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Article

Design for Disassembly and Augmented Reality Applied to a Tailstock

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Abstract: The work here described aims to offer a starting point for improving and making a generic maintenance process more efficient, first of all thanks to the use of a cutting-edge technology such as augmented reality, as a key tool that makes it possible and immediate to communicate to operators which are the fundamental stages of the maintenance process to be followed in the working area. Furthermore, thanks to the use of two methods applied in the context of the Design for Disassembly (later described), we also propose to search for all the possible sequences to get to the removal of a target component to be adjusted—in particular the optimal one (if it exists, in terms of time and costs) to be subsequently applied in an augmented reality "self-disassembly" model that can be viewed and followed by the operator, in a way that is still very little used today.

Keywords: CAD; augmented reality; optimization; DFD; industrial maintenance

1. Introduction

In engineering, the abbreviation DFD indicates the Design for Disassembly, meaning all the activities dedicated to the project of a disassembly sequence of the parts that make up a mechanical assembly of any kind, in order to obtain a list of tasks that maintenance operators have to carry out to optimize the timing and costs of this procedure [1]. Assuming that it is needed to remove a worn component inside an industrial machinery, we can understand how easy it is to waste time if the list of operations to be carried out is not clear. Especially with an assembly consisting of thousands of components, there are more possible ways to get to the "target" (a specific part that needs to be analyzed and repaired). This maintenance process can be in general preventive or corrective. In the first case, as can be guessed, its replacement occurs before it is faulty and unusable. This is the ideal form of maintenance, because it allows the long-term use of the machinery without breaking one of its components, avoiding possibly serious consequences both for its other elements and the surrounding environment (including the operators). Corrective maintenance, on the other hand, is performed once the damage has occurred. Often a part breakage damages many other components in the closest area—a classic chain effect. This is due, for example, to the presence of eccentricities during the motion of unbalanced masses, rotating shafts or gears, such as toothed wheels, or due to a piece breakage which can violently impact the surrounding parts or, in the worst case, the working operators in uncontrolled conditions. As can be understood, this second form of maintenance should be avoided as much as possible. There are several other disassembly methodologies today capable of exploiting automated and computer-controlled processes; for these, please refer to the bibliography, these themes differ slightly from the focus of the article [2–4].

In general, a mechanical piece can be repaired and reused in the assembly's future life, or replaced. In many cases, it is possible to recover part of the construction materials for a new components' manufacture [5]. DFD allows a better recovery of parts and materials, considerably efficient improvements in terms of time and costs for industrial maintenance, as well as an optimal development of the operators' technical skills and a good evaluation of their working conditions' safety, if applied together with augmented reality. In particular, they will be asked to follow a clear roadmap containing the sequence of all steps to follow during the maintenance process and useful information relating to their execution (needed tools, movements to follow, parts' arrangement in the work area, ...). Being able to carry out the activities mentioned in the shortest possible time should be a key objective for a company. The time saved in a certain number of controlling and repairing processes will obviously be dedicated to other activities, with consequent lower labor costs (or equal costs spent in a larger number of tasks). In DFD, the disassembly costs are estimated to be linear with the increase of the disassembly time, and therefore can be represented graphically by a straight line. In a completely different way, the gain obtained in terms of costs increases rapidly with the initial increase of the disassembly time, but settles on constant values when this becomes very high. From a difference between the two curves, it is evident that it is necessary to proceed with the disassembly of a mechanism, at the end of its useful life, as quickly as possible. For mechanical assemblies consisting of few components, costs and revenues will both be minimal. On the other hand, as the number of components increases, the revenue curve assumes an optimal value, and then decreases as the disassembly times increase (Figure 1).

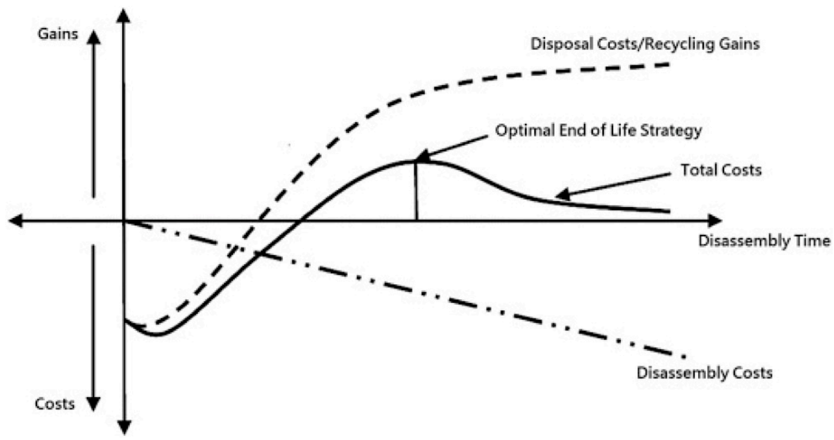


Figure 1. Total costs' function in DFD [6].

Consequently, one of the fundamental rules of DFD is to have the critical components of an assembly, in terms of functional importance, possibly located in areas that are easily accessible during maintenance [6]. Fasteners are not usually critical components (they can be immediately removed from the assembly, their removal is not prevented in any way by tightening elements as screws or space encumbrance due to other parts). Disassembly can then take place in a destructive form or not; in the first case, it is necessary to force that component's breaking or a part's breaking which is blocking it, preventing the direct access by the operator. With a good Disassembly Sequence Planning, it is then possible to evaluate what the spatial and geometric constraints are dictated by the size of the assembly and the location of the parts inside it to obtain an ideal disassembly sequence, thinking about how to minimize the operators' movement in the working perimeter and the handling of tangible objects they need to work with. DFD is also powerful for the best choice of materials used in the manufacturing process of a product (alongside the mechanical analyzes on stresses and yields, friction, fatigue, vibrations, thermal loads, ...) with a perspective view of their recycling and reuse at the end of the useful life [7]. Materials that are not compatible with each other should therefore be eliminated for a good recycling, also to be correctly separated after disposal. The same is true for components of the most varied and disparate shapes (in total disagreement with the ideal use of a few standardized elements on a large scale, as the ideal case of a single screw model used in all the mechanism design). It should be noted, then, how the result of a DSP analysis does not only concern the achievement of record times and minimum costs, but involves many issues directly linked to the context of the environmental protection and sustainable economy, operator, and people's health, discouraging as much as possible the use of harmful and dangerous materials during the design and manufacturing process. This brings practical and functional advantages to anyone who operates in the context of an organization, dedicating his time to the product design, its production and also in the procurement and logistic departments. Such an analysis often involves products already marketed; other times, it is anticipated and realized directly during their design or following the first physical prototyping, the best case without doubts. Before proceeding, a quick summary of the work phases is proposed (Figure 2).

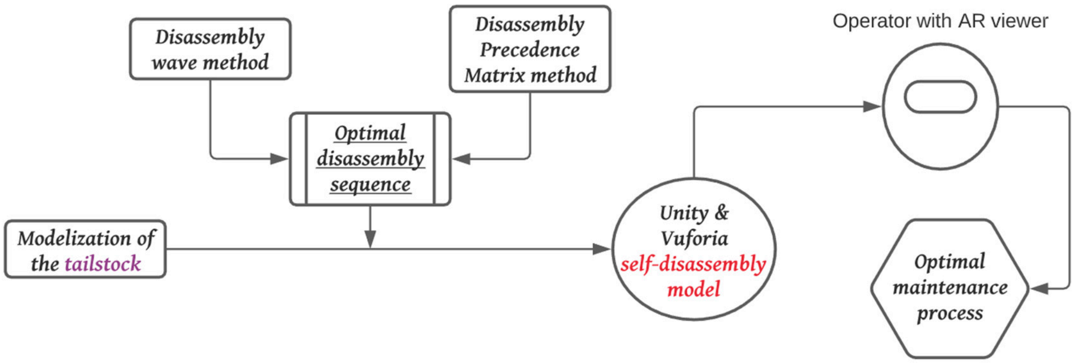


Figure 2. Logical diagram of the work.

In the second section, we will quickly talk about the industrial use of a rotating tailstock and how it was modeled using Autodesk Inventor. In the third section, we will focus on the analysis of two useful methods to find the best sequence for disassembling the parts of this mechanical assembly. In the last section, we will finally talk about how the use of augmented reality could nowadays make maintenance processes within companies more efficient, first of all because it is able to present itself as a perfect tool to teach operators how to carry out the maintenance process in the fastest and safest way.

2. Case Study: The Tailstock

2.1. Industrial Use

The studied lathe's tailstock has 10 components (Table 1), so it is a very simple model [8]. Often, before the chip removal process, a centering operation is performed on the blank mounted on the lathe, in correspondence with its rotation axis. This is useful to ensure greater stability and precision during processing, thanks to the presence of the tailstock that supports the piece needing to be turned. The tailstock therefore does not participate in chip removal, but it is necessary as a support element. As can be guessed, then, this mechanical tool is designed following the development of effective fatigue analyses on thousands of working cycles at high speeds, always subject to vibrations that stress the materials causing inaccuracies during machining. After N work cycles, part of the tailstock components will obviously be subject to wear due to internal friction in the contact between the parts [9]. Nowadays, with advanced simulation software used in the field of finite element analysis, precision estimates are possible on the useful life of a mechanism subjected to fatigue, as well as to stresses of various kinds due to concentrated and distributed external loads, vibrations, thermal loads, and so on. The use of bearings and lubricant has become essential to overcome friction, the main obstacle to be faced in the design of an assembly such as the tailstock, which is almost only involved, in most of its components, in rotational movements around the main axis. The screw in the assembly has the same function as a plug: when removed, it allows the insertion of lubricant in the volume portion between the casing and the internal bearings (Figure 3). The fixing screw, on the other hand, is required to keep the screw cap placed in the correct position; it is threaded, but subject to self-unscrewing phenomena, especially in a high speed use case, so it requires the help of the grub fixing screw. Obviously, it will be impossible to remove the ring nut (by unscrewing it thanks to a lever-tool that can be inserted in the hole recognizable in the drawing, located in its upper part) without having first removed this fixing element. Inside the ring nut, between it and the rotating tip, there is a rubber gasket that acts as a fourth bearing. It stabilizes the tip's rotation in a low friction coupling and guarantees the almost total seal of the lubricant inside its seat. In the rear part of the tailstock, there is a small bearing with 20 rolling elements, closed by a cover. It is oscillating; therefore, in addition to the classic degree of freedom of rotation around its axis, it allows small rotational movements around an orthogonal axis. Assuming such small deviations to be completely prevented, the rotating tip would be strongly stiffened and constrained in its rear part. Furthermore, the tapered roller bearing and the thrust bearing are similarly employed to respond to the normal forces acting from the outside on the rotating tip. The thrust bearing, in particular, is the most important element in terms of this kind of response.

Table 1. Bill of materials.

1	2	3	4	5	6	7	8	9	10
Casing	Rotating tip	Rubber gasket	Ring nut	Cover	Screw	Tapered rolling bearing	Thrust bearing	Oscillating bearing	Fixing screw

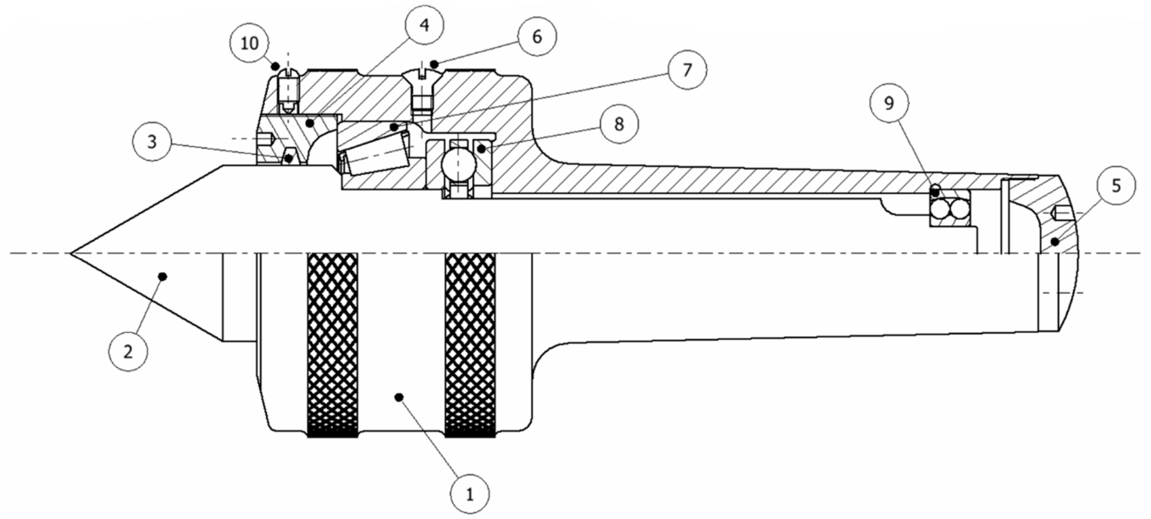


Figure 3. Design of the tailstock realized on Inventor; it is not intended as a complete project drawing.

2.2. CAD Modeling

The tailstock was modeled using Autodesk Inventor, quick and intuitive for an effective modeling of objects, thanks to its minimal interface equipped with every tool necessary even for the creation of the most complex shapes. As mentioned, parts such as the carcass (containing all the elements of the tailstock) and the cover were obtained as rotation solids. The first sketches in two dimensions were followed by the generation of the respective solids of revolution thanks to the appropriate program's commands. The holes on both pieces were made later, completed with a thread where needed. The knurling has been created on the casing at the end of the modeling (useful to guarantee a better grip by the operator more than for aesthetics). To obtain it, the polar series command is ideal, which allows for copying an element (a starting relief of the knurling) by positioning N equal ones along a predefined path (a straight line, a curved line such as a spline, a circumference). Then, with the mirror command, the orthogonal copies of these identical reliefs were made. The same procedure was performed for the second knurling. An alternative solution was chosen for the oscillating bearing located on the back of the tailstock; it was in fact obtained thanks to the functions of the accelerated drawing of Inventor, a section dedicated to mechanical design that allows automatic creation of an object such as a bearing, a shaft, a key, a spring or a bush (and so on) only by imposing the dimensional and design constraints known at the outset. For example, knowing the diametrical dimensions of the rotating tip and of the interior of the casing in the location area of the oscillating bearing, it was sufficient to impose the dimensions of its internal and external rings, coupled respectively with the two mentioned parts, to obtain it. The generic modeling procedure, starting from a drawing of the product or from a real model already built and marketed, falls fully within the context of reverse engineering [10]. It is clear that the purpose of a "reverse engineering" applied to an existing product is mainly to improve its functionalities and features, obtaining a new and modern highly performing model, better than the old one [11]. The potential offered by CAD modeling platforms in this field is almost infinite and represents the fastest and most efficient tool that can be used in the context of reverse engineering. For a direct comparison with the original drawing, the same was created on Inventor (Figure 3); this nowadays requires little time on practically every modeling platform, as the views necessary for the representation of the assembly, known to the program, are created instantly on the basis of a few useful settings entered by the designer (scale, position and choice of views, title block, related data, and so on). An exploded view was also created to show the arrangement of the internal components of the assembly, together with a rendered image of the finished model (Figure 4).

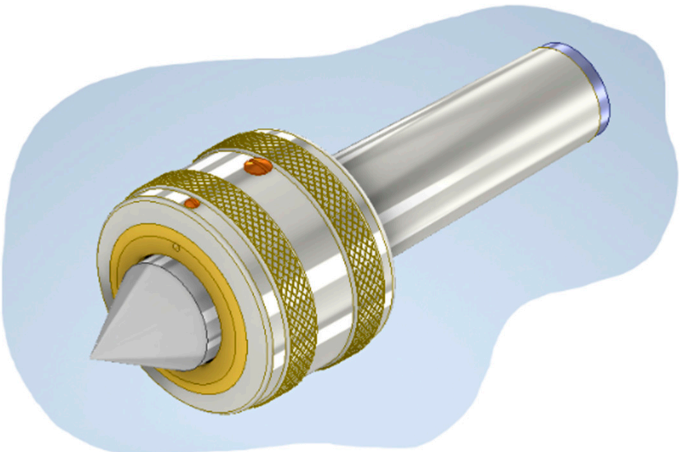


Figure 4. Rendered image of the tailstock.

3. Methods for Analyzing the Disassembly Process

3.1. 1st Method

The first method analyzed was presented for the first time by authors Jianjun Yi, Bin Yu, Lei Du, Chenggang Li, and Diqing Hu in a publication entitled "Research on the selectable disassembly strategy of mechanical parts based on the generalized CAD model" [12].

The concept underlying the method is that of a disassembly wave that propagates starting from the target component, touching all the surrounding ones in different instants of propagation time. At the first instant of time (t1), N1 elements will have been touched, i.e., the closest to the target. With the subsequent expansion steps, all the elements involved will be incorporated within the volume of space crossed by the wave. The article defines as "d-dependent" components that can be extracted only after the disassembly of those that prevent its removal. Specifically, a "1-dependent" component is expected to be removed after only one other part which will be a fastener. The latter are nothing more than small clamping elements that are easy to remove, in most cases, such as fixing screws. In a generic "removal influence graph" (Figure 5), the various components are represented by points (or nodes) while the constraint relationships present between them can be easily represented by arrows. It will obviously be necessary to proceed from the outside towards the inside to remove the target. An important rule to underline is the following: it is not necessary to cross only one component for each wave level in the graph, but it is also possible to cover all the elements of one same level before moving on to the next (innermost) one. This is due to how the disassembly wave is generated: at every instant of time (t1, t2, t3, . . .), it crosses several components together placed on the same wave level in the graph. It is possible that some of them constitute all, or only in part, a removal constraint for the component enclosed between them. Therefore, especially in complex cases, it will be almost impossible to cross the various wave levels through only one disassembly step at a time, so it is wrong to think this is necessary when looking for the best sequence. Having found all the possible disassembly sequences that lead to the extraction of the target component from the mechanical assembly, it is necessary to understand which is the best. It is possible to choose between different alternatives: there is always the best in terms of time needed, but it could be more expensive than others (for example, if it requires the use of special tools necessary for the removal of parts that, instead, could remain inside the complex when another route is followed). You could opt for the sequence that requires the least number of components to be extracted. Often, it can be the fastest, but just imagine having to remove a particularly bulky and heavy component, requiring the aid of lifting means and several operators at the same time, in order to understand how difficult it would be.

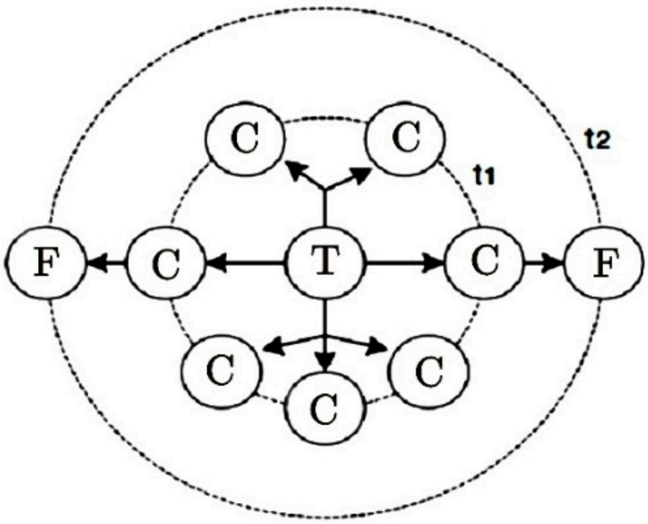


Figure 5. Example of a generic disassembly wave graph, with the target, components, and fasteners.

Application of the 1st Method

By observing the assembly in all its parts, the graph of the propagating wave in the various instants of time can be easily obtained. In fact, element 2 borders on components 3, 7, 8, 9; these will be the first to be touched by the imaginary propagation wave starting from the rotating tip. Element 3, as shown in the drawing, is positioned directly next to element 4 (they are assembled and disassembled together). The two front bearings (7 and 8) with the casing (1); from the oscillating bearing (9) on the back, however, the wave propagates towards the cover (5). According to this reasoning, the removal influence graph was obtained (Figure 6). The fastener components are 10, 6, and 5. It is necessary to start from the grub screw (number 10 in BOM) or the 6 × 10 screw to reach the target (2). Assuming the screw is the first to be extracted (6 in BOM), we proceed with the emptying of the lubricant located in the internal and free areas of the tailstock; this procedure has been estimated to take 10 s of time (this is due to the absence of detailed information concerning the case of such a procedure in the TMU table). It is necessary to continue with the removal of the element 10 to allow the subsequent extraction of the threaded ring nut at the same time, for obvious reasons of physical bulk, with the rubber gasket. These last two elements mentioned (4 and 3 in BOM) are mounted and removed together, as the gasket is entirely inserted in a cavity carved into the internal surface of the ring nut. Once these elements have been removed, it is possible to proceed with the extraction of the rotating tip; we have already talked about how its coupling with the tapered roller bearing is uncertain; therefore, the extraction of the target element (2 in BOM) in this case could be difficult. The sequence obtained is therefore the following: 6, 10, 4 with 3, 2. There is no other possible disassembly sequence to get to the rotating tip, but there is an alternative, namely that of not removing the 6 × 10 screw to free the cavities of the casing from the lubricant before continuing with the sequence. This would reduce the final time of the estimated 10 s spent to pour it, added to the seconds taken by the operator to twist off the screw and place it in a suitable space in the working area. Before continuing, a concept is reiterated; each method must be able to provide all the possible sequences, in a more or less evident and intuitive way depending on the case. Here, the comparison between those occurs at the end; therefore, it is not possible to immediately obtain the optimal solution. It is possible to observe an exploded view of the assembly in Figure 7.

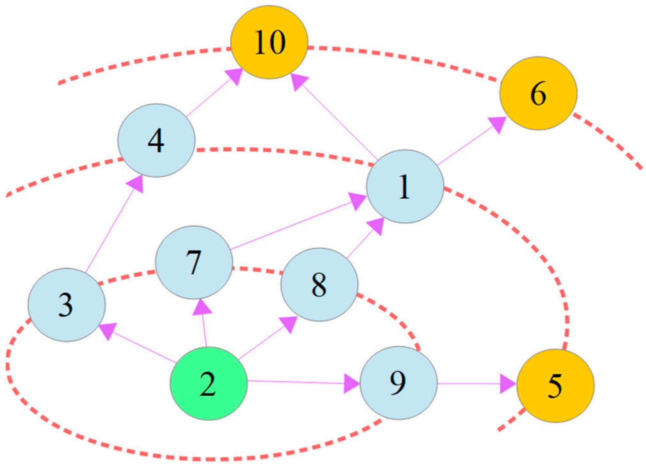


Figure 6. Resulting disassembly wave graph after the application of the 1st method.

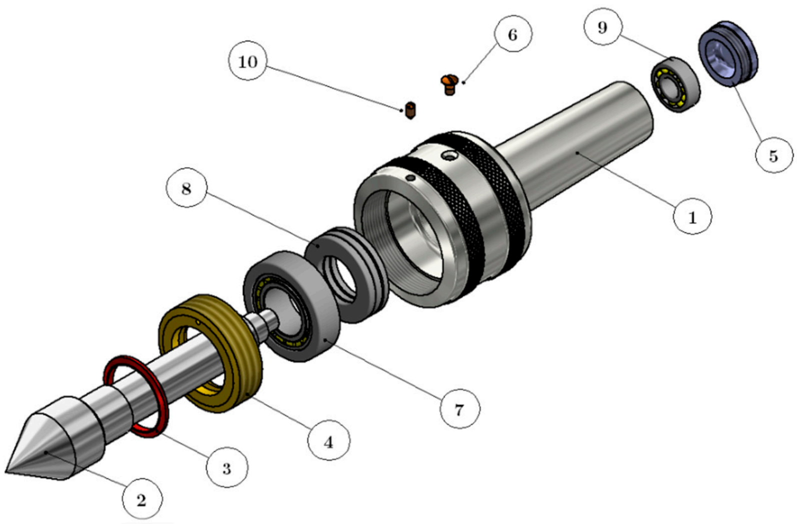


Figure 7. Exploded view.

3.2. 2nd Method

The second method proposed is the result of the work of the authors Fei Tao, Luning Bi, Ying Zuo, and Andrew Nee, described in their publication called "Partial-Parallel Disassembly Sequence Planning for Complex Products" [13]. This algorithm aims first of all to observe the starting assembly and complete a matrix based on the spatial constrains between the components present in it; then, the first fasteners are removed, each time eliminating the row and column relating to the extracted object. This is the DPM (Disassembly Precedence Matrix) and has N rows and N columns (square matrix) considering it applied to a general assembly with N components. It is nothing more than the real union of four sub-matrices: the CFM, FCM, CCM, and FFM. In each acronym used to distinguish them, the M stands for Matrix, the F for fasteners, the C for components (therefore d-dependent). Each DPMij, element of the matrix, contains a sequence of 6 digits which can be 0 or 1; as can be guessed, they correspond to the six possible spatial verses (−x, +x, −y, +y, −z, +z) in the three directions (x, y, z). Therefore, in the CFM (matrix of the relations between d-dependent components and fasteners), there is a 1 every time the *j*-th fastener blocks the *i*-th component, while, in the opposite case, there is a 0 (full absence of constraint in the considered direction). There is no need to dwell on repeating the same speech for the other three matrices. It can be thought that it makes no sense to apply this method in the calculation of the FFM and FCM matrices, since a fastener will always be removable in at least one spatial direction (as the first element of the disassembly sequence, if desired). Not analyzing these matrices would be completely wrong. In fact, if it is true that for fasteners immediate removal from the assembly is possible by definition, it is also essential to understand in which directions they cannot be removed. This becomes fundamental for the purpose of a computerized application of the method in question, for which it could be possible to use a programmed software able to work on the matrices supplied to it in input, so that it returns in output the possible sequences applicable to the mechanism or, even better, directly the best sequence. The use of these matrices is ideal to communicate with simple tables all the information needed by the software solver relating to the free Cartesian directions. Then, whenever a component is removed, the row and column associated with it in the DPM is cleared. The matrix decreases in size; this means that the DPM is a dynamic matrix in a similar process. A component can be removed when inside the line that represents it for at least one Cartesian direction there are only 0. Note that a line containing all sequences (of 6 digits) consisting only of 0 s is not needed, it must be free in at least one verse. In the case of an *i*-th fastener, it will be necessary that the terms FCM (i, :) and FFM (i, :) are equal to 0, while, in the case of a normal *i*-th component, it will be necessary that CFM (i, :) and CCM (i, :) are 0. The very simple wording used to express the conditions of freedom of removal could not be clear; it simply indicates that, within the matrices shown, on each "sequence element" of the *i*-th row and therefore relative to the component or fastener analyzed, there is at least one digit (the first in all the sequences, or the second, or the third, . . .) always equal to 0. In this method, there are no references regarding the possibility of a destructive disassembly. Usually, the information relating to this modality is indicated in different methods with the use of the number 2, i.e., if in a CPM's box, CPMij, there is a 2, the components *i* and *j* are bound to each other, (1) but they can be equally removed (0) being aware of the fact that they will not be re-usable. For example, bearings are often constrained, on their rings, in couplings with interference that make their extractability remarkably difficult in maintenance, impossible to perform without causing damage. Having found all the possible sequences reaching the target, it is possible to compare them to understand which is the best. The search for the optimal solution takes place at the end of the application of the method which, similarly to the case of the disassembly wave, is useful in searching for all the possible sequential combinations capable of reaching the target.

Application of the 2nd Method

In the tailstock case study, CPM is a 9 × 9 sized matrix, despite the presence of 10 components (Table 2). The reason concerns the fact that elements 3 and 4 are treated as if they were welded together, as these parts are assembled and disassembled at the same time. The highlighted edges help to recognize the four sub-matrices from which it is composed; therefore, FFM, CFM, FCM, and CCM. Note that, here too, the casing is considered to be fixed and therefore not removable (as the logic envisages extracting the elements inside it from it). However, the fourth row and column of the matrix are dedicated to it, with the evident presence of 0 and 1 in the various 6-digit sequences. In fact, it has been chosen to equally provide the information relating to the dimensions of the tailstock from the point of view of a different reference system (we could imagine holding the elements in place in the casing by removing this one from them). This would not be possible in a single step as there are clear constraints both in the −x direction, for the presence of the bearings and the ring nut, and the +x direction, due to the cover and the oscillating bearing. Beyond these details, the procedure described can help to understand how to think in the drafting of a matrix such as the CPM or its sub-matrices. It is necessary, strictly for the considerations on the overall dimensions, to avoid thinking in the practical field and to rely solely on the observation of the drawing from which the geometry of the parts must be clear thanks to the dimensions provided. It is necessary to start from a fastener, so it is possible to proceed with the search for a following candidate for removal, among the first lines of the CPM. It is not mandatory to remove all the fasteners present before proceeding with the other components. We return once again to the sequence 6, 10, 4 with 3, 2, which is the only one actually possible. As mentioned, the fact of having an assembly consisting of parts that can be extracted in one direction only (almost all of them must be removed outside the casing) considerably simplifies the situation, almost to trivialize it. For particularly simple cases of assemblies, it certainly makes no sense to proceed with a DSP analysis. After the application of this method, the two sequences found are reported (the second is clearly the optimal one);

(a) 6, 5, 9, 10, 4 and 3, 2
(b) 6, 10, 4 and 3, 2

Table 2. Disassembly precedence matrix.

DPM	F5	F6	F10	C1	C2	C4,3	C7	C8	C9
F5	0	0	0	101111	0	0	0	0	0
F6	0	0	0	111011	0	0	0	0	0
F10	0	0	0	111011	0	110000	0	0	0
C1	011111	110111	110111	0	101111	101111	101111	101111	011111
C2	0	0	0	011111	0	001111	011111	011111	011111
C4,3	0	0	110000	011111	001111	0	010000	010000	0
C7	0	0	0	011111	101111	100000	0	010000	0
C8	0	0	0	011111	101111	100000	100000	0	0
C9	0	0	0	101111	101111	0	0	0	0

It is important to underline that both methods described do not allow, therefore, to obtain an optimal disassembly sequence; they are useful to be able to identify all the disassembly sequences applicable to a mechanism, therefore the optimal one, undoubtedly present among them. The first method allows this thanks to a quick visualization of the assembly and of the relationships in play between the parts that constitute it (dimensions, couplings, spatial proximity), while the potential of the second method consists in containing all the information relating to these relationships in a matrix of zeros and ones (so it is undoubtedly programmable to be solved by a computer).

3.3. Estimation of Disassembly Time

The choice of the best disassembly sequence among several possible ones is not always the one that requires the least time. Costs, operators' safety, preparation of the instrumentation, standardization, and variability of the parts, sustainability and adequacy of the ways in which the disassembly process takes place, especially with regard to the removal of dangerous and potentially harmful substances from the assembly, are all variables that come into discussion. One could easily analyze the times of the different sequences obtained with the most disparate methods, timing them while they occur in parallel. This would obviously require the use of many physical tools (many prototypes, the operators, . . .). There are faster ways to approach this problem; as was also done for the rotating tailstock here, it is possible to exploit tables containing estimates of the disassembly times for each type of component, variable based on numerous drivers, including: dimensions, necessary instrumentation, effort to be applied, any presence of lubricants, type of location of the component within the assembly (cavities or easily accessible areas), and so on. These tables, present in the essay by Anoop Desai and Anil Mital entitled "Evaluation of disassemblability to enable design for disassembly in mass production" [14], reports time estimates in TMU (Time Measurement Unit) and not directly in minutes or seconds. The conversion is in any case immediate, i.e., 1 TMU is equivalent to 0.036 s. It is therefore evident that the use of the TMU is more convenient than the times in seconds, which can be obtained at the end of the process of calculating the sequence in TMU with a simple conversion between the two quantities. The use of predefined tables for estimates (certainly not exact calculations) of the disassembly times of an assembly are useful to save time on the calculation, now quickly performed. For each type of element present in the tailstock, an appropriate value in TMU was estimated, as a single weight of its removal, to be added subsequently to that of the other parts involved in a chosen sequence (Table 3). For some elements, the data are the same and, consequently, their removal weight in TMU. The 6 × 10 screw and the grub screw, for example, have both been estimated to have a removal weight of 76.8 TMU, therefore 2.76 s; this suggests that a similar application is very useful for temporal comparison between different sequences instead of estimating their actual disassembly times. No reference has been made to processes that can be performed on the components after their removal, before they are reused; cleaning processes, mechanical processes such as grinding or polishing, new lubrication, for example, have non-negligible costs that must be considered and weighed when looking for the ideal maintenance process. The use of predefined and tabulated parameters for estimating the duration of a generic maintenance process is therefore entirely useful for obtaining an initial estimate of what its cost will be. Above all, it is important to understand how many labor costs must be allocated to each maintenance service if there are many within a company department. Intuitively, it is also crucial to understand how much manpower will be needed to complete all tasks within the required deadlines.

Table 3. Values obtained by Desai's parameters.

BOM	Force	Grasp	Weight	Sim	Tools	Dim	Location	Tool Accuracy	TMU	s
2	5.5	2	2	0.8	1-1	1	2	1.2	42.24	1.52
4	3	4	2	0.8	1-3	1.6	2	2	368.64	13.3
5	3	2	2	0.8	1-1	1	2	1.2	23.04	0.83
6	1	4	2	1.2	1-2	1	2	2	76.8	2.76
7	5.5	4	2	0.8	3-3	1.6	2	2	2027.5	73
8	0.5	3.5	2	0.8	2-2	2	2	2	89.6	3.2
9	3.5	4	2	0.8	3-3	1.6	2	2	1290.2	46.5
10	1	4	2	1.2	1-2	1	2	2	76.8	2.76

4. Augmented Reality

4.1. Key Features of the AR

To understand what exactly augmented reality is, it is useful to define it together with similar virtual reality. The latter makes it possible to simulate the real environment or create a completely unlikely one with which it is possible to interact through various software and interfaces. Video games are an example of this. Augmented reality, on the other hand, allows for viewing something that does not exist in the real world, through the use of special tools such as AR cameras, HoloLens, viewers of various kinds. While in the first case any direct reference to the environment is excluded, in augmented reality, it is possible to add something more to what is normally identifiable with the five senses. The basis of this technology lies in the use of tracking devices capable of recognizing objects, shapes, curves in the set frame, useful for providing additional information in AR output observable through a viewer [15]. Imagining opening the hood of a car and shoot the interior with a special AR camera, for example, it would be possible to show the names of the components displayed in the frame; an object could be visualized in real size to understand in advance how it would appear, post realization, placed in its working environment. Almost all those directly interested in the product would benefit from it, starting with the engineers who have to design it respecting dimensional and aesthetic constraints (among many), passing to those who must sell it, being able to easily show it to the customers, arriving at these latter subjects that can take more advantage of the potential offered by technology like this. The visualization of the product in the context of destination related to its industrial application does not offer advantages only from the points of view related to costs (it avoids as much as possible the construction of a physical prototype), design, dimensioning, maintenance, but allows a decisive improvement concerning the safety conditions of operators who need, for example, to work near an automated robot. The observation of this model in 1:1 scale allows for studying its movements and tracing its dimensions (understood as areas and volumes of space involved by the fixed and mobile parts of the machinery), consequently being able to evaluate in the most appropriate way the methods of flanking of the operator to the machine. Considering the increasingly frequent use of cobots, robots designed to work alongside humans as an additional workforce, according to the programming of their work cycle, the use of augmented reality undoubtedly provides an advantage obtainable with a few efforts. The AR technology used here is of the marker based type, therefore following the recognition of an object in two or three dimensions, framed through an appropriate viewer, it places the virtual object in the relative spatial position. It will be an image, in the case studied. Other kinds of augmented reality are cited: marker-less, projection based, superimposition based, and so on. The first mentioned, in particular, differs from the marker-based AR as it is not based on the recognition of an object; on the other hand, it uses various means, primarily GPS, to allow virtual objects to appear in the image displayed by those who are moving, for example, through the streets of a city based on their spatial position.

4.2. Case Study of the Tailstock with Unity and Vuforia

Vuforia is the first software to be used if you have the aim of making a video of the exploded view of the assembly in augmented reality. It is an online platform on which it is possible to quickly and easily create a database to be downloaded as a package for Unity, the details of which will be explained shortly. First you need to create a license; it is very easy and free; after registering with Vuforia [16], it is possible to obtain one automatically generated by the platform in the form of a code to copy and, subsequently, paste in a special section of Unity [17], dedicated to the settings of augmented reality.

In parallel, it is necessary to load a desired image on Vuforia so that the software proceeds with the recognition of appropriate target points on it: they will serve as a reference for the camera when the image is taken, to correctly identify the spatial position that the assembly will have at the end. The results obtained with Kandinskij's painting "In Blue" have been rated by Vuforia as good as an Image Target for 4 stars out of the maximum obtainable (4/5 stars). The use of a complex image is fundamental, with many lines and contrasts between light and dark areas; it does not need to be in color. The target points will be, under conditions adequately met, more and more. Downloading the Vuforia database package and an additional package to make the augmented reality mode available on Unity, it is possible to switch to the latter program by importing them into a new project. The AR camera, the Image Target from the database, and the obj file of the tailstock have been imported into the Unity environment (including all the components, of course). After the assembly has been placed as a child component of the target image in the Hierarchy panel, the elements of the tailstock were colored; in fact, by importing the assembly as an obj file, the program recognizes each solid element only with its geometry. A difficult case is that of bearings, of which the software recognizes and distinguishes each part (M rings, N rolling elements) making it impractical to impose an animation on the components in question (Figure 8). It was enough to gather the (M+N) parts in a GameObject folder created in the hierarchy menu to solve the problem, so as to have the possibility to animate objects made up of a high number of sub-elements in a single shot. Using the Unity timeline, it is possible to proceed to record a quick animation of the tailstock that "self-disassembles" [18–20].

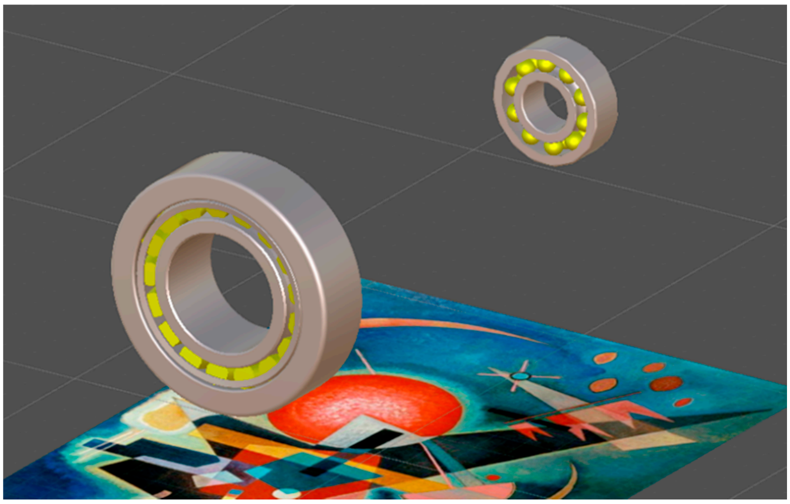
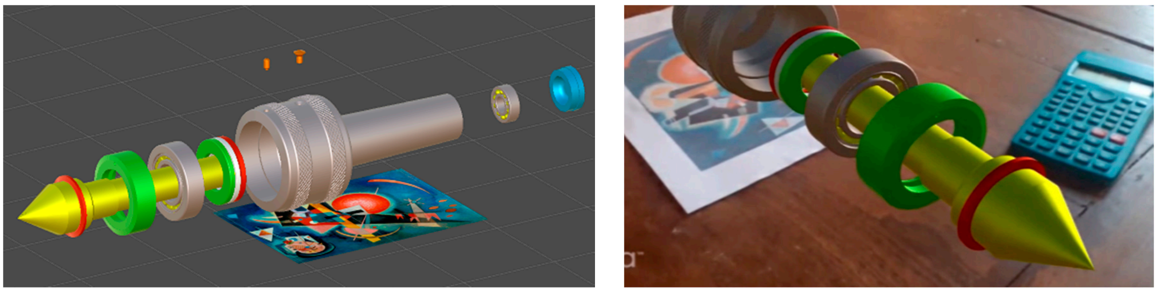


Figure 8. Display of two bearings in the Unity environment.

The best aspect of this technology is that its reliability consists first of all in its simplicity; a company employee is simply asked to wear a viewer and “copy” the actions that he observes in the self-disassembly in augmented reality, applying them to the same object on which he really has to do maintenance. In addition, the programming/implementation of such an AR model is not complicated, so much so that anyone could do it at home, as demonstrated (Figure 9). It is based on the use of low-cost technology available to everyone, thanks to a myriad of free software available online. The exploded view obtained in the Unity environment and in the real world is what we could show with simple tools in augmented reality to anyone equipped with an appropriate viewer (HoloLens) or a camera equipped with augmented reality supports. For the last image of the tailstock proposed in augmented reality, the final frame of a demonstration video, a mobile phone was used as a camera [21,22].



(**a**) (**b**)

Figure 9. (**a**) Exploded view of the assembly on Unity; (**b**) AR camera view.

5. Conclusions

To conclude, it will be enough now to imagine the use of a similar and simple technology in a company department with operators dedicated to the maintenance, assembly or disassembly of an industrial machinery. The most important thing is that they manage to complete their work in the best possible way. Loss of time due to sudden breakages, accidents in the work field, lack of adequate equipment, lack of staff skills, inability to understand the procedure to be followed to obtain the extraction of a specific component, constitute irrecoverable damage for the company in terms of lost time and costs. Furthermore, the use of manuals with hundreds of pages to learn is nowadays to be excluded considering what the times are to be respected. We have seen how there is a way to increase these types of performance. This is possible, first of all, thanks to the various tools described in the article, as the use of any CAD software for the modeling of a product to be industrialized, the application of the concepts of "design for disassembly" with a view to re-using materials and future savings on disposal costs, in addition to research efficient and optimal methodologies on the basis of which maintenance must be carried out—thus the use of augmented reality to teach operators the optimal working methods, thanks to the very visual mode offered by this still little used, low-cost, and rare technology.

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