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A Smart Sensor Box to Increase the Adaptability of Automated Manufacturing

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Abstract. A cost-effective and accurate method to add or change sensors in an automated manufacturing line is essential in order to increase the flexibility and adaptability of production systems. In particular, small to medium enterprises (SMEs) and companies offering custom solutions can only compete in the highly interconnected age of Industry 4.0 if their operations are agile and dynamic. This paper presents a new, low-cost solution to this problem through the development of a Smart Sensor Box. The paper introduces the benefits of this highly adaptable system comparing it to currently available solutions, while testing conducted demonstrates the solution's accuracy and repeatability. The layout and operational capabilities for three versions of the Smart Sensor Box are discussed in detail and example applications are presented.

Keywords. Smart Manufacturing, Automation, Flexible Manufacturing

1. Introduction

In automated manufacturing, the ability to change or add sensors to processes is essential to allow flexible manufacturing that enables a focus on quality and cost efficiency [1] [2]. There is need for a powerful, simple and adaptable solution which would allow the addition of multiple external sensors using a standard software interface across multiple robot types [3].

Robots come with, as standard, a control box that manages robot functionality. Additional sensors and connectivity to other systems can also be utilised. Two robot companies (KUKA and Universal Robotics (UR)) are used as an example in this paper. KUKA offers several variations of control box [4] whereas UR have one covering all robots [5]. Four control box options for KUKA and one for UR are shown in Table 1.

Table 1 - Control Box Comparisons

Attribute\Device	D3076-K	D3236-K	KR C5 Micro	KR C5	UR Control Box
USB2.0	8	6	2	0	1
USB3.0	0	2	0	0	1
Ethernet	1	1	1	1	1
Digital Input	0	0	16	0	16
Digital Output	0	0	16	0	16

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Analog Input	0	0	0	0	2
Analog Output	0	0	0	0	2

These control boxes are limited in the type and number of sensor inputs offered. Current solutions to add sensor capability fall into two categories: low cost with limited functionality and high cost with limited flexibility. Low-cost options are dominated by Programmable Logic Controllers (PLC) whereas Industrial PCs (IPC) are predominately the solution for higher cost options. A PLC normally contains a limited number of inputs, usually 8-12, and even fewer outputs, 4-6. Depending upon the inputs received, the PLC will carry out basic commands based on custom programming. More expensive PLCs are capable of networking, allowing readings and values from the inputs to be forwarded onto connected systems. The Siemens S7 series of networked PLCs [6] is used as a viable option for robotic arm manipulation [7]. The Siemens S7-300 PLC has 10 digital inputs, 6 digital outputs and costs almost £500 [8]. PLCs have a good level of flexibility for a reasonably low cost but lack the processing power to offer features such as AI/ML and do not have the capability to handle complex inputs such as a camera.

Industrial rail or rack mount PCs offer more powerful solutions for automated manufacturing. A rack mount PC is a specialised design of PC which provides the full capabilities of a PC system but can be mounted into a standard instrumentation rack. The Siemens Simatic Industrial Computer is an example of a rack mounted PC. One major drawback of this as a flexible manufacturing option is the cumbersome size and weight of the PC making it difficult to manoeuvre within a working environment. Pricing for an industrial PC can also be considered a drawback as systems often cost several thousand pounds. The Siemens Simatic Industrial Computer retails for just over £5,000 [9]. A solution that attempts to solve the size and cost issue is the Beckhoff C60xx Industrial PC range [10]. The systems are designed as low cost, space saving, high computing power industrial PCs. The series ranges from the C6015 Ultra Compact with an estimated cost of around £500 [11] to the C6032 with an estimated cost of around £2150 [11]. While the C6015 solves the size and cost issue of other industrial PCs, it has limited processing and IO capability with low AI processing performance. The C6032 solves the size issue and has greater processing capability but at a higher cost.

The proposal outlined in this paper aims to fill the gap between the current PLCs and Industrial PCs by offering a small, low cost, flexible solution with accelerated AI, complex input capabilities and wireless data communication. The Smart Sensor Box (SSB) is a solution for highly interconnected smart factories requiring high speed set up changes, key for Industry 4.0. A comparison of the options can be seen in Table 2.

Table 2 - Option Comparisons

	PLC	SSB	IPC
Moveability	Flexible	Flexible	Static
Cost	Low	Low	High
Processing Capabilities	Minimal	AI/ML Capabilities	AI/ML Capabilities

2. Proposed Solution

The proposed solution is a sensor hub capable of connecting multiple sensors together in any area of manufacturing. The SSB can be added at any point in a production line to increase the number of sensor inputs available. Adding multiple smart sensor boxes to any given process allows a far greater number of sensors to be implemented. By standardising the software interface, portable smart sensor boxes can be moved around and used along the production line as required. The primary function of the smart sensor box is to connect sensors to the production process. The goal is adaptability and ease of use of both hardware and interface software.

2.1. Smart Sensor Box Outline

The smart sensor box is designed as a hub to take multiple inputs for several different types of sensors and provide access to the acquired data via multiple different output methods. With simple sensors connected, the smart sensor box can take non-interconnected sensors and make results gained more accessible for Industry 4.0 connected systems. Inputs and outputs are isolated from the rest of the system, which is key in an industrial system. An outline of the smart sensor box can be seen in Figure 1.

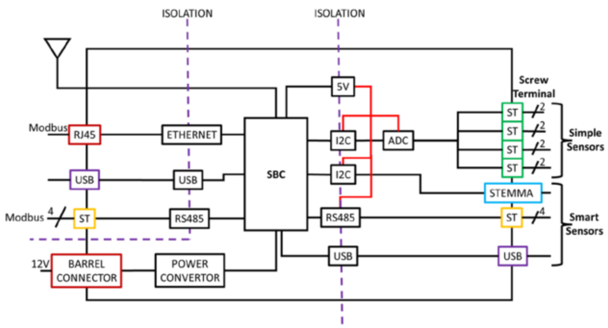

Figure 1. SSB Overview

2.2. Inputs & Outputs

Four pairs of screw terminals are situated across the box to allow a range of sensors to be connected. As separate circuits are implemented for each pair of screw terminals, multiple types of sensors can be implemented at the same time on the smart sensor box. There are two USB ports accessible on the sensor box and with USB access, camera capability is supported. The smart sensor box has libraries included to support projects, such as video compression and AI based object classification in a video stream. An I^2C port is brought out on a STEMMA QT connector. This I^2C port can be used as is or can be replaced with a secondary ADC input/output sensor circuit to provide functionality, such as a second set of analog screw terminal ports. The multiple inputs can allow real-time feedback from the smart sensor box to the connected production process. Multiple smart sensor boxes can be placed in parallel to allow an even greater number of sensor inputs to be connected. The smart sensor box can provide multiple forms of output. Four main methods of data transfer that will be initially offered are USB, Wi-Fi, Ethernet and 5G. The two boards used as different control options for the SSB are the Raspberry Pi 4 and the Qualcomm RB5 board. As standard, both the Raspberry Pi 4 and the RB5 boards come with multiple USB ports, Wi-Fi connectivity and an Ethernet port. To implement the 5G connectivity for either board, additional hardware will be required.

3. SSB Versions

To accommodate different requirements, three different versions of the sensor box are available, versions I, L, W. Version I has the standard SSB system, with all the standard input/output methods. The system employs a Raspberry Pi 4 as the main processor.

Version L is an enhanced form of the Version I and can be seen in Figure 2. Along with the Raspberry Pi 4, a Coral Accelerator will also be installed. The Coral Accelerator is a TPU that can be used as an external processor for a connected system. It allows tensor processing to be carried out at a greater speed for tasks such as AI object classification. With the addition of a Coral Accelerator, ML processes can be carried out twenty-five times faster than a Raspberry Pi 4 (using USB3.0 running Mobilenet v2) [12].

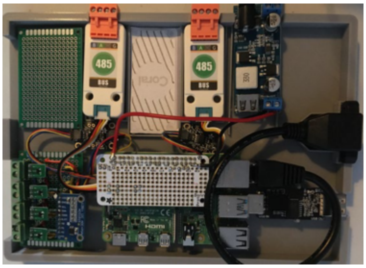

Figure 2. Version L SSB Circuitry

Version W contains the same hardware as Version I, apart from the Raspberry Pi 4 being replaced with a Qualcomm RB5 Development board. The RB5 board implements Linux and has similar cores, ARM Cortex A, to the Raspberry Pi 4. Due to this, software developed on one can be ported to the other with minimal alterations. Although they have similar cores, the RB5 is more powerful with the RB5 having 8 cores and the Raspberry Pi having 4 cores. The RB5 also comes with built in AI acceleration.

4. SSB Initial Test Results

Initial testing of the SSB was carried out to prove the repeatability and accuracy of data collection using simple sensors. Various resistive loads were connected to the SSB and repeated values taken. The results, including standard deviation, are shown in Figure 3. The small variance between readings highlights the consistency of the SSB.

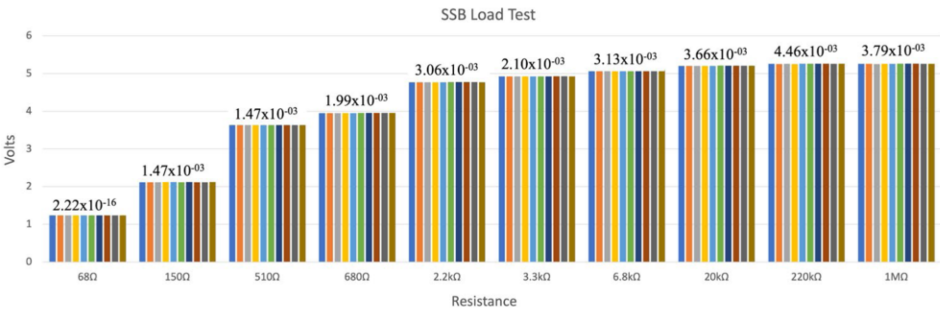

Figure 3. Resistance & Load Testing Results with Standard Deviation Values

5. Example Smart Sensor Box Applications

The smart sensor box can be used in many ways throughout an automated production line to allow the easy addition of multiple sensors and data management. The following scenarios highlight uses for the smart sensor box.

5.1. Scenario One

Sensors need to be added to production line systems to implement new production features or to enhance quality systems. The smart sensor box can be used to add additional sensors and cameras along the production line or within a production cell as shown on the left of Figure 4. A camera can be set up with the smart sensor box at the start of a production cell to monitor incoming material. Images from the camera are then processed by the smart sensor box. This processed data is then sent via 5G to a process control unit which uses the input to manage the next steps for the material. A second camera can be set up with another smart sensor box at the end of the production cell. Here images from the camera can be used for quality control to monitor the outgoing product from the cell.

An example where cameras are added into an existing production line can be found in a job listing from Tesla Inc. in 2020. The job specification for a Quality Inspection Engineer states:

"The vehicle engineering team at Tesla is looking for a highly motivated Quality Inspection Engineer to apply their experience with vehicle assembly lines and manufacturing software systems to lead the installation and operations of automation camera inspection systems into existing manufacturing lines." [13]

5.2. Scenario Two

It would be advantageous to have real time automated defect detection within the area of composite material manufacturing. Cameras and additional sensors can be deployed to analyze AFP (Automated Fibre Placement) systems allowing quality and part inspection to be carried out. In an agile production system, where many different designs are produced, AI/ML acceleration on the SSB allows defect detection to be carried out. Collaborative robots can be utilised to create composite materials and capture images suitable for AI defect detection. An example cell can be seen on the right of Figure 4.

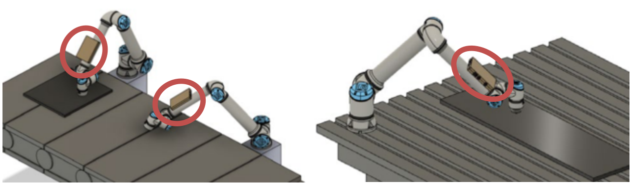

Figure 4. Scenario One & Scenario Two SSB & Cobot Placements

6. Conclusion

This paper presented a new solution to increase the flexibility and functionality of automated production systems. Testing displayed accurate and repeatable measurements taken via the sensor box system. The Smart Sensor Box acts as a highly intelligent smart sensor hub allowing the addition of multiple sensors anywhere along a manufacturing line. The key advantages of the proposed solution are that it is low cost, accurate, easily repositioned and has the capability to provide smart sensor functionality to enhance existing simple sensors. The paper introduced key application areas for the Smart Sensor Box highlighting its ability to manage AI/ML and object classification processes. This novel proposal, with its ability to add multiple sensors within a production process, offers adaptability, increased quality control and greater cost effectiveness to any production system.

7. References

[1] Y. Koren et al., "Reconfigurable Manufacturing Systems," CIRP Annals, vol. 48, no. 2, pp. 527-540, 1999.

[2] Ann-Louise Andersen et al., "Towards a generic design method for reconfigurable manufacturing systems: Analysis and synthesis of current design methods and evaluation of supportive tools,," Journal of Manufacturing Systems, vol. 42, pp. 179-195, 2017.

[3] Chen Zheng et al., "SME-oriented flexible design approach for robotic manufacturing systems," Journal of Manufacturing Systems, vol. 53, pp. Pages 62-74, 2019.

[4] KUKA, "Robot Controllers," KUKA, [Online]. Available: https://www.kuka.com/en-gb/products/robotics-systems/robot-controllers.

[5] Universal Robotics, "oem-control-box_tech-sheet," Universal Robotics, 2019. [Online]. Available: https://www.universal-robots.com/media/1808973/oem-control-box_tech-sheet_dec-2019.pdf

[6] Adriana Filipescu et al., "Multifunctional Technology of Flexible Manufacturing on a Mechatronics Line with IRM and CAS, Ready for Industry 4.0," Processes, vol. 9, no. 5, p. 864, May 2021.

[7] Cristian Barz et al., (2014). "Practical application with plc in manipulation of a robotic arm". Journal of Electrical Engineering. 8. 78-86.

[8] RS, "Siemens S7-300 PLC CPU - 10 (Digital) Inputs, 6 (Digital)," 2022. [Online]. Available: https://uk.rs-online.com/web/p/plcs-programmable-logic

[9] RS, "Siemens Simatic, Industrial Computer, Xeon E3-1275 v," 2022. [Online]. Available: https://uk.rs-online.com/web/p/industrial-computers/2009320/

[10] Beckhoff, "C60xx Ultra-compact Industrial PCs," Beckhoff, [Online]. Available: https://www.beckhoff.com/en-gb/products/ipc/pcs/c60xx-ultra-compact-industrial-pcs/

[11] Radwell, "Beckhoff C60xx," Radwell, [Online]. Available: https://www.radwell.co.uk/en-GB/Search/?q=beckhoff+c60

[12] Alasdair Allan, "Benchmarking Machine Learning on the New Raspberry Pi 4, Model B," hackster.io, 2019. [Online]. Available: https://www.hackster.io/news/benchmarking-machine-learning-on-the-new-raspberry-pi-4-model-b-88db9304ce4

[13] Tesla Inc., "Quality Inspection Engineer, General Assembly," 2021. [Online]. Available: https://www.tesla.com/en EU/careers/job/quality- inspectionengineergeneralassembly-81255