Engineering Experience 3: Design and Manufacturing

Automating the disassembly process of a Bosch Roxxter vacuum cleaner robot in a cost- and time efficient manner

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Abstract

Conventional disassembly processes are time, labour and cost demanding, this because there is still much manual labour involved. The assembly processes on the other hand are already heavily automated and show that an incorporation of electronics and robotics into a product process is feasible. The aim of this project is to develop a way of semi-automating the disassembly process and in doing so reduce the time and cost needed to take apart a Bosch Roxxter vacuum cleaner.
This process is accomplished by using a three-dimensional gantry system with an automatic screwdriver mounted on top. The screwdriver can rapidly unscrew and sort the screws that keep the vacuum cleaner together. It is necessary to hold the vacuum cleaner firmly in place via the use of a mould, which allows the machine to perform highly precise and easily repeatable operations on the vacuum cleaner. A conveyor belt system, to move the vacuum cleaner around, completes the automated side of the process. An operator is still needed to finalise the procedure, their task is to take all the loose parts out from the assembly and make any newly visible screws accessible to the machine after which the vacuum cleaner is send back to the unscrewing station. This process repeats itself until every screw is unscrewed.
By using this semiautomated process instead of the conventional one, it is possible to do a more extensive disassembly. Additionally, dismantling the vacuum cleaner semiautomatically is almost five times faster than conventionally, furthermore the cost is reduced by approximately 75%. These improvements result in a system which is both practical and economically feasible.

Keywords: Disassembly; Time efficiency; Cost reduction

1. Introduction

In modern times disassembly processes become increasingly important. Because of global warming it has become more essential to recycle or reuse components. Before recycling or reusing a machine is possible, everything must be separated back into their original components. Today, there is still much manual labour involved in disassembly processes, and these are more time and cost prone than automated processes. The assembly processes, however, uses automated systems to decrease the cost and manual tasks. The goal of this project is to design a way to semi-automate the dismantling process of a Bosh Roxxter vacuum cleaner and decrease the time intensive and high priced manual effort involved. This report explains the choices made to develop the machine and how the efficiency of the disassembly practises has increased. The question that is answered in this report: How to decrease the time consuming manual work in the disassembly process of a Bosh Roxxter vacuum cleaner and make it more practical and economically feasible?

2. Materials and methods

In order to investigate the time and cost needed to disassemble a vacuum cleaner a digital twin is needed. For this purpose, the building of a real touchable machine is not necessary. First, some brainstorming and research is done about what components could be useful for the digital twin. In this step thoughts are exchanged about how the exact working of the robot should be. Afterwards the most suited components are selected from different companies and implemented in the digital twin, which is necessary for a realistic and trustworthy model. Once all selected components and self-drawn parts form a complete digital twin the measurements can start. As the aim of the disassembly robot is to reduce the time and cost needed for dismantling a vacuum cleaner, these parameters are evaluated based on the digital twin. In Siemens NX the time usage of completing one disassembly is calculated which gives the opportunity to interpret the time usage and further optimise it. In addition, a cost analysis is made to know exactly the cost of one disassembly, allowing further optimisation of the expenses. Other relevant information such as torque and speed can be gained by graphs from Siemens NX.

2.1 Movement

The keyword of this project is automation, derived from the Greek word *automatos* which means “acting or moving on its own.” Choosing a method of movement is therefore an essential aspect that determines the effectiveness of the automatic disassembly process. There are two main movable systems: transporting the vacuum cleaner and movement of the screwdriver. For the former an Elcom TLM 2000 conveyor belt was recommended and due to its adaptability, multiple configurations are possible. On top of that is the Elcom workpiece carrier a perfect fit for the placement of the vacuum cleaner. The Elcom positioning unit ensures that all workpieces consistently are stopped at the same place in the disassembly region. This disassembly region consists of the screwdriver and a system to get it moving. For this, a three-dimensional gantry robot was opted for. A Festo system [1] was chosen over an Igus robot because Festo offered the service to totally personalise a Gantry robot, creating a perfect fit with the rest of the project. The online gantry tool of Igus was much more limited. Using a self-designed adapter, the screwdriver was mounted underneath the Z-axis of the Festo gantry robot. The screwdriver is now able to move in three dimensions.

2.2 Unscrewing

Now that all essential parts are able to move, the focus switches to the disassembly functions. A preprogrammed automatic screwdriver should remove a whole layer of screws. Changing tools during this process is required since each layer consists of multiple types of screws. When a layer is completely unscrewed, the vacuum cleaner moves to the operator who removes that layer. This is repeated until all layers are dismantled.
The screwdriver that meets all the requirements and was therefore chosen is the Kolver Pluto 10CA/N [2]. This is a PLC compatible application, thus can be easily automated. Other criteria achieved are its magnetic head, a z-axis-compensation and the ideal torque range (0,26 - 7,35) Nm. As earlier stated, the screwdriver should also be able to change toolheads. These toolheads are placed in a holder next to the conveyor belt and are easily accessible. The toolheads are held in place by a groove which runs across the toolhead, this groove slides over a ledge in the holder. The toolhead is picked up by an electromagnet located in the screwdriver, when connected the toolheads gets slid out of the holder. To disconnect the toolhead, slide it back over the ledge and as the screwdriver moves upward, the ledge will secure it resulting in the separation of the screwdriver and the toolhead. On the opposing side of the conveyor belt screw deposit boxes are provided, facilitating the sorting and dispensing of the unscrewed screws.

2.3 Construction

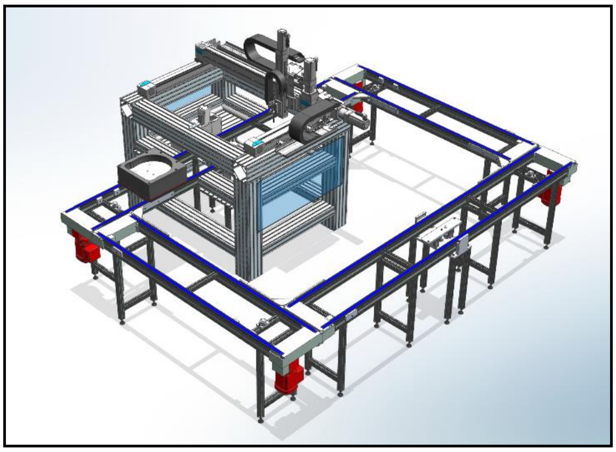


Figure 1: overview of the complete construction

The construction started by implementing the Elcom conveyor belt system and establishing the foundational structure for the entire process. Given that Elcom offers standardised components, this conveyor belt system can be fully customised to suit the specific requirements of the project. To construct the gantry system, TraceParts supplies versatile Aluminium t-slot beams of various sizes. These beams serve as essential building blocks in assembling the gantry structure. To guarantee proper functioning of the machine, it is necessary to have a sturdy and rigid frame, therefore the beams forming the outer part of the frame are (160 x 160) mm². The vertical beams are 930 mm long and anchored into the ground. The horizontal beams on top are (1160 x 1184) mm² long. In between the vertical beams, additional supportive beams measuring (80 x 160) mm² in cross section are placed. These beams not only enhance stability but also serve a vital role by connecting to the Elcom framework. Since the vacuum cleaner is positioned on the Elcom stopper unit, which is connected to both the ground and the frame for the conveyor belt system, it is important to create a strong connection between the gantry system on top and the stopper unit.
Since the entire frame consists of t-slot beams, it becomes easy to add certain parts to it. Next to the stopper unit there is a t-slot plate attached to the frame, this creates a workspace for the gantry robot to operate in. On this plate the tool bit holder and the screw deposit box are mounted, both are attached using the t-slots. The same method could be implemented to create a workspace for the operator, this however is not shown since the focus of the project is on the automatically moving components.

2.4 Automation

The importance of automation has already been addressed in previous sections. This automation is achieved through the combined use of the Elcom system and the gantry system. To process signals from multiple sensors and control the actuators, a PLC is utilised. The Elcom system creates the link between the operator and the unscrewing gantry by moving the vacuum cleaner between the workstations. In the Elcom conveyor belt, the positioning unit and the Elcom proximity switch communicate with the PLC via connection cables, while the PLC returns information to the Elcom servo motors through motor cables. Most of the automation process is set in the unscrewing machine. To check the position of the vacuum cleaner in the machine a Ricoh SC-10 Vision system [3] is connected via an HDMI cable and sends the information to the PLC. The Ricoh SC-10 is used because it is a cheap and easy to integrate system that can check if the components are at the preprogrammed position. It sends a signal to the PLC when one of the components is not where it is supposed to be. Interacting with one of the three Festo CMMT-AS-C2-3A-MP-S1 drives, the PLC communicates with the drives through motor cables to precisely control the servo motors of the gantry, ensuring they reach the desired positions. The Festo drive systems are preferred because every component is already integrated into the gantry system except for the vision system that can easily be connected to the system via the PLC.

2.5 Material Selection

For all self-designed parts selecting the optimal material is a crucial step that affects the production method and therefore has a substantial influence on the total cost of the project. Two groups of self-made parts can be distinguished: the adapter parts and the functional parts. Among the adapter parts, the piece between the screwdriver and the z-axis, and the piece between the vision system and the frame are included. These parts will be made of aluminium 6061, with the reason being that it is an inexpensive and readily available material that is easy to work with. Furthermore, the metal's ductile properties make it suitable for connecting components, as they exhibit high tensile strength without the risk of fracture and offer resistance to plastic deformation over time. To support this hypothesis, a finite element analysis was conducted, revealing that the applied forces would result in a negligible deformation of 2,156 micrometer. This deformation is well below the permissible threshold of 0,1 mm, thus affirming the hypothesis. The custom-made functional parts consist of screw deposit boxes and tool bit holders, both of which are suitable for 3D-printing and will be fabricated using polymer material. Specifically ABS, a widely used 3D-printing material, was chosen for its optimal balance of strength, impact resistance, and formability. Tolerances and deformations for these parts are of such minor significance that they do not require consideration. As a result a finite element analysis (FEA) was deemed unnecessary.

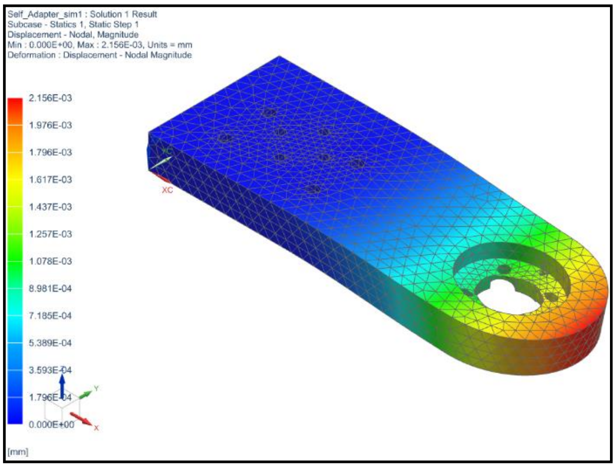


Figure 2: finite element analysis of a self-drawn part

2.6 Safety concerns

Since the machine will have multiple moving parts, safety concerns must be considered. The scope of the system is professional operators, enough space and continuous usage with short breaks. The most dangerous hazards to be considered are: loose hair can get caught by the movable elements, the movement of sharp objects like the screws and body parts caught in the motor. To reduce these risks preventive measures will be taken. Hair must be tied together whilst operating the machine. The Gantry system is required to be surrounded with plexiglass and an emergency stop is obligated to be installed. In case the plexiglass door is opened before pressing the stop button, the robot shuts itself down to prevent accidents. In addition, the motor needs to be at least IP23 rating. Further the operator is mandated to wear safety shoes and gloves in case the vacuum cleaner may fall of the conveyor belt, or he should empty the screw deposit bin. With all these safety measures the performance level a is present in the entire system.

3. Result analysis and discussion

3.1 Time optimization and Cost comparison

The collaboration between the machine and the operator is around four times cheaper and five times faster than disassembling it solely manually. For dismantling the vacuum cleaner manually an operation time of at least 15 minutes is required. When multiplied with a loan cost of 35 euro per hour, one operation has a cost of 8,75 euro. For dismantling the vacuum cleaner manually with the help of the machine an operation time of three and a half minutes is required. As of the less time needed by the operator and the relatively low cost of the machine, the cost per operation is reduced to 2,17 euro. This value is obtained by estimating a total of 3 520 working hours of the machine per year which corresponds to two shifts of eight hours for 220 days per year. Together with the three and a half minutes needed for a disassembly a total of 60 343 disassemblies per year is realised. Adding the cost of an operator per year (€123 200) and the cost of the machine for one year together (€7 681) results in a total cost of €130 881 per year. A cost of €130 881 divided by 60 343 disassemblies results in a cost per disassembly of €2,17.

Table 1: cost per disassembly without robot

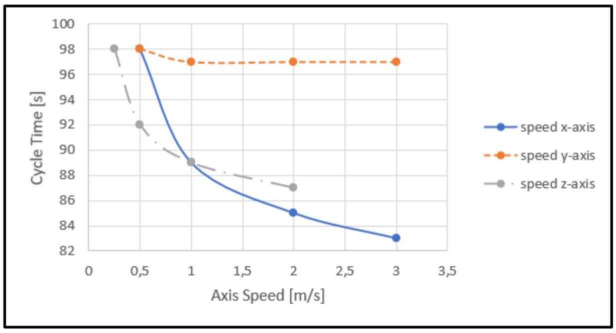
Parameter	Amount	Unit
Cost of operator	35	€/h
Time per disassembly	0,25	h/disassembly
Cost per disassembly	8,75	€/disassembly

Table 2: cost per disassembly with robot

Parameter	Amount	Unit
Working hours of robot	3 520	h/year
Time per disassembly (3,5 min)	0,0583	h/disassembly
Disassemblies per year	60 343	disassemblies/year
Cost of operator (€35/h)	123 200	€/year
Cost of robot (€76813 over 10 years)	7 681	€/year
Cost per disassembly	2,17	€/disassembly

3.2 Gantry axes speed analysis

The gantry system has the biggest impact on the cycle time, making it crucial to conduct a thorough analysis. By examining the individual impact of velocity changes on each axis of the gantry, an optimal speed configuration can be determined. Furthermore, it remains important to prioritise safety and maintain the machine's effectiveness throughout this process.
Based on the analysis, it becomes evident that altering the speed of the x-axis significantly impacts the cycle time, followed by the z-axis. Interestingly, adjusting the velocity of the y-axis shows no effect on the cycle time. This observation can be attributed to the simultaneous movement of the x and y axes. Due to its shorter distance to travel, the y-axis consistently reaches its position ahead of the x-axis.
Considering safety measures and the servo motor limitations of the gantry system, optimal speeds of 2 m/s, 1 m/s, and 0.5 m/s were assigned to the x, y, and z axes respectively. As a result of this optimization, the cycle time was reduced from 98 s to 90 s, showcasing a notable improvement compared to the standard configuration. By implementing this optimization specifically for the unscrewing process, the picks per minute were enhanced from 7,96 to 8,67, also demonstrating a significant improvement.



Graph 1: Influence of axis speed on cycle time

4. Conclusion

To conclude, it is evident that the disassembly process can be effectively semiautomated. The discussed automation method offers significant advantages over manual disassembling of vacuum cleaners, making the process more optimal and profitable. By accurately estimating the optimal axis speeds the cycle time is substantially reduced, resulting in increased efficiency and enabling a higher volume of disassemblies. Additionally the cost per disassembly is four times cheaper, indicating substantial cost savings.

Initially the disassembly time was estimated to be three times faster and the costs would be 50% cheaper. However, the analysis revealed even more impressive results.
The disassembly time with the robot proved to be almost five times faster than manual disassembly, while the costs of semiautomatic disassembly is four times cheaper than manual disassembly. These outcomes surpassed the initial expectations, showcasing the remarkable effectiveness of the automated system.

It is important to note that throughout this process, utmost consideration was given to ensuring the safety of the operator who works alongside the gantry system. The entire system was designed to prioritise operator safety, minimising risks and potential hazards.

Furthermore, the system's convenience and ease of use are notable advantages. This is primarily due to the incorporation of numerous standard components, streamlining installation and operation.

In summary, this automated disassembly process proves to be a highly efficient and cost effective solution. With significantly reduced disassembly times and costs, alongside enhanced operator safety, this automated system offers substantial improvements over manual disassembly methods.

5. References

[1] Festo. (z.d.). Zoeken C2641997 | Festo BE. https://www.festo.com/be/nl/search/?text=C2641997

[2] They feature: aluminium body for easy and quick clamp, special wiring for specific use with SG controllers with remote start and reverse and torque signal. KBL brushless screwdrivers are also available in /FN version. (z.d.). *CA series* electric screwdrivers for automated and fixtured applications | Kolver. https://kolver.it. https://kolver.it/products-list/6-CA-Series

[3] Work Assistance Camera System RICOH SC-10A | *Industrial Products | Ricoh*. (z.d.). Copyright RICOH Co., Ltd. https://industry.ricoh.com/en/fa_camera_lens/work-assistance-camera-system/sc-10a