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High Speed Fastener Inspection

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Ryan Haldimann
Electroimpact Inc.

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Abstract

Inspection of fasteners prior to installation is critical to the quality of aerospace parts. Fasteners must be inspected for length/grip and diameter at a minimum. Inspecting the fasteners mechanically just prior to insertion can cause additional cycle time loss if inspection cannot be performed at the same time as other operations. To decrease fastener inspection times and to ensure fastener cartridges contain the expected fastener a system was devised to measure the fastener as it travels down the fastener feed tube. This process could be adapted to inspection of fasteners being fed to the process head of a running machine eliminating the mechanical inspection requirement and thus decreasing cycle time.

Introduction

A method for verifying the length and grip of fasteners prior to insertion into the aircraft structure was required by the customer. Stopping the fastener to do this inspection would negatively impact cycle time of the machine. Thus a method to inspect a moving fastener was developed. A system was desired that could compensate for the unknown orientation of the fastener and measure it accurately. The solution utilizes a system of mirrors to split the image and obtain two simultaneous images so that the full fastener orientation could be determined enabling accurate measurement. A review of the existing literature could find no reference to similar imaging methods using line scan cameras to inspect fasteners while in motion.

Figure 1. Aerospace Fasteners

Method

Two options were evaluated, an area scan camera and a line scan camera. Since the fastener cannot be uncontrolled and an area camera requires a large opening or clear window susceptible to damage, a line scan camera was selected. The other issue was measuring the fastener accurately when the fastener was tilted towards or away from the camera. To mitigate this issue the optics system is designed such that two views of the fastener 90° apart are captured simultaneously by the camera.

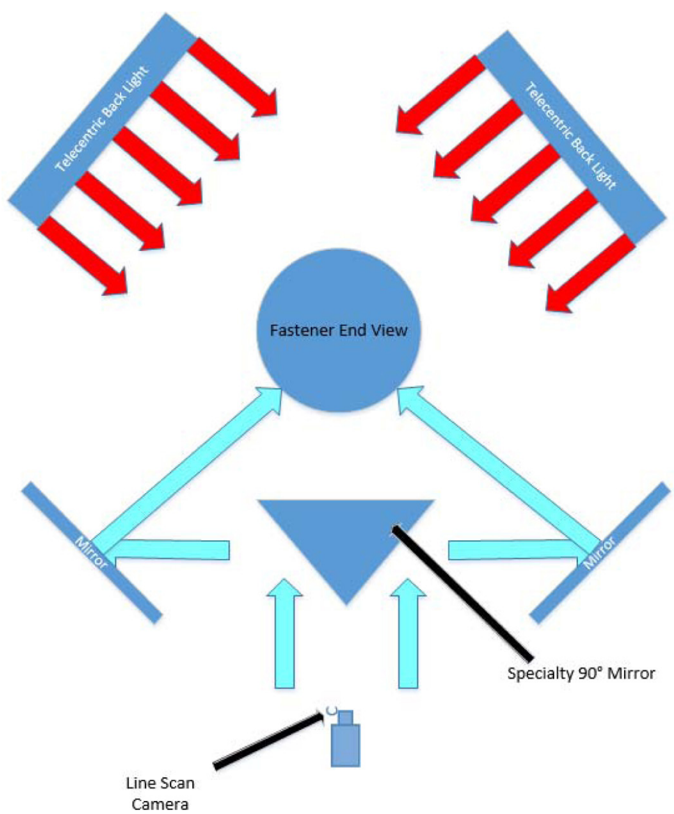

Figure 2. Optical Inspection Layout

This allows the tilt of the fastener to be measured allowing the length to be correctly calculated. The fastener is backlit using telecentric illuminators and imaged using a telecentric lens to provide optimal edge contrast. The processing of the image occurs on the camera and no PC is required. The information as to what fastener is transiting is sent to the camera including the expected diameter and overall length. As the fastener falls past the camera under gravity it passes through a light field sensor that triggers the start of the acquisition.

The path has 2 small 0.5 mm slits one for trigger and one for imaging the fastener as shown in Figure 3.

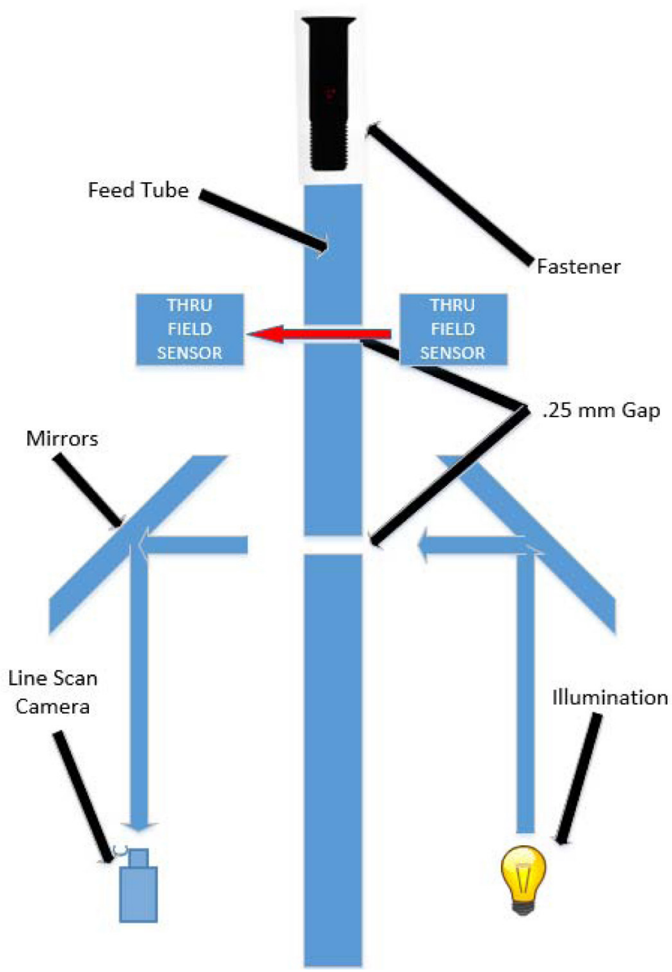

Figure 3. Inspection Method Geometry

A clear section of tube was considered but deemed too susceptible to damage thus occluding the image acquisition. After acquisition completes, the image is processed. The velocity is determined by measuring the distance from the start of the image to the first pixel of the bolt. Once the velocity is known proper scaling in the vertical direction can be applied. Subsequently various measurements are then made to determine the diameter, head geometry, and grip of the bolt as shown in Figure 4. A variety of vision processing tools, typically blob, edge and caliper tools are used for these measurements. Length is compensated using fastener tilt as shown in equation (1).

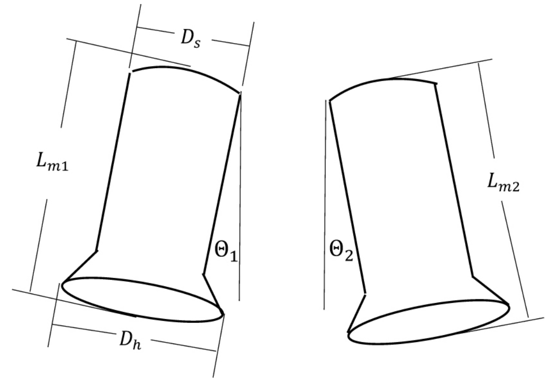

Figure 4. Fastener Measurements In Single Image

D_s = *Diameter of Fastener Shank*

D_h = *Diameter of Fastener Head*

L_m = *Measured Length*

Θ = *Fastener Angle*

L_c = *Calculated Length*

$$L_c = \frac{\left(L_{m1}+L_{m2}-\left(\frac{D_s}{2}\sin(\theta_2)+\frac{D_h}{2}\sin(\theta_2)\right)-\left(\frac{D_s}{2}\sin(\theta_1)+\frac{D_h}{2}\sin(\theta_1)\right)\right)}{2} \quad (1)$$

If the fastener fails the measurement routine the ejector is actuated and the fastener is directed to a reject bin.

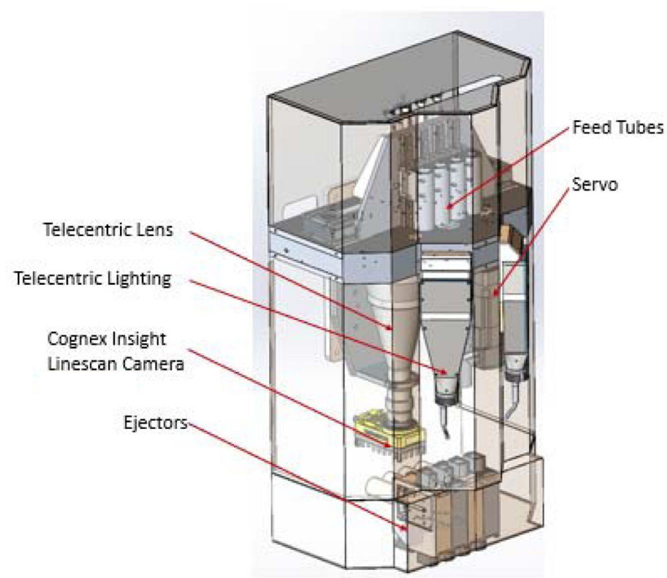

Figure 5. Inspection Assembly

Components

Hardware

The assembly was initially designed using off the shelf components from Opto Engineering. Unfortunately due to space constraints a custom optical assembly was required using off the shelf lenses and illumination. For image processing a Cognex Insight 5604 line scan, Figure 6, camera was selected, providing image processing without the need for an external PC and allowing for direct control of the escapement mechanism.

Figure 6. Cognex Insight Camera

The selection of which diameter feed tube was selected was controlled by a PLC.

High speed solenoid driven escapements, Figure 7, are used to reject invalid fasteners. These were manufactured using additive manufacturing techniques suitable for complex parts, minimizing weight and actuation time.

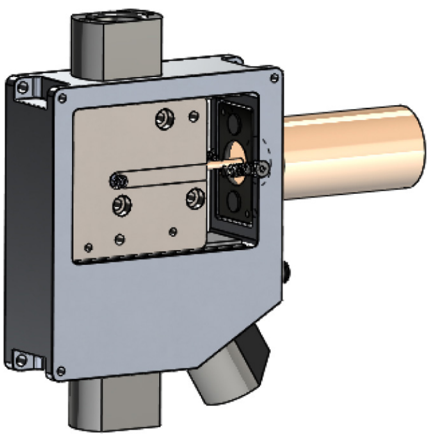

Figure 7. Fastener Eject Actuator Assembly

Software

Cognex Insight software was used to process the image once acquired. This included a custom designed job for image processing including scaling and making various measurements. The results were returned to the PLC but the accept reject status was used to directly actuate an eject escapement mechanism as shown in Figure 7.

Results

The apparatus was able to measure the length to a combined 0.26 mm standard deviation over 1193 cycles of 3 fastener diameters and 9 grips. Diameter measurement had a 0.01mm standard deviation, notably more accurate as it is not velocity dependent. Fasteners are capable of being measured consistently at variable velocities from one to four meters per second.

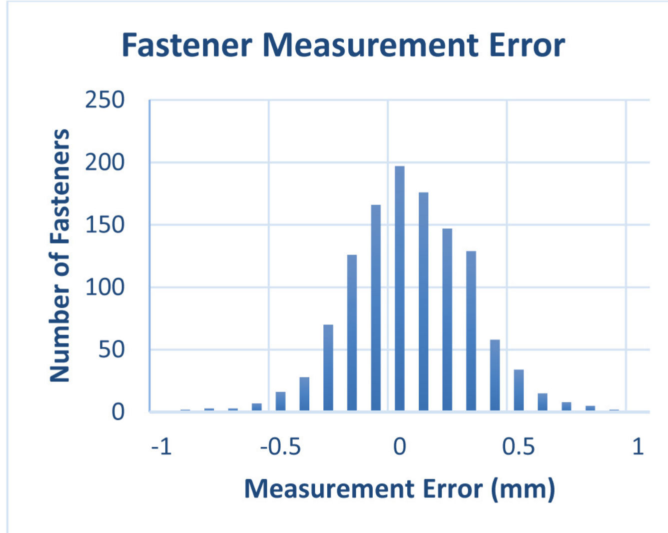

Figure 6. Measurement Error

Data on contact and trigger errors was not collected in the 1193 sample data set in Figure 8. However in a subsequent data set of 386 fasteners 4% were rejected because of contact and 0.8% because of trigger errors. Individual fastener data in this dataset is shown in Table 1.

Table 1. Measurement Data

Fastener	Diameter	Length Std Dev	Contact Errors	Trigger Errors	Rejects
WQ4K5L	.25”(6.25)	.010”(.25)	13%	3%	16%
YP10K17	.313”(7.95)	.013”(.33)	4%	0%	4%
YP12K8	.375”(9.53)	.005”(.13)	0%	0%	0%
NY14K21	.438”(11.11)	.006”(.15)	0%	0%	0%

There was no correlation of length error to velocity, grip, or diameter. Trigger errors, discussed below in the inaccuracies section, were relegated to small diameter and small grip fasteners.

Discussion

Sources of Measurement Inaccuracies

Two main sources of inaccuracies were noted, collisions of the fastener as it bounces from side to side down the tube or with the trigger or measurement slot and inconsistent triggering of the thru field sensor. Fastener change in velocity due to contact with the slots being noted as being responsible for the largest measurement error.

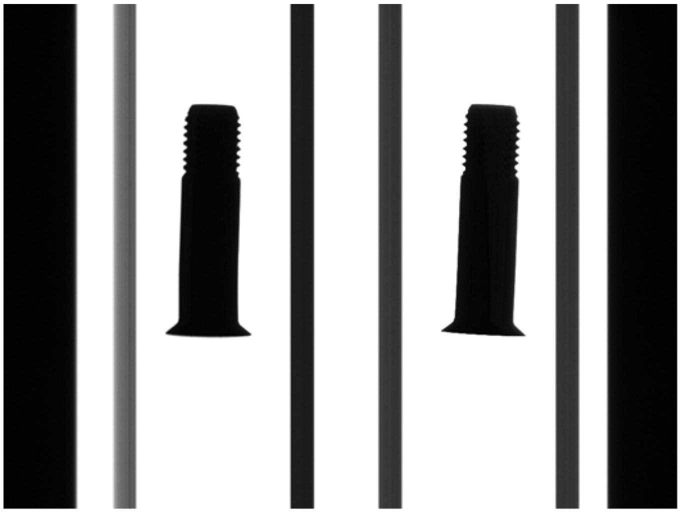

Figure 9. Good Fastener Image

Inaccuracies Caused by Contact

As the fastener travels through the tube it collides with the side in some chaotic fashion, triggering the light field in an inconsistent manner. This is evidenced in Figure 11 by the wavy appearance in one direction. The faster the fastener travels through the tube and correspondingly the camera plane, the less influence these non-axial movements and rotation have on measurement accuracy, however the overall accuracy is decreased as the fastener occupies less pixels. The errors of this type were largely coincident with smaller fasteners indicating that inertia and feature size, namely the ability of a small fastener to catch on the 0.8mm slots in the feed tube.

Figure 11. Poor Fastener Image

Trigger Timing Inaccuracies

The velocity of the fastener is determined by the distance down in the image. The fastener falling through the field sensor triggers the storage of 2048 lines which are captured sequentially at a 44khz rate. The trigger can occur at any point between line captures causing a delay of up to 22.8us. This 22.8 us at 3.6 m/sec causes a measurement error of up to 0.084 mm accounting for close to half of the measured standard deviation.

$$Intrinsic\ Error = \frac{1}{Frame\ Rate} * Velocity = \frac{1}{44000} * 3.6 = .082\ mm \tag{2}$$

Any inconsistencies in the triggering of the field cause additional error in the velocity and thus the length calculation. The effect of this error source is more frequent on smaller fasteners as the thru field sensor requires more fastener to block its beam before triggering.

Conclusion

Overall the system works as designed with a number of areas for improvement and further investigation. The higher than desired false negative reject rate is the main candidate for improvement. Grouping the smaller diameters together and using a dedicated field sensor for these could reduce or eliminate timing errors. Alternately adding a second sensor to each diameter so that the velocity could more accurately be determined. Doing this has the caveat that there are more locations that the fastener may collide and catch on the inside of the feed tube as well as increased system cost.

The apparatus as described can inspect fasteners reliably prior to insertion mitigating the need to stop the fastener at the tool-point for inspection purposes thus decreasing cycle time as the inspection would occur during feeding. The improvements noted above would further increase the measuring accuracy increasing system reliability and performance. The main caveat to this system is the expense compared to a traditional mechanical measuring methodology.

Contact Information

Ryan Haldimann
Electroimpact
4413 Chennault Beach Rd
Mukilteo, WA 98275

Definitions/Abbreviations

PLC - Programmable logic controller

The Engineering Meetings Board has approved this paper for publication. It has successfully completed SAE's peer review process under the supervision of the session organizer. The process requires a minimum of three (3) reviews by industry experts.

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