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Development of a System for the Active Orientation of Small Screws †

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Abstract: This paper reviews the process of research, development and production of a system for the active orientation of small screws. The parts feature two different shapes on each side, which is suitable for machine vision inspection and not for classical vibratory bowl traps. When a part enters the jig, it is rotated at an angle of 90° for inspection. Based on the orientation, it may stay in this position or be rotated at 180°. This allows for active orientation; regardless of how the screw is presented to the camera, it is always positioned in the correct orientation by a servo mechanism. The main challenges are related to the small dimensions of the part. First of all, it has a diameter of only 3 mm and a length of 7 mm. A vibratory bowl feeder is used only for feeding and there is no orientation functionality in it. Afterwards, a vibratory linear feeder is placed so the ready parts are stacked and, thus, some buffer is created. This is important because vibratory bowl feeders are known for having unequal productivity in time and this could be solved by the linear feeder. Another key difficulty is the quality of the source parts. They are produced by several suppliers and sometimes there are chips and other remnants alongside the packages with screws. This imposes the need for a cleaning system as part of the servo actuator's mechanism. Cleaning does not occur on every cycle; it is based on a timer that is predefined.

Keywords: automatic parts feeding; machine vision; servo mechanism

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1. Introduction

This paper follows the process of the research, design, development and production of a system for the feeding and orientation of small screws with two different shapes on the sides. The aim is to have the screws oriented in an unambiguous way. The part is made of metal, so it is not expected to have any of the issues typical for plastic parts when using automatic feeding [1,2]. A drawing is shown in Figure 1.

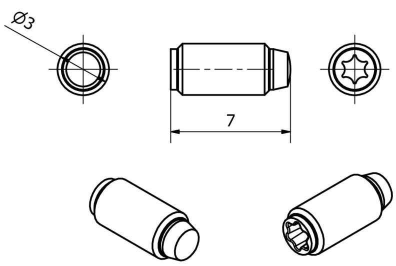

Figure 1. Part picture.

On the one hand, due to the small dimensions of the screw and, on the other, because of the tiny differences between the two sides, it is concluded that classical mechanical approaches with bowl feeders are inappropriate [3,4]. It is not an easy task to mechanically differentiate between the two ends (one of the sides is conical; the other has a star for the tool bit). A drawing of the part is shown in Figure 1. It has the already mentioned dimensions of a diameter of ϕ3 mm and a length of 7 mm. It is a relatively small part from the point of view of feeding systems. One of the main tasks in addition to feeding/orientation is the storage of quantities, enough for one shift. The part is small; therefore, with a single loading by the operator, the devices should work without interruptions.

Considering the fact that vibratory bowl feeders are the most traditional feeding devices, it is sometimes extremely hard to persuade team members or end customers to use alternative approaches and newer systems, for instance flexible part feeders.

In many cases, people, especially if they have an important job in an institution/company, are conservative in their views and are not open to new technologies, at least not at the beginning of the conversation. A lot of effort, presentations and action plans have to be prepared in order to persuade such people. The increase in the size of an institution greatly decreases its flexibility and openness to quick decisions.

2. Analysis on the Suitability of the Part for Automatic Feeding

In order to analyze the degree of suitability for automatic feeding, a methodology for quantity assessment, developed in the department of "Automation of discrete production" was used [5]. The results are presented in Table 1. The screw has only two possible stable orientations, which indicates sufficient productivity for any feeding system that would potentially be developed.

Table 1. Application of the methodology on the screw part.

Degree N	Feature	Code
I	Asymmetry on the external configuration, metal part	1,000,000
II	The parts do NOT join each other mechanically	000,000
III	Miniature, ferromagnetic	60,000
IV	Round, straight	2000
V	One plane of symmetry	600
VI	No central hole, non-symmetric ends	60
VII	Without additional features	0
	Part code number according to the methodology	1,062,660

The number of possible orientations is a major factor in the successful development of feeding systems. With the rise in the number of possible orientations, the productivity decreases. Depending on the part geometry, certain stable states are more frequent in terms of oriented parts in that state compared to others.

The result is 21, which places the part in category 3, complex parts for automation. According to the algorithm, it is necessary to perform a detailed analysis of the feeding capabilities before designing the system. Preliminary technical and economic calculations are also highly recommended in order to evaluate the potential solution. It is important to note that this approach is mainly theoretical and serves best as a starting point. There are many systems currently, including systems for flexible part feeding that could feed almost any part geometry regardless of the shape complexity. There are many cases in which the application of this methodology has led to results that are "too complex" or "inappropriate for automation" and, later, a successful and reliable system is developed.

Despite the methodology's age, it is still best used for a quick overview of parts and decisions on how to process them in the early phases of analysis. It was created back in a time when there were no smart systems, such as advanced sensors and machine vision systems; although machine vision and robot navigation existed back in 1986 at KAM factory in Plovdiv, Bulgaria, this technology was not as widespread as it is today.

Small parts are delicate for feeding because they normally require small amplitudes of vibration which are not always possible with traditional electromagnet systems [6]. One of the key approaches is to build systems at a mechanical frequency of 100 Hz because this increases the number of vibrations and decreases the mechanical amplitude, thus making the parts "jump" more gently. For small parts, it is sometimes also recommended to use piezo-based feeding systems which offer even more gentle vibrations and smaller amplitudes. These devices are not as famous as their electromagnetic analogs; however, this technology is key to conveying tiny parts.

The part is also evaluated according to the suggested author classification in Table 2, which generates unique product codes based on features of the part like material, mass, color, category of application and industry, complexity of the part for automatic feeding and orientation.

Table 2. Part code according to author classification.

#	Parameter	Value	Abbreviation
1	Shape	Conical	2
2	Geometry	Almost symmetric	2
3	Material	Metal	M
4	Mass	Lightweight	1
5	Number of stable states	-	2
6	Color	Single color	M
7	Additional geometric features	Presence of axial features	3
8	Control features (markings)	No additional information	3
9	Category of application	Electrical components	7
10	Industry	Electrical appliances	2
11	How complex is the part orientation?	Relatively simple	1
12	Design features easing orientation	Without any measures taken in design phase	1
13	Is it possible for the parts to entangle?	The parts do not entangle	1
14	Do the parts have delicate surfaces?	No delicate surfaces	1
15	Are electrostatics an impacting factor?	No influence	1
	Resulting part code	2 2 M 1 2 M 3 3 7 2 1 1 1 1 1	

As noted, this classification takes a new approach in the naming of parts. It takes certain significant features of parts #1–15 and each parameter receives an explicit value from the list that best suits the part.

In traditional systems, it is the classical mechanical traps that ensure a part's orientation process [7]. Nonetheless, when machine vision is used, the classical mechanical traps are reduced in number and complexity due to the fact that cameras allow for the inspection of various features on the part simultaneously, which is handled by the software, and results are provided by means of electrical signals and advanced serial or Ethernet-based communication protocols. This is a decent advantage of machine vision camera systems over traditional feeding systems because the latter are not so flexible. Figure 2 demonstrates the two possible orientations of the screw.

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

Figure 2. Possible orientations of the screw: (**a**) orientation with the star forward; (**b**) orientation with the conical side forward.

3. Design and Production of the System

One of the significant factors to highlight is the need to build an active orientation system. Active orientation occurs when all parts are used in the process (if the part is not properly oriented, an additional orientation occurs until it becomes in the correct orientation state). A picture of the developed 3D model is shown in Figure 3. It reveals the assembly of the bowl feeder, the linear feeder and the jig. The bowl has a diameter of approximately ϕ200 mm and is made of polyamide.

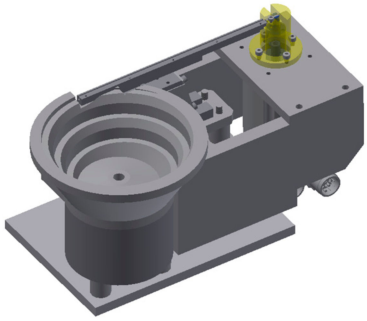

Figure 3. Three-dimensional (3D) model of the system.

The real produced system is shown in Figure 4 after installation.

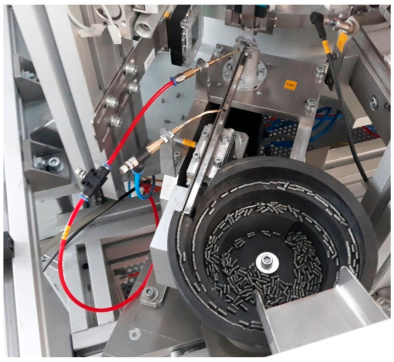

Figure 4. Real photo of the developed system.

The parts are loaded in a bulk unsorted state in the bowl feeder. They are fed forward with either the cone or the star end facing the linear feeder. Both orientations are acceptable, so in this specific project the bowl feeding is a purely feeding device. As the parts are transferred to the vibratory linear feeder, it serves as a magazine. At the end of the linear feeder, there is a rotary jig, actuated by a servo motor. The first screw on the linear feeder enters the jig and is then rotated at an angle of 90° for image processing with a machine vision camera. If the part is properly oriented, it remains like this and a manipulator picks it up directly from the jig. If the wrong orientation is presented to the camera, the servo makes a 180° turn and rotates the part so it becomes properly oriented.

The manipulator is based on a Π-cycle workflow. Both the vertical and the horizontal movements use pneumatic cylinders with two sensors (one is for the home position; the other is for the work position). A pneumatic gripper with special jaws is installed on the vertical cylinder.

Figure 5 shows the gripper for screws. It is a standard pneumatic parallel gripper with two precisely machined jaws ensuring the parallel gripping of the screw. The jig has a special cleaning nozzle which is controlled by a PLC to clean the jig of dirt, small metal particles and other impurities at certain intervals. Due to the nature of screw production and the way they are loaded into the bowl feeder (by turning the carton upside down), it is normal to have foreign parts inside the bowl. These have to be cleaned and maintained at certain intervals in order to ensure the reliable work of the system.

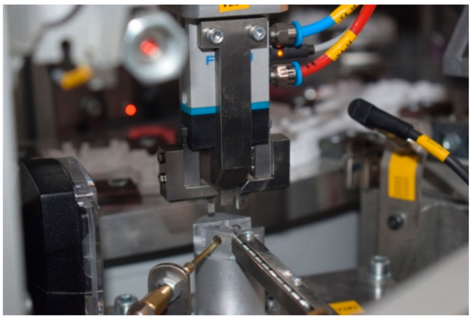

Figure 5. Gripper system for screws.

4. Experimental Research

After the system is built mechanically and electrically, detailed experimental research is performed. The first test is regarding the probability of taking one of the two possible orientations. The results from the experiment are shown in Table 3.

Table 3. Results from the experimental research on the orientation of the parts.

Trial #	Cone to the Front	Star to the Front
1	18	22
2	22	18
3	19	21
4	20	20
5	24	16
MIN	18	16
MAX	24	22
AVG	20.6	19.4

In machine vision systems, long optimizations normally take place while configuring the software part as there are multiple inspection tools that are available and there is never a single appropriate solution to a given problem [8,9]. In this particular example, the parts are static during inspection (the servo has already stopped when the camera is triggered) and this means that it is not possible to benefit from the suggested algorithm in [10] despite the interesting original ideas presented in that paper.

The normal approach for camera adjustment is to have physical samples from the parts. This is essential as parts are different and there should be enough variety in terms of quality, features, tolerances, etc. The next step is to create a new job and setup some visual tools for inspection. Then, if there is already a filmstrip based on real images, it can be used to test the job. After satisfactory results are achieved the camera, the job should be tested in real conditions.

5. Conclusions

This paper follows the process of the research, design, development and production of a system for the orientation of screws with machine vision. Due to the nature of machine vision technology, it can be reused for almost any kind of part [11–13]. Therefore, the suggested approaches in this paper could be used in other projects/research papers as key ideas.

The screws have almost identical distribution of the two orientations. Therefore, their productivity is satisfactory.

The combination of a traditional bowl feeder and machine vision guarantees that the parts are always visually checked and there are no mechanical failures with traps. It is essential to note that the bowl feeder could be replaced by a conveyor system or any other feeding device that could work similarly. Some solutions offer the key benefit of reducing vibrations that are typical for bowl feeders. In certain applications this could affect the proper functionality of the camera.

Modern problems require modern solutions or, specifically, solutions targeting Industry 4.0. The world is dynamic and so are customers—they follow tendencies, financial forecasts, market demands and other influencing factors for decision making. There should be constant development of products and effective solutions in the area of part feeding systems, automatic assembly, control measurements and other mechatronics devices due to the always increasing need for automation. A good future improvement of this project would be the connectivity of the system to the LAN environment and the possibility to share the camera images on any PC in the network [14]. This would bring the solution to a new level following the guidelines and tendencies of Industry 4.0 and the connectivity of devices within the organization. Furthermore, a separate monitor could be installed next to the camera to visualize all images for the operators and other potential users of the system.

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