Designing and building of cobot sand cleaning solution for 3D sand printed parts

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Abstract

The manual removal of residual sand from 3D sand printed parts is a time-consuming and repetitive process negatively impacting production efficiency. This article describes the design and implementation of an automated cobot-based cleaning solution developed for Hassal. The primary objective is to reduce cleaning time by introducing a collaborative robot equipped with a custom-built pressurized air nozzle. The project begins with an evaluation of the existing robot installation, followed by a 3D design phase. The resulting installation consists of a mobile aluminium profile cart, turning tables controlled by a Siemens LOGO programmable logic controller, and a Fairino FR5 collaborative robot programmed to clean cores using pressurized air. Tests show that the system cleans eight cores in 110 seconds, achieving a time saving of 11.25 seconds per core compared to manual cleaning. This results in a cost saving of €0.20 per core, with a calculated payback period of 40,676 cores.

1 Introduction

As the manufacturing industry continues to evolve through the integration of Industry 4.0 technologies, the demand for precision and automated post-processing solutions has reached an all-time high [1]. Additive manufacturing, including binder jetting, a process in which sand layers are selectively bound together to form complex molds, has revolutionized how complex components are created. However, the manual labour required to refine these parts often remains a significant bottleneck in the production chain [2]. Currently removing residual sand from 3D-printed molds is a delicate and labour-intensive process that risks deforming the final product if not executed properly. By introducing collaborative robots equipped with specialized tooling this bottleneck can be minimized. This approach not only ensures a higher level of consistency but also significantly improves overall production efficiency by allowing human operators to focus on higher-value tasks [3].

Collaborative robots, or cobots, are robotic arms equipped with force sensors allowing them to work safely alongside human operators without the need for safety cages [4]. This makes them ideal for automating labour-intensive tasks such as sand cleaning.

Despite the advancements in additive manufacturing the post-processing phase remains a critical phase in the production. The sand used in the printing process is mixed with a Furan binder making the residual sand highly abrasive and sticky [2, 5]. Currently Hassal removes this residual sand manually using brushes and compressed air. When a constant stream of compressed air is applied sand particles become airborne and create a sandblasting effect that can deform or damage the fragile 3D printed parts. Furthermore, if any residual sand remains on the mold during the casting process it leads to impurities and structural defects rendering the parts useless. This creates a labour-intensive bottleneck that impacts not only production speed but also the quality of the finished product.

To reduce the time spent manually cleaning the 3D printed parts, Hassal introduced a cobot in combination with compressed air. The following research question was defined: How can a cobot-based sand cleaning solution be designed and built to automate the post-processing of 3D sand printed parts? This question is addressed through five goals starting with evaluating the existing robot installation. Afterwards a 3D design is created along with a parts list. Next the physical installation is constructed and the cleaning tooling is researched and developed. Finally, the cobot and programmable logic controller are programmed.

To develop an automated cleaning solution for 3D sand printed parts at Hassal a structured approach is followed. First, the existing Yaskawa robot installation is evaluated to determine whether it can be used for the cleaning application. Based on this evaluation a more suitable cobot is researched and selected. Afterwards a complete 3D design of the installation is made using Autodesk Fusion alongside a complete parts list ensuring all of the required components are ordered. Using the 3D design the physical installation is constructed consisting of aluminium profiles, turning tables and the cobot. Next the cleaning tooling is researched and developed, including designing and casting of the custom nozzle. Finally, the cobot is programmed to clean 3D printed cores and the communication between the cobot and PLC is established.

It is expected that the automated cleaning system will reduce the time spent cleaning 3D sand printed parts compared to manual cleaning. By using pulsating pressurized air the sandblasting effect which occurs during manual cleaning is expected to be minimized resulting in less damage to the parts. By combining the cobot with the turning tables it is expected that the cobot will be able to reach all sides of the part without human intervention. Additionally, the automated system is expected to reduce the physical and mental workload of the operator. This allows them to focus on higher-value tasks during the cleaning process.

2 Method

The project focuses on the design and development of an automated cleaning solution for 3D sand printed parts. Hassal is a family-owned company located in Kuringen, Hasselt. Hassal specializes in gravity die casting with aluminium and has been doing it for over 50 years. Gravity die casting is a process in which aluminium gets poured into a cast iron mold, where it spreads using gravity making the final product. Due to the demand for prototyping and smaller batches Hassal invested in a 3D sand printer made by ExOne. This printer is used to make single-use molds into which aluminium is poured directly.

At Hassal, one operator is responsible for both the 3D sand printing process and the manual cleaning of the printed parts. Currently cleaning a single By-Cast core takes approximately 25 seconds, consisting of a rough cleaning phase of 15 seconds followed by a deep cleaning phase of 10 seconds. As production volumes increase this repetitive and time-consuming process takes valuable time away from higher-value tasks such as designing.

To develop an automated cleaning solution for 3D sand printed parts at Hassal a structured approach is followed. The first goal is to examine the existing Yaskawa robot installation to determine whether it can be used for the cleaning application. Based on this evaluation a more suitable cobot is researched and selected. Afterwards a complete 3D design of the installation is made using Autodesk Fusion alongside a complete parts list ensuring all of the required components are ordered. Using the 3D design the physical installation is constructed consisting of aluminium profiles, turning tables and the cobot. Next the cleaning tooling is researched and developed, including designing and casting of the custom nozzle. Finally, the cobot is programmed to clean 3D printed cores and the communication between the cobot and programmable logic controller (PLC) is established.

This project contributes to several Sustainable Development Goals (SDG). From the existing robot installation some components such as the 3/2 solenoid and air service unit are reused in the new installation. Additionally, all of the 45x45 profiles which are used come from an old CNC machine. This contributes to SDG 12: Responsible Consumption and Production [6]. Furthermore, by reducing the repetitive and physically demanding workload for the operator, the project aligns with SDG 8: Decent Work and Economic Growth [7]. Finally, by introducing collaborative robots into the production process, the project supports SDG 9: Industry, Innovation and Infrastructure [8].

3 Results

3.1 Existing robot evaluation

The evaluation of the existing robot began by visually inspecting it. It was found to be a Yaskawa Motoman MH5LN in combination with a NXC100 controller. However, the teach panel connected to the controller was missing and multiple cables guaranteeing the safety of the installation were cut. Additionally, multiple safety and control components were missing. The evaluation concluded that a new robot or cobot had to be researched and purchased for the cleaning application.

3.2 Cobot selection

Cobots were preferred over robots as cobots do not require safety fencing due to the internal force sensor guaranteeing safety [4]. The preference went to IP67 cobots as they can operate in high dust and contamination environments [9]. However, due to the limited availability of IP67-rated cobots, these fell outside the available budget. This resulted in the use of lower IP-rated cobots in combination with dust covers preventing abrasive Furan sand from damaging internal components. The Fairino FR5 was selected as it offered the best price-performance ratio with a repeatability of ±0.02mm, payload capacity of 5kg and a 922mm reach [10].

3.3 3D cart design and construction

A comprehensive 3D design was made using Autodesk Fusion. This design was used during the construction of the physical installation and aided in the development process.

3.3.1 Cart design

During the development of the installation two separate 3D designs were made. The first design used 40x40 and 40x80 aluminium profiles which were chosen for their strength and versatility. However, during the design process 45x45 and 45x90S profiles were preferred due to their higher tensile strength improving overall stability and strength [11]. Due to this change in profiles the dimensions of the 3D model were inaccurate. This resulted in the decision to design a second version instead of changing the first. The second design is shown in figure 1.

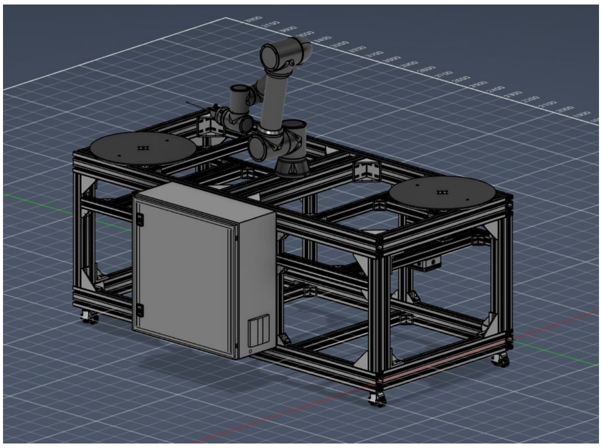

Figure 1: Second 3D design

This design featured the use of 45x45 and 45x90S aluminium profiles connected using corner brackets. Additionally, an electrical cabinet was attached to the side which housed all the electronics. On the left and right side two circular plates functioning as turning tables were attached. Finally, on the bottom of the cart caster wheels with rubber feet were added to make the installation movable.

The cobot itself was mounted on inner 45x90S profiles with thicker sidewalls helping transfer vibrations to the outer supporting structure. The main frame was made up of the 45x90S while the 45x45 profiles were used as mounting points and extra support. The rubber feet in the caster wheels could be lowered locking the cart in place.

During the construction phase precautions were taken to prevent the bolts from coming loose due to vibrations caused by the cobot. Loctite was used on every bolt used in the installation alongside a marking indicating the tightened position. Washers were used on certain components such as the turning tables and the motors. This was done as Loctite was not an option for these components. During testing none of the bolts came loose confirming the effectiveness of this approach.

3.3.2 Turning table

Turning tables were integrated as they extended the working range of the cobot without needing a larger cobot model. Multiple types of turning tables such as pneumatic, electric and hydraulic were researched. Pneumatic turning tables had a low payload compared to the price, electric tables were too big and hydraulic tables were too complicated. The research concluded that most of the turning tables available on the market did not suit the requirements for this installation. Accuracy, payload and ease of maintenance were key requirements resulting in the decision to design and construct custom turning tables.

The custom turning tables were powered using NEMA 34 stepper motors. These stepper motors were dimensioned based on a torque calculation accounting for inertia and friction forces. This calculation resulted in the need for 7.54Nm of torque, by including a 50% safety factor, 11.31Nm was required. The NEMA 34 used offered 12Nm of torque from standstill.

The friction factor used in this calculation was 0.10 which is equal to the friction between steel and Teflon. Teflon was used to support the weight placed on top of the turning tables. Custom-made Teflon rings were CNC machined and placed between the steel turning table and the supporting aluminium profile structure. This ensured all of the weight travelled through the frame.

To ensure the table stayed centred during rotation a bearing was attached to the supporting structure. This bearing was connected to the turning table using an axle driven by the stepper motor via a belt drive system. This ensured smooth and accurate rotation throughout the cleaning process.

During testing an issue was encountered where the belt slipped on the belt wheel when a significant amount of weight was placed on top of the turning table. To resolve this the underside of the steel plate was polished to reduce the friction between the plate and the Teflon rings. This reduction in friction decreased the torque required to rotate the table, allowing the belt to transfer the rotational motion without slipping under the current load. For heavier applications in the future a belt ratio of 2:1 or 3:1 is recommended to provide additional torque capacity.

The turning tables were controlled by a Siemens LOGO 24CE PLC. This PLC was selected as it featured a built-in asynchronous pulse generator capable of generating the short 5ms pulses required to drive the stepper motor drives. Additionally, two IFM240 inductive sensors were added beneath the steel turning table. These sensors aligned with two holes cut 180° apart from one another in the steel plate. This ensured that the table would only rotate 180° at a time.

Custom Dibond plates were mounted on top of the steel turning tables as shown in figure 2.

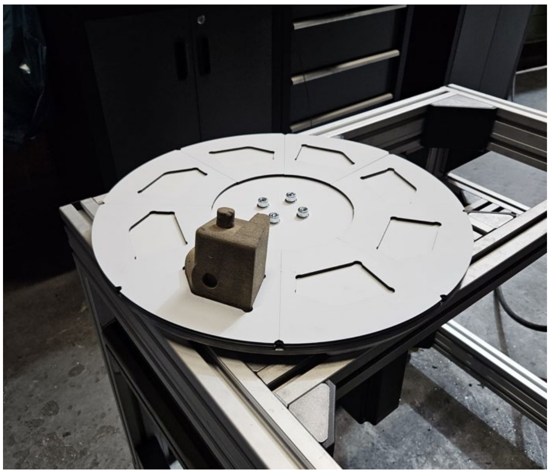

Figure 2: Dibond plates

Figure 2 shows the complete turning table including the custom-made Dibond plates attached to it. Special cutouts were made in which By-Cast cores could be placed before getting cleaned.

These cutouts were made to ensure that the cores would always be placed in the same position throughout the cleaning process. Without this consistent positioning the cobot would not be able to clean the cores accurately resulting in residual sand remaining on the finished cores.

3.4 Electrical cabinet

To house all of the electronics required for the installation to function properly an electrical cabinet was designed and built. This cabinet is shown in figure 3.

Figure 3: Electrical cabinet

The cabinet itself was made by Rittal and has an IP66 rating. Inside the cabinet all of the connection terminals, relays, breakers, power supplies, the PLC, stepper drives and cobot controller were mounted. Additionally, all the pneumatic components were mounted to the side. A fan and exhaust port with filters were added on the sidewalls.

The IP66 rating was chosen to ensure the cabinet was completely protected against the Furan sand produced during the cleaning process. The pneumatic components were mounted on the side wall to protect them from the sand. The air service unit had pneumatic tubing running to the bottom of the cabinet which served as water drainage. The fan and exhaust port provided adequate cooling to all the electronics while the filters kept the sand outside.

3.5 Tooling

For the cobot to be functional special tooling was designed and constructed. Pressurized air was chosen as the cleaning medium as it was the most straightforward way of cleaning residual sand. However, a constant stream of pressurized air caused sand particles to become airborne and create a sandblasting effect. During testing it was found that by increasing the speed of the cobot's movement this sandblasting effect was minimized for simple parts.

The pressurized air was controlled by a 3/2 electronic normally closed solenoid which was operated by the cobot's digital output. This allowed the cobot to control when the pressurized air was active during the cleaning process. Additionally, 8mm-wide pneumatic tubing was used as it offered greater air flow compared to 6mm tubing. By rapidly switching this solenoid between open and closed positions pulsating air could be generated for more complex parts where the sandblasting effect could not be sufficiently reduced by increasing the movement speed alone.

The nozzle used by the cobot consisted of multiple pieces as shown in figure 4.

Figure 4: Final tooling

Figure 4 shows the final tooling which was used on the cobot. It consisted of a base plate which was connected to the cobot's flange, a holder for the nozzle, the screw-in coupling for the pressurized air line and the blow mouth connected on top. Inside of the holder was a 90° bend pipe into which the screw-in coupling and blow mouth were connected.

When designing the tooling it was decided to make the tooling completely out of metal as it was resilient to the abrasive Furan sand and had to be as stiff as possible. Before being mounted the blow mouth was painted bright yellow to make it more visible.

The tooling consisted of multiple pieces to make replacing damaged or broken parts easier without having to construct a completely new tool. The entire tool was held together with bolts and could be disassembled in 2 minutes.

To make the base plate and the holder for the nozzle custom casts were designed and printed using the 3D sand printer. Afterwards these casts were cleaned, assembled and aluminium was poured into them forming the holder. Every cast consisted of a top and bottom part bolted together to hold them in place during casting. Five cast designs were made before the final tooling was completed.

3.6 Programming Siemens LOGO and cobot

Once the physical installation was completed, the Siemens LOGO PLC and the Fairino FR5 cobot were programmed to work together.

3.6.1 Siemens LOGO program

The Siemens LOGO PLC gathered data from both IFM240 sensors and received a starting signal from the digital output of the cobot controller. All of this data was used to rotate the turning tables using asynchronous pulses. Before the cobot started cleaning it sent a signal to the PLC, this was done as the turning tables might have been rotated before running the program. This ensured the tables were in the right place. With the signal from the cobot the PLC started generating asynchronous pulses with a duty cycle of 5ms high and 5ms low enabling smooth rotation of the tables. When the sensor detected the designated cutout it sent a signal to the PLC and the rotation was stopped. Once stopped a signal was sent to the cobot enabling it to start cleaning again.

3.6.2 Cobot program

The cobot sent starting signals to the PLC and the 3/2 solenoid. This ensured it had full control over the rotation of the tables and the pressurized air. The Fairino FR5 was programmed using the built-in Lua-based scripting language. The movements used by the cobot mainly consisted of linear movements as high precision was required. Point-to-point movements were used where possible to ensure singularity did not occur.

Additionally, an external start button was integrated into the program as a safety mechanism for the operator. After completing the cores on the left turning table, the cobot waited for a signal from this button before proceeding to the right side. This gave the operator sufficient time to prepare the left turning table while the cobot cleaned the right cores, ensuring both the cobot and operator were continuously productive. The signals sent and received from the cobot passed through relays as the cobot used a different power supply than the PLC. Due to this difference in ground, relays were used to transfer the signals between both systems.

3.7 Risk analysis

When working with any type of cobot or designing any type of machine a risk analysis has to be conducted. For this installation an analysis was conducted mainly focusing on the tooling used by the cobot. By using the ISO 15066:2020, ISO 10218-1:2025 and ISO 10218-2:2025 standards all major aspects were kept in mind [12, 13, 14].

The main risks were identified as the nozzle being long and sharp in combination with the cast aluminium holder and plate being blunt. The risks involved with the nozzle were reduced as much as possible by painting it bright yellow to improve visibility. Additionally, when selecting the nozzle the softest type of metal was chosen making it bend easily, this specific nozzle was made out of brass with a nickel-plated coating.

The main concern with the cast aluminium holder was being pinched between the cart and the aluminium holder. During testing however it was found that the holder never came close enough to the table to pinch hands or fingers. Furthermore, when the cobot intentionally bumped into the operator it was found that the cobot immediately fell into a protective stop due to the force sensors detecting the collision.

Moreover, the cobot was programmed to always keep the tooling pointed down during transition movements and it was kept inside of the cart parameters as much as possible. These programming measures were implemented to minimize the risk of injury during operation. Additionally, according to the ISO 15066:2020 cobot speeds were restricted to 250mm/s for transfer movements [12]. Lastly, safety glasses are mandatory in the vicinity of the installation to protect against airborne sand particles.

3.8 Technical economic analysis

After the entire installation was completed and all of the required parts had been ordered a technical economic analysis was made to determine the payback time of the entire installation. The total cost of the project came out to €8,135.15. This price excludes tax, shipping cost, labour hours and reused parts. The cobot was able to clean 8 cores in 110 seconds resulting in a core being cleaned every 13.75 seconds. According to the printer operator it takes approximately 25 seconds to manually clean an entire core. The result is that the cobot cleans cores 11.25 seconds faster than manual cleaning. Based on an hourly rate of €64/hr this comes out to €0.20 saved per core. Based on the following calculation the payback time in amount of cores was calculated.

$$\text{Payback period} = \frac{\text{Total investment (€8,135.15)}}{\text{Savings per core (€0.20)}}$$
$$= 40{,}676 \text{ cores}$$

Based on this calculation a total of 40,676 cores have to be cleaned before the installation becomes profitable. This calculation however does not consider maintenance costs or energy usage.

4 Conclusions

At Hassal the manual cleaning of 3D sand printed cores formed a significant bottleneck in the production process. This project addressed the following research question: How can a cobot-based sand cleaning solution be designed and built to automate the post-processing of 3D sand printed parts? This research question has been addressed and a fully automated residual sand cleaning solution for 3D sand printed parts has been designed, constructed and programmed.

First an evaluation was made of the existing robot installation to determine if it would be suitable for the residual sand cleaning application. After inspecting the installation it was found to be damaged, with critical components missing. The components which were still functional such as the 3/2 solenoid and air service unit were reused and a different suitable cobot was researched. This research resulted in the purchase of a Fairino FR5 cobot in combination with a dust cover.

Secondly a comprehensive 3D design was made using Autodesk Fusion to assist in the development of the installation. This 3D design consisted of an aluminium profile cart made using 45x45 and 45x90S profiles connected using corner brackets bolted together. The 45x45 profiles served as extra support and mounting points while the 45x90S profiles formed the main supporting structure. The cobot was mounted on inner 45x90S profiles to ensure efficient vibration distribution. To assist the cobot two self-made turning tables were designed and installed on either end of the cart. Finally, while working on the 3D design a complete parts list was kept ensuring everything was ordered before construction.

After all of the parts had been ordered the physical cart was built. All of the bolts used in the construction were marked and secured using Loctite. To supply the installation with power an electrical cabinet was designed and built housing all the connection terminals, relays, fuses, power supplies, the PLC, turning table drives and the cobot controller. Furthermore, all the pneumatic components were mounted on the inside of the electrical cabinet protecting them from the abrasive Furan sand coming from the cleaning process.

With the physical installation completed, the cleaning tooling could be developed. Pressurized air was used as cleaning medium as it was the most straightforward solution. A custom nozzle was designed to be placed on the flange of the cobot. To do so a holder was developed out of cast aluminium, the molds used for this holder were 3D sand printed. Before getting the casting right five different molds had to be designed. Aluminium was chosen over PLA as it was more resistant to the abrasive Furan sand. The tooling was made up out of a blow mouth, 90° bend pipe and a screw-in coupling. Additionally, 8mm-wide pneumatic tubing was used to supply the pressurized air as it offered greater flow compared to 6mm-wide tubing. All of the used parts were bolted together making it easier to replace broken parts without needing a completely new tool. Furthermore, the blow mouth was painted bright yellow to be more visible.

Following the construction of the installation the Siemens LOGO PLC and cobot could be programmed. The PLC was programmed to rotate the turning tables using pulses and the sensor data provided by the IFM240 inductive sensors. After the turning tables were functional the cobot was programmed to clean the cores using the custom tooling. Lua-based programming was used with mainly linear and point-to-point movements in combination with the inputs and outputs of the cobot controller to control the 3/2 solenoid and send signals to the PLC.

In conclusion each component of the cleaning installation, from the mechanical design and custom tooling to the PLC and cobot programming, was developed to create an integrated and automated cleaning solution for 3D sand printed parts. Testing demonstrated that the system was able to clean eight By-Cast cores in 110 seconds, achieving a time saving of 11.25 seconds per core compared to manual cleaning. Based on an hourly rate of €64 this resulted in a cost saving of €0.20 per core with a calculated payback period of 40,676 cores. This project not only reduced the repetitive workload for the operator at Hassal but also laid the foundation for future expansion towards more complex cores using pulsating air.

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