elements.

5.1 System description

As part of the *Digital Manufacturing on a Shoestring* project, authors have developed a low cost bolt-on monitoring prototype on a 3D printer for evaluating the proposed blueprints, as shown in Figure 5. A low-cost bolt on monitoring system has been built according to the: a)

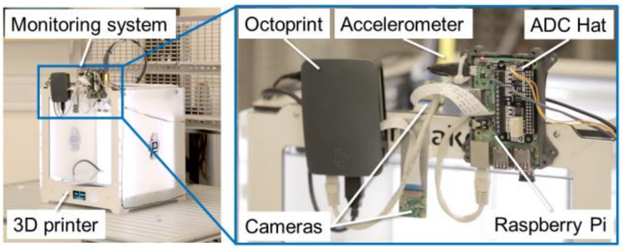

Fig. 5. Low cost monitoring system demonstrator

centralised, stand-alone; b) decentralised low cost monitoring system architectures proposed in Section 3.3. The bolt-on monitoring system consists of a Seed 101020051 three axis analogue accelerometer (£8), a Pimoroni Automation pHAT analogue-to-digital converter (£13), Raspberry Pi 3B (£34). Authors note that the monitoring system is not limited to use on a 3D printer alone, but can be used with any type of manufacturing machinery.

5.2 Low cost elements

a) Data collection. The data collection elements for the case study were the same for centralised and decentralised blueprint. The 3D printer has integrated RTD temperature sensors placed on the extruder nozzle and on the platform. The monitoring demonstrator extracted this data via the API. To measure the vibration data, an additional accelerometer was placed on the 3D printer’s extruder head for nozzle condition monitoring. Since an analogue accelerometer was used, it was connected to the Raspberry Pi via an analogue-to-digital converter – Pimoroni Automation pHAT ADC hat. To monitor the fabrication process, 2 additional Raspberry Pi Camera Modules were installed.

b) Centralised, stand-alone architecture implementation. The centralised, stand-alone system was implemented using the blueprint in Figure 6. A Raspberry Pi was used to perform all the functional blocks after the data collection block: analyse data, manage and store data, and present the data. Open-source software libraries have been utilised: data analysis was done using Pandas and SciPy; data management and storage were done using file access library and SD card; presentation was done using Matplotlib and Plotly.

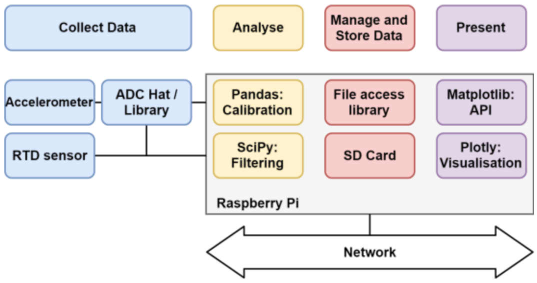

Fig. 6. Example of centralised, stand-alone low cost monitoring system blueprint

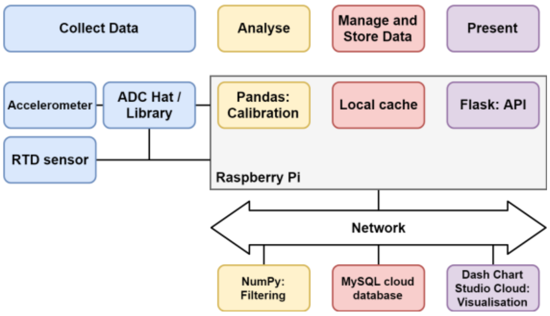

Fig. 7. Example of decentralised low cost monitoring system blueprint

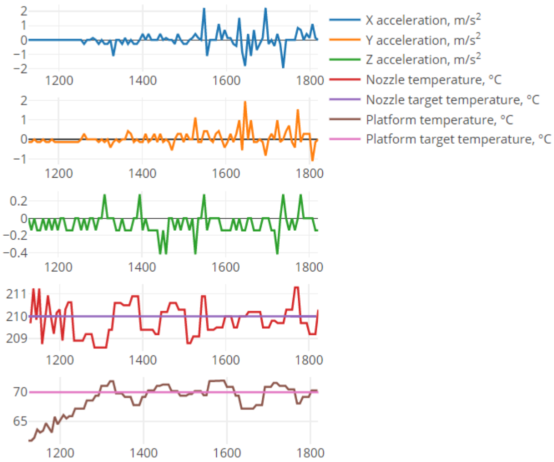

Fig. 8. Sensor data streaming from low cost monitoring system demonstrator

b) Decentralised architecture implementation. The decentralised blueprint (Figure 7) was also implemented. Unlike the standalone blueprint, the Raspberry Pi was only used to gather the data and send it over to the wireless network for further processing. Analysis, data management and storage, and presentation functional blocks were implemented separately on the cloud. Similarly to the previous example, open-source software libraries were utilised: analysis was done using NumPy on the Dash cloud platform; data management and storage was done using MySQL cloud database; presentation was done using Dash Chart Studio Cloud.

Figure 8 shows that the bolt-on monitoring system was able to obtain data from the machine (temperature) as well as monitor an additional physical property (vibration), analyse the data, store the data, and visualise the data at the cost of less than £100. This case study has shown that the blueprints proposed in Section 3.3 can be effectively used to develop a low cost monitoring solution for digital manufacturing.

6. CONCLUSION

The purpose of the current study is to present blueprints for low cost monitoring in digital manufacturing and identify candidate low cost technologies with which the blueprints could be implemented. This study has identified centralised and decentralised blueprints for monitoring. This study suggests that low cost, off-the-shelf components could be used for the following non-critical industrial monitoring scenarios. First, for important, yet inexpensive assets, where the cost of typical monitoring systems cannot be justified. Second, for the quick deployment of proof-of-concept, prototype systems when the return on investment is yet to be determined. And third, as a temporary installation for troubleshooting, diagnostics and integration testing. Future work will evaluate the presented decentralised monitoring blueprint within the Digital Manufacturing on a Shoestring building block framework and test it in a real-world setting. In addition, the security of the low cost monitoring technologies need to be considered.

REFERENCES

Abraham, S. and Li, X., 2014. A cost-effective wireless sensor network system for indoor air quality monitoring applications. Procedia Computer Science, 34, pp.165-171.

Basto, C., Pelà, L. and Chacón, R., 2017. Open-source digital technologies for low-cost monitoring of historical constructions. Journal of Cultural Heritage, 25, pp.31-40.

Behrens, B.A., Bouguecha, A., Buse, C., Wölki, K. and Santangelo, A., 2016. Potentials of in situ monitoring of aluminum alloy forging by acoustic emission. Archives of Civil and Mechanical Engineering, 16(4), pp.724-733.

De Silva, L., Hawkridge, G., Terrazas, G., Perez Hernandez, M., Thorne, A., McFarlane, D. and Tlegenov, Y., 2020, March. An Application of HRI in Low-Cost Digital Manufacturing. In Companion of the 2020 ACM/IEEE International Conference on Human-Robot Interaction pp.71-71.

Engeler, M., Elmiger, A., Kunz, A., Zogg, D. and Wegener, K., 2017. Online condition monitoring tool for automated machinery. Procedia CIRP, 58, pp.323-328.

Fraden, J., 2016. Handbook of modern sensors: physics, designs, and applications. 5th ed. Springer Science & Business Media.

Fuentes, M., Vivar, M., Burgos, J.M., Aguilera, J. and Vacas, J.A., 2014. Design of an accurate, low-cost autonomous data logger for PV system monitoring using Arduino™ that complies with IEC standards. Solar Energy Materials and Solar Cells, 130, pp.529-543.

Garbhapu, V.V. and Gopalan, S., 2017. IoT based low cost single sensor node remote health monitoring system. Procedia computer science, 113, pp.408-415.

Hawkridge, G., Hernandez, M.P., De Silva, L., Terrazas, G., Tlegenov, Y., McFarlane, D. and Thorne, A., 2019, September. Tying Together Solutions for Digital Manufacturing: Assessment of Connectivity Technologies & Approaches. In 2019 24th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA) (pp. 1383-1387). IEEE.

Karami, M., McMorrow, G.V. and Wang, L., 2018. Continuous monitoring of indoor environmental quality using an Arduino-based data acquisition system. Journal of Building Engineering, 19, pp.412-419.

Lewis, A.J., Campbell, M. and Stavroulakis, P., 2016. Performance evaluation of a cheap, open source, digital environmental monitor based on the Raspberry Pi. Measurement, 87, pp.228-235.

Liu, X., Pang, Y., Lodewijks, G. and He, D., 2018. Experimental research on condition monitoring of belt conveyor idlers. Measurement, 127, pp.277-282.

McFarlane, D., Ratchev, S., Thorne, A., Parlikad, A.K., De Silva, L., Schönfuß, B., Hawkridge, G., Terrazas, G. and Tlegenov, Y., 2019, October. Digital manufacturing on a shoestring: low cost digital solutions for SMEs. In International Workshop on Service Orientation in Holonic and Multi-Agent Manufacturing (pp. 40-51). Springer, Cham.

Nandi, S., Toliyat, H.A. and Li, X., 2005. Condition monitoring and fault diagnosis of electrical motors—A review. IEEE transactions on energy conversion, 20(4), pp.719-729.

Oberloier, S. and Pearce, J.M., 2018. Open source low-cost power monitoring system. HardwareX, 4, p.e00044.

Ogorodnyk, O. and Martinsen, K., 2018. Monitoring and control for thermoplastics injection molding a review. Procedia CIRP, 67, pp.380-385.

Pereira, R.I., Dupont, I.M., Carvalho, P.C. and Jucá, S.C., 2018. IoT embedded linux system based on Raspberry Pi applied to real-time cloud monitoring of a decentralized photovoltaic plant. Measurement, 114, pp.286-297.

Perumal, V.S.A., Baskaran, K. and Rai, S.K., 2017. Implementation of effective and low-cost building monitoring system (BMS) using Raspberry PI. Energy Procedia, 143, pp.179-185.

Rao, B.K.N. ed., 1996. Handbook of condition monitoring. Elsevier.

Schönfuß, B., McFarlane, D., Athanassopoulou, N., Salter, L., De Silva, L. and Ratchev, S., 2019, October. Prioritising low cost digital solutions required by manufacturing SMEs: a shoestring approach. In International Workshop on Service Orientation in Holonic and Multi-Agent Manufacturing (pp. 290-300). Springer, Cham.

Tlegenov, Y., Hong, G.S. and Lu, W.F., 2018. Nozzle condition monitoring in 3D printing. Robotics and Computer-Integrated Manufacturing, 54, pp.45-55.

Watkins, T., 2013. DRAFT roadmap for next generation air monitoring. Environmental Protection Agency.

Zhang, X.Y., Lu, X., Wang, S., Wang, W. and Li, W.D., 2018. A multi-sensor based online tool condition monitoring system for milling process. Procedia CIRP, 72, pp.1136-1141.