Center for Embedded Systems (CES)
Request for Proposals Template – YEAR 5

DUE: Monday, April 8, 2013, by 5 p.m.

TITLE:	Feasibility Study for an RF-Based Proximity Sensor using Embedded Antennas in High Velocity Projectiles				
PI:	C.J. Hatziadoniu	**EMAIL:**	hatz@siu.edu	**TEL:**	(618) 453-7036
DEPT:	Electrical and Computer Engineering	**SCHOOL:**	Engineering		
Co-PI:	Frances Harackiewicz	**EMAIL:**	franharackiewicz@gmail.com	**TEL:**	(618) 453-
DEPT:	Electrical and Computer Engineering	**SCHOOL:**	Engineering		

ABSTRACT: (250 OR FEWER WORDS)

This project proposes to study the feasibility of an embedded RF-based proximity sensor in a high-velocity projectile. The sensor will incorporate an RF antenna. The study will investigate the design requirements of the antenna with regards to transmitting and receiving RF signals at significant levels and with sufficient SNR in order to enable the detection of proximity. Along with the antenna investigation, the project will also investigate appropriate signal processing algorithms that will enable the quick and reliable detection of proximity based on the signals received by the antenna. One part of the methods will include numerical simulation of both the antenna and the signal processing under variable environment. Another part of the methods will include studying the possibility of using the projectile body as antenna and perform experimental tests in the anechoic chamber in order to verify the antenna patterns versus frequency relation and its power requirements. The project deliverables include (a) the data and outcomes from the investigative studies; (b) a preliminary antenna design; (c) and a suitable signal processing algorithm for fast proximity detection. A fully developed embedded RF-based proximity sensor will improve significantly the accuracy and efficacy of the projectile. The outcomes of the proposed work will provide the basis for a later effort to refine, optimize and subsequently develop and test a prototype RF-based proximity sensor. In this regard, the proposed work will be of benefit to the related industry. The proposed work is for 1 year and the requested budget is $50k.

PROBLEM:

In certain high-velocity projectile applications, effectiveness of the projectile greatly improves when operation is achieved at an optimum distance from a target. One method of achieving this is presetting the operation time based on a speed-distance estimation. This method even though can provide a back-up is not always reliable or accurate. A more accurate method is to incorporate into the projectile a proximity sensor. This project proposes to use an RF-based sensor because it offers greater capabilities and flexibilities concerning range control environment interference and versatility of programming and design.

The problem that this work proposes to investigate includes the following aspects of the sensor: (a) the sensor RF antenna. The project will investigate what patterns are suitable for the particular application given the limited size and operating conditions of the sensor. The project will also investigate using the projectile body (with some minor modifications) as an antenna; (b) the signal processing algorithm which will provide the proximity detection threshold is the complementary problem that this study will investigate. The primary challenge here is the necessary accuracy and speed of the detection method in order to produce a reliable and easily implementable sensor.

RATIONALE:

The proposed project is necessary in order to lay the ground work for developing a prototype. Given the importance of the sensor in improving the performance of the projectile, a significant amount of study, including experimental work, is necessary to guarantee a successful outcome. This project provides the first significant step in this direction.

APPROACH:

The antenna design must meet the criterion for impedance to match with the sensor circuitry and size to fit within the boundary of the projectile body. In addition, the antenna design will include the frequency of operation, polarization of signal, and shape of pattern which will give the best return for the specified projectile paths and terrains. The trajectory, projectile, operation frequency, polarization and location of the designed antenna will determine if a single element for transmit and receive will suffice or whether two separate elements will be required. Once all of these design parameters are determined, the antenna types will be chosen and designed which best match them. RF proximity development goes back to the days of WWII. A general (within security regulations) summary article of the time [1] describes two classes of antennas that could be used in such devices: longitudinal or ring-type and transverse or bar-type. The former giving a directivity pattern perpendicular to the shell and thus more useful for trajectories that are horizontal. The latter giving a directivity pattern tangent to the line of the shell and thus more useful for vertical trajectories. In [1], the longitudinal antenna is said to employ the body of the projectile as the antenna. Although detailed specifications including dimensions are not given in [1], they are likely not the same as in this application. The main challenge will include making the antenna compact enough to fit in the size requirement and still perform with reliable electromagnetic requirements. One recent advancement in compacting the size of an antenna in a projectile application, albeit to communicate with 1.6 GHz GPS satellites, used four inverted-F type elements to fit in a cone with base diameter of 36mm [2]. If the signal processing determines that the cone is a useable location for the antenna, something similar may be an option in this case. Whether the antenna will be embedded in the outer surface of the shell or within the cone, it will be designed using numerical simulation tools. A mock-up of the best design will be constructed and tested for its circuit performance of impedance versus frequency. In addition, it will be tested in an anechoic chamber for polarization and pattern shape. The power budget of the antenna will also be computed.

The signal processing algorithm is the critical part of the sensor with the potential to optimize the overall detection performance. The main challenges include (a) variable environments yielding variable return ratios from the antenna; (b) interference from asynchronous emissions from other RF sensors operating in proximity; returns due to multiple paths—reflections from nearby obstacles; other potential malleus interference; (c) the requirement for quick response under the previous adverse conditions, given the projectile high velocity and the short proximity of operation required. Approaches that will be investigated to deal with these problems include (a) budgeting the spectrum and allocating spectrum at random; (b) investigating the signal timing and modulation properties. Typically, in this type of detection systems a burst signal is send out by the antenna while the receiver is in silence. Subsequently, the returns are counted by the receiver and detection is achieved when a threshold is reached [3-6]. Numerical simulation will be used to represent the antenna-environment path assuming varying path properties (e.g. attenuation and distortion). The simulation studies will provide the sensitivity of the detection algorithm to environment and operating conditions variations. Under the previous studies it will be possible to improve the robustness of the detection algorithm in order to further enhance the sensor reliability.

NOVELTY:

There are two potential scientific advancements under this project: (a) the use of the projectile body as antenna that could be useful in other applications in addition to proximity detection; (b) the characterization of the environment under the RF signals and the development of the detection algorithm.

POTENTIAL BENEFITS TO INDUSTRY MEMBERS:

An accurate and reliable RF-based proximity sensor can significantly improve the accuracy of the projectile and its effectiveness. This project will provide the ground work for developing and testing a prototype detector based on the discoveries in this work.

DELIVERABLES:

The following will be delivered by the end of the project: (a) the data and outcomes from the investigative studies; (b) a preliminary antenna design along with the power budget requirements; (c) and a suitable signal processing algorithm for fast proximity detection.

TIMELINE/MILESTONES: (PER QUARTER)

The project duration is for 1 year. The following are the project mile stones.

Task/Milestone	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
Investigation of the antenna				
Anechoic chamber tests				
Preliminary antenna design				
Detection algorithm development and fine tuning				

TECHNOLOGY TRANSFER:

The PIs will cooperate closely with General Dynamics—OTS for the purpose of receiving data necessary for the investigations proposed herein and for the purpose of exchanging ideas/receiving guidance to fine tune the research outcomes to be most practicable and applicable to developing useful technical applications.

BUDGET:

The project is requesting $50,000 for one year to be spend as follows:
PI Hatziadoniu: $19,120
Co-PI Harackiewicz: $6,740
PhD Student (50%): $20,259
OTS (Travel, eq., etc): $3,880

BIBLIOGRAPHY: (ATTACH IN IEEE CONFERENCE OR JOURNAL FORMAT)

[1] W. S. HINMAN, JR. AND CLEDO BRUNETT, "Radio Proximity-Fuze Development," *Proceedings of the I.R.E. and Waves and Electrons*, December 1946, pp.976-985.

[2] Jae-Hoon Bang, Member, IEEE, Bayanmunkh Enkhbayar, Dong-Hyun Min, and Bierng-Chearl Ahn, "A Compact GPS Antenna for Artillery Projectile Applications," *IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS*, VOL. 10, 2011.

[3] Sant, L.; Torta, P.; Fant, A.; Dorrer, L., "A system containing an ambient light and a proximity sensor with intrinsic ambient light rejection," *ESSCIRC (ESSCIRC), 2012 Proceedings of the* , vol., no., pp.97,100, 17-21 Sept. 2012.

[4] Sabatini, A.M.; Genovese, V.; Guglielmelli, E.; Mantuano, A.; Ratti, G.; Dario, P., "A low-cost, composite sensor array combining ultrasonic and infrared proximity sensors," *Intelligent Robots and Systems 95. 'Human Robot Interaction and Cooperative Robots', Proceedings. 1995 IEEE/RSJ International Conference on* , vol.3, no., pp.120,126 vol.3, 5-9 Aug 1995.

[5] ElShafiey, T.M.F., "Design and implementation of a museum and banks security system using antenna as IR proximity sensor and PSoC technology," *Wireless Technology and Applications (ISWTA), 2011 IEEE Symposium on* , vol., no., pp.156,161, 25-28 Sept. 2011.

[6] Zeng, S.; Powers, J.R.; Jackson, L.L.; Conover, David L., "Digital measurement of human proximity to electrical power circuit by a novel amplitude-shift-keying radio-frequency receiver," *Circuits and Systems, 2005. ISCAS 2005. IEEE International Symposium on* , vol., no., pp.576,579 Vol. 1, 23-26 May 2005.

CONSTANTINE J. HATZIADONIU, Professor, hatz@siu.edu
Electrical and Computer Engineering at Southern Illinois University
1230 Lincoln Dr.
Carbondale, IL 62901-6603

Education

Diploma in Electrical Eng., University of Patras, Greece, 1983
Ph.D. in Electrical Eng., West Virginia University, Morgantown, 1987

Professional Experience

- Professor of Electrical and Computer Engineering, Southern Illinois University Carbondale. July 2003-present.
- Associate Professor in the Department of Electrical and Computer Engineering, Southern Illinois University Carbondale. August 1993-2003.
- Assistant Professor in the Department of Electrical Engineering, Southern Illinois University Carbondale. August 1989-August 1993.
- Visiting Assistant Professor in the Department of Electrical Engineering, Southern Illinois University Carbondale. September 1987-1989.
- Teaching and Research Assistant. Department of Electrical Engineering, West Virginia University, Morgantown. August 1984-1987.
- Consulting engineer, Greece. August 1983-1984.

Research Interests

Power electronics, Energy harvesting devices, wind and photovoltaic energy systems, power system modeling and simulation; power system control and protection.

Recent Publications.

C.J. Hatziadoniu, N.B. Harp, and A.J. Sugg, "Finite-Element Models for Open-Air Power Lines in Broadband PLC", IEEE Trans. On Power Delivery, Vol. 21, No. 4, Oct. 2006, pp. 1898-1904.

Hany A. Abdelsalam and **C.J. Hatziadoniu**, "A Robust Wide Area Controller of Multiple FACTS for Damping Oscillations in Multi-Area Power System Using the H∞ Method", Power System Conference 2011 PSC11, March 15-18, 2011 at Clemson University, Clemson, SC, USA.

F. Pourboghrat, F. Farid, C.J. **Hatziadoniu**, M. Daneshdoost, F. Mehdian, M. Lotfalien, "Local Sliding Control for Damping Inter-Area Power Oscillations", IEEE Trans. On Power Systems, PES 19-2, May 2004, pp. 1123-34.

A. Albanna and **C.J. Hatziadoniu**, 'Harmonic Modeling of Hysteresis Inverters in the Frequency Domain', IEEE Trans. on Power Electronics, Vol. 25, No 5, May 2010, pp.1110-4.

Ahmad Albanna, **C.J. Hatziadoniu**, "Harmonic Modeling and Analysis of Multiple Residential Photo-Voltaic Generators", Power and Energy Conference, University of Illinois Urbana-Champaign, February 2010.

Ahmed Albanna, **C.J. Hatziadoniu**, "Harmonic Modeling of Three-Phase Neutral-Point Inverters", Proceedings of the 2009 North American Power Symposium, Mississippi State University, Starkville, MS, Oct 4-6, 2009.

Ahmed Albanna, **C.J. Hatziadoniu**, "Harmonic Modeling of Single-phase Three-level Hysteresis Inverters", Proceedings of the 2009 North American Power Symposium, Mississippi State University, Starkville, MS, Oct 4-6, 2009.

G. Chang, **C.J. Hatziadoniu**, W. Xu, P. Ribeiro, R. Burch, W.M. Grady, M. Halpin, Y. Liu, S. Ranade, D. Ruthman, N. Watson, T. Ortmeyer, J. Wikston, A, Medina, A. Testa, R. Gardinier, V. Dinavahi, F. Acram, P. Lehn, "Modeling Devices with nonlinear Voltage-current Characteristics for harmonic studies", IEEE Trans. On Power Delivery, Vol. 19, No. 4, Oct. 2004, pp. 1802-11.

Synergetic Activities.

- "Pilot Study of Energy Harvesting Devices towards the Development of a Prototype", (PI C.J. Hatziadoniu, Co-PI Tsuchin Chu and Fran Harackiewicz), NSF, I/UCRC for Embedded Systems August 2012-August 2013.
- "Resolver Sensor Conditioning Size Reduction", (PI C.J. Hatziadoniu, Co-PI W. Haibo), NSF, I/UCRC for Embedded Systems, August 2012-August 2013.
- "Distribution System Modeling for Power Line Communication", Research grant, AMEREN-UE, 2001-2002.
- "Software for the optimum operation and planning of high-data rate PLC Systems", Research grant, AMEREN-UE 2003-04.
- "Workstation Computer Program for Insulation Coordination of ac and dc Substations"
- Research grant (EPRI 1989-1992), RP 2323, with G.D. Galanos and M. Daneshdoost.
- "Advanced Voltage Systems", Research grant (EPRI 1990-1992), RP 4000-22, with G.D. Galanos and F. Pourboghrat.
- "Faraday's Law Electric Machine Laboratory", Equipment grant (NSF 1991), with G.D. Galanos, V. Feiste and M Daneshdoost.

Collaborators and Other Affiliations.

Collaborators: D. Takach, Ameren UE, Saint Louis, Missouri.
Graduate Advisor: Dissertation Advisor: G.D. Galanos, Department of Electrical and Computer Engineering, SIUC.
Thesis and Dissertation Advisor (recent): A. Albana (PhD), H. Ahmed (PhD), Dler Dler (MS), H. El-Hadji (MS), D. Schleeper (MS).

Frances J. Harackiewicz, Ph.D., P.E.
Professor
SIU Carbondale
Carbondale, IL 62901-6603
e-mail: fran@engr.siu.edu

(i) Professional preparation.

Ph.D. University of Massachusetts, Amherst, February 1990
M.S.E.E. University of Massachusetts, Amherst, May 1986
B.S.E.E. University of Massachusetts, Amherst, May 1984

(ii) Appointments.

2006-present Professor, SIUC Department of Electrical and Computer Engineering
1996-2006 Associate Professor, SIUC Department of Electrical and Computer Engineering
1994, 1995 ASEE-NASA Summer Faculty Research Fellow, Cleveland, Ohio
1990, 1994 AFOSR Summer Faculty Research Fellow, Rome Development Labs
1989-1996 Assistant Professor, SIUC Department of Electrical Engineering
1988 Summer Intern, Atlantic Aerospace, Greenbelt, MD

(iii) Publications.

(i) 5 relevant publications

1. B. Jung, J-S Lee, M-J Park, Y-S Chung, FJ Harackiewicz and B Lee, "TDMB/AMPS/GSM/DCS/PCS/SDMB internal antenna using parasitic element with switching circuit," Electronics Letters, v 42, n 13, Jul 22, 2006, p 734-736.
2. Sung-Joo Kim, Byunggil Yu, Young-Seek Chung, Frances J Harackiewicz and Byungje Lee, "Patch-type radio frequency identification tag antenna mountable on metallic platforms," MOTL, v 48, n 12, December 2006, pp 2446-2448.
3. Rhyu, Hanphil, Jo, Jae-Hoon; Harackiewicz, Frances J.; Lee, Byungje, "Multiband internal antenna using two layer shorted patches for mobile handsets," Microwave and Optical Technology Letters, v 49, n 1, January, 2007, p 176-179.
4. Yu, Byunggil, Kim, Sung-Joo; Jung, Byungwoon; Harackiewicz, Frances J.; Lee, Byungje, "RFID TAG antenna using two-shorted microstrip patches mountable on metallic objects," Microwave and Optical Technology Letters, v 49, n 2, February, 2007, p 414-416.
5. B. Lee, C. Jung, B. Yu, K. Kong, N. Choi, F.J. Harackiewicz, I. Lee, S. Cho, M.-J. Park, and Y.-S. Chung, "Design concept of compact antenna for SDARS applications," Electronics Letters, 2 August 2007, Volume 43, Issue 16, p. 845-846.

(ii) 5 other recent publications

1. Rhyu, Hanphil, Harackiewicz, Frances J.; Lee, Byungje, "Wide coverage area of UHF-band rfid system using a pattern reconfigurable antenna," Microwave and Optical Technology Letters, v 49, n 9, September, 2007, p 2154-2157.
2. Morsy, Mohamed M., Harackiewicz, Frances J, "Stacked aperture-coupled coplanar patch antenna," Microwave and Optical Technology Letters, v 51, n 5, p 1228-1230, May 2009.
3. Rhyu, H.; Byun, J.; Harackiewicz, F.J.; Park, M.-J.; Jung, K.; Kim, D.; Kim, N.; Kim, T.; Lee, B., "Multi-band hybrid antenna for ultra-thin mobile phone applications," Electronics Letters, v 45, n 15, p 773-774, 2009.
4. Bae, Hongpyo; Harackiewicz, Frances J.; Park, Myun-Joo; Kim, Taekyun; Kim, Namhoon; Kim, Deokyun; Lee, Byungje, "Compact mobile handset MIMO antenna for LTE700 applications," Microwave and Optical Technology Letters, v 52, n 11, p 2419-2422, November 2010.
5. Sung-Joo Kim, Frances J. Harackiewicz, Myun-Joo Park, Taekyun Kim, Woojae Jung, Jeongkwan Lee, and Byungje Lee, "Isolation enhancement between two closely mounted antennas for indoor repeater systems," Microwave and Optical Technology Letters, v 53, n 3, pp. 697-700, March 2011.

(iv) Synergistic activities.

- Research interests and contributions are in the areas of electromagnetic simulations, small, multi-band and broadband antennas and especially ferrite, printed, dielectric and low-profile antennas.

- Teaching and service interests and contributions are in the areas of engineering education, especially capstone design, electromagnetics, numerical modeling, and antennas.
- Chair of the IEEE Education Society St. Louis Chapter 2006-2012, also organized and spearheaded the formation of this chapter
- Twenty years teaching at university. Introduced and taught several courses such as Antennas I and II, Microwave Engineering I and II, Advanced Electromagnetics, and Numerical Electromagnetics.
- Developed and supervising the ECE Antennas Laboratory at SIUC. Planned, specified, and acquired hardware, software. Labs are used extensively for research by graduate students and for numerous courses including many senior electrical engineering projects.
- More than 60 peer-reviewed journal publications and conference proceedings, co-inventor on one patent.

(v) Collaborators and other Affiliations

- Directly supervised or supervising 20 M.S and Ph.D. students (Kang Mark Lee, Dan Lee, Jinwook Cho, Byungje Lee, Jayanthi Srinivasan, Dean Banerjee, Joonho Byun, Seok Choo Han, Kiyun Han, Robert Guennewig, Adriano Raiva, M.S. Murthy Karripeddi, Seung Hoon Baek, Deepak Vittaldevara, Jon Okon, Mohamed Morsy, Muhammad Raashid Khan, Hemachandra Gorla, David Addison, Ali Al-Azza)
- Other Collaborators on grants: C. Hatziadoniu, T. Chu, S. Tragoudas, W. Osborne, P. Wang, S. Marikunte, M. Wright, S. Shea, R. Viswanathan, J. Spoerre, L. Chevalier, J. Lindsey, Dan Lee, J-P Bayard
- Supervised 11 Undergraduate Researchers: Jon Okon, Marcy Rugland, Raoul Ouedraogo, Steven Dame, Jonathan Fesler, Farrukh Sajid, Eric Dobey, David Addison, Brittany Murphy, Nathan Smith, Kaylyn Shaw

I/UCRC Executive Summary - Project Synopsis		Date:
Project Title: Feasibility Study for an RF-Based Proximity Sensor using Embedded Antennas in High Velocity Projectiles		
Center/Site: I/UCR for Embedded Systems, Southern Illinois University		
Principle Investigator: C.J. Hatziadoniu		**Type: New**
Tracking No.: (CES office to input)	**Phone :618-453 7036**	**E-mail : hatz@siu.edu**
		Proposed Budget: $50,000

Abstract: This project proposes to study the feasibility of an embedded RF-based proximity sensor in a high-velocity projectile. The sensor will incorporate an RF antenna. The study will investigate the design requirements of the antenna with regards to transmitting and receiving RF signals at significant levels and with sufficient SNR in order to enable the detection of proximity. Along with the antenna investigation, the project will also investigate appropriate signal processing algorithms that will enable the quick and reliable detection of proximity based on the signals received by the antenna. One part of the methods will include numerical simulation of both the antenna and the signal processing under variable environment. Another part of the methods will include studying the possibility of using the projectile body as antenna and perform experimental tests in the anechoic chamber in order to verify the antenna patterns versus frequency relation and its power requirements. The project deliverables include (a) the data and outcomes from the investigative studies; (b) a preliminary antenna design; (c) and a suitable signal processing algorithm for fast proximity detection. A fully developed embedded RF-based proximity sensor will improve significantly the accuracy and efficacy of the projectile. The outcomes of the proposed work will provide the basis for a later effort to refine, optimize and subsequently develop and test a prototype RF-based proximity sensor. In this regard, the proposed work will be of benefit to the related industry.

Problem: The problem includes the following aspects of the sensor: (a) the sensor RF antenna. The project will investigate what patterns are suitable for the particular application given the limited size and operating conditions of the sensor. The project will also investigate using the projectile body (with some minor modifications) as an antenna; (b) the signal processing algorithm which will provide the proximity detection threshold.

Rationale / Approach: The proposed project is necessary in order to lay the ground work for developing a prototype.

Novelty: There are two potential scientific advancements under this project: (a) the use of the projectile body as antenna; (b) the characterization of the environment under the RF signals and the development of the detection algorithm.

Potential Member Company Benefits: An accurate and reliable RF-based proximity sensor can significantly improve the accuracy of the projectile and its effectiveness.

Deliverables for the proposed year: The following will be delivered by the end of the project: (a) the data and outcomes; (b) a preliminary antenna design along with the power budget requirements; (c) and a suitable signal processing algorithm for fast proximity detection.

Milestones for the proposed year:

Task/Milestone	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
Investigation of the antenna				
Anechoic chamber tests				
Preliminary antenna design				
Detection algorithm development				

Progress to Date: **THIS SECTION TO BE UPDATED IN JANUARY**

Estimated Start Date: August 15, 2013	**Estimated Knowledge Transfer Date**: