Digitisation and development of a tracking system for small rental equipment

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Abstract
The company 'Alpha', which was a collaborative partner in the project, provides rental services of small and large-scale equipment. Tracking of large-scale equipment is currently being integrated, however, it has proven difficult to ensure the same degree of control for smaller equipment, due to the number of individual pieces. This paper investigates the capabilities of UHF RFID, for the purpose of tracking small scale equipment.

Keywords: Digitisation, Scalability, Logistics, Tracking, Integration

1. Current logistical challenges

The small equipment which Alpha rents out amounts to more than 100,000 pieces of materiel. Whereas expensive, large rental equipment is tracked with GPS, smaller equipment is tracked as pools using barcodes without unique IDs. Hence, a single barcode is shared between items of the same type.

When a rental period is over, the equipment is repackaged by the customer, before being picked up by Alpha. This leads to loss of control over the repackaged equipment, which has to be recounted manually for it to be inventoried.

At best, this is a time consuming process. At worst, during busy periods, recounting equipment is not feasible due to tight delivery schedules between renting periods. This results in equipment being sent directly from one customer to another to meet deadlines, which leads to a further loss of control. If equipment is lost or broken, it is impossible to determine which party to hold liable.

In general terms, Alpha faces the following logistical challenges:

- Difficulty to know the location or state of equipment when it is rented out.
- Manual recounting of equipment.
- Imprecision due to lack of unique IDs.
- Implausible to teach customers to repackage correctly.

2. Goals, delimitations and methodology

There exists a number of technologies which a used for logistical tracking in various industries. A list of candidate technologies were curated to prepare for an evaluation of their suitability wrt. Alpha's needs and wishes, and for testing thereafter.

Among the equipment which Alpha rents out, are types of plastic insulated metal objects. These were assessed to be the hardest equipment to track. This is due to their number being approximately 40,000, and the unpredictable state with which they're packaged when returned from customers. Furthermore, there were potential pitfalls due to environmental interference, caused by the their' materials, the metal crates within which they are packaged, and the density with which they are packaged, These factors all presented difficulties for a number of the technologies used for logistics tracking. Therefore, the insulated objects were chosen as benchmark for the initial development of a tracking solution, with the assumption that a solution for these, would be scalable to other small equipment.

3. Technology analysis

Several technologies were analysed, all of which are used in problems of or related to tracking of items. A summary is presented below.

3.1 Machine readable symbols

'Machine readable symbols' are printed 2D labels, commonly bar codes and QR codes. The bar code itself holds simple coded information used for identification. As compared to alternative tracking solutions, printed labels are cheap in terms of equipment, and can be printed on-site. Their primary cost lies in the development of the physical system they're implemented in, and software to handle read data. [1]

These solutions require direct line of sight between the printed label and a reader device, typically a scanner or a camera. For the barcode, the distance between label and scanner is typically less than 50 cm.
Compared to bar-codes, QR codes can encode more data as they encode in two dimensions rather than one. They can be read from any orientation, and has feature error correction, such that if some parts of the label are damaged or covered, the label can still be read.[1]

3.2 Vision-based

Vision systems utilise camera's to read image data, which is then handled within software code to identify and handle equipment autonomously. Systems must often be custom-made for their environment, and are therefore expensive in terms of development and skilled developers, much more so in comparison to the low operating costs. They are well suited for consistent environments which change little visually. They can optionally use QR codes to help identify objects.

3.3 GPS

Global Positioning System (GPS) is a widely used tracking technology.
A GPS system sends a signal from an active GPS tag within a determined interval. This signal is picked up by satellites with line of sight and, through the use of triangulation, the real time, global position is determined. [2]

3.4 Radio frequency solutions

Radio frequency technology, specifically RFID, has seen a wide array of use cases within logistics tracking.
RFID works within three radio bands. The three bands are Low Frequency(LF) at 135 KHz, High Frequency(HF) at 13,56 MHz, and Ultra-High Frequency(UHF) at 860-960 MHz. [3] A RFID tag is read by having a scanner read the unique signal from a RFID tag. How the tag sends the signal defines whether it's an active or passive RFID system.
A passive RFID tag is powered by the scanners signal. for LF and HF, this is done by induction coupling while for UHF, it is done by backscattering. [4]
An active RFID tag has an internal battery and can send signals periodically, which can be read by a scanner within range. The battery allows for stronger signals less susceptible to interference, and with longer range. [5, 6]

4. Technology Selection

The technologies were independently assessed based on parameters such as degree of automation, cost, lifetime of chips, degree of reliability, precision, integration. A rating of 1-5 was then assigned to the technologies' parameters. The respective ratings for each technology and parameter are shown in Table I.

Tab. I The technical evaluation of each technology based on their capabilities within the parameters.

	Technologies							
Parameters	Bar-code	Vision	Z-wave	GPS	BLE	Active RFID	Passive RFID	UHF RFID
Automation	2.5	3.5	5.0	5.0	5.0	4.0	3.5	4.0
Cost	4.5	5.0	1.0	2.0	2.5	2.5	4.5	4.0
Lifetime	4.0	5.0	3.0	1.0	4.0	3.0	5.0	5.0
Reliability	2.0	2.0	5.0	2.5	4.0	5.0	3.5	3.0
Precision	1.0	5.0	3.0	2.0	4.5	4.5	3.0	5.0
Integration	4.0	1.0	2.0	5.0	3.5	3.5	3.5	3.5
Sum score	18.0	21.5	19	17.5	23.5	22.5	23	24.5

Among the evaluated technologies, UHF RFID received the highest score of 24.5. UHF RFID was, however, followed closely by BLE, Passive RFID, Active RFID, and vision, with a difference of only 13%.

To further evaluate the technologies, with respect to Alpha's priorities, a weighting of the parameters was done based on input from relevant Alpha employees. Through this weighting, UHF RFID was cemented as the most promising technology for a solution.

5. Testing methodology

For testing, a TS-407 Handheld UHF RFID reader was used in combination with several TS-9201 UHF RFID stickers and TS-A8520 anti-metal UHF RFID tags.

The testing was divided into 5 categories: control, configuration, interference, use-case and scalability.

In the control test, the read-range , and the effect of orientation, were measured. It was performed by mounting a sticker or tag, on a flat surface and scanning from various distances and angles.

The configuration test determined the best tag fitting configuration. This was done by testing the read-ranges of three positions of tags on the objects for four configurations. The configurations were:

1) Sticker on the insulated object.
2) Anti-metal tag on the insulated object.
3) Sticker inside of plastic housing connected to the object.
4) Sticker on plastic housing connected to the object.

Isolated interference tests were conducted to identify potential integration problems. The tests were performed for the worst interference sources; metal and water.
The metal test was done by scanning a UHF RFID chip through a metal container wall, from various ranges.
For the water test, it would ideally have been done in the rain, however, due to the weather, it was instead done by soaking a tagged object and redoing the configuration test.

Use case tests were done by packaging tagged objects alongisde non-tagged objects, in a fully packed crate. Scans were then done from multiple stationary positions, with vertical or horizontal orientations, and dynamic scannings patterns. These tests were done in a warehouse, and repeated inside a container. The noted results are for when, in a given position, 100% of the tags or objects were found.

Additionally, a short test was conducted on fences to assess the feasibility of using UHF RFID for tracking other equipment. The tests were done by tagging the innermost fences, and cinder blocks, in a stack, to simulate the worst-case scenario while scanning from various ranges.

6. Testing Results

The following chapter covers the results from the tests, which were performed.

7. Control Test

The control test covered the range- and angle tests. In these tests all chip types where used and had the following IDs:

- TS-9201 sticker: CA86
- TS-A8520 Anti-metal tag: 000C
- Larger TS-9201 sticker: 13CD

7.1 Range Test

From the Range test, the effect of the chip type was observed. On Figure 1, it can be seen that the larger chip, 13CD, was more reliably read up to 5 meters, where as the smaller chip, CA86, could only be read reliably up to 2 meters. Lastly, the anti-metal tag, 000C, was only read reliably at 1 meter.

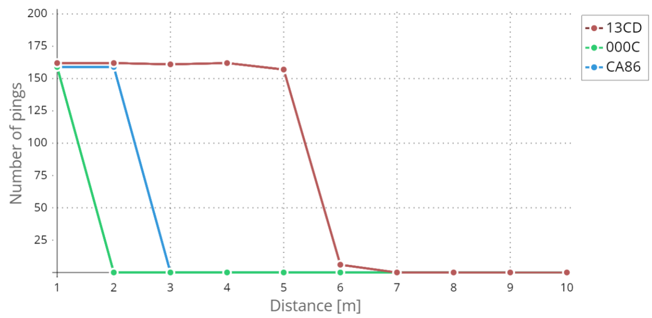

Fig. 1 Distance test results.

The reason, that the 13CD performed best, was attributed to the larger antennas on the chip compared to the CA86, since a lager antenna generally results in a longer read range [7].

7.2 Angle Test

In the 45 degree angle test, which can be seen on Figure 2, the distance was about halved for the TS-9201 stickers. This was, however, not the case for the anti-metal tag, 000C, which doubled in performance, to 2 meters.
For the 90 degree test, which can be seen on Figure 3, only the anti-metal tag was read.

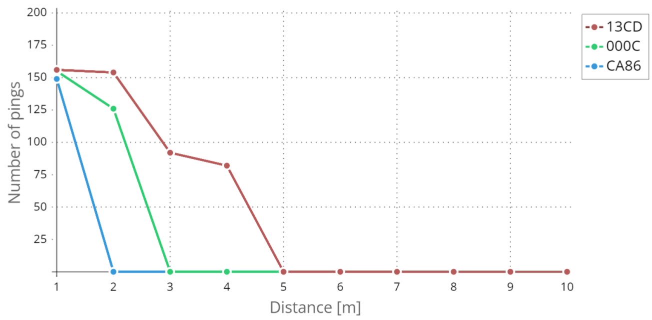

Fig. 2 Distance test results with the reader at 45° wrt. the tag in the horizontal plane.

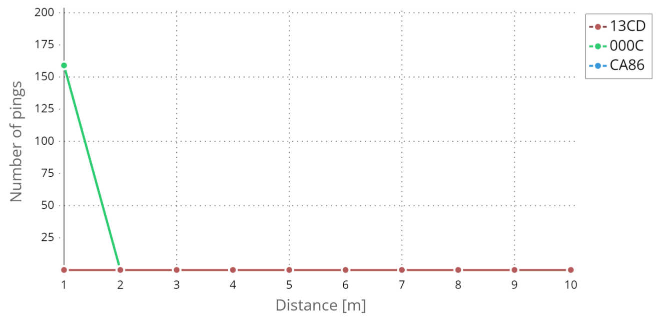

Fig. 3 Distance test results with the reader at 90° wrt. the tag in the horizontal plane.

From the angle test it was apparent that the anti-metal tags, while low in read range, was much more resilient to non-optimal orientations than the stickers.

8. Chip Configuration Test

While the 13CD performed best in range, the size proved difficult for mounting. Therefore, the CD86 was used for 3 of the 4 mounting tests, while the 000C was used for the last.

8.1 Sticker on the insulated object

Due to the small size of the tagged objects diameter, the CD86 sticker was challenging to mount on the objects. While the stickers could be mounted on the objects, the resulting bending of the chip on the rounded surface meant that the configuration was unreadable. Even when a larger object was used, the test yielded 0 pings at 1 meter. The configuration was therefore deemed a failure.

8.2 Anti-metal on the insulated object

The 000C fared better on the insulated objects, and the results, for all 3 positions, can be seen on Figure 4. From the graph it can be observed that position 1 and 2 both had a success rate of 12/12 chips at 1 meters, while Position 3 only scanned 9/12 chips at 1 meters.

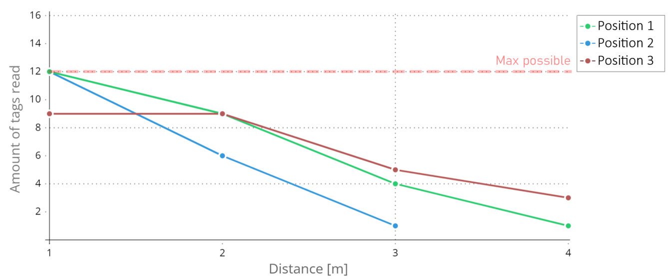

Fig. 4 The number of **tags read**, for different positions, at different distances, with **anti-metal tags** attached to the object. Green = position 1, Blue = position 2, and Red = position 3.

However, since the objects were double tagged, scanning only one chip was required to find the object. The amount of times an object was scanned can be seen on Figure 5. From this graph it is apparent that all 3 positions read, at least, 1 chip from 6/6 objects, at a distance of up to 2 meters.

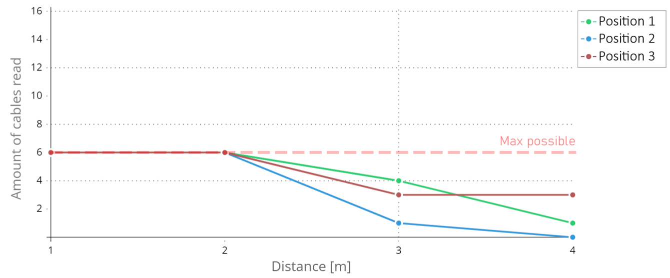

Fig. 5 The number of **object read**, for different positions, at different distances, with **anti-metal tags** anti-metal tags attached to the object. Green = position 1, Blue = position 2, and Red = position 3.

8.3 Sticker inside of plastic housing connected to the object

Compared to the metal tags, the stickers mounted inside the housing had less successful reads, which can be seen on Figure 6. While position 3 had a 100% scan rate at 2 meters, position 1 and 2 only had 8/12 and 9/12 scans, respectively, for 1 meters.

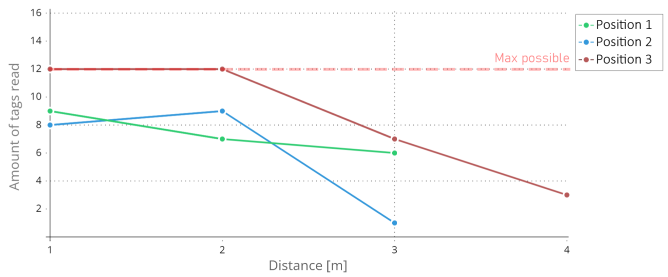

Fig. 6 The number of **chips read**, for different positions, at different distances, with **sticker tags** mounted inside the housing. Green = position 1, Blue = position 2, and Red = position 3.

However, the performances of position 1 and 2 is increased when looking at the number of scanned objects, which can be seen on Figure 7. For position 1 at least 1 tag from 6/6 objects out to a distance of 3 meters, while position 2 scanned 6/6 objects to a distance of 2 meters. Unfortunately, though position 2 had 6/6 scanned objects at 2 meters, one objects was missed at 1 meters.

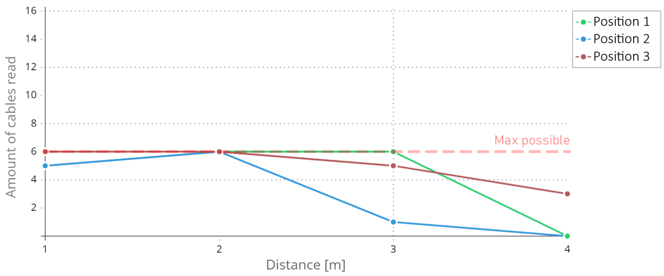

Fig. 7 The number of **objects read**, for different positions, at different distances, with **sticker tags** mounted inside the housing. Green = position 1, Blue = position 2, and Red = position 3.

8.4 Sticker on plastic housing connected to the object

For tags mounted outside the housing, the number of chips scanned, as seen on Figure 8, were comparable to the anti-metal tag configuration. 2 positions, position 2 and 3, scanned 12/12 chips at 1 meters, while 9 chips were scanned for position 1 at 1 meters.

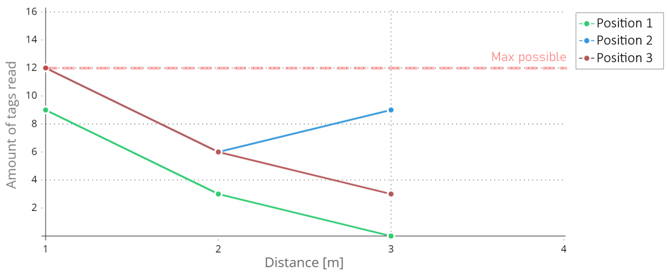

Fig. 8 The number of **chips read**, for different positions, at different distances, with **sticker tags** mounted outside the housing. Green = position 1, Blue = position 2, and Red = position 3.

For scanned objects, as seen on Figure 9, the test performed worse than the other configurations. Even though position 2 had 6/6 scanned objects for up to 3 meters, position 1 and 3 only had 100% scan rate at 1 meter.

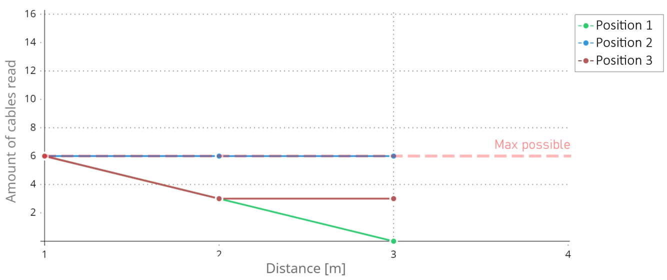

Fig. 9 The number of **objects read**, for different positions, at different distances, with **sticker tags** mounted outside the housing. Green = position 1, Blue = position 2, and Red = position 3.

8.5 Configuration conclusion

Based on the test results, the anti-metal mounting on the object would have been the best choice, since it was the only configuration which yielded 6/6 object success rates for all positions up to a distance of 2 meters. Furthermore, from the control test, the anti-metal tags were less susceptible to bad orientation.
however, concerns wrt. the anti-metal tag mounting being in the way of the important post-rental processes, in addition to being visibly exposed, and, therefore, susceptible to damage or removal during renting periods.
It was therefore decided to mount both an anti-metal tag on the object, and two TS-9201 stickers inside the housing, for future testing, since the inside housing mounting almost had 6/6 scan up to 2 meters, and a solution using this configuration would be integrated more easily.

9. Interference Test

9.1 Metal interference

It was quickly verified, during the metal interference test, that it was not possible to penetrate any thickness of metal walls. The test yielded 0 successful scans at 5 cm, and was therefore deemed unsuccessful.

9.2 Water interference

For the water interference tests, it was not possible to perform it in the rain at the time. Therefore, the test was performed by soaking the object within water. The test results can be seen on Figure 10. From the graph, it can be seen that the anti-metal tag had an increased range to 8 meters, which however is attributed to optimal orientation between tag and reader antennas, while the TS-9201 stickers reads reliably up to 2 meters, which is comparable to the configuration test.

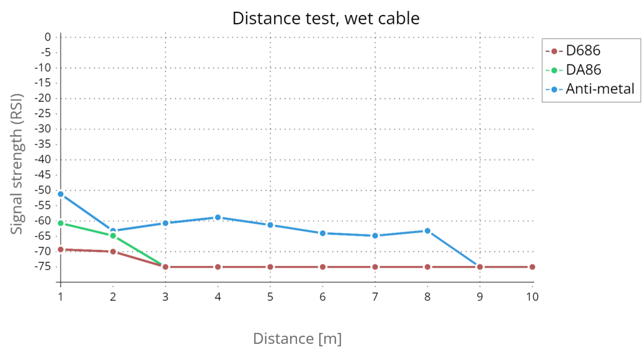

Fig. 10 Configuration test with tags inside the wet housing.

10. Use case test

In the use case tests, the anti-metal generally performed remarkably worse than the stickers, for that reason, the results shown for the use case tests are for the TS-9201 sticker, which are mounted inside the housing.

10.1 Use case: ordered crate test

In ordered crate tests, the 10 chipped objects were arranged as follows: 1-4 were positioned at the bottom of 4 stacks, 5 was positioned horizontally in the middle of a stack, 6 was positioned vertically between the stacks, and 7-10 were positioned at the top of the 4 stacks.

For the stationary scans, the results can be seen on Figure 11. From the diagram, it can be seen, that position 8 and 9-13 generally performed best, with position 12 scanning 15/20 chips. This was assumed to be because position 8, which was positioned in-front of the open crate gate, and position 9-13, which were the vertical scans, were less obstructed by the crate and, therefore, experienced less interference from the metal.

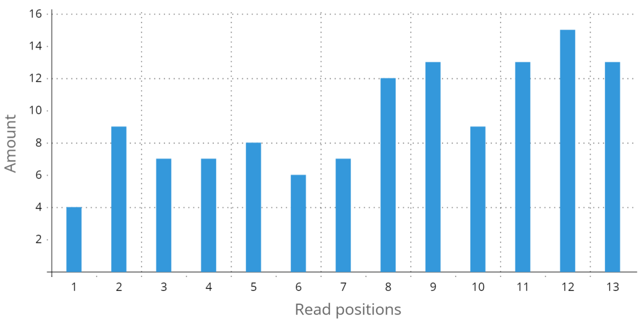

Fig. 11 Number of chips scanned per position for ordered crate.

Furthermore, when looking at the scan rate for each object , which can be seen on Figure 12, it was observed, that the least scanned objects were read 10/10 times for 6 different positions. This suggests that some of the positions were redundant, and that fewer positions could yield an acceptable result.

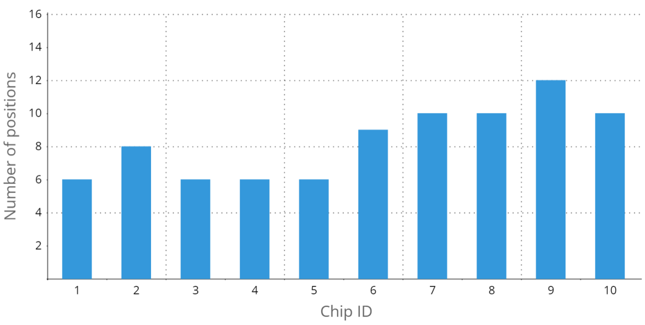

Fig. 12 Number of positions scanned per objects for ordered crate.

For all 3 dynamic motions, every object was scanned 10/10 times. This can be seen on Figure 13.

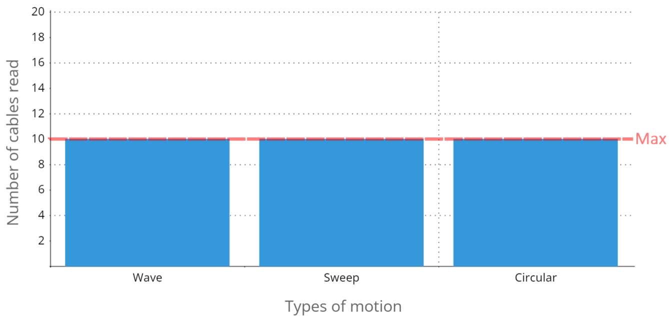

Fig. 13 Dynamic motion results for ordered crate.

10.2 Use case: Tangled Crate Test

Unlike for the ordered crate, the positional scan rate, for the tangled crate, was more sporadic. This can be seen on Figure 14. While the maximum scan rate decreased to 13/20 for position 1, the overall scan rates was comparable to the ordered crate.

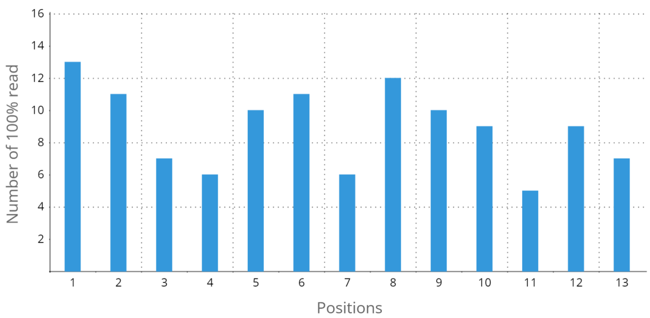

Fig. 14 Number of chips scanned per position for tangled crates.

However, when looking at the object pickup rate, which can be seen in Figure 15, it became apparent that object 5 was only scanned 10/10 times in a single position. This was due to it's position at the bottom of the crate, within the tangle.

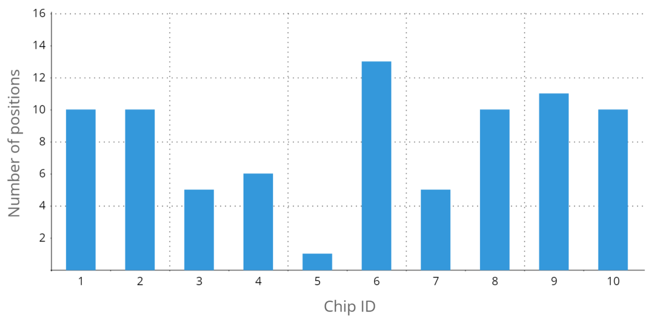

Fig. 15 Number of positions scanned per object for tangled crate.

For the Dynamic motions, the object scan rate can be seen on Figure 16. While the sweeping motion only scanned 7/10 objects, both the wave and circular pattern scanned 9/10 objects, with only object 5 missing.

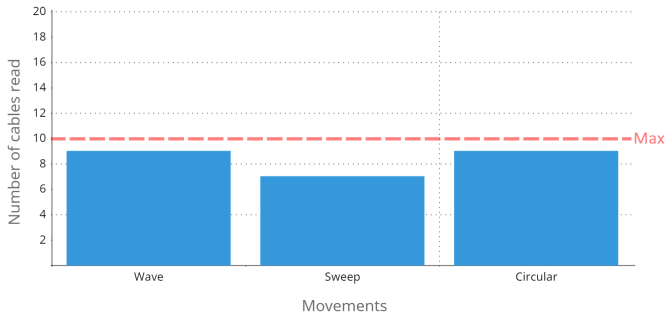

Fig. 16 Dynamic motion results for tangled crate.

10.3 Use case: Ordered Crate Test in Container

Figure 17 shows the chip scan rate for the 8 stationary positions within a container. The results were comparable to the ordered container within the warehouse, with multiple positions scanning 15+ chips. The largest of which were positions 5 and 8, which scanned 17/20 chips.

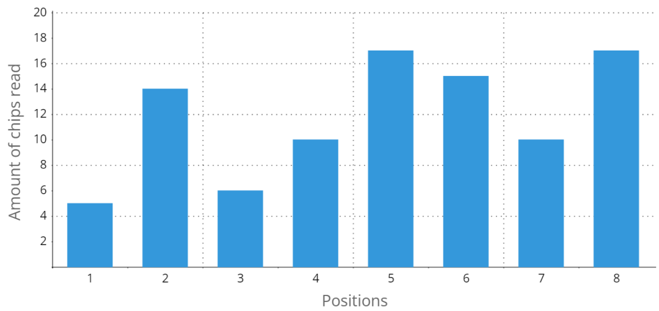

Fig. 17 Number of chips scanned per position for ordered crate in container.

Likewise, the object scan rates, which can be seen on Figure 18, were comparable to the former ordered test. While the lowest object scan rate was 4 different positions for object 1 and 9, the decrease was due to the reduction of stationary points for this test. Furthermore, the ordered test, in a container, managed to scan object 2 and 7 10/10 times for all 8 positions.

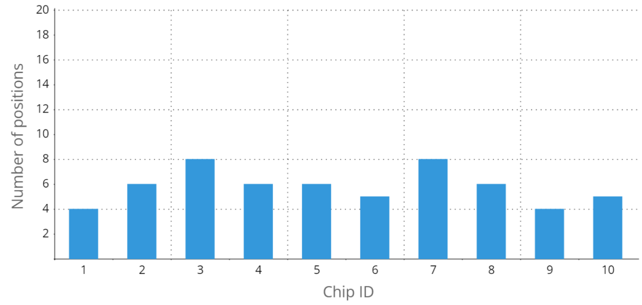

Fig. 18 Number of positions scanned per object for ordered crate in container.

Looking at object scan rate for the dynamic motions, which can be seen on Figure 19, all objects were scanned 10/10 for the 3 motions.

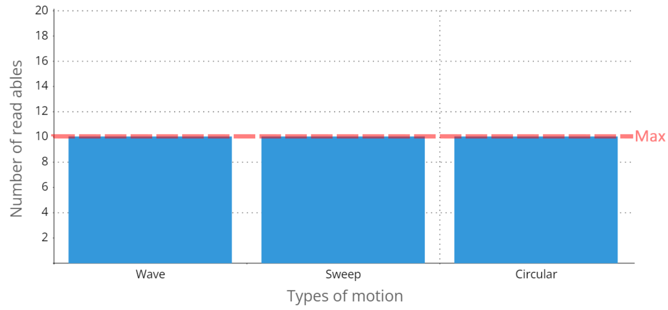

Fig. 19 Dynamic motion results for ordered crate in container.

10.4 Use case: Tangled Crate Test in Container

For the tangled test in a container, the general scan rate was significantly lower than for the former use case tests, with position 2 only having scanned 3/20 chips consistently. This can be seen in Figure 20.

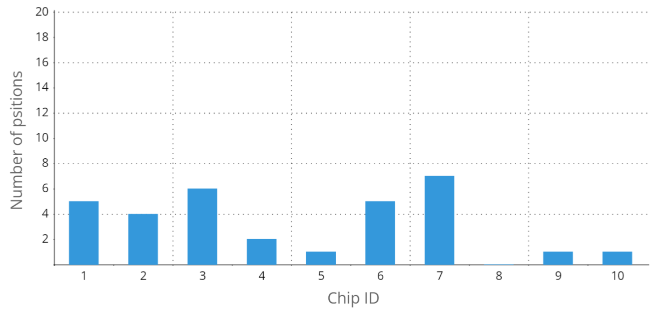

Fig. 20 No. of chips scanned pr. position for tangled crate in container.

As seen on Figure 21, object 5, 9, and 10 were only scanned 10/10 times for 1 position. Furthermore, object 8 was not scanned at all. However, after the tests were concluded, it was discovered that object 8 had not been a part of the test, as it had been misplaced and, therefore, was not in the container.

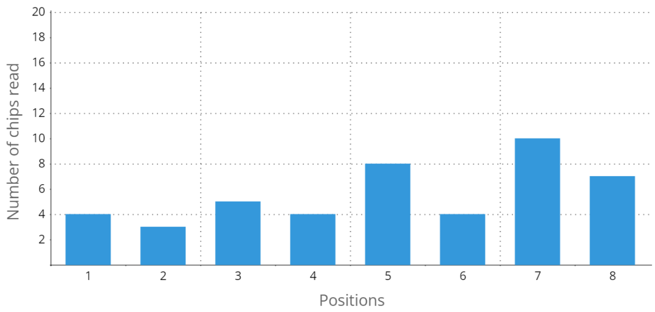

Fig. 21 Number of positions scanned per object for tangled crate in container.

For the dynamic motions, which can be seen in Figure 22, the wave and circular motion scanned every object, excluding object 8, while the sweeping motion only scanned 5 objects consistently.

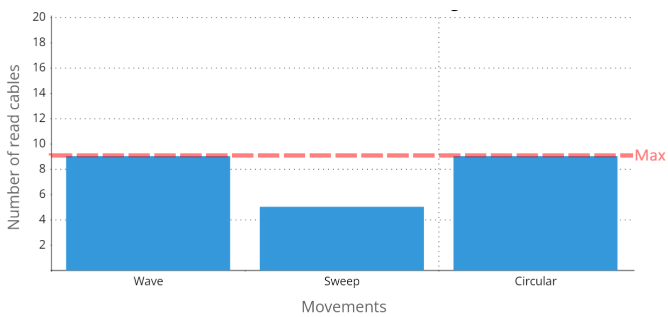

Fig. 22 Dynamic motion results for tangled crate in container.

11. Fence

The results from the fence test can be seen on Figure 23. It was observed that from one meters distance every fence and cinder block was able to be scanned 15/15 times.

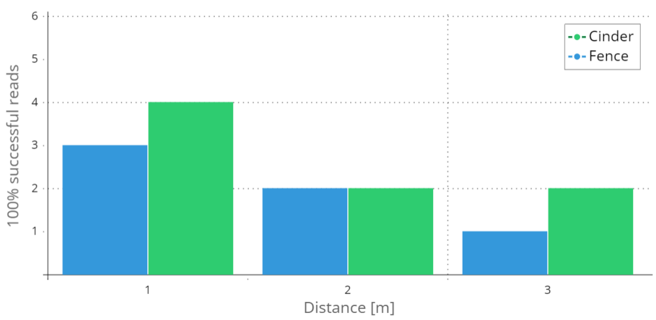

Fig. 23 Range test results for fences.

12. Conclusion

The objective of the stationary test was to determine the feasibility of creating a scanning zone for detailed readings of crate contents and to assess gate performance. During the tests, every object was at least consistently read from a single position, which provided 100% coverage, however, it would not be unreasonable to require at least two positions per object for increased reliability. However, using mounted antennas at static positions with optimal orientations, it is assumed to be feasible to achieve proper two-position reliability. Although distance could be an issue for gates, experience suggests that range is not a significant problem compared to interference. [8]

The testing with natural hand-scanning motions shows that a slower scan can read everything in the crate. However, in the test, fast movements, such as the sweeping motion, resulted in some objects not being found, especially in tangled crates.
Therefore, to ensure reliability of reads, the discipline of the scans should either be ensured, or the interference should be reduced by removing the objects from the crate before scanning. Since this is already part of the pre-roll process, using hand scanning would be faster because manual counting will not be unnecessary.

The insulated metal objects were chosen for testing because they were deemed the most challenging to track. They are typically received in a random state, while stored in metal crates, and their materials poses an interference challenge for general tracking technologies. Therefore it is assumed, that valuable extrapolations from the tests can be made to other equipment, as no other equipment exhibits the same material complexity or interference risk. Most other equipment is stored in a structured manner in "magazines," ensuring systematic retrieval. [8] also emphasised that from their perspective, the insulated metal objects were the most challenging and recommended starting with objects as integrating other equipment would be significantly easier.

To further support this assumption, a small test was conducted on fences. In this test, fences were consistently detected a meter away from the truck bed. Although not every scan at larger distances scanned 7/7 chips, every chips was scanned in some instances.

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