Robust Low-Cost Passive UHF RFID Based Smart Shopping Trolley

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***Abstract*—Retailers are often interested in low cost mechanisms to maintain stocks as well as for tracing products across the supply chain in an efficient and effective manner. In addition, shoplifting is another concern faced because of the lack of effectiveness in product tracing technique such as "barcode" used in retail super markets. "AmazonGo" a smart retail layout which was introduced by Amazon, to address above issues was found to be inefficient due to the over dependency of system based on historical purchased patterns of consumers. In this paper, we propose a low-cost, robust, passive UHF RFID based shopping trolley system which allows tracing and processing shopping data in real time. The UHF antenna mounted shopping trolleys are defined "Smart Trolleys" while shopping items are tagged using UHF RFID tags with unique identification codes.**

***Index Terms*—Smart shopping trolley, UHF RFID, RSSI, circular polarised antenna, branch line coupler.**

I. Introduction

PEOPLE used to have a list of items written in a piece of paper when they went shopping for groceries; however, the advancement of technology has changed how people do shopping over the last decade [1]. In addition, the emergence of smart phone has changed the retail shopping experience drastically. The retailers are continuously working on improving the shopping experience to make sure their customers are satisfied in overall shopping experience.

There have been various attempts which were carried out in the past to eliminate lengthy shopping lines in retail stores. One of the famous approaches is the introduction of self-checkouts where customer convenience has been improved drastically [2]. Self-check outs have been popular since then due to low overhead cost; however, the shoplifting and lower operating efficiencies are considered as major drawbacks in the retail environment.

The selection of a single technology that can be used to enhance shopping experience is a difficult task as the expectation in a brand clothing store to grocery store can be quite different, and can also depend on individual perception [3]. In addition, it was found that the consumers prefer to have item level information to make purchase decisions [4]. Moreover, demands for visual technology and privacy have a greater influence in consumer satisfaction. Therefore, it is important to identify ways to improve shopping experience while the factors such as return on investment, expected sales growth and meeting customer expectations are also considered.

There have been three major attempts, where shopping trolley was used as the medium to improve shopping experience. In 2005, Fujitsu, a Japanese company has demonstrated a shopping trolley with an inbuilt barcode scanner. The barcode scanner was used to scan both products and loyalty cards in real time [5]. However, this shopping trolley does not fully solve issues such as in store stock management and shoplifting. Amazon has recently come up with a smart retail store concept "AmazonGo" [6] where the customer pick a product from the product gets tracked and self-checked. The AmazonGo system uses image processing, neural networks and deep learning algorithms to forecast which item is picked by the consumers. The system accuracy largely depends on consumers historical purchased patterns. AmazonGo also uses sensor fusion techniques to process multiple images taken from cameras around the retail store to predict best estimate of an item picked by the consumer in real time [7]. Finally, Panasonic, another Japanese company has come up with a RFID based shopping basket where each item is tagged using UHF RFID (ranging from 916-924MHz) [8]. Panasonic has revealed that this smart basket is part of "cashier free convenient store concept" where customers can drop items into the basket and each product gets scanned through a self-serving kiosk as shown in Figure 1. Higher capital cost as well as the limited size of the basket have been identified as the major drawbacks of this implementation [9].

In another comparison, there are several UHF RFID based smart container applications have emerged in recent times [10]–[12]. Most of these applications discuss the development of RFID with ZigBee system to establish the wireless communication between main server and each smart container. Moreover, detailed analysis has not been conducted in the accuracy of readings / miss counts when the smart container is full with items and there is also lack of study in cost comparison. In some other systems, additional components were added (e.g.: camera and anti-collision sensors) to ensure the accuracy of the readings [13]. The proposed smart trolley in this paper evaluates the ability to integrate all components (reader + antennas + user interface) to the shopping cart itself at a lower cost and communicate through low-power

Manuscript received November 26, 2017; revised March 7, 2018 and July 31, 2018; accepted August 15, 2018. Date of publication August 20, 2018; date of current version October 4, 2018. *(Corresponding author: Tharindu Athauda.)*

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Digital Object Identifier 10.1109/JRFID.2018.2866087

(a) (b)

Fig. 1. Self Registration Machine Console (a) Shopping Basket (b) RFID integrated shopping console.

Fig. 2. Convergence Systems Limited – CSL468 RFID Reader.

Bluetooth (only uses 1/4 of power in contrast to ZigBee [14], hence increase battery life for the same cost) with kiosk. The proposed system also provides evidence of high accuracy when the cart has multiple products mimicking the real life scenario.

It is clearly evident from the above explanations that shopping trolley is considered preferable over self-checkout systems. It also concludes that there is a clear need for a low cost and robust technology implementation which is efficient and highly accurate when dealing with shopping information.

Therefore, this work aims to design and implement UHF RFID based smart trolley which can track products and provide item level information to consumers in real time.

II. System Design

UHF RFID was renowned for traceability applications and it was introduced to the mainstream by Wal-Mart [15]. Today UHF RFID continues to thrive in retail applications and fit well with shopping trolley application due to the following attributes.

- *Non-line-of sight reading ability* – In the shopping trolley items can be read without a necessity to maintain a clear line of sight.
- *Reading distance* – UHF RFID tags can be used in both near field or far field applications which is useful in reading items close to the antenna and also from a considerable distance.
- *Higher date rates* – which is very useful in storing more data efficiently.
- *Tag readability* – UHF RFID tags can read multiple tags at one time (300 tags/seconds) which increases reading efficiency.
- UHF RFID tags are globally standardized under the ISO 18000 in particular and GS1 standards on EPC Global based on its application. Other standards such as GATG, and CEPT also found to be relevant in industry deployment.

The above has been taken into consideration when drawing the requirement specification. The following requirements are taken into consideration to design and develop smart trolley application.

- *Every item that goes in and out of the shopping trolley should be detected* – In such a case, antennas should be placed in strategic positions where the radiation patterns able to cover the entire area inside the trolley irrespective of tag orientation.
- *Capability of UHF RFID Reader* – UHF RFID reader should be able to deal with multiple antennas with different configurations simultaneously.

It is essential to understand how UHF RFID system works in order to find solutions that cater to above stated requirements. Every UHF RFID tag has its own identity and it also consists of a RF trans-receiver. RFID reader transmits the encoded radio signal to check the presence of UHF RFID tag using the transmitter antenna. In the event that the UHF tag is within the reading range of the transmitter antenna, the tag will receive the transmitted signal. Once the tag receives the signal, the induced power in the tag antenna will activate the IC on the tag by the induced current on tag antenna and then the signal backscatters to the receiver antenna with the information retrieved from the Tag IC. Thereafter, the receiver antenna receives the tag information and send to the RFID reader for further processing. In this application, it is important to consider both near field and far field patterns in antenna development as both regions will be used for the tag detection. More detail about field analysis will be explained in the implementation section.

UHF RFID tags typically operate from 860-960MHz where each country has its own UHF bands. Specifically, for Australian standards, the RFID spectrum is 918-926MHz at 1W EIRP (Equivalent Isotopically Radiated Power) or 920-926MHz at 4W EIRP.

The main aim of this research is to develop a UHF RFID system that works simultaneously with multiple antennas inside a shopping trolley. The RFID reader can connect with the interface and show real time information to consumers. Therefore, significant effort is needed to design the required antennas and its optimization, to implement hardware configuration with RFID reader (CSL468 UHF RFID reader from Convergence Systems Limited), to validate system using UHF RFID tags and to develop the user interfaces.

The necessity to read RFID tags in different orientations is considered essential; hence, circular polarized (CP) patch antenna was selected. CSL468 RFID reader as shown in Figure 2 is selected as it provided multiple antenna ports as part of system configuration. A low cost RFID reader can be suggested later, to gain the commercial advantage in mass deployment of this application.

Considering above research goals and requirements, following smart trolley design as shown in Figure 3 is suggested.

The next step is to understand the directional gains needed for the applications of the CP antennas in order to obtain RSSI (Return Signal Strength Indicator) values for the application.

TABLE I
CSL468 RFID READER PROPERTIES

Property	Value
Number of ports	16
Tagging Speed	300 tags / second
Read Range	12meters

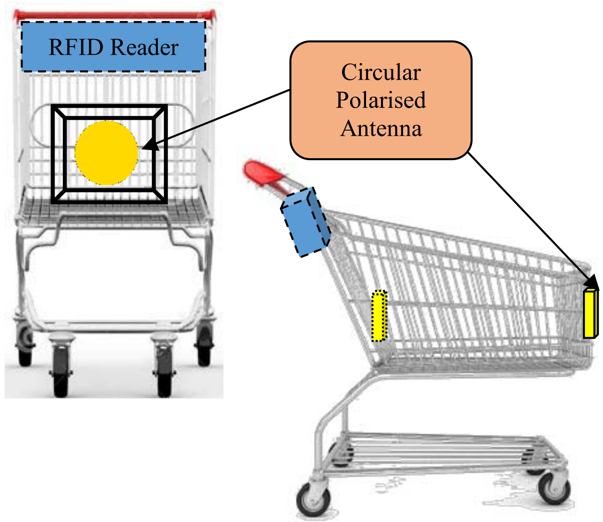

Fig. 3. Systematic (a) Front view (b) Side view with Circular Polarised Antennas of the Smart Shopping Trolley.

III. SYSTEM DEVELOPMENT

As the passive UHF RFID tags are not inbuilt with a power source, the readability of the tag purely based on the transmitted power from UHF RFID reader through the transmission antenna to the tag. Such a signal in real time application travels two times along the path of the signal. Friss has explained this scenario by considering the power received by the UHF RFID reader (P_R) once it is transmitted and backscattered by the UHF RFID passive tag [16] along with RSSI (Return Signal Strength Indicator) measurement can be deduced as follows.

$$P_R = RSSI = -20\ logD + T_x Power$$

RSSI measurement plays a significant role in this smart trolley application as RSSI measurement indicates the directional gains that are needed for the antenna development. Furthermore, CSL486 RFID reader capable of providing derived measurement such as the "Geiger count" which indicates average RSSI value as a % of transmitted signal power. A higher number will stand for a closer tag reading [17] and "0" will represent that the tag is not reachable at all. Geiger count can also be used to change transmitted power on demand, in order to increase the chances of tag readability.

Even though the RSSI is heavily dependent on distance, it is a well-known factor in the state of the art. It is also known that RSSI is heavily dependent on environmental conditions. Metal objects, liquids and human interference can greatly alter the RSSI measurement. RSSI value can also be dependent on the tag orientation [18]. The distance vs RSSI measurement also plays a critical role when considering the dimensions of the shopping trolley because a given antenna system should only consider reading items in the trolley at a given time but not items located outside the trolley boundaries. On the other hand, the beam pattern of the antenna should cover the full internal area of the trolley, in order to reach each tag attached to the products. Furthermore, it was decided to develop an antenna system that can cover the full range of UHF; therefore, it can cover global UHF standards (850 - 960 MHz) [19] enabling the use of developed system implementation across any country without a limitation.

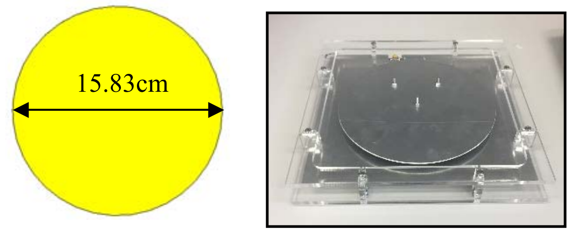

Fig. 4. Circular polarised patch antenna (a) Simulated design (CST Microwave studio 2016) (b) Fabricated patch antenna.

CP antenna has a shorter reading range compared to linear polarized (LP) antenna; however, CP antennas are capable of reading tags in different orientations. On the other hand, CP antenna should ideally have a wider beam width with lower gain. This helps to scan more items in near field as well as to avoid reading items beyond the trolley. Therefore, considering above facts, the CP antenna was selected for the application along with the hybrid coupler which aids CP antenna to provide circular polarized behavior.

Considering the directional gains from UHF RFID tags, the antenna gain can be calculated for a given wavelength. In order to make the antenna design simpler and cost effective, the below circular patch was selected. The reason behind the selection of circular shape antenna design [20] for its ability provide better bandwidth in comparison to rectangular shape and this circular antenna patch was custom made to keep the cost down in comparison to commercially available antenna and custom made frame was used to hand the antenna easily in the shopping trolley for the demonstration purposes as shown in Figure 4.

Feed points were selected based on the locations which provide highest return loss and the simulations were carried out using CST microwave studio. In here, the coaxial probe feeding technique was used [21].

The simplest form of coupler, the branch line coupler was selected for the application. Each transmission line is a quarter wavelength; however, this may result in reduced bandwidth which may adversely affect system requirements [22]. As shown in Figure 5, branch line coupler has 4 ports for input, output, coupled and for isolation. 900MHz has been selected as the center frequency based on the required bandwidth and wavelength which was calculated accordingly. FR4 has been selected to fabricate the coupler; hence, it is essential to calculate effective wavelengths as $\frac{\lambda_g}{4} = 38.854mm$.

A characteristic impedance of 50Ω was used, as the cables and connectors had an impedance of 50Ω and the following

Impedance required	Impedance Value
Z_0	50 Ω
$Z_0 / \sqrt{2}$	35.355 Ω

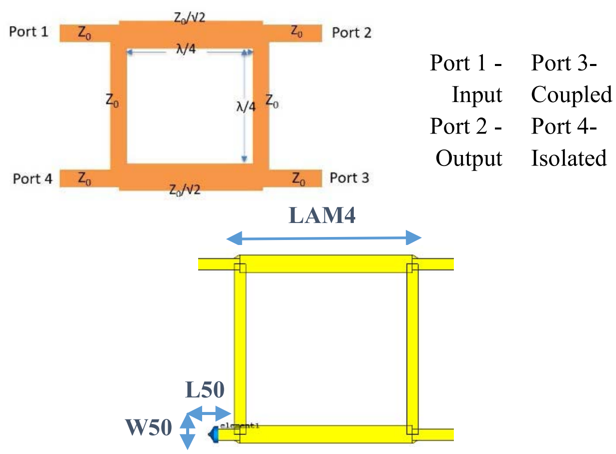

Fig. 5. Branch line coupler (a) Schematic (b) CST Microwave Studio 2016 Simulation.

TABLE II
COUPLER DIMENSIONS

Variable	Dimension
LAM4	46.500 mm
L50	11.511 mm
W50	3.103 mm
W35	4.992 mm
Substrate thickness	1mm
Substrate length	81.795mm
Substrate width	69.522mm
Conductor thickness	17µm

impedances and corresponding micro strip widths were calculated using ADS Linecalc [23]. The coupler dimensions mentioned in Table II, was used to design the coupler. Thereafter, coupler was simulated to measure values of return loss (S11), S21 and S31. To have a successful working simulation, S11 should be less than −10dB and S21 = S31 = −3dB as power gets divided equally between ports 2 and 3. Moreover, the difference between phases of ports 2 and 3 has to be 270 degrees (out of phase by 90 degrees) in order to get ideal circular polarization where two signals from ports 2 and 3 are perpendicular to each other.

As shown I Figure 6, it was observed that the outcomes S11/S21/S31 were within the acceptable ranges in power (magnitude in dB). In addition, phase difference of 270° provides the required phase change to propel circular polarized properties. Therefore, the measurement of return loss of CP antenna and coupler together can be observed as in Figure 9. The return loss shown in Figure 9 indicates that the CP antenna and coupler provide the required bandwidth from 850-960MHz. Thereafter, both CP antenna and coupler were fabricated, to measure its performances for the smart trolley application.

On the other hand, the directivity pattern of the circular patch antenna in both near field and far field were considered as elaborated in Figure 7. Axial ratio at the single frequency mode was also added as shown in Figure 8, for the analysis to provide a clear idea about the antenna performances.

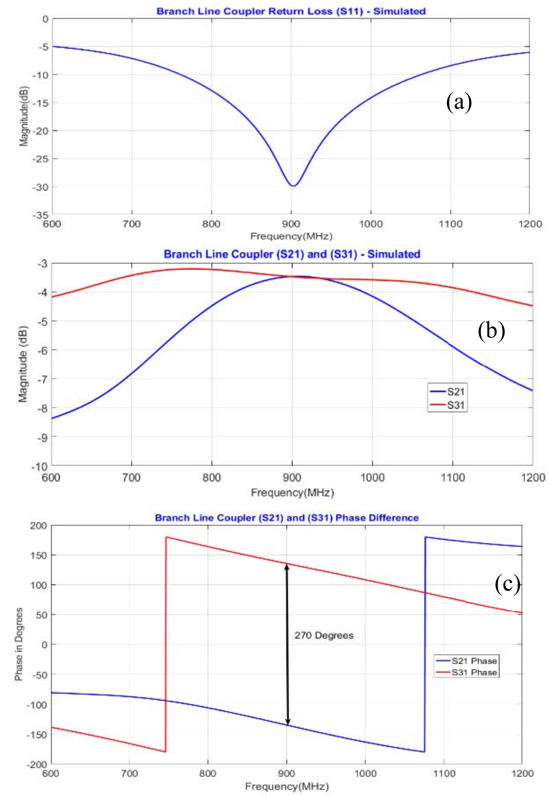

Fig. 6. Branch line coupler (a) Return loss (S11) (b) S21 and S31 (C) Phase difference.

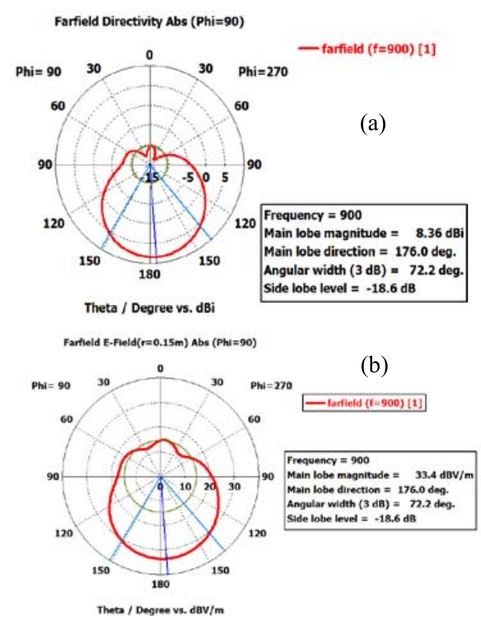

Fig. 7. (a) Far field directivity pattern of CP antenna (b) Near field E field pattern of CP antenna.

As explained in the Figure 7 (a), the main lobe covers a significant area in front of the CP antenna; however, some products may not reachable by the antenna pattern especially in the corners of the trolley as shown in Figure 13. Such

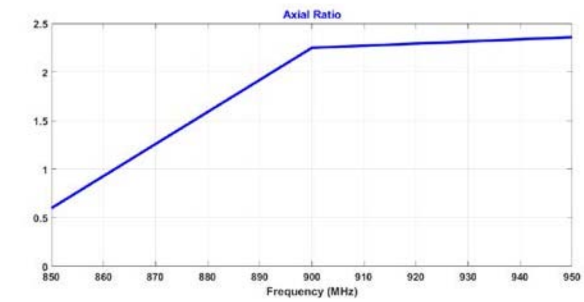

Fig. 8. Axial ratio in single frequency mode of the circular patch antenna.

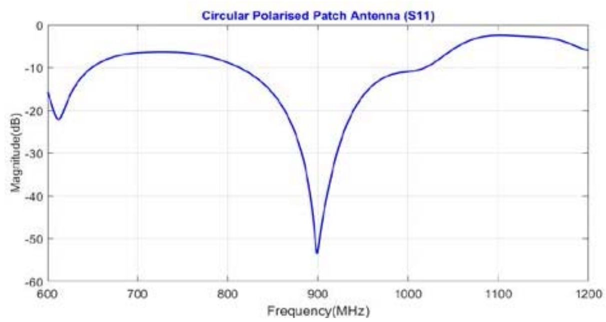

Fig. 9. Simulated S11 CP patch antenna and coupler together (CST Microwave Studio).

(a) (b)

Fig. 10. (a) Fabricated Circular Patch Antenna (b) Fabricated branch line coupler (Top View).

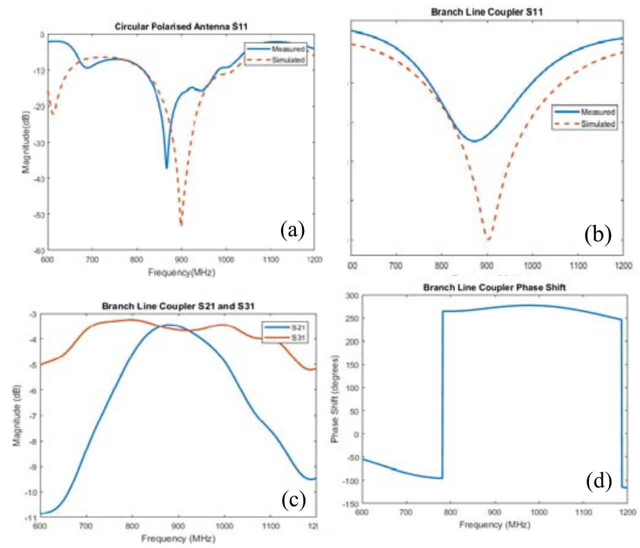

Fig. 11. (a) S11 CP antenna simulated vs measured performance (b) Coupler S11 simulated vs measured (c) Coupler S21, S31 simulated vs measured (d) Coupler S21 & S31 phase difference measured.

Fig. 12. CP antenna attached to the shopping trolley.

scenario can be explained using the near field pattern (at 15cm based on $2D^2/\lambda$) as in Figure 7 (b). In near field, CP antenna has a greater field intensity in both longitude and the plane parallel to the antenna. At the same time the directivity is comparatively higher in near-filed in comparison to far field. This understanding helps to explain the CP antenna's capability to detect tags at a closer proximity as well as in a distance.

On the other hand, the axial ratio provides the polarization nature of an antenna. In this case, axial ratio is 0.6 and gradually increases with the frequency. The value close to 0dB in the axial ratio is considered the best in terms of circular polarization behavior and this patch antenna 0.6dB considered to be good enough for the given application.

Finally, the fabricated outcomes (as in Figure 10) were compared against the simulation results as shown in Figure 11. Vector Network Analyzer (VNA) was used to measure the actual performance once the antenna and coupler were integrated to perform as one system.

As shown in Figure 11 (a), the measured S11 of the circular antenna has slightly shifted to the left from the simulated result; however, it still manages to maintain the bandwidth requirement of 850-960MHz. In the coupler, measured S11 has a lower amplitude (return loss of -17.35dB) and a frequency shift (870MHz) compared to simulated S11. S21 and S31 of the coupler were recorded as -3.46 and -3.65dB at 900MHz (center frequency) respectively. The lossy nature of FR4, could be the reason behind the variations of results in contrast to simulation. Finally, the phase difference between ports 2 and 3 is found to be 272.74 degrees, where the slight mismatch in magnitude and phase represent the non-perfect behaviour of CP antenna system. Nevertheless, for the UHF RFID tag reading purpose, these differences can be negligible.

IV. Implementation and Configuration

As the next step, fabricated CP antenna and coupler was mounted to the shopping trolley as shown in Figure 12. The positioning of antennas has been done in a way that, it maximizes the area of coverage considering the gain and directivity of the CP antenna. The effectiveness of such placements in both near field and far field can be elaborated using E field and directivity configuration @ 900MHz as shown below.

Fig. 13. Product testing with smart shopping trolley.

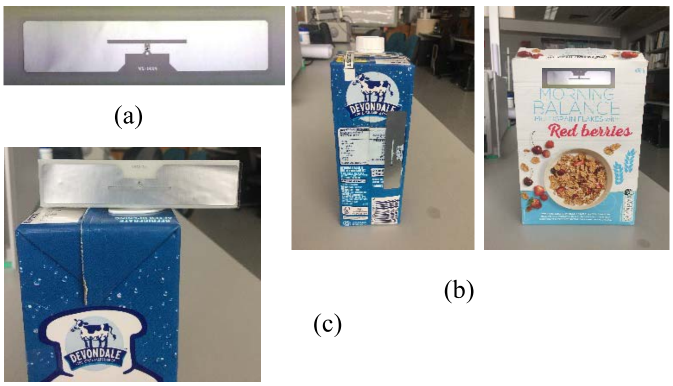

Fig. 14. (a) UHF RFID Tag from Robot Gear Australia (b) Tagged products with UHF RFID tag (c) Augmented placements to support read range.

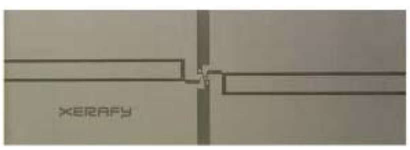

Fig. 15. Xerafy metal skin inlay tag.

Thereafter, the item level tracking test was carried out by tagging individual products using UHF RFID tags where each tag has a unique EPC (Electronic Product Code) code. The UHF RFID tags from Robot gear, Australia [24] has been used for this experiment which has following properties.

- ISO / IEC 18000-6c
- EPC Global Gen 2
- 512 User bits and 800 Bits of memory
- 64 Bit unalterable serial number as unique ID
- EM-4124 RFID IC
- -19dB sensitivity at IC level and -21dB at tag level

Interestingly, there are instances where UHF RFID tags show poor reading performances in the presence of metal packaging such as canned foods and liquids [25]–[27]. Augmented placements were implemented using 3D printed (using relatively lower cost ABS (acrylonitrile butadiene styrene)) frames and use those frames as a base to sticker UHF RFID tags to avoid problematic reading zone as shown in Figure 14 (c). However, this augmented carrier is not a cost viable solution in mass deployment; hence, the development of a flexible folded dipole UHF RFID tag with a ground plane is necessary to get rid of a separate carrier. For example, Xerafy Mercury metal skin inlay UHF RFID label [28]

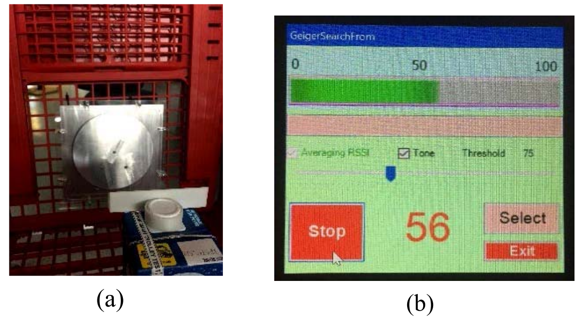

Fig. 16. Geiger count measurement.

(Figure 15) may be considered as an alternative UHF RFID tag that can be used for item level tagging where aluminum foil are wrapped around (to connect both antenna and ground) a thin plastic sheet which acts as a dielectric substrate.

The alternative benefits brought by this tag is, its alignment with EPC Class 1 Gen 2; ISO18000-6C and works from UHF 860-960MHz covering the global range of UHF RFID. The main concern of such a tag is the cost compared to the non-specialized UHF RFID; however, smaller size, volume in mass deployment will reduce the unit cost drastically. The use of Xerafy tag can only get an estimation of the performance and also for the demonstration purpose.

In the implementation process, it was decided to use existing reader hardware as explained in Figure 2 as well as to use reader software to verify initial readings of the UHF RFID tags with the products. Each UHF RFID tag has given an EPC code where each tag ID can be reprogrammed to get detailed information such as product name, expiry date, batch number, manufacture information etc. In practice, RFID reader gets directly connected to the PC via a standard network cable and transferred data such as RSSI readings use for analysis of gathered information.

As the final experiment, the detecting of tags from various locations inside the trolley has been performed. This experiment was conducted to validate the fabricated CP antenna and coupler performances inside the smart shopping trolley. The software which was inbuilt to CSL CS-468 reader used to determine the existence of the tag by using an inbuilt Geiger counter as shown in Figure 16.

The gathered values of RSSI, has been plotted to show the tag detection space inside and outside the trolley using a 3D space modeling as shown below. It is important to consider that these values were obtained from a single CP antenna. It is useful to identify the coverage produced by each antenna and then evaluate performances of combined antennas in the trolley application as shown in Figure 17.

- *Green circle* - Average RSSI over 50
- *Yellow circle* - $40 <$ Average RSSI < 50
- *Red circle* - Average RSSI < 40

For this experiment, 30dBm transmitted power was used and experimented using the UHF RFID tags from Robert gear Australia. The tags were randomly oriented in the shopping trolley to mimic real life scenario of using a shopping trolley. The antenna were acted as a mono static system [29]. Only

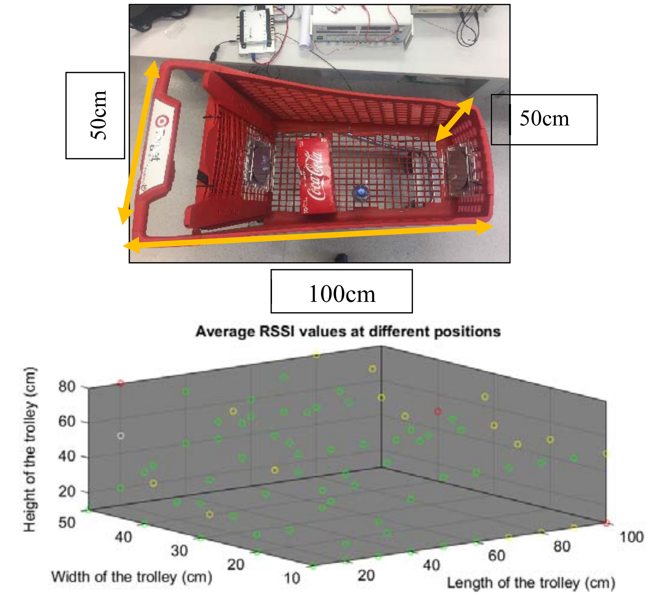

Fig. 17. Geiger count vs Distance measurement using singular circular polarised antenna as compared to trolley measurements.

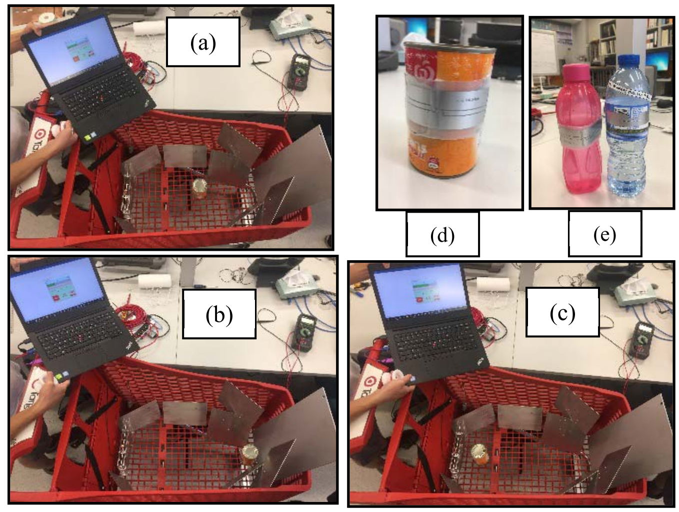

Fig. 18. (a) Reading of canned food with xerafy tag @ 50cm (b) @ 90cm (c) @ 12cm from CP antenna (d) Canned food (e) water bottles tagged with Xerafy metal skin tag.

Index	PC	XPC_W1	XPC_W2	EPC	TID	USER	RSSI	Count
0	3000			E20000173801024511 50A428			50.4	3807
1	3000			E200001738010242115 0A41F			45.6	4220
2	3400			E2000015860E02851710 6BFB			38.4	1877
3	3400			E2000015860E02861710 6C03			40	470
4	3000			E200001738010239115 0A425			55.2	4150
5	3400			E2000015860E02801700 6E34			54.4	2639
6	3400			E2000015860E0265116 0A7EF			40	1223
7	3000			E200001738010247115 0A435			58.4	3466
8	3000			E200001738010248115 0A42E			51.2	2515
9	3400			B3000000000000000000 0000			46.4	24
10	3400			E2000015860E02471150 AA01			39.2	307
11	3000			E200001738010246115 0A42D			53.6	60
12	3000			E200001738010243115 0A427			51.2	27
13	3000			300833B2DDD901400000 0000			51.2	37
14	3000			E200001738010254115 0A43D			34.4	45
15	3400			E2000015860E02051700 6D9B			42.4	33
16	3000			E200001738010256115 0A43E			36.8	18

Fig. 19. Shopping trolley is densely packed with multiple items.

one antenna is used here for the experiment as a single CP antenna is capable of detecting fewer number of products and may need both antennas when the product density increases inside the trolley.

It is quite evident that even a single antenna can produce a significant coverage inside the trolley; hence, it can be concluded that when both CP antennas in operation, it can result a better coverage. The final experiment was carried out, to verify the effectiveness of tag readings in presence of metal frames. In this experiment, metal skin UHF RFID tag used with metal products and the following observations are recorded.

In this experiment in Figure 18 similar to experiment in Figure 17, the antenna kept static while products were moved around to see how often it gets detected. We also used both Xerafy and UHF RFID tags from Robert gear Australia to conduct the test based on the nature of the product (e.g.: Metal and liquid products were tagged with Xerafy tag). As seen in the figure above, Xerafy tagged (aluminum ground plane with dielectric substrate) can be easily detected in a closer proximity. The Geiger count shows over 30 as a validation of the experiment of all products tested with in the trolley. The Geiger counter value gets higher when the object is closer to the antenna and reduced when it's far away. The use of metal frames has not significantly impacted the Geiger count (when compared with Figure 18 (b)) and the test has validated the tag reading is quite possible in presence of metal and liquid. The readings which was observed from the outside (very close to the antenna) of the trolley has a lower Geiger count which can be used to filter products detected from the adjacent trolleys (usually less than 30).

The over the counter software inbuilt to the RFID reader also has the functionality to detect multiple tags at the same time as long as the antenna can read the tags with over 30% Geiger count. These Geiger count value which determines the detectability of a given tag quality can be rearranged in the software application; however, it was decided to maintain higher Geiger count in order to discourage readings coming outside the shopping trolley (e.g.: Tag IDs from an adjacent trolley).

As the next step of validation, multiple items (16 items) were added to the trolley as shown in Figure 19. As proposed in Figure 3, both CP antennas were deployed to get a high accuracy in reading zone in comparison to use one antenna in previous experiments in Figure 17 and 18.

As expected, all 16 products which were inside the trolley have been detected and shown as in Figure 19 with their respective RSSI values. This observation helps to conclude that the beam pattern of both CP antennas has managed to cover the areas inside the trolley resulting high accuracy detection.

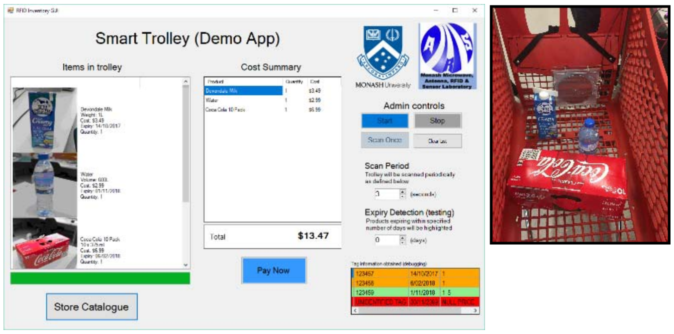

Fig. 20. Shopping trolley user interface.

It can be further concluded that the suitable tag development which has a ground plane, and two optimized CP antennas with correct tuning of RSSI filtering can lead to high accuracy tag detection inside the trolley environment in real-life scenario.

Finally, the smart trolley interface was developed which helps to provide real time information to consumers. The interface provides real time information to the consumer while the app get refresh at every 2 seconds to capture new information. The item level price / total and expiry dates of each item are shown on the interface and the interface will link the trolley to the payment gateway for payment processing.

The flow chart in Figure 20 can be used to summarize the complete working cycle of the UHF RFID smart shopping trolley system. In this flow diagram, critical activities are taken in to account which needs careful consideration in practical implementation. It is always recommended to improve this platform when it comes to integrate with 3rd party vendor platforms; however, main core activities of the development of UHF RFID for shopping trolley application will remain same.

V. Cost Analysis

An approximate cost analysis has also been conducted at the end of the development. The approximated cost was calculated considering the market demand (e.g.: approximate number of shopping trolleys in Australia), hardware cost (UHF RFID reader, antennas, jigs, tags, augmented placement carriers), Repetitive use [Replace annually], Shopping trolley shrinkage [10% per store] and the software platform.

According to the investigation from Web sources, it was revealed that Australia [30] has over 650,000 shopping trolleys across multiple super market (over 3500 outlets) chains where each store has approximately 200-350 shopping trolleys. Above approximations are considered along with the 10% shrinkage for the following calculations as shown in Table III.

As can be seen from Table II, the existing shopping trolley with no intelligence can be converted to an intelligence system with more customer engagement by investing approximately AUD $500. If this approach of using UHF RFID to convert a shopping trolley by using existing hardware available off the shelf, this may cost approximately $500-$650 more predominantly from two antennas [33] and hybrid coupler [34].

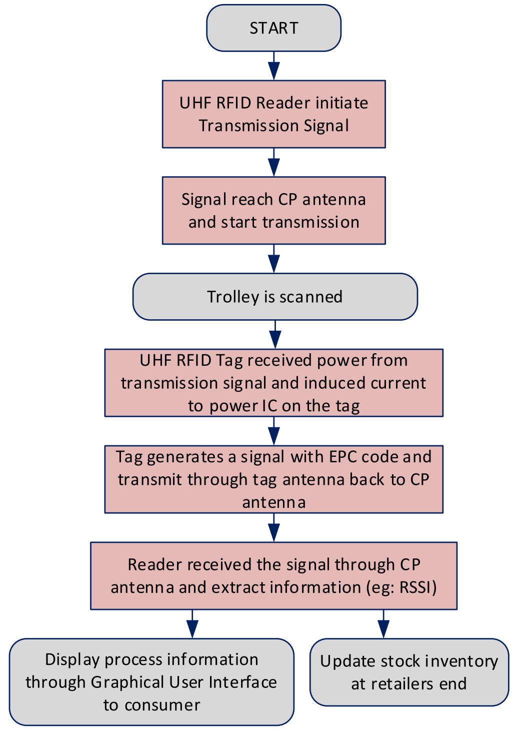

Fig. 21. Process flow chart of the system.

TABLE III
Cost Analysis

Hardware cost (Approximate)		Volume	AUD $
	UHF RFID reader with 2 antenna ports [31] for 650,000	1	$250
	UHF RFID tag [considering the average of 9000 - 47000 products per grocery store [32]]	1	$0.05
	Aluminum Antenna + Coupler + Laser perforated plastic jigs [02 antenna per each trolley]	2	$28
	Powering the reader system using an rechargeable integrated battery	1	$150
	Bluetooth adapter to communicate with kiosk	1	$6
	Localization receiver (Installed in super market and depends on the size of the super market) – Not considered in calculation	10-30	$100-200
Software Cost (Approximate)			
	Reader platform (Inbuilt)		No cost
	Configuration with existing retail platform (App + Graphical User Interface)	Per store	13,000
		Per Trolley	$30
Maintenance (10% of total cost)			
Total Cost (Approximate)			$465

Therefore, by adopting this proposed and validated approach, we may foresee that intelligent UHF RFID based shopping trolley is not far from reality.

VI. Future Work and Recommendation

It can reasonably justifiable that this application can further be improved in several aspects. The Geiger count based RSSI average is not a perfect measurement to ensure that the antenna only reads the tags inside the trolley. The Geiger count is calculated based on the distance between tag and antenna and the environmental conditions may also have an impact over the readings. Therefore defining Geiger count % threshold will be very useful (as it defines for this application) to avoid reading tags far away from the shopping trolley boundaries.

Furthermore, a RF insulation for the shopping trolley can be suggested in order to avoid reading tags outside of the trolley. It may also need to encounter any potential coupling between antenna and trolley frame once the insulation is in place which needs further investigation. Furthermore, the accuracy of items in the trolley can be enhanced by scanning the items multiple times (e.g.: every 1second) which also provide more accurate real time information to the shopper.

Alternatively, the user interface can be further improved by providing shopping history which may aid the shopper to make purchase decisions. Alternatively, the facility to download a pre-arranged shopping list also be useful for consumers.

The development of "low cost" UHF RFID tag that can aid the reading in presence of metal (where Tag ID is difficult to read due to the interference generated from the radio frequency (RF) reflection from metal surfaces) and liquid (where RF energy gets absorbed due to continuous reorientation of polar molecules) are also a key future aspect to consider. Careful consideration of dielectric substrates (e.g.: thermoplastics) which may separate the antenna and ground plane and use of printed folded dipole antenna (for a compact size) will be an interest to explore to address a low cost UHF RFID label that may be used for the item level tagging.

The implemented system can be further improved by use of data mining techniques to gather product data at multiple points and also improve to identify consumer purchased patterns using neural networks.

VII. Conclusion

In this paper, successful use of UHF RFID system for the smart shopping trolley has been demonstrated. The items can be detected irrespective of its tag orientation, size and shape. These were the drawbacks addressed in previous shopping trolley applications which were overcome in this application. The development of antenna and hybrid coupler is based on the original work which has been carried out by Monash Microwave, Antennas, RFID and Sensor laboratories. Finally, this particular application may bring novel experience for shoppers when they benefit from coordinated collaboration among technologies.

Acknowledgment

Special thanks goes to Monash Engineering workshop for their continuous support for the fabrication of antennas and preparing relevant jigs for the antenna frames as well as Geoffrey Ramadan, the managing director of UMD (Unique Micro Design) for providing the hardware support needed for the application development.

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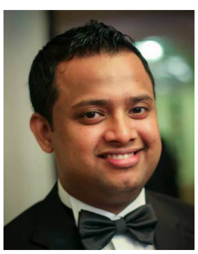

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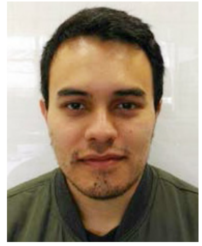

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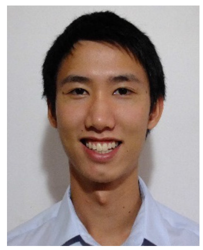

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