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In-Line Profile/Easy Open Inspection

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Defect Zipper Detection System

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Agenda

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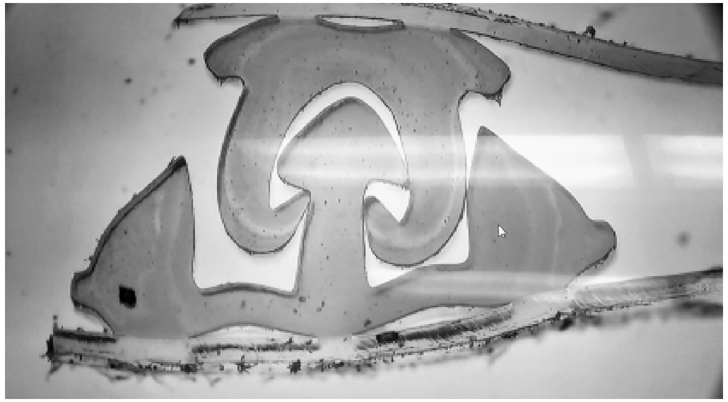
Sponsor Background

- Manufacturing plant owned by ITW (Illinois Tool Works)
- Based in Manteno, IL
- Manufacturer of re-closable plastic zipper
  - Manufacturer of multiple zipper types
  - Including the "Zip-Pak 3" zipper

Problem Background

- Extruded zipper is coming off the line with defects
- Defect zipper is getting shipped to customers
- A defect zipper will pop open when a finger is run along the opening
  - “Pop-error”
- A solution is needed to detect when the zipper is defect
- An effective solution could be implemented in other plants around the globe



Zipper profile cross section

Need Statement

"It is necessary to design a method to detect pop-errors and reduce the volume of faulty product that ITW Zip-Pak sells to its clientele. Zip-Pak must pay to return any faulty material, which drives up company spending. Implementation of a pop-error detection system could reduce company spending on return shipping costs."

Design Objectives, Functional Requirements, and Design Constraints

Design Objectives

- Solution must be easy for operators to understand
- Device must be simple in order to be easily repaired and modified
- System should be precise in nature

Functional Requirements

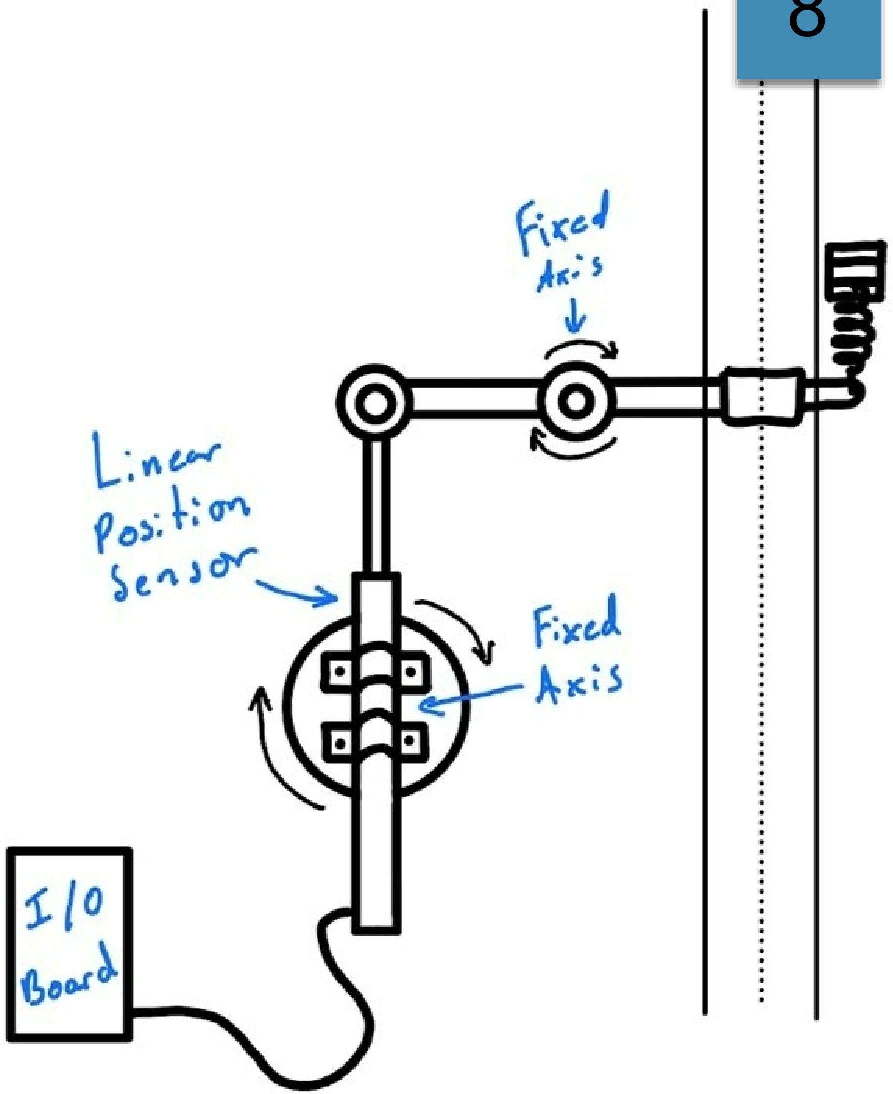
- Identify when a defect comes through the line
- Alert operator of defect
- Display collection of defect information such as severity and frequency of occurrence
- Autonomous operation

Design Constraints

- Ability to operate under 240V AC
- Ability to check zipper at least once every 1 inch of material
- Must cost under $10,000 to build and implement

Design Alternatives

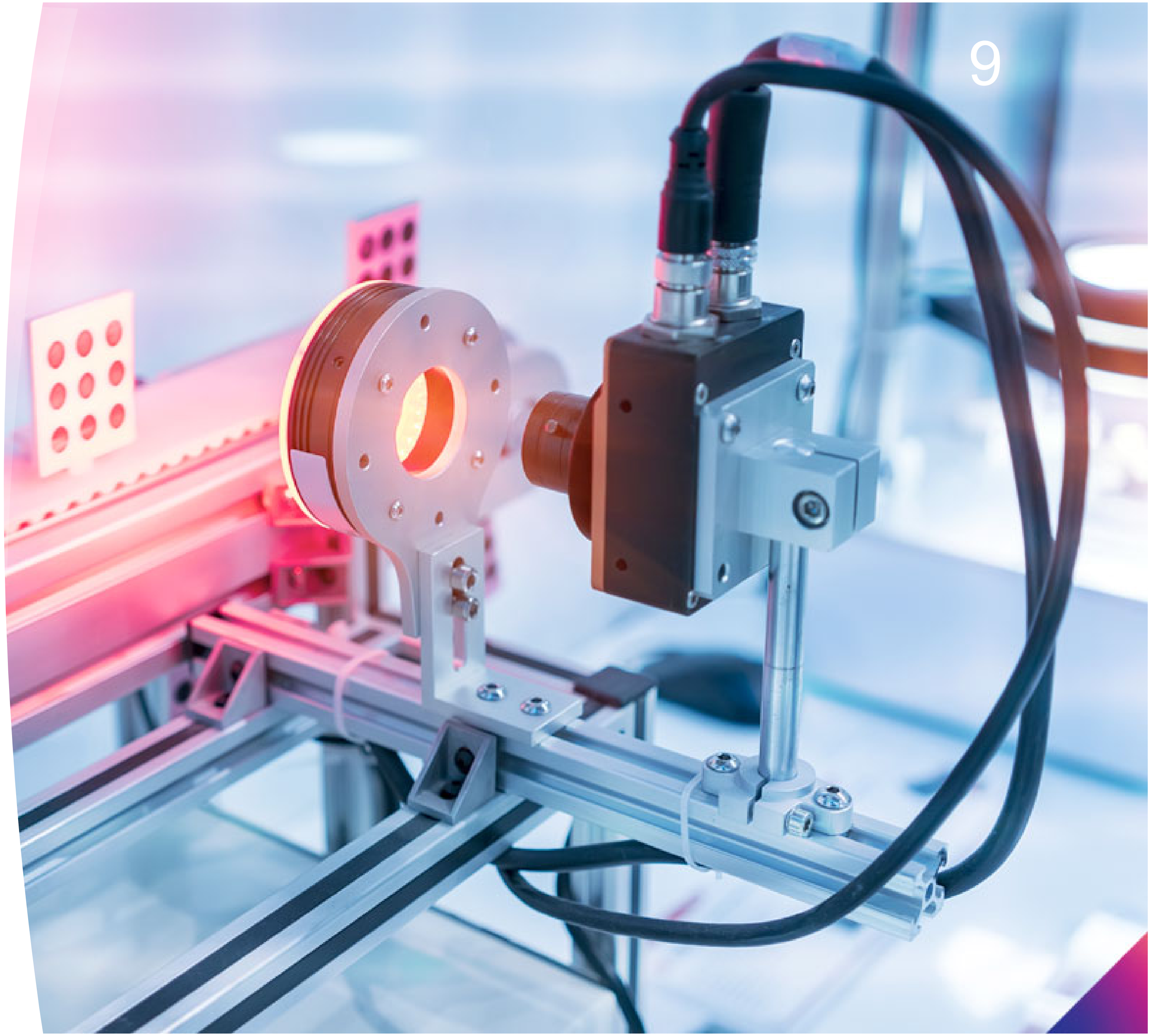
- **Linear Position Sensor**
  - Linear position sensor attached to an opening device
  - Arduino board that reads any sudden movement



Linear position sensor system concept

Design Alternatives Continued

- **Camera-Based Solution**
  - Detection camera (capture rate at least 60Hz)
  - A macro lens
  - Camera placed on the line and connected to an I/O board such as an Arduino



Design Alternatives Continued

- **Vibration Analysis Solution**
  - Need to be put on a mount
  - Mechanical deflection device to measure the amount of force required to separate the zipper
  - Accelerometer or frequency sensor
  - Arduino board

Design Analysis & Selection

- Camera-based solution
  - Expensive
  - Heavyweight code
  - Difficult to maintain/modify
  - Imprecise
  - Not robust

Design Selection Continued

- Linear position sensor
  - Inexpensive
  - Easy to understand
  - Easy to maintain, but parts wear out
  - Easy to modify
  - Must make custom parts
  - Imprecise, cannot tell pop-error severity
  - Difficult to tune

Design Selection Continued

- Vibration sensor solution
  - Inexpensive
  - Easy to understand
  - Easy to maintain
  - Easy to modify
  - Can use pre-existing components
  - Precise, can tell severity
  - (Later) Adjusts to line speed

Design Matrix

Design matrix					
Design Decisions	**Criteria**				
	Cost	Simplicity	Longevity	Accuracy	Score
Vibration-based solution	7	6	8	8	29
Linear deflection-based solution	6	7	7	5	25
Camera based solution	3	8	5	6	22

Final Design Description

2 sections: assembly line & components case

- Assembly line
  - Splitting device: torpedo
  - Sensor: ADXL-345 accelerometer

System Operation - Accelerometer

Actual system vibration response

- Accelerometer samples as often as it is polled (checked).
- When it reads an acceleration significantly different from the norm, it “sees” a pop-error.
- Note the blue line, showing the acceleration parallel to the line. A pop was detected midway through this test run for our equipment.

Design Description Continued

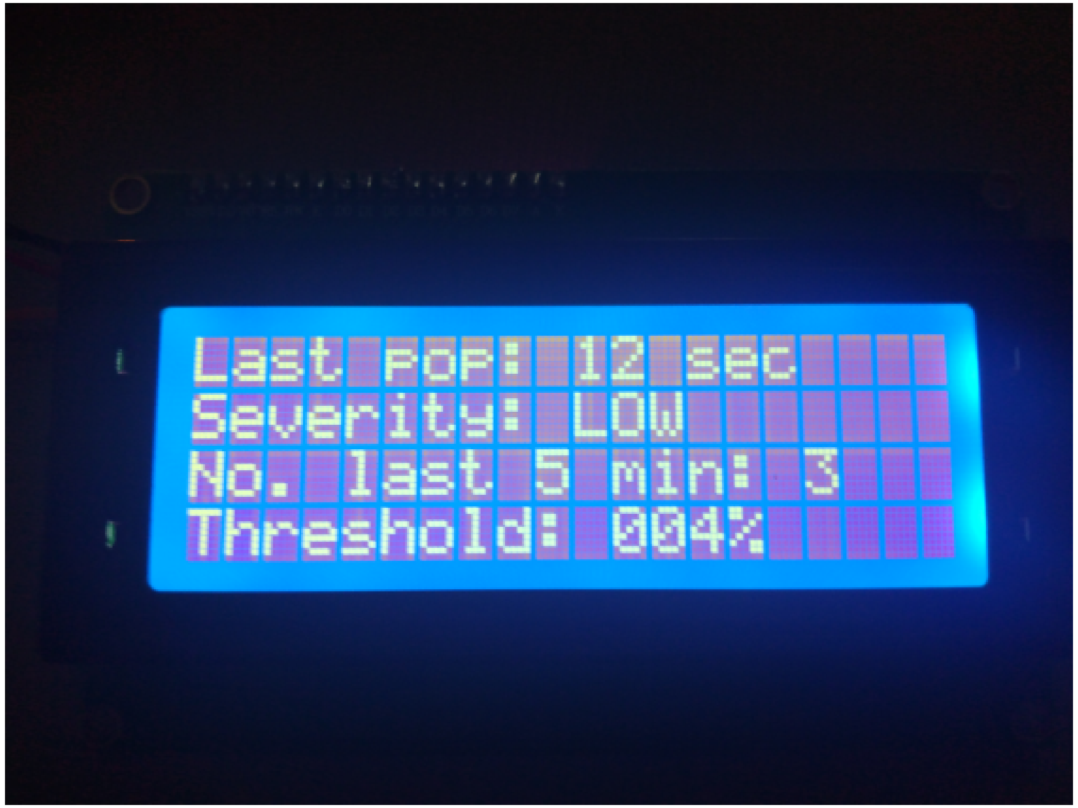
- Components case
  - 2 microcontrollers (Arduino UNO R3)
  - 3 buttons
  - 1 screen
  - 2 10W power supplies

Components box – screen, microcontrollers, buttons, power supplies

System Operation – UI Board

- Buttons operate on an interrupt-based system
  - Hardware reacts immediately to each button press
- Screen communicates with the board via Serial
  - Runtime not important, focus on accurate/readable data
  - Control loop consists of setting values and displaying them to screen, values are global and update when the UI board receives communication from the detection board

User Interface



Testing & Validation Plan

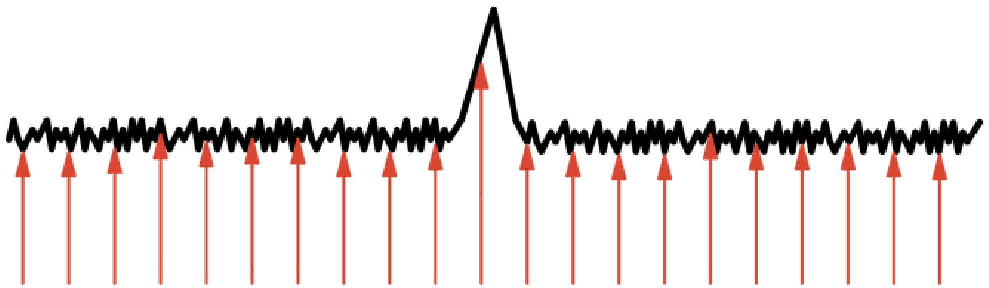
- Initial testing – make-shift line with wooden prototype
  - Needed to make pops artificially

- Final testing – Real-time assembly line
  - Found pops on the line as they would normally appear

Testing & Validation Plan

- Sampling rate – design must react to pops as they occur
  - At max line speed (300 ft/min) it must sample every 16 ms
- False discovery rate – what the design measures must match what is present
  - Must minimize false readings

Procedure:
1. Measure number of pops manually
2. Measure number of pops using design (simultaneously)
3. Compare results

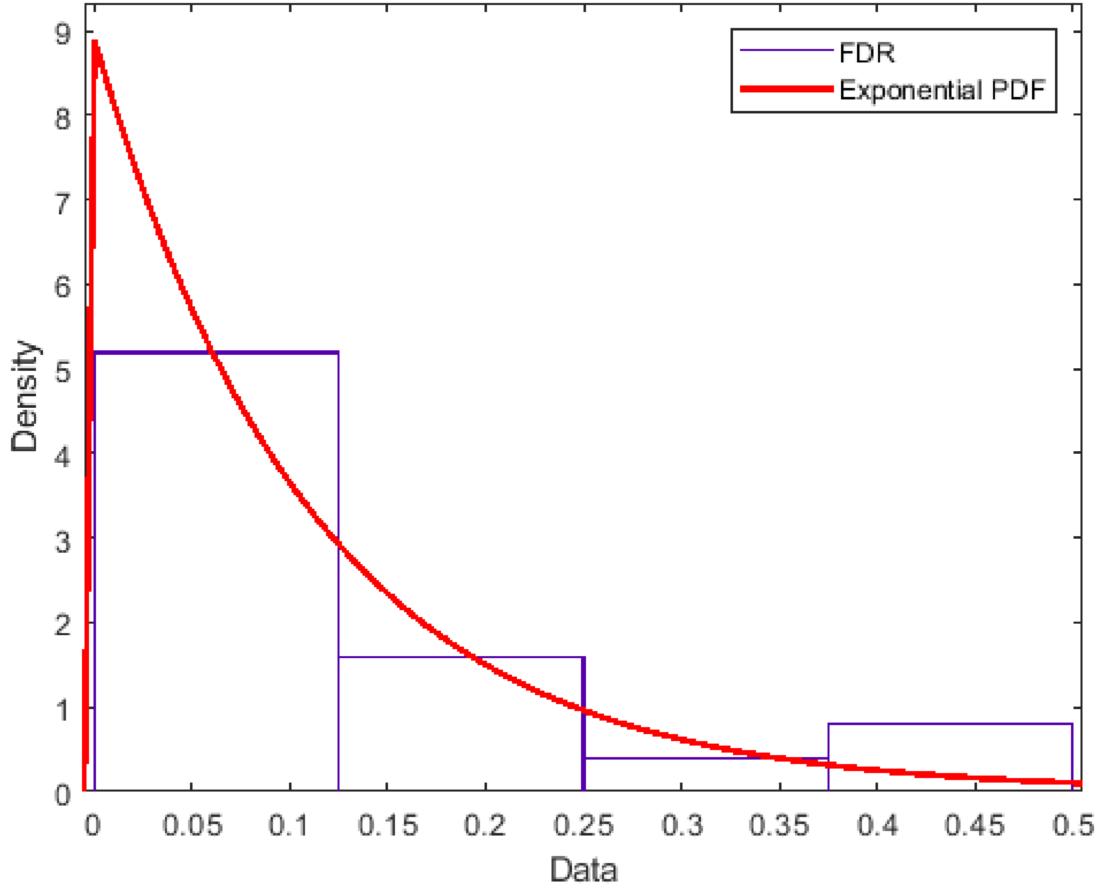


Testing & Validation Results

- 20 trials, 1 speed
- False discovery rate
  - Mean: 0.113
  - Standard deviation: 0.144
- Response time results
  - T = 2 * (cycle time) + (detection CT – regular CT)
  - T <= 12ms (< 16 ms)

FDR Distribution

- Using MATLAB's Distribution Fitting app, we find the exponential PDF that fits our FDR data
- Estimation for the mean (population)
  - 95% C.I. (0.11051, 0.18378)



Final Design Analysis

Design objectives:

- Understandable
- Easily repaired
- Precise

Functional Requirements:

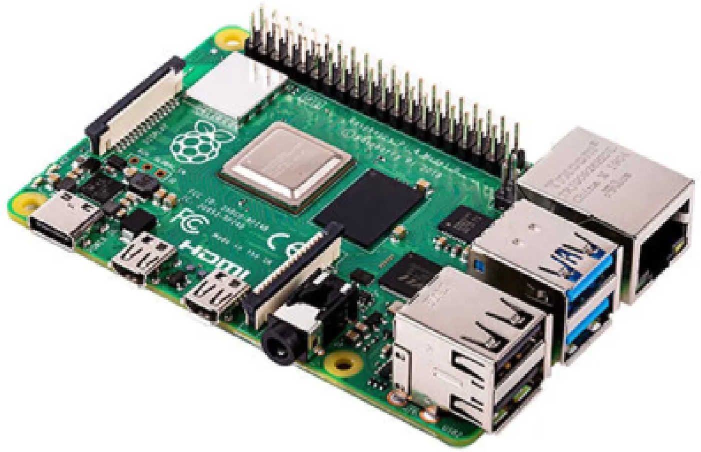
- Notifies the user
- Keeps track of occurrences
- Shows pop severity
- *Not autonomous

Constraints:

- Under budget
- Sufficient sampling rate
- 20W power requirement

Possible Improvements

- Industrial accelerometer
- Use of Raspberry Pi
- Larger display
- Display current roll status
- Alarm system integration



Conclusion

Fulfills the design objectives

- Cost-efficient
- Easy to understand and repair
- Accurate enough

Two metrics:

- False discovery rate
- Response time

Highlights of our system:

- Low false discovery rate
- Pop errors detected at fast line speed

Q & A

Appendix


Last pop: 4s
Severity:
No. last 5min: 0
Sensitivity: 100%
DECREASE
RESET