RFID Tag Antenna Based Sensing: Does your Beverage Glass need a Refill?

Rahul Bhattacharyya, Christian Florkemeier and Sanjay Sarma
Auto ID Center
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139
Email: rahul_b, floerkem and sesarma@mit.edu

***Abstract*—Liquid level detection in customer beverage glasses and liquor bottles in the service industry is important for maintaining quality of service and good approval ratings. Current sensing approaches rely either on visual inspection or expensive sensor electronics to detect liquid levels. In this study, we investigate how the paradigm of RFID tag antenna based sensing can be used as a low-cost alternative in the service industry, to detect the volume of liquid in a beverage glass by mapping a change in RSSI power measurements from RFID tags to the level of liquid in the glass. We demonstrate that this sensing technique when deployed in a real restaurant-like setting can be used to accurately predict the state of the glass over 80% of the time, and thus has good potential as a low-cost sensing methodology for applications in the restaurant industry.**

I. Introduction

Research efforts to make RFID a viable technology for track and trace applications have provided us with a low cost, standardized, wireless communication infrastructure which can be exploited for applications beyond identification such as sensing. There have been several efforts to develop RFID based sensors either by using RFID as a backend to sensor electronics integrated with the RFID chip, such as the WISP Platform [1] or by utilizing the RFID tag antenna itself as a sensor [2] [3] by making use of the fact that RFID performance is known to degrade in close proximity to metals and fluids [4]. Our approach focuses on the tag antenna based sensing paradigm where we attempt to map a change in the level of liquid in a glass to changes in the electrical properties of the RFID tag antenna[1].

In this paper, we discuss an application of RFID tag-antenna based sensing in the restaurant industry as a low-cost method to detect empty drink glasses in need of a refill. This application examines our ability to detect whether the glass is empty or full, and also whether it is possible to approximately localize an empty glass' position based solely on RSSI power measurements. In this specific application scenario, this would entail detecting which table the empty glass is placed on.

Section II motivates the application we are trying to target and introduces the localization methodology we will attempt while comparing and contrasting it with prior art in the literature. Section III discusses the sensing principle exploited that will help differentiate between full and empty glasses. Section IV discusses the efficiency of state detection and approximate localization of RFID enabled drink glasses in a controlled laboratory setting. Section V then applies the lessons learned in the previous two sections in a restaurant experience that will be used to test the application of tag antenna based sensing in beverage glass state detection. Finally Section VI will comment on the effectiveness and current limitations of this approach, list other potential applications and scope for future work.

[1]We request the reviewers to maintain confidentiality as we are currently in the process of filing intellectual property on this technique

II. Problem Motivation

Customer satisfaction is a very important factor in deciding any commercial venture's success and the restaurant industry is no exception. Customer satisfaction is gauged by several metrics and quality of service is an important factor. With the advent of the Internet, restaurant reputation and customer goodwill can be gained or lost very easily as can be seen from the presence of a plethora of blogs and review websites that list customer ratings and satisfaction levels [5] [6] [7]. It is interesting to note that a common peeve customers have is the slow response time for drink refills [8] [9].

There have been prior instances of research involving smart cups and drinking devices. For example the Media Cup project [10] instruments a coffee mug with sensors that convey information like usage or drink temperature to interested parties. However the sensor electronics associated with this are expensive. In related research, Deitz et.al [11], use RFID reader units mounted under restaurant tables to sense the level of fluid in instrumented glasses placed on top of the tables. This approach is electronics intensive and it would be useful to develop a low-cost, less intrusive sensing methodology for a problem like fluid volume detection in glasses. In this paper, we examine the promise of UHF RFID enabled drink glasses. The larger detection range associated with UHF RFID, allows us to deploy reader antennas in unobtrusive locations like the ceiling which is an advantage over the previous approaches. The problem of detecting the presence of an empty glass can thus be broken down into two sub-problems. First, we need to have a mechanism to detect whether or not a glass is empty or full. Second, it would be useful to have a method to approximately localize the empty glass - in this case be able to discern which table it is located on.

We use the principle of RFID tag antenna based sensing to detect the state of the glass. Aroor and Deavours [4] categorize the reduction of performance of some RFID tags in close proximity to water. By pasting an RFID tag on the outside of a drink glass, we create a low-cost state sensor capable of detecting whether or not a glass is empty or full. When full, the tag has a background dielectric of water behind it and this manifests itself in a reduction in backscatter power from the RFID tag. When empty, the tag will have a background dielectric of air, and this manifests itself in improved backscatter power from the tag. Thus by detecting a sudden improvement of backscatter power (or merely by detecting the tag once again), it is possible to infer that the glass has gone from the full state to the empty state.

RFID based localization is a challenging problem. Environment specific distortions such as fading and multipath render triangulation based on the backscatter power response of a tag inaccurate and prone to significant localization errors [12]. There have been several instances of prior research into using RFID for localization. For example, Philipose *et.al* [13] propose a probabilistic measurement model for RFID readers to accurately localize RFID tags in an office environment. Their system makes use of laser sensor data to learn the geometric structure of the environment which increases the efficiency of the localization estimation. In other research involving probabilistic models, Liu *et.al* [14] design an RFID based localization system by using RFID reads in tandem with multimedia devices like a video camera. Ni *et.al* [15] discuss a methodology to localize the coordinates of a test tag via a KNN (K-Nearest Neighbour) algorithm using active RFID reference tags, the coordinates of which are known precisely. The authors quantify the errors in localization as a function of the number of neighbours (K) and demonstrate that they can accurately locate the tag to within 2 meters.

Because of the simplicity of implementation, our localization approach follows the KNN classification scheme outlined in [15]. However, unlike [15], we do not focus on the localization accuracy of the scheme. Accepting the fact that the localization errors associated with RFID are indeed large, we merely use RFID tag RSSI measurements to detect the *approximate* location of the RFID tag. In other words, we are concerned with classifications that merely correctly point us to the table on which there is a glass that needs a refill and argue that this might infact be enough as a low-cost alternative for the restaurant application. The feasibility of this approach is dependent on several parameters such as the spacing between restaurant tables, the effect of people and other objects moving around in the environment and this will be the subject of experimental investigations in the sections that follow.

III. Tag Antenna Based Sensing Principle

Tag Antenna based sensing works on the principle of relating a controlled degradation of RFID tag power characteristics to a change in some physical parameter [2]. In this case, we try to relate a change in RFID tag backscatter power to the state of a RFID enabled drink glass. In the full state, the background dielectric to the RFID tag is a water based fluid such as a soft drink or alcoholic beverage. Water is a polar dielectric and the molecules tend to orient themselves so as to cancel out most of the incoming electric field [16] from the RFID reader. We would thus expect the range of detection of the RFID tag to be severely reduced and the tag to respond with a poor backscatter power response. Conversely, in the empty state, the background dielectric to the RFID tag is air and this should manifest in both an improvement of read range and backscatter power characteristics of the tag. Thus by observing a sudden improvement in power performance or, for that matter, a sudden detection of the RFID tag, it should be possible to infer the change in state of the glass from full to empty. The verification of this hypothesis is the subject of this section of the paper.

Fig. 1. RFID enabled glass

A. Binary State Sensing

We develop a sensing scenario where the RFID enabled glass acts like a binary state sensor and reports whether the fluid level in the glass is greater than or less than a certain level. We paste a commercial off-the-shelf Alien Squiggle tag [17] to a drink glass as shown in Fig. 1. We note that the RFID tag is pasted at the bottom of the tag at the quarter volume level mark. We can thus define the two states of the threshold sensor as:

- **Empty**: If the water level is less than a quarter of the glass by volume
- **Full**: If the volume of water exceeds a quarter of the glass by volume

This may be a good classification because in many beverages, the bottom quarter of the glass may contain ice or other sedimentary deposits such as those associated with coffee or tea based drinks.

In Fig. 2, we plot the backscatter power as a function of distance from two RFID enabled glasses, one which is in the *Empty* state and one which is in the *Full* state, along with an Alien Squiggle tag in free space. For this experiment, the reader transmitted power is fixed to a maximum of 36 dBm. This should give us an indication of not only how significantly the water detunes the RFID tag, but also how the material of the drinking glass affects the tag. We make the following

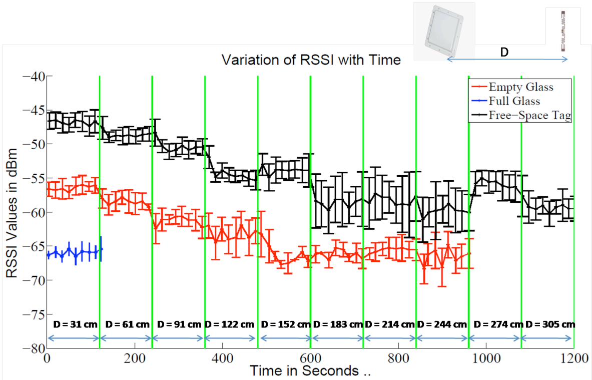


Fig. 2. Response of tag on different media

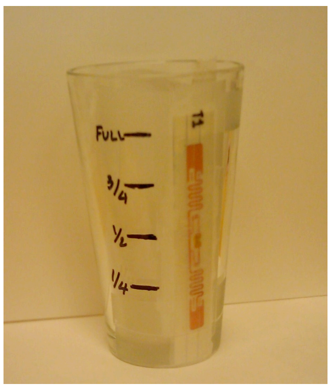


Fig. 3. RFID enabled glass with volume demarcations

observations from Fig. 2

- The RFID glass with water as the backdrop is not detected for distances more than 31 cm. Thus a constant failure to detect an RFID enabled glass for reader-glass separations of more than 31 cm can be interpreted as the glass being in the *Full* state.
- The glass detunes the RFID tag as can be seen from the worse performance of the *Empty* RFID enabled glass relative to the tag in free space. The *Empty* glass can be detected by the reader upto a range of about 244 cm. However, we notice that the backscatter power response of the tag is more or less constant beyond 152 cm and it might be difficult to localize tags at these ranges based on power responses.

Section IV discusses the effectiveness of tag antenna based binary state sensing using the KNN classification algorithm.

B. Tag Antenna Based Fluid Level Detection

While binary state sensing will certainly be beneficial to restaurants seeking to detect empty glasses, it would be useful to consider the applicability of tag antenna based sensing to sense the level of fluid in the glass. In order to test this, we change the orientation of the tag as seen in Fig. 3. The glass is demarcated into four levels and each demarcation corresponds to about a quarter of the volume of the glass. The backscatter power response of the tag is plotted as a function of glass water level for a given reader-tag separation. The water levels are varied from empty-full-empty in steps of a quarter volume. For each step, the state is maintained for a period of two minutes in order to get a stable set of power measurements. Data is plotted at a granularity of 15 seconds, so each step has a set of about 8 measurements (4 per minute) associated with it. Fig. 4 captures the power measurement plot for a reader-tag separation of about 3 feet (91 cm). 3 feet is much beyond the near-far field boundary of 1.8 feet so we can be sure that there is no inductive coupling effect. The shape of the graph makes logical sense. It is difficult to distinguish between the empty, quarter-filled and half-filled states of the glass due to the associated standard errors, but we can clearly see the reduction in reply power of the RFID tag as the water level approaches the three-quarter filled mark. For a full glass, the tag is not detected at all. We examine the effect of read range on the backscatter power measurements to see if we get repeatability of measurements. Fig. 5 summarizes the results for a reader-tag separation of 91, 122 and 183 cm respectively. There are a couple of interesting observations we can make here.

- If we look at Fig. 5, we observe that the power response for the tag in the half-full state is consistently better.

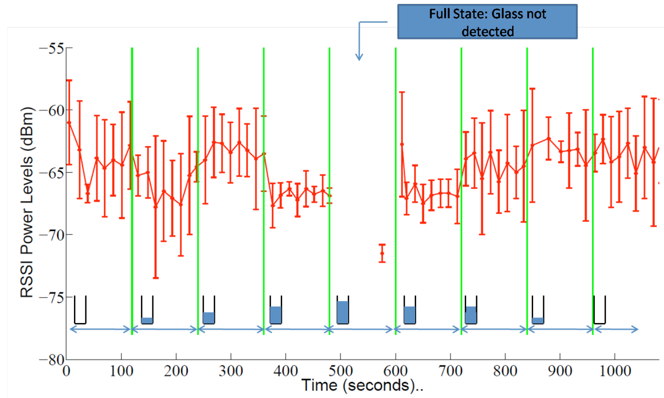


Fig. 4. Backscatter power as a function of water level for reader-tag separation of 91 cm

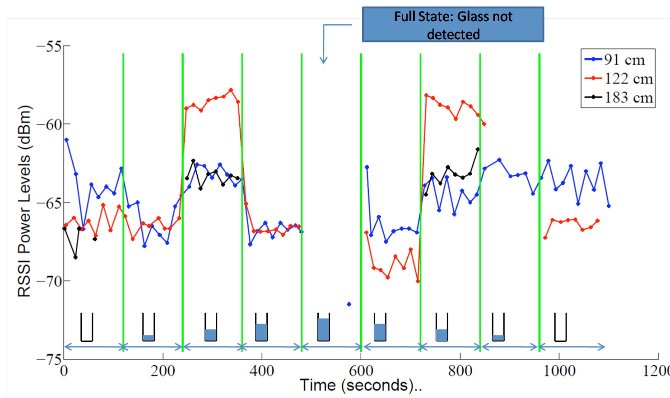


Fig. 5. Backscatter power as a function of water level for different read ranges

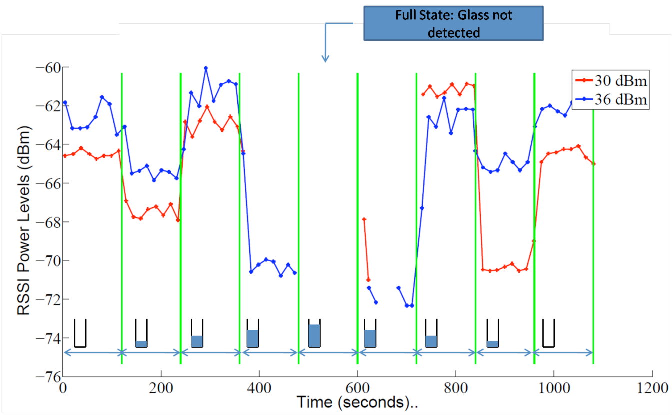


Fig. 6. Backscatter Power as a function of transmitted power at a reader-tag separation of 4 feet

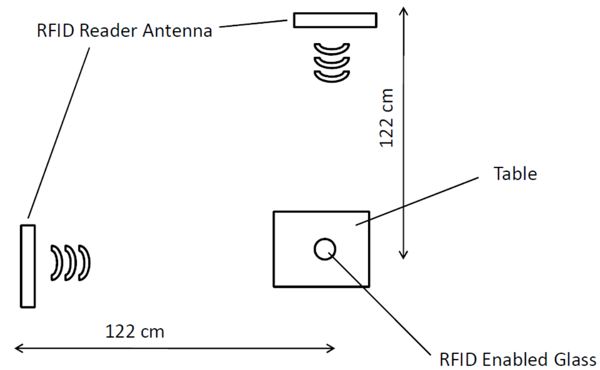


Fig. 7. Laboratory Setup to test the effectiveness of state classification

In fact, for a tag-reader separation of 6 feet, the tag is only picked up in this state while hardly picked up in the other states. This may be due to a number of possible reasons. The RFID chip impedance is a function of the reader operating frequency and transmitted power as highlighted by Loo *et. al* [18]. It is possible that at the supplied transmitted power of 36 dBm, the RFID chip impedance is better matched to the antenna on the glass-water dielectric. In order to confirm this power dependence, we decrease the transmitted power by 6 dB and check whether the nature of the graph changes. We choose a reader-tag separation of 4 feet since the tag's performance is clearly better for the half full glass at this range as noted in Fig. 5. Fig. 6 demonstrates that the matched impedance state of the chip does not significantly depend on the input power, as one graph is simply a scaled version of the other. Investigation into why this phenomena is consistently observed is the scope of future research.

- By looking at Fig. 5, we also conclude that the power response of the empty state tends to be slightly better than the response in the quarter or three-quarter filled state - although the results are not appreciably noticeable. As the glass approaches the completely full state, it fails to be detected for all read ranges.

From the experiments conducted in this section, we see that there is great variability associated with measurements from the RFID tag as the level of water in the glass is being varied. We note that it is, in general, possible to differentiate between the empty, half-filled and filled states of the glass as we've seen in Fig. 5. Looking at Fig. 5, we see that it might be difficult to differentiate between the empty, quarter-filled and three-quarter filled glass states based solely on the mean values, however it might be possible to differentiate between the states based on taking both the mean and standard deviation into account. Verification of the efficiency of a KNN pattern classification in predicting the state of fluid level in a glass using these mean and standard deviation measurements is the focus of the next section.

IV. State Classification and Positioning Classification Efficiency

In the previous section, we've examined the response of an RFID enabled drink glass as both a binary state sensor and as a fluid volume sensor. In this section, we use those observations to estimate the effectiveness of these hypotheses in glass state classification and approximate positioning.

A. *Classification Efficiency of the Fluid Volume Sensor*

As we observed in the previous section in the case of RFID based fluid volume sensing, it is possible to distinguish between the empty, half filled and full state, but there could be possible ambiguity in distinguishing between the empty, quarter and three quarter filled states. In order to test this, we conduct a simple experiment. We setup an RFID enabled glass shown in Fig. 3 at a distance of about 4 feet from two mutually perpendicular RFID reader antennae connected to the same reader as shown in Fig. 7. Our experiment is thus conducted for the use case where the distance of the test table is known precisely with respect to the two reader antennae. For fill volumes varying from empty to full in steps of a quarter volume, we compute the mean and standard deviation for each step. For each step, averages were taken over about 120 data points since it was observed that the means and standard deviations gained significant t-statistics at 95% confidence at this point. These set of averages were used as the training set (T) for the pattern classification.

We next conducted a set of 10 tests where the volume of water in the glass was randomly varied between empty and full. We chose two metrics to classify the state of the glass as outlined below:

- *Metric 1*: Let $(\mu 1_t, \sigma 1_t)$ and $(\mu 2_t, \sigma 2_t)$ be the mean and standard deviation of the power levels at antenna 1 and 2 for the test observation and $(\mu 1_i, \sigma 1_i)$ and $(\mu 2_i, \sigma 2_i)$ be the corresponding values for state i (iϵT) in the training

TABLE I
STATE CLASSIFICATION EFFICIENCY USING KNN FOR THE FLUID VOLUME SENSOR

True State	State: Metric 1	State: Metric 2
Empty	Empty	Empty
Half Full	Empty	Half-Full
Quarter-Full	Full	Three-Quarter Full
Three-Quarter Full	Full	Full
Full	Empty	Full
Half Full	Empty	Half-Full
Quarter-Full	Full	Full
Full	Empty	Full
Half Full	Empty	Half-Full
Three-Quarter Full	Full	Full

set. Then classify the test set as State i for that observation iϵT for which $\sqrt{(\mu 1_t - \mu 1_i)^2 + (\mu 2_t - \mu 2_i)^2}$ is minimized.

- *Metric 2*: Metric 2 includes the effect of standard deviation. Here the test state is classified as state i for that observation iϵT for which $\sqrt{(\frac{\mu 1_t - \mu 1_i}{\sigma 1_t{}^2 + \sigma 1_i{}^2})^2 + (\frac{\mu 2_t - \mu 2_i}{\sigma 2_t{}^2 + \sigma 2_i{}^2})^2}$ is minimized.

The performance of both test metrics is illustrated for the 10 test cases below: As we can see from Table. I, the performance of the classification improves significantly after including the effect of the standard deviation and we can successfully differentiate between empty, half full and full glasses. However, we are not able to distinguish between the full, three-quarter and quarter-full states. Thus a quarter filled glass will be mistakenly classified as a full or almost full glass. This introduces an element of uncertainty in our classification paradigm, which defeats the purpose of the application. Although it would have been useful to detect the volume of water in the glass, we need to modify the problem to remove this ambiguity in state classification and opt for the simpler (but surer) metric of binary state classification.

B. Classification efficiency of the Binary State Sensor

From the discussion in Section III and Section IV, we've oriented the tag to serve as a binary sensor to detect whether the glass is less or more than a quarter full. Also, from Section III, we've noticed that the RFID glass in the *Full* state is not picked up if the reader-tag separation exceeds 1 feet (about 31 cm). Furthermore for a mean operating frequency of 915 MHz, the near-far field boundary is about 1.8 feet (55 cm). Thus by ensuring that the minimum distance between any restaurant table and any antenna exceeds 2 feet, we ensure that the only condition under which an RFID tag is detected will be if the background dielectric for the tag is air i.e it is in the less than quarter full state. By doing this, we also ensure that the tag is never in the near-field zone of any reader and subject to inductive effects.

From Fig. 2, we see that there are 3 regimes in which the mean backscatter power from the tag is significantly different - at about 85 cm, between 122 and 152 cm and more than 183 cm. These differences could be useful if exploited by KNN classification scheme, using Metrics 1 and 2 as outlined in Section. IV-A which makes use of tag power measurements

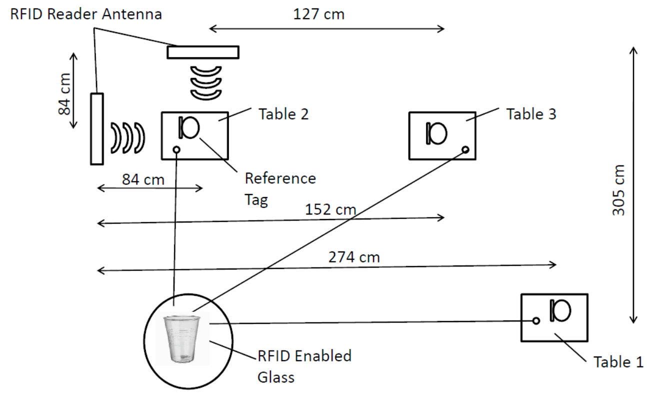


Fig. 8. Laboratory Simulation Environment

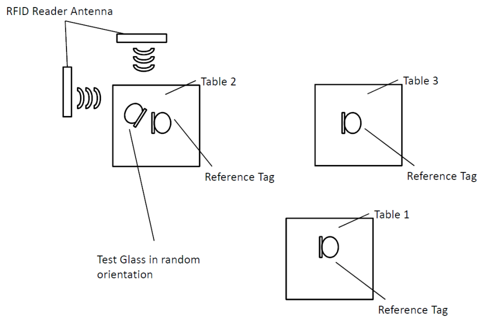
TABLE II
KNN STATE CLASSIFICATION EFFICIENCY FOR THE BINARY STATE SENSOR

Glass Details	Metric 1	% Metric 2
1-Full	Full	Full
2-Empty	2	2
2-Full	Full	Full
1-Empty	1	1
3-Full	Full	Full
2-Empty	2	2
3-Empty	3	1

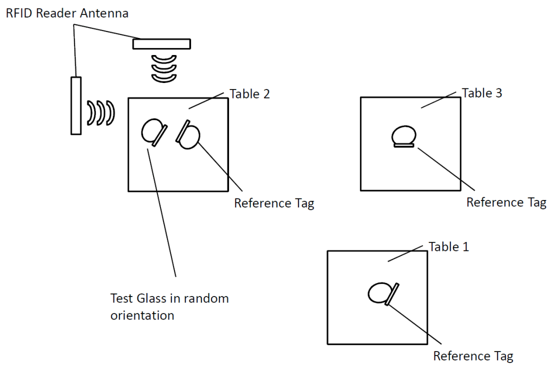
to discriminate between different locations. Via an experiment, we test this hypothesis in the placement of tables and see whether it would be possible to use tag antenna based sensing to not only detect the state of the glass as *Empty* and *Full*, but also be able to localize which table the empty glass is located on. Each of the restaurant tables have a reference empty glass on them, the power measurements of which will be used as a training set for the test glass. Fig. 8 shows the setup used for the experiment.

The experiment was conducted in a static room with no special anechoic provisions. Both reader antennas were transmitting at a power of 30 dBm. Furthermore, the tag antennas on all the reference glasses were oriented so as to face one of the reader antennae.

Table II demonstrates the results of a KNN based classification used to differentiate between states. The classification algorithm detects the state of the glass and attempts to approximately localize the empty RFID enabled glass. As we can see in Table. II, the empty glass is always correctly localized to table 2. The algorithm also correctly recognizes the *Full* state but is unable to predict where the full glass is situated. We notice that the algorithm tends to mis-classify the glass when it is empty on table 3. To confirm the performance, we run the KNN classifier 20 times, placing the empty glass on tables 1 through 3 in turn. We then repeat the experiment this time for random antenna orientations for the test tag and reference tags as shown in Fig. 9(a) and Fig. 9(b) The results of the classification are highlighted in Table. III As we can observe from Table. II, it is possible to unequivocally



(a) Test Glass with random antenna orientation



(b) Test and Reference Glasses with random antenna orientation

Fig. 9. Laboratory experiment with random tag antenna orientation

TABLE III
KNN LOCATION CLASSIFICATION EFFICIENCY FOR DIFFERENT ANTENNA ORIENTATIONS

Experiment	**Reference tags: Face Reader Antenna 1**		**Reference tags: Random Orientation**	
Glass Location	*% Metric 1*	*% Metric 2*	*% Metric 1*	*% Metric 2*
1	85	50	60	35
2	100	100	80	65
3	65	80	40	50

differentiate between full and empty glasses, however upon referring to Table. III, we see that the KNN classifier does rather poorly in predicting the location of the empty glass, despite our attempts to make use of the differences in mean RSSI values during positioning of the test tables and the fact that the experiment was conducted in a controlled laboratory setting with no dynamic movements in the environment. In a crowded restaurant setting, where there will be multiple reflections and tag shielding from people, waiters and service carts moving around, this performance will reduce further.

We thus confine our attention to the simpler problem of detecting a full or empty glass in a crowded restaurant like setting where there is ample scope of reflections and tag shielding. We conduct an experiment of detecting the presence of empty RFID enabled drink glasses at a social gathering and this is the focus of the next section.

Fig. 10. Hall with test subjects and RFID enabled glasses : Picture taken at the level of RFID Reader Antennae

V. RFID BASED STATE DETECTION PERFORMANCE IN PRACTICE

RFID based state detection works very well in a controlled laboratory environment as seen in Section IV. It is important to see how this technique performs in a real setting with people moving around and shielding the RFID enabled glasses. To quantify the performance, we conducted an experiment of detecting the presence of empty glasses at a social gathering of about 15 people in a hall of about 6 m x 8 m as seen in Fig. 10. Eight RFID enabled glasses were handed out to participants and the experiment was initialized by having all eight test subjects fill their glass with a drink of their choice. Four of the glasses were made of glass and the other five of disposable plastic, so as to get an understanding of how material affects the performance. The participants made no attempt to idealize experimental conditions. Specifically,

- No attempts were made to keep a clear line of sight between the RFID enabled glass and the reader antennas
- The participants did not take special care to leave the tag antenna exposed. At times, their fingers and palms obscured the tag antenna
- Depending upon the motion of the participant the distance of the RFID enabled glass from the reader could vary between about 2.5 m and 6 m. As we observed in Section. III, this will ensure that the only condition under which a glass is detected is if it is in the ’empty’ state.
- At least one participant (with glass number 9) filled the glass with ice upto the quarter volume mark.
- One of the glasses, glass 8 was placed empty on a table to serve as a baseline reference.

Over the course of the evening, as the subjects emptied their glasses, they at times reported this event. They remained in view of the reader antennas with the empty glasses for about one or two minutes before getting a refill. These events were then correlated to the RSSI values detected at two RFID reader

TABLE IV
GLASS STATE EVENTS

Event	Time from start (s)	Antenna 1 Detection (Y/N)	Antenna 2 Detection (Y/N)
Experiment Start	0		
Glass 7 Empty	0	Y	Y
Glass 9 Empty[1]	60	N	N
Glass 1 Empty	60	Y	N
Glass 2 Empty	120	Y	Y
Glass 3 Empty	180	Y	Y
Glass 4 Empty	240	Y	Y
Glass 6 Empty	300	N	N
Glass 4 Empty	360	Y	Y
Glass 3 Empty	720	Y	Y
Glass 5 Empty	900	N	Y
Glass 2 Empty	1100	Y	Y

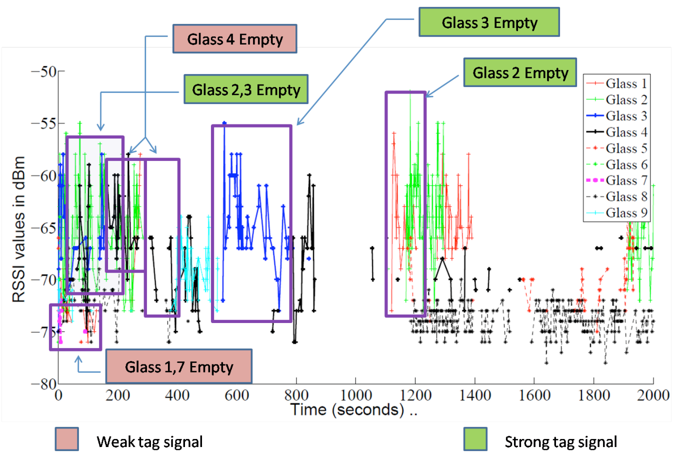


Fig. 11. Restaurant-Like Simulation: RSSI Power at Antenna 1

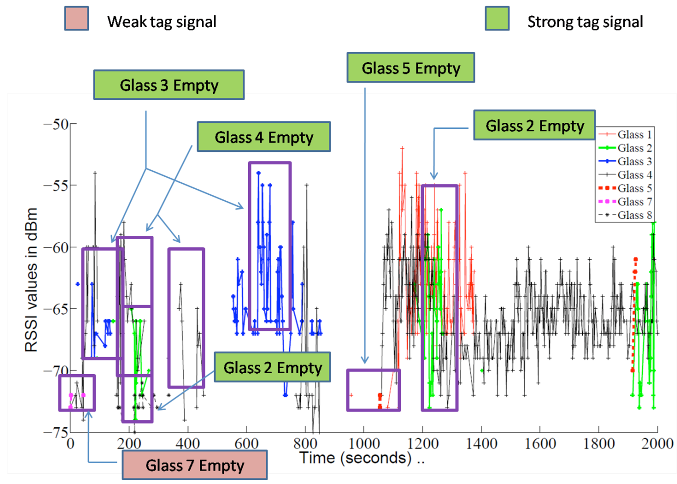


Fig. 12. Restaurant-Like Simulation: RSSI Power at Antenna 2

antennae which were mounted at an elevation of about 3 meters so as to cover most of the hall area. Both antennas transmitted at a maximum power level of 36 dBm.

Table IV highlights the times at which different subjects reported emptying their RFID enabled glasses. We then attempt to correlate these events with a map of mean RSSI values reported from the tags within the field of view of the two reader antennas as shown in Fig. 11 and Fig. 12 over the entire experiment. Some important observations we can make by referring to Fig. 11 and Fig. 12 are as follows:

- 9 of the 11 events were correctly captured via RSSI measurements at either or both of the antennas, indicating a 81% state detection efficiency. 6 of the 11 events are clearly noticable with a sustained RSSI power response from the glasses. This is encouraging considering the experiment was conducted in a room with ample scope for reflection and shielding with commercially available off-the-shelf RFID tags and RFID readers designed to maximize EPC reads rather than take sensitive power measurements.
- We see that there are huge variations in the RSSI values depending upon how far away the person was from the reader and the material of deployment. In general responses from glasses 2,3,4 were much stronger and these corresponded to the plastic cups which do not detune the RFID tag as much as glass.
- Glass 9 was not detected due to the presence of ice in the bottom quarter of the glass. The adverse effects of ice were confirmed by asking test subject 9 to empty the ice after the glass failed to be detected. As we can see from Fig. 11 (at t>400s), the empty glass 9 was detected at Antenna 1.
- Responses from glass 1 and glass 5 were poor despite these being plastic cups. It is possible that subjects 1 and 5 obscured the tags with their palms or fingers. Subject 5 in particular was noted to spend most of the time at least 4m from the reader antennas, which might account for the low strength signal detected in Fig. 12.
- Subject 7 was noted to spend most of the time within 4m of the reader antennas. Thus response from glass 7, which is made of pyrex, was consistently observed by both reader antennas, however the signal was very weak.

VI. CONCLUSIONS

In this paper, we examined the practical applicability of RFID tag antenna based sensing as a means to detect the level of fluid in a glass with the intent of minimizing refill latency in crowded restaurant settings. We attempted to use the RFID tag to serve as a fluid volume sensor to detect the volume of water in a glass, but highlighted the uncertainties associated with this approach. We then demonstrated that RFID based binary state sensing works without any uncertainty provided the full glass is beyond a certain minimum distance from the reader. This implies that several binary state sensors could be used to serve as a fluid volume sensor. We examined the feasibility of the binary state based sensing approach in a restaurant or pub like situation and obtained a good state detection rate of about 81%.

In this study, our sensing approach used custom off-the-shelf RFID tags pasted on drink glasses. As seen in Fig. 2 and Section V, the pyrex glass reduces the backscatter performance of the RFID tag. Fabricating an antenna custom designed to complex match the RFID chip on pyrex glass would thus significantly enhance RFID based state detection. Also, as seen in Fig. 5, we observed the tag performance was consistently better for the half-full state than the empty glass state. Investigation into why this phenomenon is observed is also the subject of future work.

We must also consider the problem of condensation. A lot of drinks are cold and this causes water vapour to condense on the outer surface of the glass, arbitrarily detuning the tag. Designing a hydrophobic coating that sheds water on build up in another important research avenue being explored. Furthermore, fabricating a pyrex glass with an inbuilt RFID tag is also a necessity, for this application in practice, since the RFID enabled glass will undergo several washings in its lifespan.

We attempted to use power measurements from two RFID reader antennae to approximately localize empty glasses using a KNN classification approach using RSSI measurements. Our hypothesis was that for the problem of approximate localization to different tables, this approach might work well enough. However, even for a controlled laboratory settings the results were not encouraging. As part of future work, we will continue to investigate techniques that provide good approximate localization of RFID tags based on RSSI and other tag measurement data.

In this paper, we calculated the effectiveness of this sensing paradigm in detecting empty glasses, but in general, by using multiple binary sensors, the concept can be extended to measuring the level of liquor in bottles at a bar - a scenario which is much more static and less prone to shielding than drink glasses moving around in a crowded restaurant. Liquor inventory is an important issue [19] [20] in the restaurant industry and this sensing paradigm would provide a reliable, low cost solution. Similarly, this sensing paradigm can be used to measure level detection in plastic overhead water and chemical storage tanks.

In conclusion, the more control we have over the environment of deployment, the better this sensing paradigm works. Static environments, where the tag is at a fixed distance from an RFID reader antenna and where shielding is minimized are ideal for this technology. Tag antenna based sensing does not provide a silver-bullet solution to all fluid volume sensing problems, but under the right conditions can provide an accurate, low cost sensing alternative for many applications in industry.

REFERENCES

[1] D.J Yeager, A.P Sample and J.R Smith, *WISP: A Passively Powered UHF RFID Tag with Sensing and Computation*, S.A Ahson and M.I. Eds, Ed. CRC Press, March 2008.

[2] R. Bhattacharyya, C. Floerkemeier and S. Sarma, "Towards Tag Antenna Based Sensing - An RFID Based Displacement Sensor," *IEEE International Conference on RFID*, pp. 95–102, 2009.

[3] J. Siden, X. Zeng, T. Unander and H.E Nilsson, "Remote Moisture Sensing utilizing Ordinary RFID Tags," *IEEE Sensors Conference*, pp. 308–311, 2007.

[4] S.R Aroor and D.D Deavours, "Evaluation of the State of Passive UHF RFID: An Experimental Approach," *IEEE Systems Journal*, vol. 1(2), pp. 168–176, December 2007.

[5] My City Restaurant Reviews: . http://www.mycity.com/s/restaurant.

[6] City of Boston Restaurant Reviews:. http://www.zagat.com/boston.

[7] http://dine.com/cgi-bin/public/main.cgi.

[8] Tell us about the worst restaurant service youve ever had. http://foodfrenzy.freedomblogging.com/2009/08/24/tell-us-about-the-worst-restaurant-service-youve-ever-had/7119/.

[9] How to Refill Customer Drinks as a Waiter. http://www.ehow.com/how_2318649_refill-customer-drinks-as-waiter.html.

[10] H.W. Gellersen, M. Beigl and H. Krull, "The MediaCup: Awareness Technology embedded in an Everyday Object," *1th Int. Sym. Handheld and Ubiquitous Computing* , 1999.

[11] P. Dietz, D. Leigh, and W. Yerazunis, "Wireless liquid level sensing for restaurant applications," *Sensors, 2002. Proceedings of IEEE*, vol. 1, pp. 715 – 720 vol.1, 2002.

[12] Y. Zhou, W. Liu, and P. Huang, "Laser-activated rfid-based indoor localization system for mobile robots," pp. 4600–4605, April 2007.

[13] D. Hahnel, W. Burgard, D. Fox, K. Fishkin, and M. Philipose, "Mapping and localization with rfid technology," vol. 1, pp. 1015–1020 Vol.1, April-1 May 2004.

[14] X. Liu, M. D. Corner, and P. J. Shenoy, "Ferret: Rfid localization for pervasive multimedia." vol. 4206, pp. 422–440, 2006. [Online]. Available: http://dblp.uni-trier.de/db/conf/huc/ubicomp2006.html#LiuCS06

[15] L. Ni, Y. Liu, Y. C. Lau, and A. Patil, "Landmarc: indoor location sensing using active rfid," pp. 407–415, March 2003.

[16] Dobkin, Daniel M., "The RF in RFID: Passive UHF RFID in Practice," *Elsevier Inc*, 2008.

[17] Alien Technologies. RFID Tags: The Squiggle Tag. http://www.alientechnology.com/tags/index.php.

[18] C.H Loo, K. Elmahgoub, F. Yang, A. Elsherbeni, D. Kajfez, A. Kishk, T. Elsherbeni, L. Ukkonen, L. Sydänheimo, M. Kivikoski, S. Merilampi and P. Ruuskanen, "Chip Impedance Matching for UHF RFID Tag Antenna Design," *Progress in Electromagnetics Research*, vol. 81, pp. 359–370, 2008.

[19] iBarControl : Inventory control software for the hospitality industry, "http://www.ibarcontrol.com/."

[20] Accubar: Liqour Inventory, "http://www.accubar.com/."