Design and Application of Automated Robots Powered by Inductive Smart Tiles

A study in industrial inventory automation

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Abstract

Imagine automated robots, moving freely around a warehouse 24/7, free from the weight, and cost, of a battery pack powered through a grid of wirelessly inductive “Smart Tiles” in the floor, each loaded with sensors to help coordinate robot movement, avoid obstacles and report on warehouse conditions. This experiment aimed to determine if Automatic Induction Robotics were safer, smarter, and more efficient than standard, battery-powered systems. This was determined by using long-term ROI, measuring power consumption, and key robotics metrics such as Overall Equipment Effectiveness (OEE), Cycle Time, Cycles Completed, Utilization, Efficiency, and Wait Time. To test this, a 5 by 5 grid of smart tiles was assembled, and robots executed randomized 'jobs'. The robots gathered data as they worked, which was stored and analyzed in the cloud to determine the above KPIs.

Design and Application of Automated Robots Powered by Inductive Smart Tiles

Automation is a global market that was worth over 175 billion dollars in 2018 and is expected to grow close to 250 billion in 2021 (*Statista*, 2019). Amazon has been identified as a leader in inventory automation, with its acquisition of Kiva in 2012 (Kessler, 2019). In visiting their fulfillment center in Baltimore, I was wowed by their army of robots, rushing around to move shelves full of Amazon products to stations where workers restock and “pick” items to be shipped. My tour guide shared some shocking statistics. Amazon has over 100,000 robots. Each robot weighs an impressive 320 pounds and can lift to 1500 pounds (*Amazon Day One*, 2019). Lastly, each has a 20-hour run time. Those statistics stuck with me. The more I thought about the seemingly impressive numbers, the more I realized their flaws.

First, 4 hours is a lot of downtime per robot, and with each robot costing at least a couple thousand dollars, that is a lot of overhead plugged into an outlet for 4 hours a day. Conversely, wireless induction robots can work 24/7.

Second, each robot comes equipped with a slew of sophisticated, and pricey, sensors, including a LIDAR. LIDAR modules can cost upwards of $150 (*RobotShop*) in addition to the near-$1000 battery (*Aegis Battery* and *Mobile Industrial Robots*). Smart Tiles, with their weight sensors and IoT capabilities, could eliminate the need for those expensive parts, therefore decreasing the overall cost of the robot and, thus, overhead.

Third, the sheer weight of the battery, as mentioned above, can be detrimental to the robot’s performance. Compared to wireless induction, it is effectively dead weight (and a lot of money down the drain due to the cost of such a heavy-duty battery) since wirelessly inductive robots do not need a battery pack. This leads to an improved ‘robot weight to lifting capacity’ ratio, increased energy efficiency, and decreased unit cost.

Fourth, data is what separates successful companies from dead ones. This is especially important in the blooming Industry 4.0, where the Internet of Things and automation are treasure chests and the key to unlocking their full potential is data. Big companies like Amazon and Google are so successful because of how much data they collect and how they use it effectively. Smart tiles can fill a company’s need for data with sensors to monitor various conditions of the robot’s environment.

My last epiphany came to me while watching the Amazon robots work. Our tour group watched while an Amazon product fell off a moving shelf. And watched still as another robot simply ran into it, sophisticated LIDAR failing to recognize an object in its path. This is where Smart Tiles can prove their usefulness. The robots at Amazon navigate via a grid of QR codes plastered to the floor, so they cannot sense if an unidentified object is on a specific tile until a robot's LIDAR detects it (which does not always happen) or a worker notices it. However, Smart Tiles have weight sensors to automatically detect such an object and reroute the robots to avoid it. This makes them much safer and less prone to disruption or damage.

In all, Automated Induction Robotics has the potential to be smarter, safer, and more efficient than the outdated methods used today.

When it comes to implementing wireless induction in robots, there have been a few studies done on the topic. These studies revolve mostly around long-range power transmission. One such study experiments with delivering power to a robot up to 160 cm away (Arunkumar et al, 2010). My particular experiment involves short-range transmission since the technology is much less experimental (the feature comes standard on most phones and electric toothbrushes). Papers written by Jay Lee *et al* (2015) and Jay Lee *et al* (2014) were most useful. Outlining the "5Cs" of automation, these papers identify the key attributes of cyber-physical systems. These are: "self-aware, self-predict, self-compare, self-configure, self-organize, and self-maintain. This experiment aims to incorporate all of these into an induction system, however, due to time constraints, they may not all be achievable. So, I will start at the most basic levels of automation and work my way up, adding attributes along the way.

Method

This experiment aims to find out if Automatic Induction Robotics are safer, smarter, and more efficient than standard, battery-powered systems. I will determine this by using long-term ROI, measuring power consumption, and key robotics metrics such as Overall Equipment Effectiveness (OEE), Cycle Time, Cycles Completed, Utilization, Efficiency, and Wait Time.

To test the benefits of this induction system over a battery-powered one, I built a simulated warehouse floor for three robots to run on top of and to house the induction hardware underneath, as seen in *Figure 1.1*. To simulate Amazon's order process, I used an Amazon Web

Services Internet of Things button to trigger a java algorithm in the cloud to create instructions for so-called jobs for the robots to complete. As outlined in *Figure 1.2*, in each job, the robot would have to travel to a shelf, pick it up, deliver it to a pick or stow station where, in real life, an Amazon employee would interact with it, then deliver the shelf to another spot of the warehouse floor. The algorithm calculates the kinematics of the robot to accurately predict its position on the coordinate plane within a fraction of a second. This allows multiple robots to work together and avoid collisions. The algorithm's instructions are then placed in a cloud database which is constantly being queried by a Python script running on a Raspberry Pi. This Python script checks to see if there are any available instructions for the robot at the current time, and if there are, these instructions are sent in JSON format to an Arduino MKR WiFi 1010 controlling the given robot. The robot parses these instructions and uses an absolute orientation sensor and dual encoders to complete its job. The robot's main components were designed, and 3D printed by me, you can see an example CAD drawing under *Figure 1.3*. It is fully capable of carrying up to 300 pounds. A few complete images of the finished robot can be seen in *Figure 1.4*.

In induction tests, the robot's Arduino sends the position of the robot, whenever it changes, to a secondary Arduino controlling a relay board, seen in *Figure 1.5*. This information tells the send Arduino which relays to turn on or off, thereby controlling the induction coil of its respective tile. The robot also has an identical receiving coil hanging underneath it to receive power from the transmitting coils underneath the tiles.

This system will be tested against a control group of battery-powered robots. Identical in hardware but lacking the benefits of Smart Tiles (weight sensors and wireless induction) and weighed down by a heavy battery, they will use the same algorithm to navigate and complete the same "jobs" as the induction robots. However, they will have to stop and recharge automatically when the battery is depleted.

Results

Due to delays and multiple issues regarding the robot's drive system, full-scale, real-world tests were not achievable by the project's deadline. As an alternative, the fully operational Java algorithm that coordinates the robots' movement, which was accurate in predicting the robot's real-world movement within a fraction of a second, was retooled to output theoretical data of real-world tests. It ran 1000 simulated ‘jobs’ for 3 robots running on a 5 x 5 grid carrying shelves weighing 68, 91, 113, and 137 kilograms. Battery tests had each robot stop to recharge for 30 minutes every 3 hours. This value was determined by the runtime of Amazon’s Hercules robots, 20 hours of runtime with a 4-hour charging period. To compare the two, I used the industry-standard co-working robot KPIs. These were Overall Equipment Effectiveness, Efficiency, Cycle Time, and Net Weight or the total load carried. Overall Equipment Effectiveness (OEE) is a metric used for measuring productivity in working robots. It was calculated using the formula: (actual run time / planned run time) x ((average cycle time x total cycles completed) / run time). Efficiency was determined by 100% - the sum of all the robots’ downtimes divided by the total run time. Net weight is determined by the sum of the weights of all the shelves the robots picked up and moved in the simulation.

Overall, the induction system performed much better than the battery-powered one. In *Figure 2.1,* Induction robots boasted a 30.7% higher Overall Equipment Effectiveness rating, 18.4% higher efficiency in *Figure 2.2*, and, in *Figure 2.3*, carried a total load of over 101,000 kilograms compared to about 90,000 for the battery-powered alternative. However, all these accomplishments are overshadowed by the average cycle time of the induction system, shown in *Figures 2.4 and 2.5*, which was less than half of that of battery-powered tests, which showed a 117.14% increase in average cycle time when compared to induction. This means that Amazon, when properly fitted with an induction system, could do the same amount of work with half the robots. That is a lot of overhead that could just be cut altogether.

Conclusion and Justification

“Simplify, then add lightness” - Colin Chapman. Of course, being the person who founded Lotus, he was talking about race cars. However, there is no reason this should not be applied to virtually any industry.

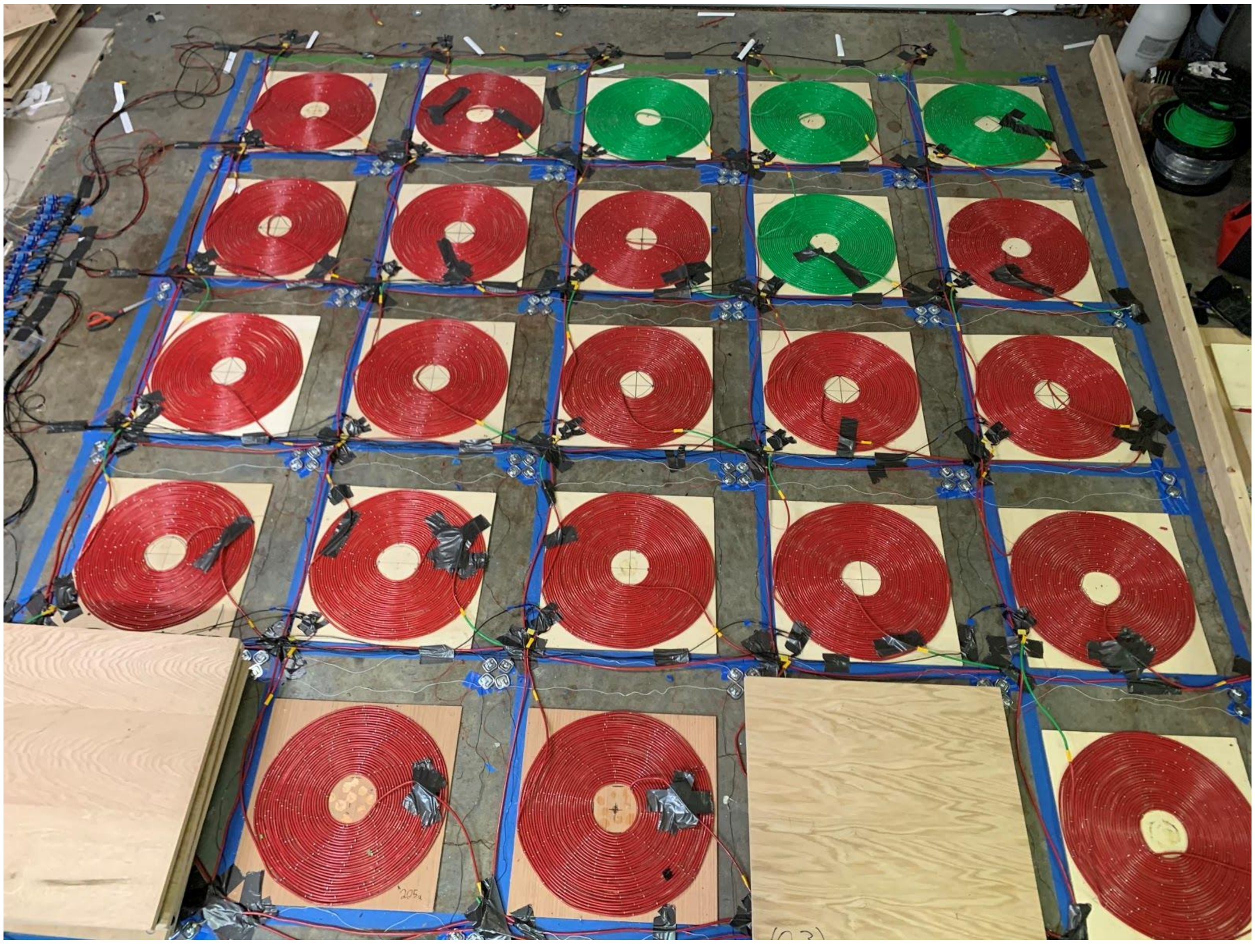
The Industry 4.0 is the next generation of connected manufacturing and IoT, but there are barriers. Automation systems do not always work as intended, Elon Musk found this out the hard way during his Model 3 production ramp-up (Nast, 2018). They are also very expensive, involving a lot of overhead that typically only large, established companies can afford. Wirelessly Inductive Smart Tiles have the potential to be safer, more efficient, and boast a larger ROI than battery-powered alternatives. They could minimize incidents, mechanical costs, power consumption, and overhead. A disruption of this magnitude in a $250 million industry could be worth equally as much and attract the attention of large eCommerce businesses like Amazon as well as appeal to well-funded startups.

When reviewing the data, it is clear that an induction system has numerous benefits over a typical battery-powered system. Robots powered by induction boasted better OEE, Efficiency, and Cycle Times comparatively. This confirms the hypothesis that an induction system would win out when it comes to KPIs. However, there are a few drawbacks to this system that was discovered in testing: induction requires extensive infrastructure and the high amperage draw of multiple robots would require regulated ‘grids’ of tiles to avoid failure. When it comes to ROI, induction could be well suited for large-scale warehouses due to its potentially lower maintenance costs and robot overhead, making it better for companies like Amazon that can afford the larger upfront cost in exchange for a larger ROI down the line.

Overall, this project was exhausting. It took up pretty much every spare moment of my life for the better part of half a year. However, I would gladly do it all over again because being able to build and create my vision is one of the most rewarding things that I have ever had the privilege of doing.

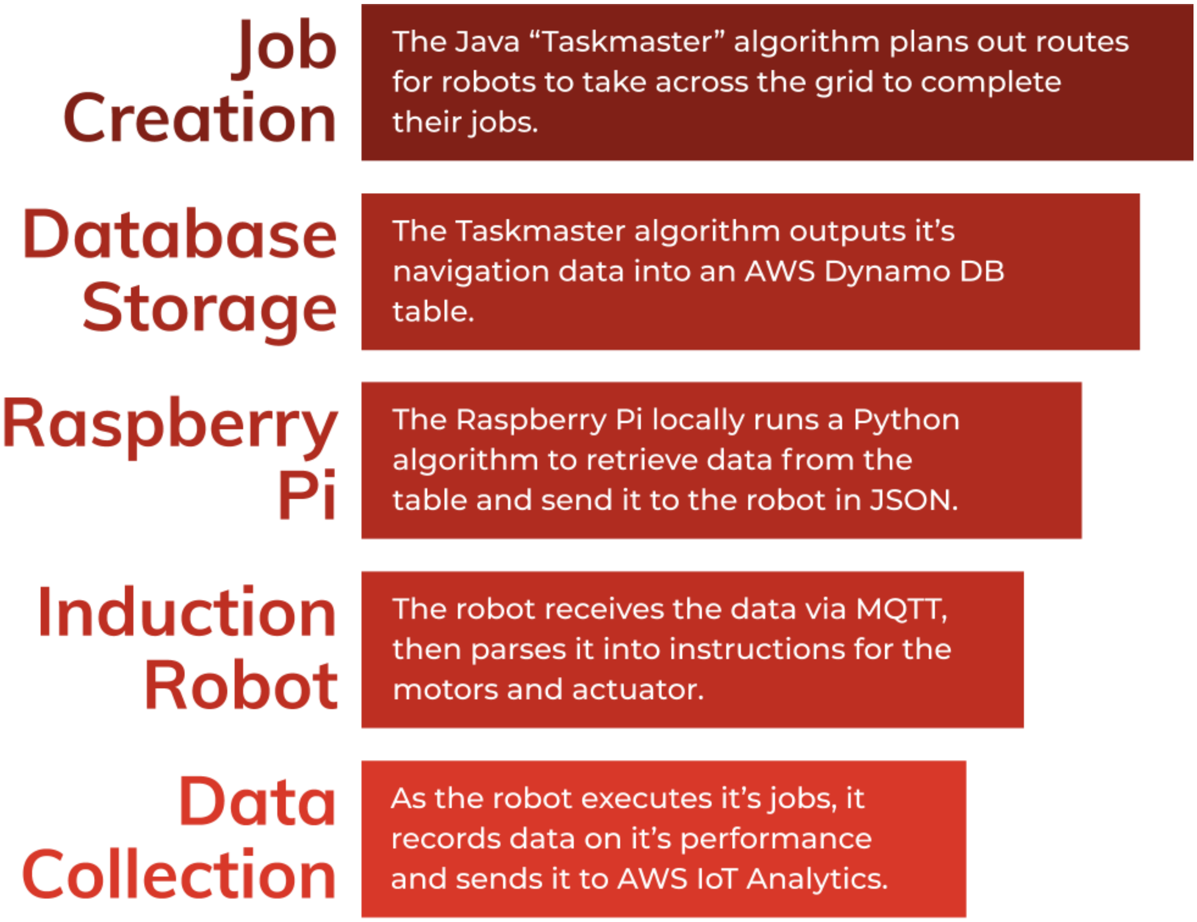
Figures and Tables

Figure 1.1



The array of inductive coils used to power the robot. Shown without their elevated covers that the robot physically runs on.

Figure 1.2



Job Creation

The Java “Taskmaster” algorithm plans out routes for robots to take across the grid to complete their jobs.

Database Storage

The Taskmaster algorithm outputs it’s navigation data into an AWS Dynamo DB table.

Raspberry Pi

The Raspberry Pi locally runs a Python algorithm to retrieve data from the table and send it to the robot in JSON.

Induction Robot

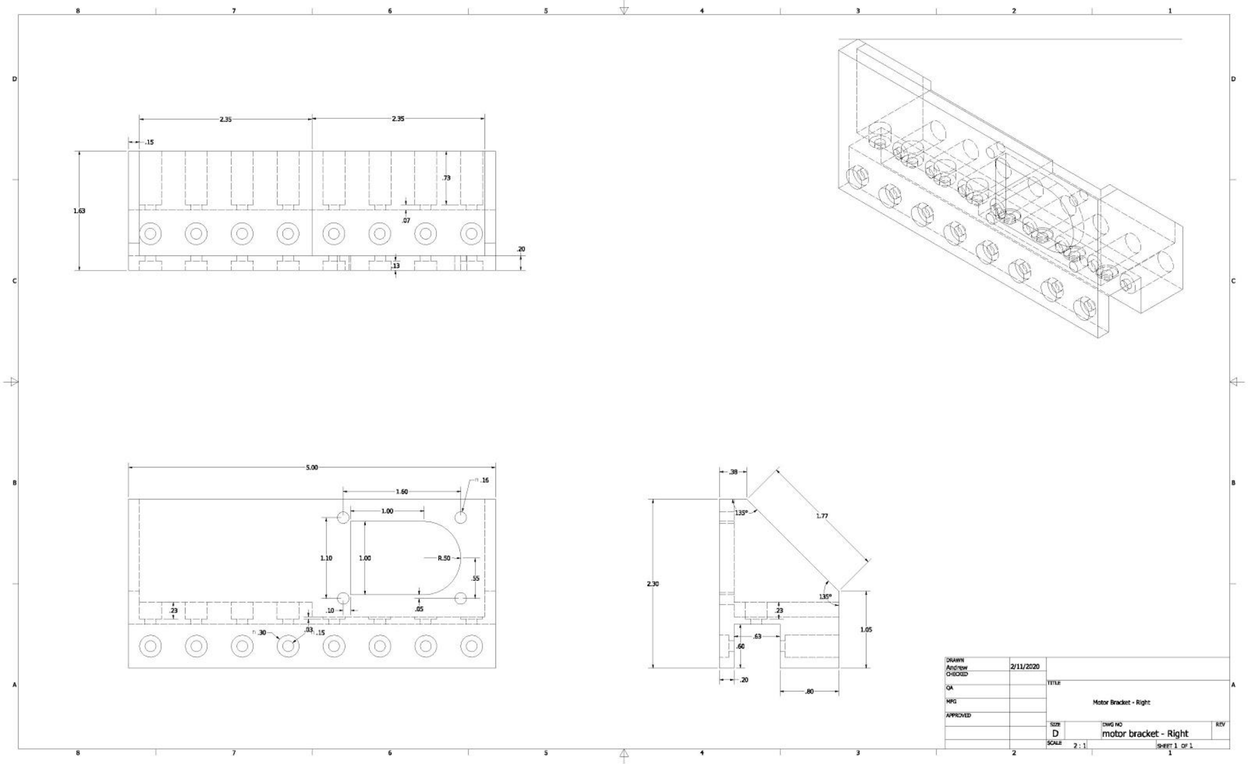
The robot receives the data via MQTT, then parses it into instructions for the motors and actuator.

Data Collection

As the robot executes it’s jobs, it records data on it’s performance and sends it to AWS IoT Analytics.

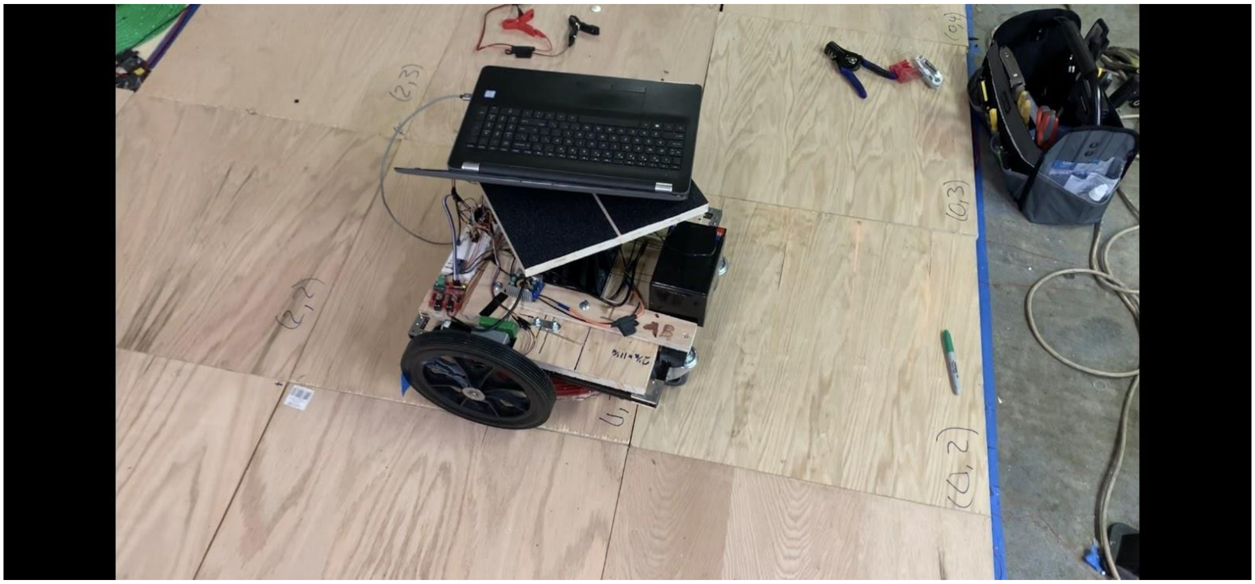
This is a flowchart of the steps the cloud app takes that lets a robot log and execute its job.

Figure 1.3



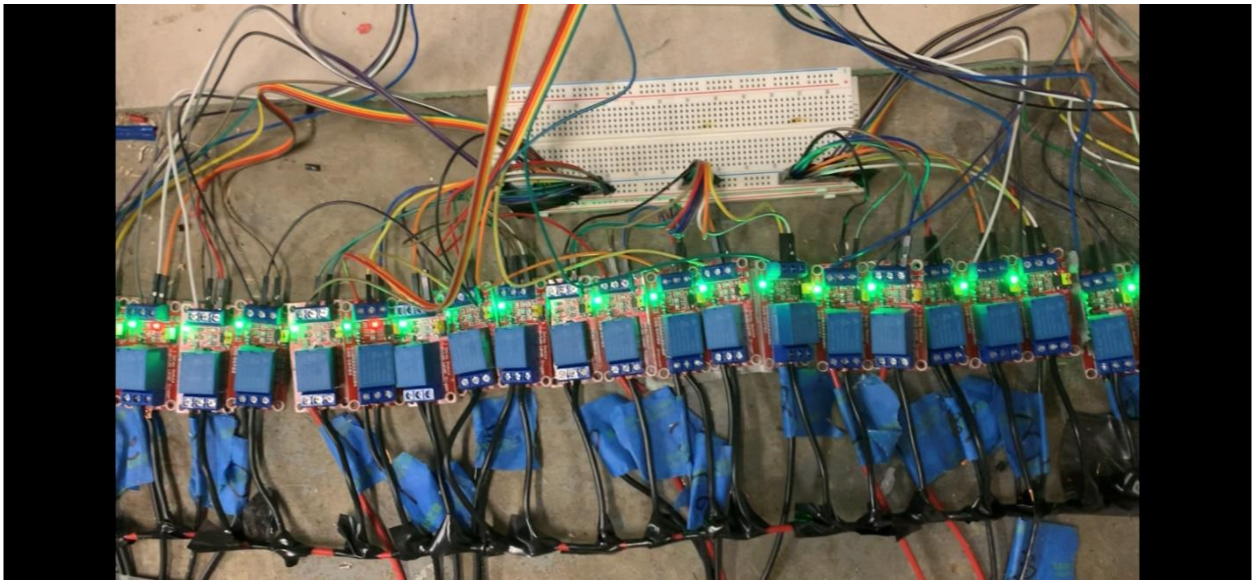
This is a drawing of one of the many 3D printed parts used in the final robot. This particular part held the high-torque motors and was designed to fit perfectly on the bot’s 15 mm x 15 mm slotted aluminum frame.

Figure 1.4



An image of the robot during testing running on top of the platform that houses the induction coils. The laptop was used only to collect logs from the Arduino to debug the program.

Figure 1.5



This is an image of the makeshift relay board used to switch each tile/induction coil on and off as per instructions sent by the robot.

Figure 2.1

OEE of Induction Robots is

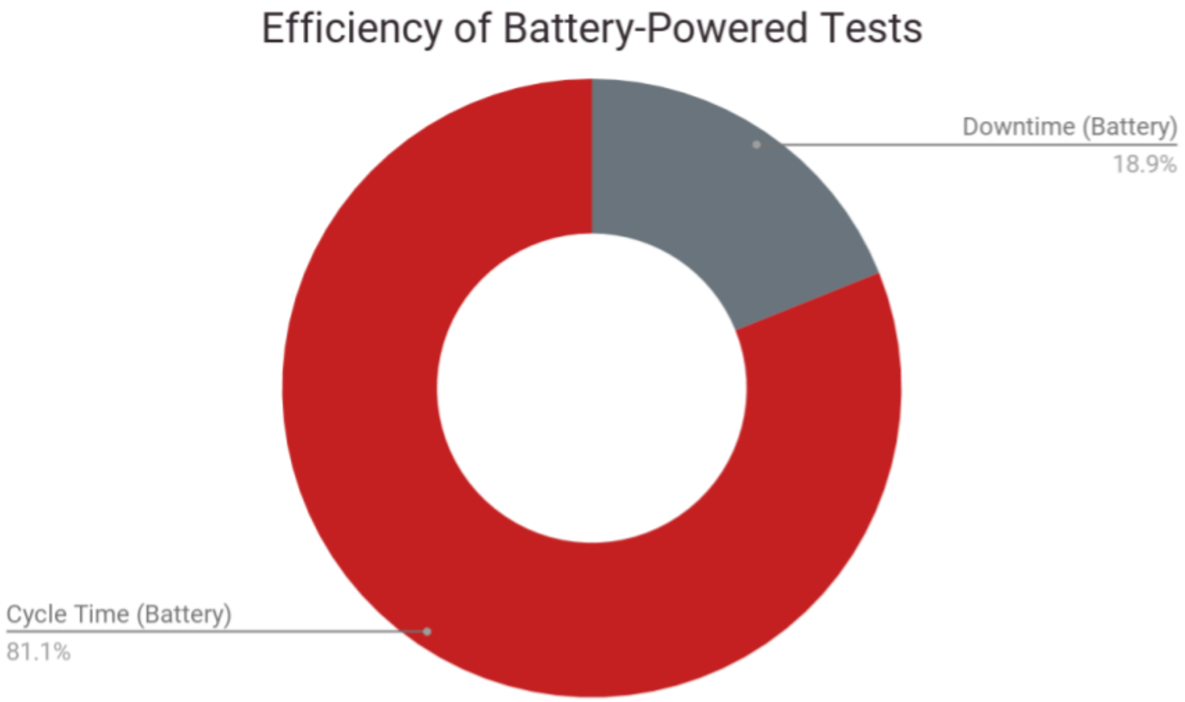
30.7%

Higher

Than Battery-Powered
Alternatives

Overall Equipment Effectiveness (OEE) is a metric used for measuring productivity in working robots. It was calculated using the formula: (actual run time / planned run time) x ((average cycle time x total cycles completed) / run time).

Figure 2.2



Efficiency was determined by 100% - the sum of all the robots’ downtimes divided by the total run time.

Figure 2.3

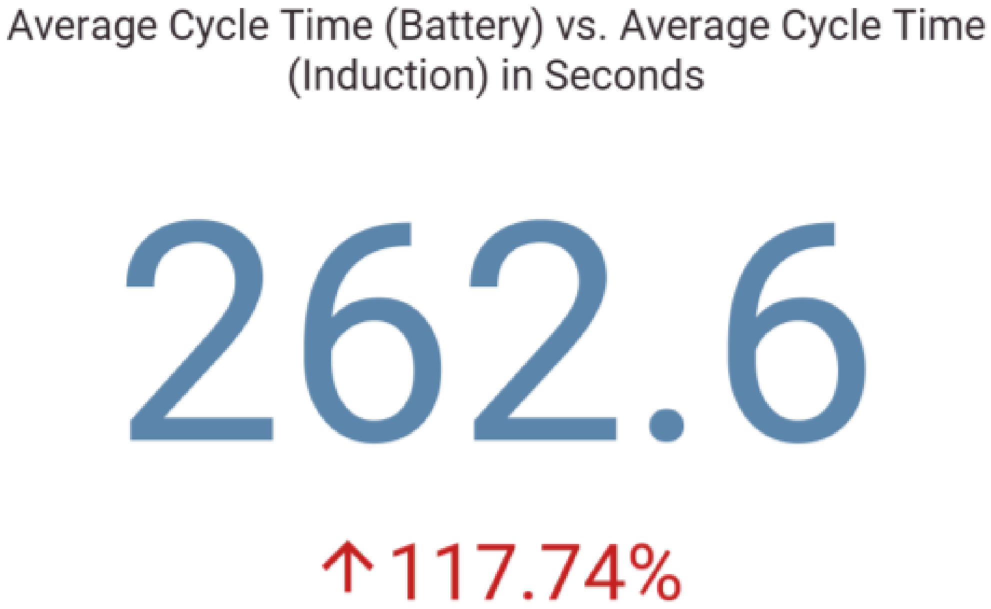
Net Weight Transported by Induction

101,858

Kilograms

Net weight is determined by the sum of the weights of all the shelves the robots picked up and moved in the simulation.

Figure 2.4



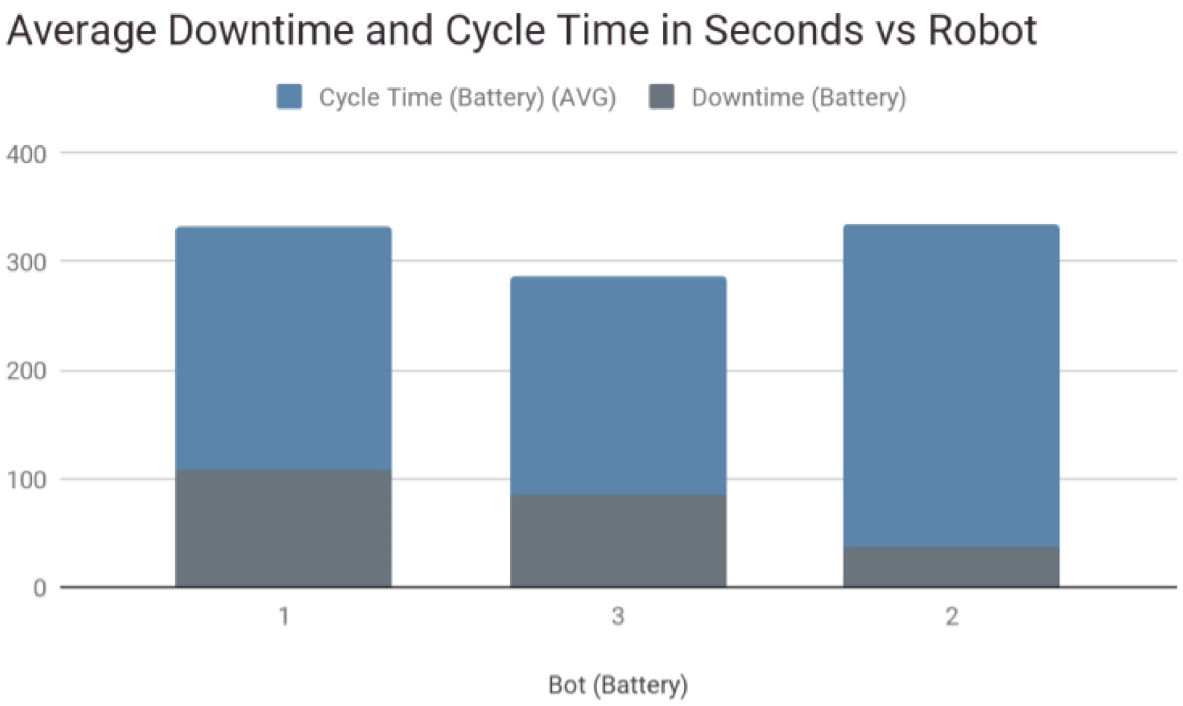
Average Cycle Time (Battery) vs. Average Cycle Time (Induction) in Seconds

262.6

↑117.74%

This graphic shows the average cycle time for battery-powered tests and its percent increase when compared to the average cycle time of the induction system.

Figure 2.5



This graph shows a breakdown of the average downtime and cycle time for each of the three robots in the battery-powered tests.

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