Barcode Scanner Snappiness Procedures

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A. Recommendation Summary

Over the next six months, we recommend that Honeywell implement the proposed testing procedures and generate results for internal and competitive scanner devices. The cost of performing the test procedure is negligible (~$8,000). However, the inclusion of testing procedures into Honeywell's marketing campaign would require substantial investments. Honeywell should seek feedback from engineers, customers, and competitors to perform an iterative improvement to the procedure in order to further minimize human variance and environmental factors.

Within the next six to twelve months, the results should be integrated in sales and marketing activities to raise customer awareness of the new testing procedures. The value gained by including these metrics in Honeywell's marketing programs depends heavily on the scanner performance as compared with competitor products. Honeywell should also seek customer validation of the procedures. We believe that the demonstration of product differentiation will allow Honeywell to increase sales and gain market share.[1]

After twelve months, we recommend Honeywell further refine the procedure by testing the influence of environmental factors on results, such as varying lighting conditions, software, temperature, and the presence of obstruction over the barcode (e.g., plastic film, glass). Honeywell could also incorporate automation to further remove human influence and increase standardization of the procedures and their results.

B. Sponsors' Needs and Objectives

Vision & Mission

Honeywell aims to become a leader in the handheld scanning industry by differentiating from their primary competitor, for e.g., Zebra. To achieve this, they are developing the FlexRange XLR scanners that feature an increased range, compact design, better machine learning algorithms and advanced optical sensors.[2] Prior to launching the XLR scanners, they must prove that they have a differentiated product. To do this, Honeywell believes that it is essential for them to utilize a reputable and impartial third party, such as CMU, to confirm their claims.

Strategic Priorities & Results

To complete this mission, the Carnegie Mellon E&TIM team was tasked with developing testing procedures that are accurate and repeatable. Success will be determined by three dimensions: the degree of automation, standardization, and repeatability of the testing procedures.

Project Innovation Type / Innovation Portfolio

Honeywell's new XLR barcode engine is a technology that enables users to scan faster, from a further distance, and more efficiently than ever before. This technology has a smaller form-factor than previous-gen as well as competitor products. Since the target market and business model remain the same with the improved technology, the project falls under technological breakthrough innovation (denoted as the "Disruptive Innovation" quadrant in Figure 1 in the Appendix).

Honeywell Safety & Productivity Solutions offers mobile computers for retail, healthcare, and transportation & logistics (T&L). They include handheld and vehicle-mount devices, associated software, and accessories.[2] The products have a global market and are generally sold through 2-tier distributors to business end users.

Honeywell is a multinational conglomerate, with an annual revenue of over $36 billion.[3] Their innovation portfolio demonstrates a balance of 70–20–10 (incremental – breakthrough – transformational). This project showcases Honeywell's commitment to innovation by recognizing that innovation is a network, leveraging their relationship with universities to perform unbiased research on their products.

Problem to be Solved

"Snappiness" is defined as how fast the scanner locates, recognizes, and extracts information from a series of barcodes.[2] This metric is meaningful because a snappier barcode scanner can realize significant time savings for an operator and the company. As large facilities usually employ more workers that use the scanners, a snappier device that shaves one second off of each scan can save the company minutes, hours, and days of labor.

In the past, Honeywell performed a suboptimal testing procedure for snappiness. This procedure included soliciting volunteers to scan a set of barcodes mounted on a piece of cardboard as fast as possible. After scanning, the team took the average time of the multiple trials and used that time to characterize snappiness. This procedure was heavily reliant on humans and carried little statistical significance.[2] Honeywell wishes to standardize this procedure for more accurate and repeatable results.

In addition to snappiness, the range of the sensor is important for improving the speed of the scanning process. If a worker is scanning a near object and needs to scan another object far away subsequently, the worker may need to reposition himself/herself or the object to scan it. Honeywell would like to increase the range flexibility of the scanner, making the job of the end user easier in the process.

The Honeywell team provided E&TIM with scanners, barcodes, demo software, and documentation. The team will use these scanners to develop a set of standardized testing procedures.

Financial Targets

The new procedures will be at a minimal cost (~$8,000), which is negligible for a large corporation. Accommodating results in Honeywell's marketing claims is likely to incur additional costs. Figure 6 in the Appendix shows a complete breakdown of the cost structure. With these proposed testing procedures, Honeywell will be able to increase the market share and grow the revenue in the industrial scanner market.

Differentiated Insights

Long range, high precision, and high accuracy in the scan engine aid operators in rapid scanning across varying conditions, including lighting, proximity, and barcode contrast. With an improved overall performance of the scanning engine, the process of scanning would be simpler and end users are less likely to experience fatigue. This could translate into substantial cost savings and reduced turn-over rates for Honeywell's clients. The most difficult use case for the scanners is warehousing, but may also include distribution centers, healthcare, and manufacturing plants.[2] Some barcodes in warehouses are placed 40 feet above ground with very limited visibility. The new snappiness procedures will enable the sales team to quantify the scanners' performance in these use cases.

There is an increasing trend to automate warehousing.[4] Automation solutions typically include warehouse planning systems, which digitally store the location of each item in the warehouse. The industry is also moving toward fully automated retrieval systems, which makes the job of a human operator redundant. Thus, it can be argued that Honeywell is developing a new product for a market which is at risk of shrinking due to disruptive innovation. However, the majority of warehouses in North America are not at this stage yet, and warehouses in the rest of the world would need even more time to adopt full-scale automation. In this case, Honeywell would be able to capture value efficiently before full-scale automation takes place. We recommend that Honeywell look into warehouse automation systems and seek new benchmarking opportunities in that space. The benchmarking in autonomous scanners would be very different from benchmarks in human operated handheld scanners. This will be valuable in the long term, as automation largely eliminates the need for handheld barcode scanners.

Subject-Matter Experts & Knowledge

We interfaced with several subject-matter experts throughout the project. Our Honeywell contacts, Kelley Wood and Scot Stelter, ensured that we had the resources to complete this project, such as barcode scanners and printed barcodes.[2] They also connected us with Honeywell engineers, including Erik Van Horn and Sean Kearney, who provided us with adequate baseline knowledge of barcode scanning technology. These sessions helped us better define the core needs and scope of the project.

C. Differentiated Attributes of the Targeted Technology

Both the customer and the end user will benefit from the proposed innovation idea. Customers will have the opportunity to directly compare different scanner products, empowering them to make smarter purchasing decisions. In turn, the end users, typically employees of the customer, will experience the benefits of having access to a superior product in their daily jobs.

Compared with Honeywell’s current solution, our new testing procedures have major competitive advantages along three dimensions: a high degree of automation and standardization, high repeatability, and minimized human involvement and variance.

D. Ethnographic Study: Market Research and Observation

Initially, the CMU team planned on visiting customer locations that used Honeywell handheld scanners. Instead, the Honeywell team provided us with some prior ethnographic and market research studies, from which we were able to gain insights about end users. Based on Honeywell case studies, market research reports, and ethnographic studies, one of the most important factors for customers is to improve scanning speed from varying distances.[5,6,7]

In addition, we were able to find some YouTube videos that supplemented the Honeywell case studies. These videos showcased user interaction with the device, examples of scanning distances, and scanning speeds. These insights helped us refine our testing procedures by giving us a sense for real industry use cases.

The team considered these end user needs when selecting the core needs of the project. We chose to design procedures that include speed and distance during scanning in order to best address the demands of the end user. Considering Honeywell’s desire to enable the sales team to quantitatively show the differentiation of the scanner from a key competitor, Zebra, we defined the two core needs:

1. Ensure that the testing procedures are based on real-world scenarios and guided by the desires of the end-user.
2. Develop a standardized method for measuring snappiness that will help customers repeat the tests and confirm results for themselves.

E. Technology Options, Objectives, and Uncertainties

Technology Overview

There are two aspects of device “snappiness” that the team desires to measure:

- **Barcode Skewness Tolerance** is a measure of how the device performs when scanning barcodes from an angle. This affects the ability of the scanner to quickly infer barcode information. This procedure simulates the scenario where a worker cannot scan the barcode directly and must do it at an angle.

- **Scanning Transitional Delay** is a measure of how fast the device can transition from scanning short-range barcodes to scanning long-range ones, and vice versa. The scanner has a two-camera imaging system. One camera is best suited for capturing short-range images, whereas the other camera can capture images at a greater distance with autofocusing capabilities. The scanner’s snappiness is mainly determined by how fast the scanner can switch between the two camera modules and the delay involved in adjusting the optical focus of the long-range camera module. This procedure simulates a scenario where a worker must scan a barcode that is near, and then scan another that is far away.

The key technologies involved in creating the testing procedures are listed below. These technologies all have a technology readiness level (TRL) of 9, since they are off-the-shelf products that can be easily acquired in the market. The technologies will be used in the test procedure in the following ways:

- **Tripod** – A device to mount the scanner, keep it stationary, and keep it at a fixed position and/or angle.

- **Measurement Tools** – Ascertain the angle and distance at which the scanner is scanning the barcode images.

- **Layout Tools** – Model and diagram the physical positions of the tripod and barcodes in the 2D/3D space (e.g., AutoCAD).

Technical Objectives

The main technical objective is to design repeatable, standardized, and quantifiable procedures to assess a key aspect of scanner performance called snappiness.

- **Quantify** means the snappiness of the device can be measured in absolute units, such as time (e.g., seconds).

- **Standardize** means the definition of snappiness is generally applicable to barcode scanners produced by Honeywell and its competitors.

- **Repeatable** means the procedures can be independently and easily attempted by customers or competitors. They will produce similar results if they follow the instructions of the test setup.

Technical Uncertainties

- **Data Collection:** Automated data collection is an integral part of the procedure. We would prefer the time signature of each inferred barcode and the number of correctly inferred barcodes for final measurements. If the scanners are not able to provide this with sufficient precision, then it will be difficult to assess the accuracy of the results.

F. R&D Strategy and Plan

- **Scanner Usability –** We start by observing scanner usage and the key aspects of snappiness.
- **Key Variable Identification –** Currently, snappiness is a tacit quality experienced by the user while using the scanner. We define snappiness quantitatively. We identified the snappiness in terms of two factors: *Camera Transitional Delay*, and *Skewness Tolerance*.
- **Identifying Overall Procedure Approach –** We came to the conclusion that it is best to develop procedures that test the two components of snappiness individually. We would then assess snappiness through these two separate procedures and measurements.
- **Minimizing Human Variance –** We brainstormed on how to create the testing procedures such that the measurements are not subject to a high degree of human variance, and yet the metrics are comparable across different scanners for their snappiness in real-world use.
- **Procedure Design –** We then finalized the testing procedures by hashing out comprehensive technical specifications and details.
- **Setup and Test Run –** We plan on creating the test setup and selecting competing scanners to use for the test run. We will analyze if the procedure works smoothly and fulfills every expectation. This includes minimizing human variance and ensuring that the procedure is indeed repeatable and scalable. We will repeat the previous step if gaps are identified. We were able to flesh out the details of the draft procedures over the semester, since almost all the technologies used are at TRL 9. However, the procedures themselves are at TRL 5 at this point. Thus, they need to be elevated from TRL 5 to around TRL 8 in the final step. Once this stage

is complete, we ascertain that the procedure is at TRL 8 and is ready to be applied across the industry.

The detailed draft procedures for testing camera transitional delay, skewness tolerance and maximum inference frequency (rejected) can be found in the Appendix Part 2.

G. Market Strategy

Market Opportunity

The final deliverables for this project include the testing procedures that better quantify the snappiness performance of barcode scanners. The procedures will help Honeywell penetrate the existing market by enabling the sales team to better understand and articulate how their scanners solve customer problems.

We have designed a three-phase go-to-market approach for the procedures. In Phase I and II, we will work with Honeywell to ensure that the testing procedures will work well for their products and can be validated by third parties in the future. In Phase III, the customer base will be expanded to competitors who can repeat the procedures with their own devices. The end goal is full market adoption of these testing procedures.

There are several barriers to entry in using the procedures to test scanner performance. The engineering team at Honeywell will need to delegate engineering talent to complete these procedures, as the procedures will need to be further developed. They will need to purchase a small amount of hardware to carry out the tests, including tripods and distance/angle measurement devices. They would also need to implement some simple software program to fully implement the procedures.

To minimize the effort of implementation, we have simplified steps within each procedure, ensuring a greater likelihood of success during the first two phases of implementation. Similarly, reducing costs by utilizing widely available tools will allow the procedures to be more readily repeated by customers. Finally, to ensure that the results of our procedures will be accepted on a scientific basis, we opted to test for one independent metric at a time, and limited human variance wherever possible.

Competitive Landscape

Game Theory is a strategic decision-making framework where the player (firm) makes a move by thinking ahead of the competitors' possible response.[8] Based on this framework, Honeywell's competitor could make one of the two moves; the first of which requires adopting Honeywell's procedures and the second is to re-define snappiness on their own. The first move would be welcomed by Honeywell. Having competitors follow the moves set by Honeywell further legitimizes the testing procedures. It would be very difficult for competitors to make the second move, since Honeywell's testing procedures would be the first-to-market and will gain recognition among customers. The first-mover advantage gives Honeywell significant influence on how the industry will define snappiness for years to come.

Market Potential

Phase I will not include significant value capture. Phase II will see the deployment of the results in sales and marketing materials. Honeywell will begin to use the test results to articulate the benefits of their scanners to their customers, which will result in increased sales. The new procedures will be validated by customers, competitors, and third parties. The increased adoption and acceptance of the new test procedures will increase the sample size of results and enable direct comparison of scanner snappiness between brands. Phase III consists of further automation and standardization to mitigate human variance in the procedures, leading to further market adoption and industry standardization.

Our proposal consists of multiple testing procedures that assess device performance and enables the sales team to better speak on the differentiation of their barcode scanners. Honeywell can use the snappiness metrics for their advertisement campaigns directed to a large audience through TV ads, print ads, online ads, etc. Honeywell's customers include distributors, retailers, and franchise owners. These customers are encouraged to use the testing procedures to assess device performance as well.

Long-Term Market Strategy

- **Earn Industry Consensus** – We are creating a procedure for Honeywell, but the procedure must gain industry approval to ensure meaningful results. Thus, we want major industry competitors to adopt the procedures for their own products. If there are objections to the procedures, Honeywell may need to iterate on the procedures, tweaking them until gaps are addressed.

- **Establish Trade Associations –** Another way for Honeywell to create benchmarks would be to set up a trade association, similar to the American Petroleum Institute (API) in the petroleum industry. An association established by the major barcode scanner companies would create benchmarks for performance levels, guiding new product development within the industry.

H. Business Model Value Proposition

Customer Value Proposition

Honeywell will reap significant benefits from the proposed testing procedures. Results from the procedures will be used by the sales team to better quantify and articulate the differentiation of Honeywell's products to customers and end users. While there will be zero direct revenue from the procedures (i.e., the procedures themselves will never be sold as a product or service), the procedures will act as an indirect revenue generator. The sales team can use them as a tool to increase sales by making a more convincing case in presentations to customers. Other benefactors from these testing procedures might include Honeywell customers, who can use the testing procedures to verify results on their own. Customers will have more confidence in the procedures since they were created by a credible and independent third party (CMU).

Channels

The testing procedures will be communicated with customers through the sales and marketing materials. Specifically, Honeywell's technical sales team can incorporate the results from the testing procedures in their sales documents to better articulate Honeywell's device performance. In addition, results from the procedures can be included in Honeywell's digital marketing materials, or in physical marketing materials such as print ads, direct mail, sales brochures, and trade show artifacts.

Key Resources

The resources necessary to perform these tests include physical holdings, software, transfer of knowledge, and an experienced technical sales staff. Physical holdings include a testing location, standard printed barcodes, and the barcode scanners themselves. Transfer of knowledge will occur between the engineers and the technical sales team, which requires the sales team to understand what the testing procedures actually measure. Finally, the technical sales team must translate the results into something that Honeywell's customers can utilize in their decision-making process.

Key Activities

To differentiate from its competitors, Honeywell not only needs to create a competitive device, but must also better articulate the device's value to customers.[8] Honeywell must further distinguish itself from the market competition by using objective test results to convince customers that its device is superior to the competition.[1] This can be achieved by integrating the proposed testing procedures in sales & marketing activities.

Key Partners

Honeywell should continue to leverage its relationship with Carnegie Mellon University to further develop and implement the new testing procedures. This will help the procedures gain industry recognition and validation.

Appendix - Part 1

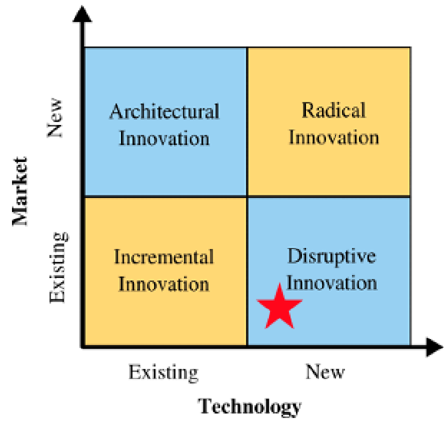


Figure 1. *The four innovation quadrants, with a red star representing the Honeywell FlexRange XLR project.*

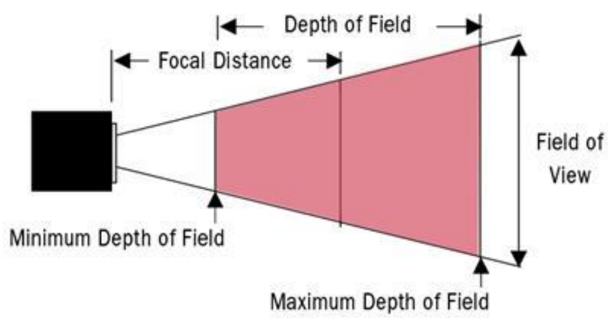


Figure 2. *A diagram of a barcode sensor, including different important parameters in the scanning process.*

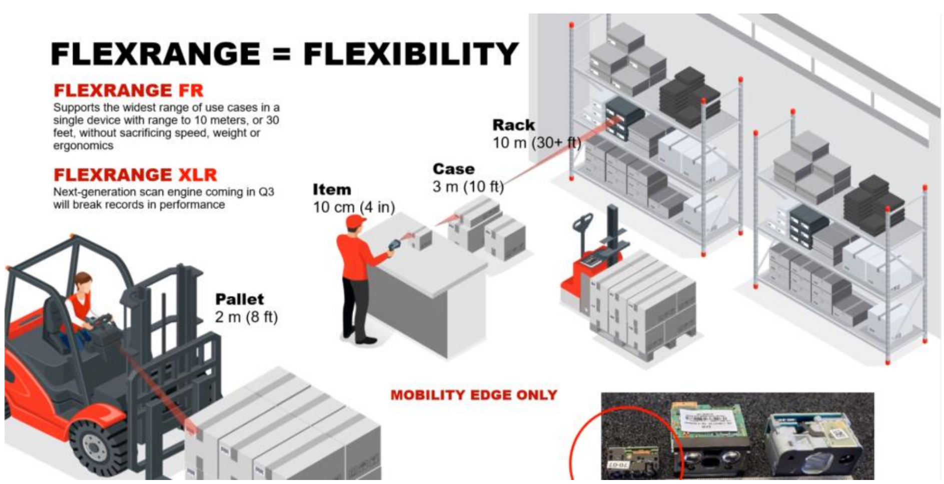


Figure 3. *The showcase of main use case & product differentiation*

DESIGN PRINCIPLES	FUNCTIONAL ELEMENTS	INTERNAL TECH OPTIONS	INTERNAL TECH READINESS	EXTERNAL TECH OPTIONS	EXTERNAL TECH READINESS
Benchmarking Skewness Tolerance	Barcode Scanner, Rotation Control	Honeywell's Barcode Scanner Honeywell-provided barcodes	9 9	Zebra's Barcode Scanner Servo Motor Servo Controller Laser distance measure Digital protractor	9 9 9 9 9
Benchmarking Delays in Autofocusing (Differing Distance)	Barcode Scanner, Screens, Distance measurement, Angle measurement	Honeywell's Barcode Scanner Honeywell-provided barcodes	9 9	Zebra's Barcode Scanner Laser distance measure Digital protractor	9 9 9
Ensuring Real Use Case Approximation	Orientation/Layout of Testing Procedure	AutoCAD or Similar Simple 2D Layout Tool	9	AutoCAD or Similar Simple 2D Layout Tool	9

Figure 4. *Tech options for design principles.*

	FlexRange (Belfast)	Flexrange XLR (Belfast DF) (Predicted)	EX30	EX20	SE4850 (Claimed)
Mechanical/ Electrical					
Cost	$43.20	~$53.11	$63.98 (30k, MIPI)	$49.20	~52.80 (material Cost $44)
Dimensions	6.8 x 23.5x 16.7mm	6.8 x 23.5x 16.7mm	13 x 30.5 x 22.2mm	21 x 34 x 33.7 mm	19 x 38 x 25mm
Weight	3g	3g	23.5g		40.2g
Typical Current Draw	100mA	TBD	340 mA	450mA	600mA RMS
Performance					
FPS	~30 combined	~30 Combined	60	30	30Near , 55 Far
Illumination	White	White	White	red LED	Red
Field of View	Near 48 x21 degrees Far 20 x12 degrees	Near 48 x21 degrees Far 13.7 x7.8 degrees	Near 40 x26degrees Far 11.5 x7.8 degrees	14 x 8.7 degrees	Near 32 x 20 Far 12 x7
Print Contrast	20%	20%	20%	40%	25%
Environemental / Other					
Shock Rating	3500 G for 0.4 ms at 23 degrees C	3500 G for 0.4 ms at 23 degrees C	3500 G for 0.4 ms at 23 degrees C	2000G, 0.7ms, half sinus, 3 axes	2500G at 0.7ms
Operating Temp	-25C to 50C	-25C to 50C	-20C - 60C	-20 to +60 C	?
Typical Depth of Field (inches)					
5mil C39	5-16"	5-16"	8.4-21.6"*		5-54"
13mil	3-63'	3-115"	2-110"	6-63"	3.5-90"
20mil C39	2-104"	2-199"	3.1-232"	6-110"	4-172"
55 C39	281"	539'	590"	16-283"	429"
100 C39	425"	977"	1063"	472"	700"

Figure 5. *Honeywell FlexRange sensors specifications vs. competitor products.*

Test Specific Costs		
Particulars	**Explanation**	**Costs**
Labor Cost (setting up and implement procedures)	Team of 3 working for 4 hours	$560
Scanner Cost	Honeywell's + Competitors	$1000
Other Equipment Cost	Tripod + Screen	$1000
Software Development Cost	1 engineer's work of 3 hours	$240
Total Cost (for performing tests 10 times) = $2240 + ($560*10) =		**$7840**
(Variable costs listed above get multiplied with the number of times the procedure is performed)		

Extraneous Post Testing Costs		
Particulars	**Explanation**	**Costs**
Incremental cost (of updating marketing material)		$20,000
Cost of raising awareness (about the procedure among channel partners)	Team of 3 engineers working for 1 month	$57,600
Cost of liaising (between industry competitors to address concerns)	Team of 3 Managers working for 10 days	$36,000
Cost of Legal Counsel (for de-risking the marketing claims)	Team of 5 Senior Counsel & paralegal working 3 days	$17,280
Total Cost of inclusion of procedure in Honeywell's Marketing		**$130,880**
TOTAL OVERALL COSTS: ~$140,000		

Figure 6. *Total Cost Breakdown & Estimation.*

Appendix - Part 2

Test Procedure 1 - Transitional Snappiness

Introduction
This method is used to test the transitional delay between short-range and long-range scanning modes of barcode scanners. The method presented should be followed in its entirety to ensure the accuracy, repeatability, and reproducibility of results.

Equipment Requirements
The following equipment is required to complete the tests:

a) Measuring tape
b) Digital protractor
c) Tight string
d) Light measurement device
    i) Ensure barcodes are illuminated at ~200lux in each location
e) 2 printed barcodes
    i) UPCA, 1ft away
    ii) 100-mil C39, 27ft away
f) Scanner mount (tripod)
    i) The tripod should be able to pan back and forth between two barcodes
    ii) The tripod's panning positions should be fixed so that the tripod can only pan from the initial position to a second position and back.
    iii) The default positions (the initial and the second position) for the scanner would be calibrated so that the scanner would point to the center of the barcode with a tolerance within ___ centimeters.

Test Setup

a) Mount the barcodes on stands.
    i) Ensure that barcode images are scannable from both distances.
b) The scanner is only allowed to rotate around the vertical axis to point at two barcodes.
    i) Physically mount the device on a stand.
    ii) Check that the axes of both barcodes are perpendicular to the scanner to ensure there is no skewness. Note that the barcodes must be perpendicular to the scanner along both axes: side-to-side and up-and-down.
    iii) Set the distance between the barcode scanner and barcode at 1 foot (UPCA) and 27 feet (100-mil C39).
c) The human operator is tasked with panning the scanner back and forth between barcodes.
    i) The scanner mode is set to automatic, rather than manual triggering.
    ii) The operator pans the scanner once he hears 5 correct inference beeps, indicating that the scanner has inferred the same image 5 times.

Determination of Transitional Delay

- Benchmarking

    - Set the scanner to automatic mode and set the auto-scan delay to 1 second.
    - The scanning time for Barcode A is benchmarked by taking the average scanning time of 10 continuous scans of Barcode A.
    - The scanning time for Barcode B is benchmarked by taking the average scanning time of 10 continuous scans of Barcode B
- A-to-B Transitional Delay
    - Scan 5 A’s and switch to B
    - Measure the scanning time of the first B after the transition from scanning A’s
    - Subtract the benchmarked B scanning time from the scanning time of the first B after the transition; this is the transitional delay caused by the switch from barcode A to barcode B (A-to-B)
- B-to-A Transitional Delay
    - Scan 5 B’s and switch to A
    - Measure the scanning time of the first A after the transition from scanning B’s
    - Subtract the benchmarked A scanning time from the scanning time of the first A after the transition; this is the transitional delay caused by the switch from barcode B to barcode A (B-to-A)

Note: Repeat this procedure 5 times to obtain the average transitional delay of A-to-B and B-to-A.

Measurement of Device Performance

- Device performance is measured by:
    - Long-range to short-range transitional delay
    - Short-range to long-range transitional delay

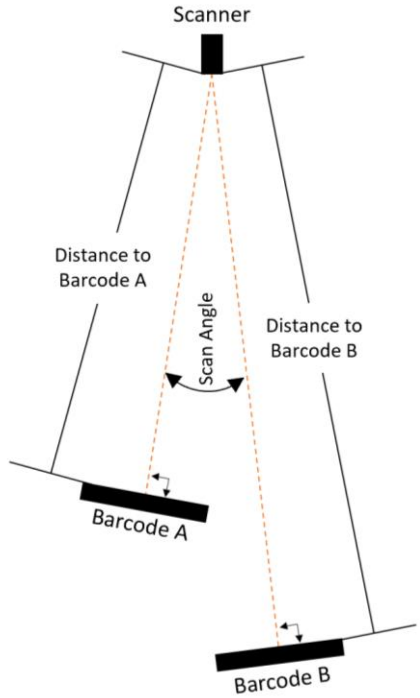


Figure 1. *A bird's eye view of the testing procedure setup.*

Test Procedure 2 - Skewness Tolerance

Introduction

This method is used to test the skewness tolerance of barcode scanners for both cameras in the scanner. The method presented should be followed in its entirety to ensure the accuracy, repeatability, and reproducibility of results.

Equipment Requirements

The following equipment is required to complete the tests:

a) Measuring tape
b) Digital protractor
c) Tight string
d) Light measurement device
    i) Ensure barcodes are illuminated at ~200lux in each location
e) 2 printed barcodes
    i) 6”-1” UPCA, 1ft away
    ii) 100mil C39, 27ft away
f) 2 Servos with controller (e.g., Arduino)
g) Scanner mount (stationary tripod)

Test Setup

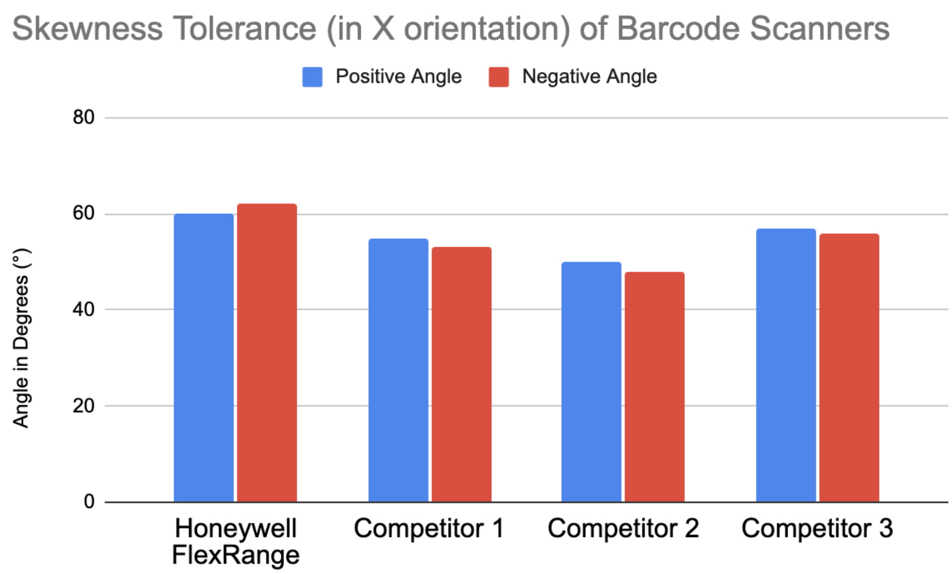
a) Mount the servo on the stand.
b) Mount the barcodes onto the servos.
    i) Make sure that the laser beam of the scanner is perpendicular to the barcode prints in the initial state.
    ii) Make sure the barcode print in an upright position that is perpendicular to the ground.
c) The servos are pre-programmed to rotate in 1 degree increments from 0 to +90° and 0 to -90°.
    i) Set the distance between the barcode scanner and barcode at 1 foot away (UPCA) and 27 feet away (100mil C39).
d) The human operator is tasked to pull the trigger of the scanner after the servo rotates the barcodes to a new position.
    i) The scanner mode is set to manual triggering.
    ii) The operator keeps the scanner in session until the operator hears a beep indicating a successful scan or sees an error message on the scanner app signifying scan failure.
    iii) After the operator finishes the scan session for one orientation, they should increment the servo orientation by 1°. They should undertake step ii) again for the new orientation.
    iv) The operator records the cumulative degrees of rotation until the scan failure happens for 5 successive orientation. (e.g., failure at 50° but the operator continues to 51°, 52°, 53°, 54°, and 55°). This is to ensure that the failure was not a fluke.

Determination of Skewness Tolerance

- Orientation of last Successful Barcode Inference is the tolerance for the engine
    - Set the servo such that the barcode is perpendicular to the scanner. This is the 0° mark.
    - Trigger the scanner and determine whether the barcode was correctly inferred by the scanning engine.
    - Activate the servo to rotate 1°.
    - Repeat the above two steps
    - Identify the angle at which the scanning engine is able to accurately infer the barcode
        - For angles above this, ensure the trigger is held for 5 seconds (the maximum inference time limit), the scanner will give a “Scanning Failed” error.
    - This angle is the scanner’s *Skewness Tolerance* in one direction (if the successive 5 orientation fails as well).
    - Repeat this test by rotating the servo in the other direction.
    - *Skewness Tolerance* will be reported as ($-X_1°$, $+X_2°$)
        - $-X_1°$ denotes the maximum angle of rotation of the barcode in the negative direction (0° to -90°)
        - $+X_2°$ denotes the maximum angle of rotation of the barcode in the positive direction (0° to +90°)
        - If $X_1° == X_2°$, we infer that the engine has similar tolerance on either sides
- In addition, consider rotating the barcode by 90° on the stand, so that it is in a vertical orientation. By repeating the process, a skewness tolerance could be determined in a different orientation.
- At the end of each scanner will have a range of skewness tolerance in all 3 axes (Roll, Pitch & Yaw).

Measurement of Device Performance

- Skewness Tolerance Range
  - As stated previously, tolerance will be reported as ($-X_1°$, $+X_2°$), ($-Y_1°$, $+Y_2°$) and ($-Z_1°$, $+Z_2°$)
  - Figure 1 below shows how Honeywell could incorporate results into their sales and marketing materials.



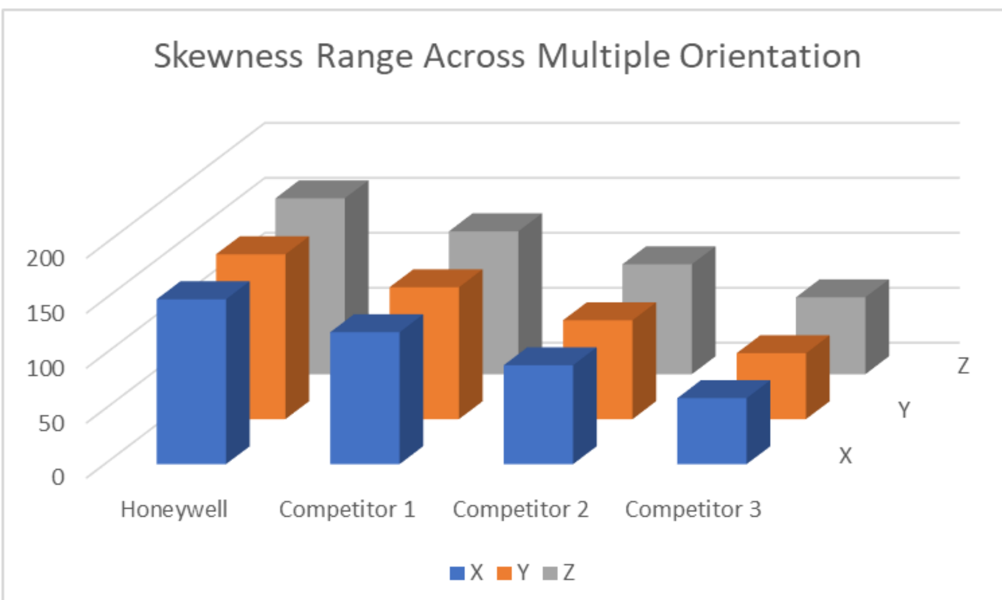


Figure 1. *Examples of how Honeywell might report results in sales and marketing materials.*

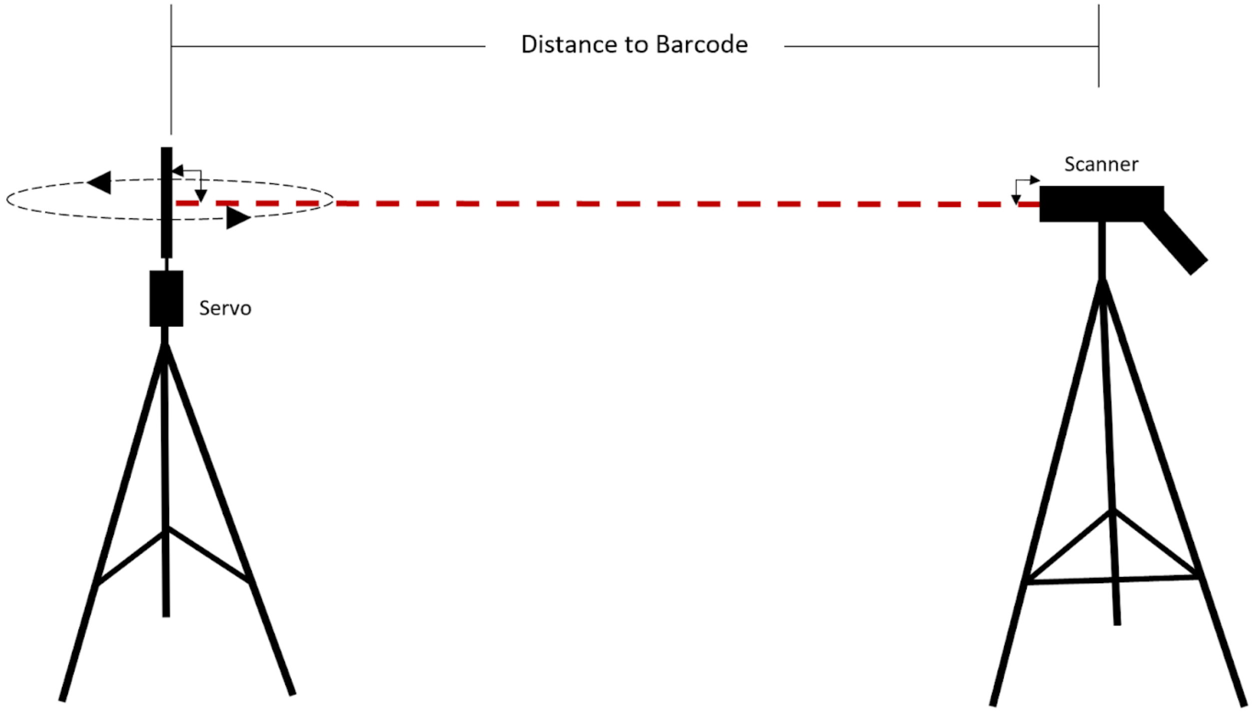


Figure 2. *Skewness Procedure Set-Up: Side View*

Figure 3. *Skewness Procedure Setup: Top View at Stationary and During Testing.*

Test Procedure 3 - Max Inference Frequency (Rejected by Honeywell)

- **Overview:**
  - **Maximum inference frequency** is a measure of how fast and robust the device can perform continuous scanning of different barcodes. The scanner has a continuous mode that allows the operator to trigger the device once and point the scanner at different barcodes. This procedure simulates the scenarios where an operator wants to quickly scan a series of barcodes without pulling the trigger every time a barcode is scanned.
- **Technology:**
  - **Digital screens** – Display barcode images at a distance from the scanner.
  - **PowerPoint** – Create a continuous slideshow of different barcode images, with specified intervals in between images.
- **Reasons for Rejection:**
  - The use of digital screen introduces additional factors - reflectivity and luminance - to the measurement of snappiness
    - The reflectivity and luminance of digital screens do not approximate the real-world use cases where the barcodes are printed on paper-based substrates
  - The maximum scanning frequency that the scanner can achieve is high enough that pushing it to the limit will not significantly impact the user experience, since end users will not be able to scan at such a fast pace
- **Key Uncertainties:**
  - **Session Delay:** The scanner received from the Honeywell has a software-induced delay of 1 second in the automatic scanning mode. This severely hinders our frequency snappiness measurement process, which relies on the scanner's ability to scan barcodes as fast as the hardware permits.
  - **Test Procedure Equipment limitation**
    - **Screen Refresh Rate:** We can rely on digital screens to have a standard refresh rate of 60Hz. Thus, the max frequency with which we can test the scanner is 60Hz. For this reason, we are unable to test scanners that perform above the frequency of the standard screen refresh rate.
    - **Slide Refresh Rate:** We plan on using Microsoft PowerPoint presentation to flash various barcodes using the built-in automatic slide change rate. The accuracy of this slide transition time is highly uncertain, especially at high frequencies.

Introduction

This test provides the method that should be used to test the maximum continuous scanning frequency of Honeywell barcode scanners. The method presented should be followed in its entirety to ensure the accuracy, repeatability and reproducibility of the tests.

Equipment Requirements

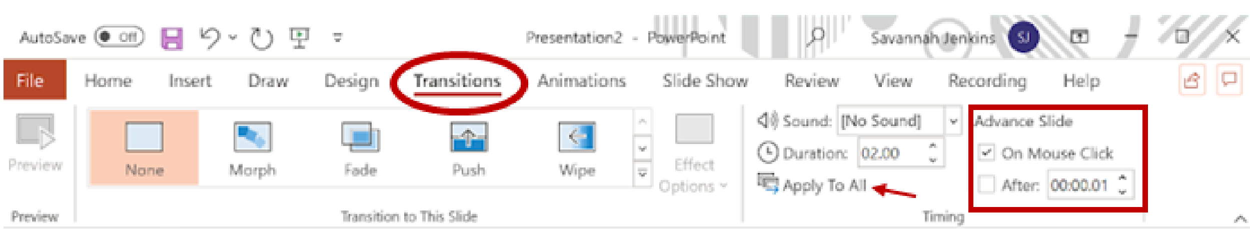
The following equipment is required to complete the tests:

a) Measuring tape
b) PowerPoint software
c) Screen
d) Scanner Mount (Tripod)

Note: The screen should be at least ____ size and have a minimum quality of ____ resolution, ____ Hz refresh rate, and ____ ppi of pixel density.

Test Setup

a) Setting up PowerPoint
    i) Select two or more barcodes to be used in the test
    ii) Create a number of blank slides equal to the number of barcodes
    iii) Paste the desired barcode image to the middle of the slide. There should be only one barcode per slide.
    iv) Repeat until the desired number of slides are created. At a minimum, there should be 60 slides.
    v) Create a “Title Only” slide in the Slide 1 slot, replace the title with “Start”
    vi) Select the “Transitions” tab at the top of the page, to the right, you should see a section titled “Advance Slide”



    vii) Next to “After:” you can input the desired time intervals between slides. Select the box next to “After” and unselect “On Mouse Click”
    viii) To the left, select “Apply To All”, this will apply the desired time interval between barcodes to all slides.
    ix) Go back to the “Start” Slide in the first slot, select “On Mouse Click” in the Transitions tab, and unselect “After”. This will allow the tester to choose when to begin the testing procedure.
b) The barcode scanner must be stationary and pointed at the screen.
    i) Physically mount the device on a stand.
    ii) Check that the screen axis and scanner axis align so that image skewness is zero.
    iii) Set the distance between the barcode scanner and screen at ____ inches.

c) Set the scanner to "Automatic"
   i) The trigger will only need to be activated once, then the scanner will continuously look for barcodes to scan thereafter.

d) Open the "Frequency Testing Procedure" PowerPoint Presentation.
   i) Create a presentation of 100 slides
   ii) Test the scanner on the presentation with varying slide change frequency
   iii) Record the number of correct inference
   iv) Plot the number of correct inference Vs frequency
   v) Calculate the Area under the curve of the plot and its ratio with a perfect scanner. This is the final metric for testing the inference frequency, which can be used to compare across different scanners

Figure 1. Diagram of the testing procedure setup.

Measurement of Device Performance

a) Figure 2 shows the expected results for this testing procedure, plotted with arbitrary numbers.

   i) We expect that the performance of the scanner will drop off at a certain frequency.

   ii) The device performance can be measured in terms of the first point in which the percent accuracy drops below 100%. For example, in Figure 2 below, the device was 100% accurate up to 4 Hz. In other words, it was able to correctly infer up to 4 barcodes per second.

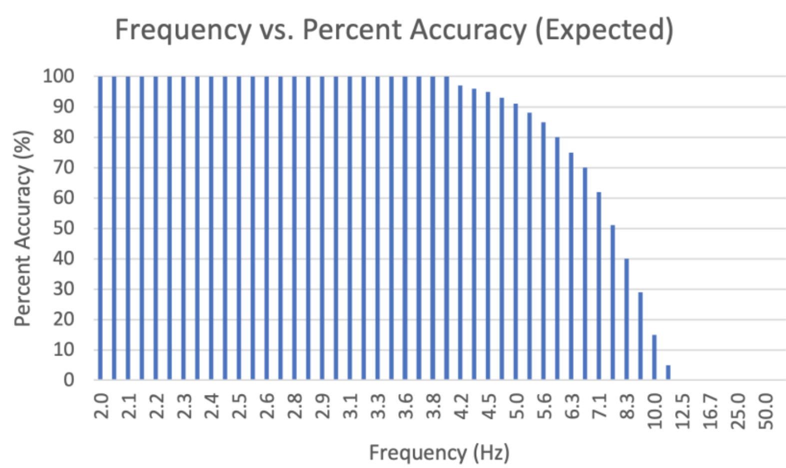


Figure 2. An example of how Honeywell might report results in sales and marketing materials.

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