Feasibility and Efficacy of BLE Beacon IoT Devices in Inventory Management at the Shop Floor

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ABSTRACT

Inventory Management is a key area for customer service and cost optimization in any manufacturing setup. As companies turn global and have thousands of components and hundreds of warehouses the inventory becomes a nightmare and a lot of time is spend in tracking inventory and ensuring right shipments. Traditional systems of robotic arms for inventory pick and drop have been based on premises of marking areas of the warehouse and tracking it. However with the advent of IoT all this is set to change as inventory objects become more self-aware and self-broadcasting. This paper technically suggests an approach of managing inventory using low energy blue tooth beacons and also does a statistical case research on two groups of the same organization one before the pilot run where traditional barcode scanners are used to track inventory and other one where the pilot trial BLE beacon technology was used. Statistically the IoT-beacon users are much more efficient and accurate and save lot of time and costs in the short run itself.

Keyword:
Android
Bluetooth
Internet of things
Inventory
Location tracking
Low energy beacons
Manufacturing warehouses

1. INTRODUCTION

Inventory Control in shop floors is necessary in production systems which are complex structurally and process wise [1]. Inventory control policies need to be adopted in shop floor, production network, logistics and stores or warehouses. Inventory management influences decision-making in almost all firms and has been extensively studied in the academic and corporate spheres [2].

A conceptual framework of inventory management focussing on low consumption and pattern of demand has statistically existed [3]. However in continuous manufacturing focussing on export sales it may become imperative to stock finished goods till the time of container shipment arrives and cannot be avoided.

Traditionally inventory control systems are a combination of physical cycle counting and enterprise resource planning automation systems which are IT driven. The traditional approach to tag inventory items has been either as a bar code sticker or a RFID tag. RFID has had a lot of positive impact on business operations and is predominant technology in the shop floor global [4].

However with the advent of Internet of Things as a global network allowing communication between objects-objects and objects-humans which is anything in the world by providing unique identity to each and every objects new technology horizons have opened up which is being proposed in this paper [5].

Bluetooth beacons are basically sensors embedded with Bluetooth trans-receivers which can send and receive bi-directional information and are powered by small Li-on batteries and have with advancements become more and lower energy consuming. BLE Beacons have become the front runners for creating contextual and location based experiences for customers as part of forward thinking strategies tailor made to a customer [6].

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2. PROPOSED SOLUTION

In the proposed solution we have done a pilot trial in a process manufacturing company warehouse shed spread over 3600 square meters (60 meters X 60 meters). The solution consists of the following subsystems.

- Subject matter to be tracked consists of large size polyester flexible packaging rolls wound on a thick paper hollow core in a cylindrical format which have different combination of dimensions: Length of wound material 3000-4500 meters, diameter up to 0.5 - 1 meter, width ranging from 1-2 meters and microns of each layer of film from 8mm-12mm.
- BLE beacons with internal batteries and supporting configurable ranges (tap mode i.e. no distance between detector and beacon, near proximity mode around 1 meter between detector and beacon and far proximity mode (1 meter to 25 meters). The BLE beacons come with coin cells which have a shelf life over 2 years of continuous running. The beacons have inbuilt sensors for temperature and pressure monitoring which however do not form part of the current solution (Estimote BLE).
- Android based Bluetooth reader tablets placed across the warehouse to detect incoming BLE beacon signals and register presence or absence or track any movements of the BLE beacon. These tablets are placed at intervals of 20 meters each. Each of the scanners has a fixed location and is assigned a fixed coordinate.
- Android application to transmit information to a database for further analysis and reporting on the beacon and their movement trajectory.

The solution starts at the manufacturing start where the subject matter is produced and wound on cores using winders. The BLE beacon is placed inside the core and mapped to each role identity in the IT systems. From here as and when the rolls and corresponding beacons are moved by cranes or forklifts the nearest Bluetooth fixed scanners catch the signal. The strength of the signal averaged over a time interval of 5 seconds is used to triangulate the position of the roll and its distance from the scanners. This way the roll is mapped on a map of the warehouse layout and its entire movement is tracked.

Our simulation has ascertained previous research study findings that smartphones reliably report BLE measurements with RSS values as low as -100 dBm [2]. Since the warehouse is open we did not observe any loss of signal due to walls. Also the placement of the roll and the Bluetooth reader at a height of 2 meters further avoided any signal change due to human obstruction.

3. RESEARCH METHOD

Limited scholarly articles exist on the BLE beacon technology and its application. It has been specified Bluetooth as a set of specifications for common short range applications, traditionally Bluetooth is connection oriented and peak transmit current is 25mA which is higher for small coin cells [7].

Bluetooth low energy is a new radio protocol stack and enables the IoT with features low latency and fast transactions. The range varies from 150 meters to a max current drawn of 15mA with a sleep current of 1uA. BLE is not meant for streaming of data and has a max rate of 1MBps and can send small locational data.

Earlier study has explained the accuracy of Bluetooth low energy for indoor positioning applications. BLE for proximity detection also provides possibilities of positioning. As per previous studies while indoor positioning using WiFi can give accuracy up to a few meters but it is power hungry while BLE working in the same band 2.4 GHz is efficient as a machine to machine protocol for short messages. Earlier study also explained the influence of human body obstruction on the accuracy of positioning but concludes with establishing the possibility of having BLE accuracy more than WiFi when it comes to positioning by having many beacons [2].

Contextual information is of great relevance in Inventory tracking using positioning applications [8]. In traditional interactive computing, users have a poor mechanism for providing input to computers. Consequently, computers are not currently enabled to take full advantage of the context of the human-computer dialogue. Using BLE beacons and IoT we can improve the computer’s access to context making it possible to produce useful computational services.
4. RESULTS AND ANALYSIS

The above mix of technology prototyping and a statistical survey for the acceptance of such a concept has resulted in establishing technical feasibility to establish an inventory management system using the IoT technology which has the potential to further be scaled up for other types of asset monitoring and logistics monitoring, vehicle monitoring, theft detection, transport management and many others. The statistical survey has indicated that the pilot run has shown a decrease in inventory tracking and also improved efficiency.

4.1. Sample Size, Survey methods and Scales

To understand the efficiency of the proposed solution using observation methods on locations of the company was taken one where the solution was piloted for two months and we made note of around 25 observations before and after the solution was implemented of two forklift operators who were directly involved in inventory and logistics management and movement at a specific shift time. One was to detect the material using the current barcode scanner program or using manual guidance while the other was equipped with a tablet providing the exact location based on the BLE beacon.

The following steps were taken

- The dependent variables are on a continuous scale namely time to detect a roll (time in minutes rounded off) and accuracy of a roll being identified by the forklift operator e.g. is he picks up a wrong roll on attempt 1st and the right roll in attempt 2nd it will be considered .5 accuracy but if he picks up the correct roll in 1st attempt its accuracy is 1.
- Independent variable is a matched pair that is it remains same for both before and after scenario.
- No significant outliers are observed.
- Approximately normal values are verified using Shapiro-Wilk test of normality.

The following hypotheses were drawn up (given the collected sample results at 95% confidence levels).

HA0: Null Hypothesis” There is no difference in efficiency in time of detecting an inventory by introducing the BLE beacon technology.

HA1: Alternate Hypothesis” There is significant difference in efficiency in time of detecting an inventory by introducing the BLE beacon technology.

HB0: There is no difference in the accuracy of information i.e. retrieving the correct roll by forklift operator by introducing the BLE beacon technology.

HB1: There is a significant difference in the accuracy of information i.e. retrieving the correct roll by forklift operator by introducing the BLE beacon technology.

4.2. Statistical Tests

We first find out if the survey response data is normally distributed for the above two points being considered. For the first question we draw the test of normality of the data as below.
Table 1. Tests of Normality

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After</th>
<th>Kolmogorov-Smirnova</th>
<th>Shapiro-Wilk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Time Detect</td>
<td>AFTER</td>
<td>.208</td>
<td>.007</td>
<td>.844</td>
</tr>
<tr>
<td></td>
<td>BEFORE</td>
<td>.254</td>
<td>.000</td>
<td>.769</td>
</tr>
<tr>
<td>Average Accuracy Percent</td>
<td>AFTER</td>
<td>.506</td>
<td>.000</td>
<td>.445</td>
</tr>
<tr>
<td></td>
<td>BEFORE</td>
<td>.506</td>
<td>.000</td>
<td>.445</td>
</tr>
</tbody>
</table>

Table 2. Descriptive Statistics

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
<th>25th</th>
<th>50th (Median)</th>
<th>75th</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before Time Detect Inventory</td>
<td>25</td>
<td>4.1400</td>
<td>3.93309</td>
<td>1.00</td>
<td>15.00</td>
<td>1.5000</td>
<td>2.5000</td>
<td>5.5000</td>
</tr>
<tr>
<td>After Time Detect Inventory</td>
<td>25</td>
<td>1.8080</td>
<td>.82205</td>
<td>1.00</td>
<td>4.00</td>
<td>1.0000</td>
<td>2.0000</td>
<td>2.0000</td>
</tr>
</tbody>
</table>

Table 3. Ranks

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>After Time Detect Inventory</td>
<td>14a</td>
<td>9.46</td>
<td>132.50</td>
</tr>
<tr>
<td>Before Time Detect Inventory</td>
<td>3b</td>
<td>6.83</td>
<td>20.50</td>
</tr>
<tr>
<td>Ties</td>
<td>8c</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>25</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The above ranks indicate that fourteen cases saw a drop in timings while three cases saw an increase in timing and eight had near about the same timings.

Table 4. Test Statistics

<table>
<thead>
<tr>
<th></th>
<th>Z</th>
<th>Asymp. Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>After Time Detect Inventory - Before Time Detect Inventory</td>
<td>-2.656b</td>
<td>.008</td>
</tr>
</tbody>
</table>

The test statistics table shows that Z has a value < -1.96 for p=.05 hence we reject the null hypothesis HA0.

4.4. Testing Hypothesis HB

We run the tests in SPSS using the data gathered for accuracy of retrievals.
Table 5. Descriptive Statistics

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Min</th>
<th>Max</th>
<th>25th</th>
<th>50th (Median)</th>
<th>75th</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before Accuracy Percent</td>
<td>25</td>
<td>88.3332</td>
<td>24.29595</td>
<td>25.00</td>
<td>100.00</td>
<td>100.0000</td>
<td>100.0000</td>
<td>100.0000</td>
</tr>
<tr>
<td>Inventory</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>After Accuracy Percent</td>
<td>25</td>
<td>100.0000</td>
<td>.00000</td>
<td>100.00</td>
<td>100.00</td>
<td>100.0000</td>
<td>100.0000</td>
<td>100.0000</td>
</tr>
<tr>
<td>Inventory</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

There is a change in the mean scores and the minimum scores before and after the BLE beacon introduction.

Table 6. Ranks

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>After Accuracy Percent</td>
<td>5</td>
<td>3.00</td>
<td>15.00</td>
</tr>
<tr>
<td>Inventory – Before</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy Percent Inventory</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negative Ranks</td>
<td>0</td>
<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>Positive Ranks</td>
<td>5</td>
<td>3.00</td>
<td>15.00</td>
</tr>
<tr>
<td>Ties</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>25</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. AfterAccuracyPercentInventory < BeforeAccuracyPercentInventory
b. AfterAccuracyPercentInventory > BeforeAccuracyPercentInventory
c. AfterAccuracyPercentInventory = BeforeAccuracyPercentInventory

The positive ranks showed five cases where accuracy has increased and twenty cases where it is similar and there are no cases where accuracy has decreased.

Table 7. Test Statistics

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Z</td>
<td>-2.060</td>
<td>.039</td>
<td></td>
</tr>
<tr>
<td>Asymp. Sig. (2-tailed)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Wilcoxon Signed Ranks Test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. Based on negative ranks</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The z value is < -1.96 at p < .05 hence we reject the null hypothesis and conclude an improvement in accuracy of tracking inventory.

4.5. Analysis

The literature research, current study and data gathered shows that there could have been three approaches for indoor positioning namely Wi-Fi, Bluetooth or GPS. While GPS in indoor positioning has not been successful the cost of Wi-Fi sensors to be fitted at each inventory item seems to be very high. Also the power consumption of Wi-Fi devices make it necessary for any Wi-Fi client to be constantly powered by auxiliary sources which is very difficult in case of moving inventory items.

4.6. Comparing Approaches

Though the use of similar approach of BLE devices seems to be very rare due to the advent of this technology only in the last two years, there has been some study and implementation of BLE for indoor positioning [11]. The following positioning methods have been considered and compared in our research: Angle of Arrival (AOA), Cell Identity (CI), and Time of Arrival (TOA), Time Difference of Arrival (TDOA), and RX power level. Our study validates the earlier finding that all the above parameters in combination help pinpoint the accuracy levels of the BLE beacon. Similarly the use of BLE beacons in managing moving inventory is a very less researched topic and one of the most innovative uses of BLE beacons. This is highlighted by the above findings on increased productivity. No comparative with earlier work is possible due to the less explored nature of this solution.

5. Conclusion

The above mix of technology prototyping and a statistical survey for the acceptance of such a concept has resulted in establishing technical feasibility to establish an inventory management system using
the IoT technology which has the potential to further be scaled up for other types of asset monitoring and logistics monitoring, vehicle monitoring, theft detection, transport management, and many others. The statistical survey has indicated that the pilot run has shown a decrease in inventory tracking and also improved efficiency.

The IoT concept aims at making the internet even more immersive and pervasive but it is very difficult to build a general architecture for the IoT because of large number of devices, link layer technologies and services [12]. Similar framework studies have suggested the success in location based IoT sensors in cases like elderly life style management and care which can gather data for further analysis and prediction, the same seems to be useful in the context of inventory management as well [13]. The server analyzes and reports the daily activities and activity patterns of inventory movement and forklift operations. In addition, unexpected emergency situations can be estimated and prevented through analysis of the activity information.

While the technology above considers only a limited role of detection by BLE sensors, a combination of low power CPU models like Cortex-M0 which is low power hungry and uses smaller gate counts with the BLE can help avoid round trip data to the servers and reduce load of computing on central resources while managing peer to peer object pairing for faster results [14].

Smart Manufacturing can help companies gather and consolidate data at each step of their operations to get meaningful insights for proactive decision making [15]. Smart Manufacturing combined with Smart Inventory management can help reduce costs and increase customer service quality many folds.

The paper leaves scope for further research in both the technology front and the management area of statistically finding acceptability levels of the technical model. The technology model needs to be tested considering different warehouse layouts and obstacles or radio interferences to BLE devices. The samples could have been drawn from a skewed distribution due to convenience nature of sampling hence a more elaborate study of a larger sized sample with distribution will be advised as the next step for further research.

ACKNOWLEDGEMENTS

The initial idea for the research was generated post a study of a routine problem of Indian process manufacturing companies of physical stock not matching with the system stock balances and due to the continuous nature of movement of material to and from inventory due to round the clock operations physical counting required down time leading to productivity losses. We are also strongly indebted to the Indian company who helped us implement the trial run and also take statistical measurements to ensure it was successful.

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BIOGRAPHIES OF AUTHORS

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