NOVEL TECHNIQUES FOR IMPROVED INDOOR POSITIONING AND LOCALIZATION USING HF RFID

By

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CERTIFICATION

I certify that this thesis has not already been submitted for any degree and is not being submitted as part of candidature for any other degree.

I also certify that this thesis has been written by me and that any help that I have received in my research work, preparing this thesis, and all sources used, have been acknowledged in this thesis. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Candidate

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Signature removed prior to publication.

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(Mohd Yazed Ahmad)

DEDICATION

To my family members for their
patience and consistent support

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During the period of four years of my PhD candidature, I have received consistent support from my supervisor, friends and staff at the UTS. Firstly, I would like to thank my supervisor Associate Professor Dr. Ananda Mohan Sanagavarapu (a.k.a A. S. Mohan) for giving me opportunity to work under his supervision. His tireless support and critical comments have helped me to excel in achieving many of my research goals and that extremely helped me in producing this thesis.

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ABSTRACT

This thesis investigates High Frequency Radio Frequency Identification (HF RFID) based positioning using a novel concept of multi-loop bridge reader antenna to localise moving objects such as autonomous wheelchairs in indoor environments. Typical HF RFIDs operate at 13.56 MHz and employ passive tags which are excited by the magnetic field radiated by the reader antenna. Positioning of moving objects using HF RFID systems derive location information by averaging the coordinates of detected passive floor tags by a portable reader antenna which are then recorded in the reader's memory and database. To successfully detect floor tags, the reader's antenna usually installed at the base of a moving object needs to be parallel to the floor. The magnetic field radiated by the HF RFID antenna is confined within its near field zone i.e., it is confined to a very close proximity of the antenna. This property of HF RFID helps to minimise interference to other appliances that may be present within the localisation area. Thus, HF RFID based positioning offers great potential benefit in providing location assistance in environments such as nursing homes, health care facilities, hospitals etc.

However, despite the significant developments that have occurred in this field, there still exist problems with positioning accuracies obtainable mainly due to the uncertainty of the reader recognition area (RRA) of the reader antenna, which has not been fully addressed in literature. This thesis aims to address this problem by proposing the concept of multi-loop bridge reader antenna so that the reader recognition area is divided into multiple sub zones and an error signal (bridge signal) in terms of the position of the tag will be generated that helps to reduce the position uncertainty.

The thesis starts with an investigation of the methods for creating multiple zones of RRA and the concept of bridge loop antenna from point of view of near magnetic fields. Different types of loop antennas for employing at the reader are electromagnetically analysed using both closed form solutions and numerical computations. The formation of reader recognition area (RRA) from different arrangements of loop reader antennas is also studied.

To ensure that proposed bridge antennas can perform in realistic, non-ideal indoor environments where they are affected by proximity of metallic objects etc, we proposed

methods of improvement. Equivalent circuits that reduce the computational complexity but can provide a broader understanding of the behaviour of bridge antennas have been formulated. This has lead to investigation of methods to minimise and/or eliminate the effect of metallic objects on the bridge signals.

Next, we investigate the applicability of the proposed bridge loop antenna for the localisation and positioning of an autonomous wheel chair resulting in a realistic implementation of HF RFID based positioning system. The system is then tested to localise an autonomous wheelchair in an indoor environment using a grid of passive floor tags. Novel algorithms are proposed to estimate the position and orientation of the moving object using bridge signals generated by the bridge antenna coupled with the available dynamic information of the wheelchair. A comparison of our experimental results with the published results in the literature revealed significant improvements achieved by our proposed methods over existing techniques for estimating both, the orientation and position. Further, we demonstrate that the proposed technique obtains accurate position and estimation using much lesser number of floor tags (increased sparcity) than any of the currently published method, thus, contributing to simplified and easily expandable tag infrastructure deployment.

We further extend the use of bridge loop antenna for situation when multiple tags are detected using the method of load modulation of the tags. When multiple tags present within the RRA of the bridge loop antenna, the resulting bridge signals incorporate information from all of the detected tags thus making it difficult to locate individual tags. To overcome this, we utilise states of the tag’s load modulation to separate these bridge signals, which then allow us to utilise them to estimate instantaneous position and orientation of the moving object. We performed analysis using equivalent circuits, as well as computational electromagnetic modelling of realistic antennas, which are then compared with experimental measurements carried on prototype systems. The comparison showed good agreement which validate our proposed method.

Thus, the thesis incorporate contributions on various aspects of bridge loop reader antenna for HF RFID based positioning system. All full wave electromagnetic computations and simulations were carried by using a well known antenna design package “FEKO”. All the key analyses, equivalent circuits, antenna models and

computational results for the proposed antennas and algorithms have been verified using extensive experimental campaigns to demonstrate the practical usefulness of the proposed methods. It is hoped that the findings in this thesis will result in newer efficient positioning systems in future.

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List of Symbols

θ_β	θ_β is the angle between radial line r_β and the line along X_β-axis (see Figure 4-8)
θ_k	Heading of the object relative to the floor tags x-axis
ΔZ_m $m \in$ (Tag, Metal, Tag_Metal)	Change in impedance due to proximity of either or both tag and metal
C_{modul}	Capacitive load for modulation in a passive tag
d_{tag}	Inter tag separation distance
H	Magnetic field (A/m)
h_a	Separation between the plane of reader antenna and the plane of tag
h_m	Separation between the plane of reader antenna and the plane of metallic plate
Im(..)	Imaginary part
L	Length of the antenna
Loop-n ($n \in$ a, b, c, d)	Notation for loop elements in a bridge antenna
M_{ij} $i \in (R,T,R',T')$ $j \in (R,T,R',T')$	Magnetic coupling between loop i and j R: reader loop, T: tag loop, R': image of reader loop, T': image of tag loop
P_a, $P_{c,d}$ and P_f	Points on the path of the object (PO_i) corresponding to the time flags of tag_i
Phs(..)	Phase component
POi	Path/trajectory of the moving object during the period of the presence of tagi
Q	Quality factor
R_{modul}	Ohmic load for modulation in a passive tag
RRAn $n \in (1,2,3,4)$	Sub zones of RRA i.e. zone-1, 2, 3, or 4.
RRA-n $n \in$ (i, ii, iii)	Type of reader recognition area, i.e. type-i, ii, or iii (see section 2.3)
S_{Rmodul}	Switch for load modulation of a tag
t_n $n \in$ (a, b, c, d, e, f)	Time-Flag-of-Tag_i a: when tagi starts to appear in RRA1, b: tagi in the middle of RRA1, c: RRA1 leaves tagi, d: tagi starts to apper in RRA2, e: tagi in the middle of RRA2, f: RRA1 leaves tagi
U_{Mij}	Potential due to magnetic coupling M_{ij}
V_β	Bridge potential signal i.e the potential signal between arm-1 and and-2
$V_{\beta 1}$, $V_{\beta 2}$	Signal at bridge arm-1, Signal at bridge arm-2
V_p	Voltage potential at a bridge source terminals (see Figure 3-14)

W	Width of the antenna
X_β ,Y_β	X and Y axes cantered at a bridge antenna
$X_{(C \text{ or } \beta)}$	The estimated position of the object carrying reader antenna C:conventional reader antenna, β: bridge reader antenna
X_{Cmodul}	Reactive impedance of capacitive load modulation
$Z_n \quad n \in (a, b, c,d)$	Impedance of the loop elements in a bridge antenna
r_β	Radial distance between centre of RRA to the estimated tag position

List of Abbreviations

BP	Bridge potential
CW	Continuous wave
DBRLA	Dual bridge rectangular loop antenna
HF	High Frequency
IC	Integrated Circuit
MBRLA	Multi bridge rectangular loop antenna
MoM	Method of Moments
PC	Positioning Controller
RFID	Radio Frequency Identification Device
RRA	Reader Recognition Error
SBRLA	Single bridge rectangular loop antenna
SBTLA	Single bridge triangular loop antenna
TLB	Triangular Loop Bridge Reader Antenna