EXPERIMENTAL INVESTIGATION OF RADIO FREQUENCY IDENTIFICATION RANGE FOR INTRAOCULAR IMPLANTS

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ABSTRACT
Application of RFID technology to intraocular instrumentation requires an understanding of the reliability of propagation through optical tissues and fluids. In this study, the working distance for passive RFID operation is measured in a simulated intraocular environment using porcine eyes. Results are obtained in three common RFID ranges: low frequency, high frequency and ultra-high frequency. Several media were tested to assess the possible impact of intraocular materials. Variations in the possible working distance were observed for certain media, but the data suggest that reliable RFID operation for intraocular sensors is possible at a range of 2-4 cm.

KEY WORDS
Electronic Medical Devices, Bioinstrumentation, RFID, IOP Sensing.

1. Introduction

Improvement of Radio Frequency Identification (RFID) technology in recent years presents engineers with a number of potential applications with respect to human implants. Toward this end, Aubert [1] has presented a broad overview of the recent advances and remaining challenges for implanted RFID systems. The author provides technical details regarding theory of operation and frequency-specific characteristics and also concludes that an RFID implant, which will likely consist of a passive tag, has great potential to interface with a nearby interrogator but long distance communication is not a realistic use for current passive tag systems. Researchers and engineers in the field of ophthalmology are seeking to develop sensor-embedded ocular implants that can continuously read the Intraocular Pressure (IOP) in real-time [2]. Commercialization of such a device would provide Glaucoma clinicians with extensive and dynamic IOP data for monitoring their patients [3,4], leading to earlier warnings and improved treatments for eliminating and/or mitigating glaucomatous damage.

The purpose of the experiment described in this report is to investigate the read range between a passive RFID tag implanted near the Intraocular Lens (IOL) in the eye and a nearby reader. In a prototype version, which is outside the scope of the current study, the read values present on the tag would represent the IOP data from an onboard sensor and the reader hardware is possibly integrated into a wearable, such as a pair of eyeglasses. Such a system requires an RF read range of about 2 cm.

Novel applications of passive-tag-based RF measurement are mainly focused on inventory control or other industrial uses, such as pinpointing the location of an object [5-11] and employing signal strength indicator images for robotic navigation [12]. Gao [13] and Seshagiri Rao et al. [14] provide in-depth discussions on antenna designs in the UHF range. However, it should be noted that the focus of the above papers is inventory-related applications, whereby long read range (several feet) is often necessary and manufacturing costs drive the hardware design. In contrast, medical applications require emphasis on material selections and optimal performance at short range. Nonetheless, these papers provide some reference for RFID theory, performance and modeling data, and rationale for antenna design elements.

In the present work, we employ off-the-shelf tags as a means for primary investigation of the effect of ocular tissue presence on read range for various RFID frequencies. As a secondary element of this study, it is of interest to note the variation of range based on frequency, though we acknowledge that a more in-depth study would be required to draw any strong conclusions from that information since the antenna designs were not optimized for use in ocular implantation. In addition, safety concerns, such as those raised by [15], are likely to vary based on frequency.

2. Experimental Setup

In this study, three off-the-shelf RFID readers and compatible passive tags were used that had the following frequency characteristics: low frequency (LF) at 125 kHz, High Frequency (HF) at 13.56 MHz, and Ultra-High Frequency (UHF) from 902-928 MHz (EPC Gen2). The make and model of the readers were: ID-innovations ID-12LA with SEN-11827 Reader Attachment (LF), Freaduino UNO V1.8.1 with NFC/NFC Shield V1.6 (HF), and RFID ME™ RU-888 (UHF); and the tags used were: Parallax 28161 Tag (LF), SEN-10128 Tag (HF), and UHF KEY TAG Cutedigi.com (UHF). The three tags selected are shown in Fig. 1. All were approximately 2 cm in diameter. However, the UHF tag was packaged as a 4 cm

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wide unit that included a center loop portion of approximately 2 cm in diameter, from which the dipole extensions were cut, as illustrated in Fig. 2, to provide a form factor similar to that of the LF and HF tags. It should be understood that further work is required to study read ranges in an absolute sense since the possibility remains for these tags to be optimized for intraocular use. Therefore, in this paper we highlight our experimental findings of relative read ranges for varied ocular tissue presence.

Fig. 1: Passive tags used in experiments. From left to right: LF, HF, and UHF

Fig. 2: Cutting pattern for the UHF tag

Custom mounting was designed and realized, which was necessary to vertically suspend an RFID tag above its reader and allow the tag to be brought closer to the reader in a slow, steady, and linear manner. Nonconductive mounting components were drawn using Solidworks parts and 3D printed in ABS plastic using a Dimension SST 1200ES printer. The setup is shown in Fig. 3, which also includes two vertical polycarbonate rods. Six porcine eyes (http://www.sierra-medical.com/) within 72 hours of extraction were used to simulate human ocular tissue. Surgical scissors were used to cut the porcine eyes along the equator for about 11 clock hours, leaving one clock hour to serve as a hinge. To simulate a "worst case" presence of ocular tissue, a mixture of aqueous humor and vitreous humor was placed in the anterior portion of the eye by removing approximately half of the vitreous gel with the eye facing downward. A passive RFID tag was then placed on top of the vitreous humor remaining in the eye with the electronics side facing upward to minimize exposure to the medium. The posterior segment (mainly sclera) was laid back on top of the tag. For the other data sets, the anterior segment of the eye was washed out with saline solution (off-the-shelf for contact lens use) and then refilled with either saline solution or left unfilled, the latter allowing for an isolated attenuation measurement due only to the presence of solid ocular tissues (mainly the cornea and anterior sclera). It should be noted that initially some data was collected for eyes filled with distilled water. However, such data sets varied significantly when rinsed and refilled. Therefore, we postulate that small remaining impurities in distilled water may vary from sample to sample – even if originating a single container – and significantly impact the electromagnetic behavior.

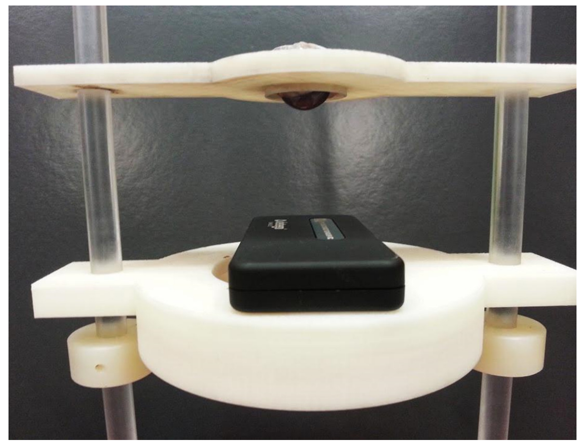

Fig. 3: Experimental setup for determining the RFID read range through Porcine Eyes

A fresh eye was used for each run (six runs in total: three frequencies each performed for two different eyes). Upon completion of the setup for each data set, the upper plate upon which the eye and passive RFID tag rested was manually lowered in a slow, consistent fashion until the earliest recognition of the tag by the reader was established. Then high precision Vernier calipers were used to measure the distance between the two mounting plates (upper side of lower plate and underside of the upper plate). This process was repeated four more times prior to changing the test medium in the eye, providing five measurements for each scenario, per run. Two offset values, the height of reader above bottom mounting plate and the distance from the lower surface of the upper plate to the reader tag, were measured once and then applied to each data set (for that reader/tag) for consistency.

3. Results and Discussion

The experimental results are shown in Figs. 4-6. Data was collected independently for the three selected RFID frequencies: LF (125 kHz), HF (13.56 MHz) and UHF (~900 MHz), as described in Section 2. The heights of the bars correspond to mean values of the five measurements with error bars indicating maximum and minimum values. Within each band, comparisons can be made between the various media; however, use of different readers and RFID tags limit conclusions comparing absolute range measurements between the frequency bands. Thus, our conclusions and insights are primarily based on the variations across the media present in the anterior segment and provide only secondary insight to approximate read ranges across common RFID frequencies.

Results in the LF band were consistent with expectation based on the electrical conductivity and propagation coefficients of the media used. Air gave the largest overall working distance, with distinct and consistent decrease through saline solution and aqueous/vitreous humor (AH/VH), with a reduction in range of nearly 50%. There was negligible attenuation due to simply the presence of the cornea.

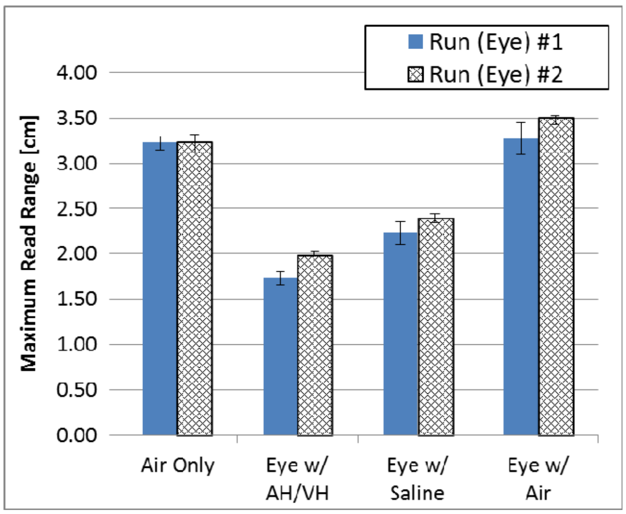

Fig. 4: Tested read ranges for the LF (125 kHz) system

However, the experimental data at 13.56 MHz revealed an interesting behavior. Fig. 5 shows a consistent realized range for the HF system, indicating negligible attenuation caused by the presence of any of the tested media. Both 1% saline and aqueous/vitreous humor have much higher electrical conductivities than air [16] [17], and it would be expected that the RF absorption is also higher. Yet the experimental data sets show no observable attenuation, despite the fact that significant attenuation is observed in this study for both a lower (Fig. 4) and a higher (Fig. 6) frequency. Further investigation to determine the mechanism of this performance is recommended.

The performance of the UHF RFID system (near 900 MHz) is mostly consistent with that measured in the 125 kHz band in that, in general, the presence of the testing media caused significant reduction in the maximum read distance. However, a reduction in range was observed for the presence of the shell of the eye only (essentially cornea and anterior sclera), though none was observed for the shell under the LF system. In both cases, significant attenuation was observed when the aqueous humor and vitreous humor mixture was present. For the UHF system, much variation was observed for the saline medium between the two runs. This is most likely explained by changes in the physical condition of the UHF tag during testing since, for each frequency, the same physical tag was used for all testing.

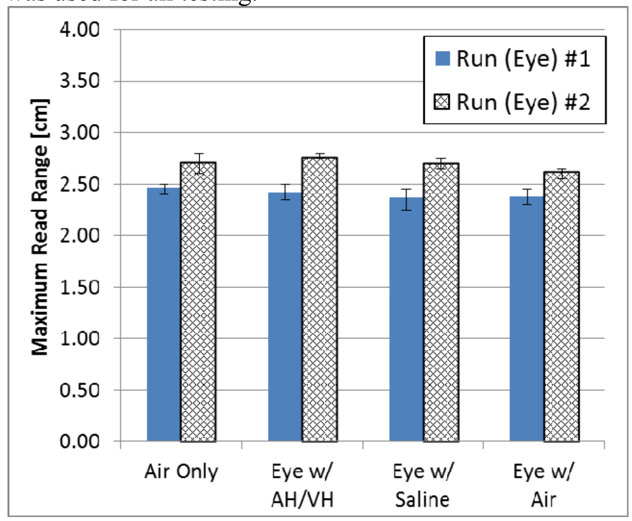

Fig. 5: Tested read ranges for the HF (13.56 MHz) system

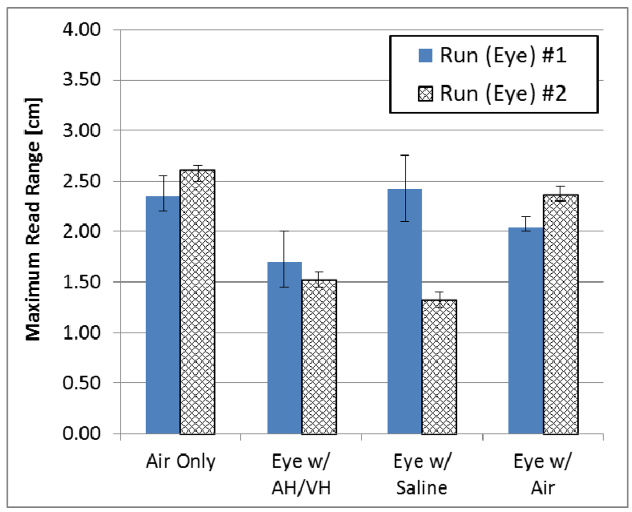

Fig. 6: Tested read ranges for the UHF (~900 MHz) system

Other than the unexpected constant - and sometimes subtle - increase in working distance for some select cases (implying improved RF propagation), the relation between media type, electrical conductivity and working distance is intuitive. Our experimental data suggests the following. Generally, media with lower electrical conductivity and density provide longer working distances, likely due to lower electromagnetic attenuation. At 13.56 MHz, RFID technology appears completely insensitive to the presence of ocular tissues in the radiative path. Even for a system not optimized for ocular implantation, the 13.56 MHz band demonstrated *in vitro* a wireless range greater than the required 2 cm range for nearby wearable (eyeglasses). To accomplish this same performance in a robust manner, design optimizations are required for systems using LF and UHF bands.

4. Conclusion

Our studies on *in vitro* porcine eyes showed the ability to communicate via passive RFID with intraocular devices. Measurements involving a variety of media showed working ranges to several centimeters, adequate for communicating with a small reader in a wearable such as eyeglasses. Though different materials in the anterior chamber of the eye had an effect on the working distance, communication was observed for all substances likely to be involved in the propagation path. Data was collected in the LF, HF and UHF RFID bands; operation in the HF (13.56 MHz) was the least sensitive to intervening media. Some aspects of the use of passive RFID for communication with intraocular devices bear further investigation. Even for a system not optimized for ocular implantation, the 13.56 MHz band demonstrated *in vitro* a wireless range greater than the required 2 cm range for a nearby wearable (eyeglasses); however, design optimizations are required for systems using LF and UHF bands.

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