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| **Proposal Name:** A Novel Wireless and Batteryless RF (WBRF) Sensor for Detection of Black Ice |
| **STIC/State Name:** Jorge Salazar-Cerreno and Musharraf Zaman, The University of Oklahoma, Norman | **FY:** 2020 |
| **Innovation:** (Describe the innovation that the state is looking to implement on a statewide basis including the purpose and benefit to the state.)STIC funds are requested to develop and demonstrate a wireless and batteryless RF sensor or *WBRF sensor* for detection of pavement conditions, specifically black ice, wet surface and standing water and to enhance safe driving through warning. The novel design of the WBRF sensor along with the existing RFID technology is expected to provide affordable ways to avoid traffic fatalities and loss of properties due to accidents caused by unfavorable pavement surface conditions, namely black ice, wet surface and standing water. The target cost of each WBRF sensor is $10, when produced in large volume. The idea has been tested at OU. STIC funds are requested to formalize and demonstrate it. Black ice is dangerously hazardous and a major cause of many car accidents each year in Oklahoma and many other states in the U.S. According to the USDOT statistics, icy roads cause more than 200,000 auto crashes annually, which is more than 10% of all weather-related crashes in the U.S. The proposed novel WBRF sensor will be a cost-effective solution for detection of black ice, wet surface and stading water on roadway pavements and provide warning through transportation agencies. Agencies such as Oklahoma Department of Transportation and the Office of Highway Safety can use these warnings to post safe driving speeds and display messages to enhance safe driving and traffic flow.The proposed novel WBRF sensor development aligns well with the “innovation” goal promoted by STIC and with the development of connected and autonomus vehicle and smart road technolopgies that are moving very rapidly. Access to powerful wi-fi connectivity based on embedded fiberoptic cables will enable easy integration of the novel RF sensor in future smart roads and provide real-time alert about road hazards and traffic conditions. Development of the novel WBRF sensor, however, does not rely on the fiberoptic connectivity and relieability. |
| **Description of the Proposed Work:** (Describe the scope of work that is to be completed with this funding request, whether this is a complete project or part of a larger phased project, how it will have a statewide impact in making the innovation a standard practice in your state. Only include work that is eligible for STIC Incentive funding).This project aims to develop a prototype (both hardware and software) of a novel RFID-based WBRF sensor and demonstrate its feasibility of deployment on actual roads for detecton of ice, wet surface and standing water. The Principal Investigator and his team have already tested several possible off-the-self RFID tags and readers and devised ways to improve their functional features. STIC funding will be used to formalize the process and integrate the components to a functional WBRF sensor. To maximize the range of the sensor and high signal integrity, electrical properties of both asphalt and concrete materials will be tested and used in the design. Upon laboratory validation, the sensor will be installed in the field and tested under simulated weather conditions, namely wet pavement, standing water, and icy pavement. Based on the laboratory and field performance some fine tuning may be needed for broader deployment and additional functional features. The proposed WBRF sensor intelligently combines the existing RFID technology, modified RF sensors and artificial intelligence (AI) algorithm to classify pavement conditions in real-time. As illustrated in Figure 1, the WBRF sensor with a protective housing is installed in the pavement and remains in the sleeping mode most of the time. When an automobile approachs the affected area due to ice or water, the RF signal transmitted from the RFID reader in the car will activate (wake-up) the RF sensor. Within a few milliseconds, the sensor will transmit the road condition to the RFID reader in the car and go back to inactive or sleeping mode. The road condition data received by the RFID reader will warn the driver about the road condition. The data can be transmitted wirelessly to state agencies and used to provide warning on safe driving speed. Figure 1(a) illustrates the overall concept of the proposed sensor. In this case, the approaching vehicle activates the sensor, the sensor retransmits (opposite directions) the signal with information that indicates the condition of the road (black ice, wet surface and standing water) and goes back to inactive mode. Figure 1(b) is a basic block diagram of the proposed sensor and Figure 1(c) shows a 3-D representation of the proposed sensor and dimensions.   |
| **Figure 1 (**a)Concept of a novel wireless and batteryless RF sensor (or WBRF sensor) for detection of road conditions; (b) Block diagram of the proposed sensor; (c) 3-D view of the sensor embedded in concrete or asphalt pavement. **End Product:** (Identify what the final deliverable will be when the project is complete. Include the Expected Outcomes, Benefits and/or Results)Prototype of a novel WBRF sensor will be developed. The sensor will be tested in the laboratory by installing in a concrete slab and also in an asphalt slab and testing under simulated surface conditions, namely wet surface, surface with standing water, and icy surface. Laboratory data will be used to train the artificial intelligence (AI)-based model. With proper training the AI model will recognize the surface condition type. A comercial RFID reader will be used to read the signal from the WBRF sensor. As noted above, the RFID reader will be mounted in the automobile when testing in the field. Field demonstration will involve both concrete pavements and asphalt pavements.**Proposal Schedule:** (Anticipated start date and when will product be delivered? The anticipated project schedule is required. The schedule should show how the work will be advanced in the fiscal year for which the funds are being requested, and the anticipated completion date of the work. This should directly reference each line item in the cost estimate. Applications should only be submitted for projects that are ready to advance if the minimum partial funding request is met.)1. **Characterization of electrical properties of road materials:** In this phase, the OU team will be focused on the characterization of electrical properties of asphalt and concrete materials that are commonly used in roadway pavements. Among other parameters, these characterization will ensure that the WBRF sensor when installed in the actual pavement, the integrity of the RF signal between the sensor and the RF reader will be maintained. A new RF setup for low-frequency material characterization will be developed for frequencies between 10 MHz to 1 GHz. Results from this phase will be used to develop appropriate antennas, RFID tags, and RFID readers. Initial work by the team has shown that some changes in the off-the-shelf sensor are needed to ensure signal integrity and strength. RFID devices are inherently wireless. The batterless option is achieved through the sensor in the “sleeping” mode most of the time.This phase is expected to take about two months from the start of the project. Assuming a start date of October 1, 2020, this phase can be completed by November 30, 2020.

**Time Period: October 1- November 30, 2020****Deliverables:** * Short technical report with electrical properties of asphalt and concrete materials for the 10 MHz to 1.2 GHz range.
* Test setup for chacterization of asphalt and concrete materials for the 10 MHz to 1.2 GHz range.
1. **RF sensor design and electromagnetic performance testing:**In this phase, numerical simulation using ANSYS-HFSS software will be performed to identify the impact of the pavement materials on RF signals from sensor and RFID reader.  Results obtained from these tests will be used to identify sensor cover material, power budget (gain of the transmitter and receiver RF system), frequency, type of RF sensor and time response of the sensor. RF sensor design will be carried out in this stage. This phase is expected to take about three months, December 1, 2020 – February 28, 2021. The deliverables for this phase are given below.

**Time Period: December 1, 2020- February 28, 2021****Deliverables:** * Short technical report with prelimianary results of the RF antenna sensor’s interaction with road materials
* Test setup for antenna, refelectometer, asphalt and concrete
1. **Design and testing of WBRF sensor.**In this phase, commercially available RFID tags and readers will be evaluated and selected. Design modifications and integration with humidity (moisture, water, ice) and temperature sensors will be be conducted. Evaluation of time response of the sensors are critical for the safety of both non-autonomous and autonomous vehicles when driving on hazardous roads. This phase will focus on optimizing the time response of the sensors. Passive versus active sensors including the battery-free sensor operation will be evaluated and the most suitable WBRF sensor selected. This phase is expected to take three months.

**Periode: March 1-May 31, 2021****Deliverables:** * Technical report including WBRF sensor design simulation and performance evaluation.
* Test setup for sesnor, WBRF sensor and RFID tags and readers.
1. **Demonstration of the developed sensor:** Once the hardware and software of the WBRF sensor are developed, the team will focus on developing a testbed that can be used for visual demonstration showing the capabilities of the WBRF sensor. The sensor will be mounted on concrete and asphalt slabs and tested in the lab under simulated surface conditions (dry, wet, standing water, ice). Then field demonstration (with simulated wet, ponding and icy conditions) will be conducted with support from the Oklahoma Department of Transportation, with assistance from the Office of Research and Implementation. This phase is expected to take about two to two months.

**Periode: June 1 - July 31, 2021****Deliverables:** * Final technical report presenting WBRF sensor prototype.
* Complete test setup demonstration of WBRF sensor
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| **Champion(s):** (Who will be reporting progress on this work to the state STIC? Progress Reports are to be provided to FHWA every 6 months, with a Final Report at conclusion of work.)The proposed project will be pusued jointly by the multidisciplinary team (Electrical and Civil Engineering) from the University of Oklahoma. Dr. Jorge L. Salazar, Assistant Professor of Electrical and Computer Engineering, will serve as Principal Investigator and be responsible for the overall execution of the project in a timely manner, including submission of progress reports and the final report. Dr. Musharraf Zaman, Professor of Civil Engineering and Professor of Petroleum and Geological Engineering, will oversee the selection of concrete and asphalt materials and prepation of slabs for laboratory testing. He will also assist with the field testing and the overall execution of the project for ensuring a successful outcome. He is a highly accomplished researcher and has successfully obtained and directed a large number of projects (worth more than $30 million), including some highly competitive national-level projects. Dr. Zeshaan Qamar, a senior Postodoctoral fellow in Electrical and Computer Engineering along with an undergraduate student will conduct the sensor design and testing. Dr. Salazar and Dr. Qamar will be responsible for preparing the progress reports and the final report and in making recommendations for additional functional features and broader deployment.  |
| The ODOT Office of Research and Implementation (QRI), under the leadership of Mr. David Ooten, will assist the team with periodic meetings and objective assessment of results and performance of the WBRF sensor. ORI is committed to providing the required (20%) matching support ($10,161). |
| **Estimated Total Cost:** **$53,269** | **Amount of STIC****Funds Requested:** | **$42,615** |
| **Source of Other Funds or Sponsors:** (20% match required. Indicate the amounts and sources of any private or other public funding and/or third party in-kind services being provided as part of this project. Only indicate those amounts of funding that are firm and documented commitments from the entity controlling the funds.) It is expected that the matching support for this project will be provided by the Office of Research and Implementation.**Estimated Total Cost/Budget Breakdown:** (Provide a cost estimate that is reflective of the total cost of the proposed work by line item. Each line item should be associated with a completed task, deliverable, or outcome that contributes to the completed funding request. In the event that partial funding is available, this information will aid in the development of funding recommendations and provide the applicant the opportunity to fully complete individual components of the funding request. If the applicant is willing to accept partial funding of the request then that should be indicated as well.)The total estimated cost of this 10-month study is $53,269 including F&A or indirect cost (IDC). Of the total estimated amount ($53,269), $42,615 is requested from the STIC program and $10,654 is expected to be provided by the ORI . An itemized budget for the proposed work is given below.

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| **Itemized Cost/Budget Breackdown** | **Amount** |
| Faculty summer salary | $3,222 |
| Post Doctoral salary (1 month ) | $6,000 |
| Undergraduate student (6 months) | $5,400 |
| Undergraduate tuition fees (6 months) | $5,838 |
| Finge benefits | $2,393 |
| Material and setup | $10,500 |
| ARRC Facilities usage (3%) | $1,014 |
| Total Direct Cost | $34,367 |
| Indirect Cost 55% of Total Direct Cost |  $18,902  |
| **Total Project Cost** | **$53,269** |
| **Amount Requested from STIC** | **$42,615** |
| **Amount Contributed by Match** |  **$10,654** |
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**Personnel**: Dr. Salazar will lead the proposed study and be responsible for its execution in an efficient and timely manner. The budget includes $3,222 for Dr. Salazar to support his role in this project. It also includes $6,000 to support one-month salary for Dr. Zeshaan Qamar, a senior Postodoctoral fellow. An undergraduate research assistant (URA) will be appointed to assist Dr. Qamar with laboratory testing. The URA is expected to work about 15 hours per week for 6 months @ $15/hour. The budget also includes $5,838 for the URA tuition fees. Dr. Zaman will contribute his time free of cost to this project.**Fringe Benefits**: A total of $2,393 is budgeted for fringe benefits for Faculty, Post-Doctoral Fellow and undergraduate student. At OU, the current fringe benefit rates, as negotiated with DHHS, are:  39.95% for senior personnel, 18.09% for postdoctoral associates, 9.70% for graduate research assistants and 0.4% for undergraduate research assistant. These benefits may include FICA, workmen's compensation, unemployment compensation, retirement, and life, dental, and health insurance.  Additional information about the rates can be found in the following link:   <https://ors.ou.edu/about/rateagr.html#fringe_rate>**Materials:** A total of $10,500 is estimated for experiment setup, materials and electrical and RF components. **Other Direct Costs**: Laboratory fees of 3% are predetermined by the Advanced Radar Research Center (ARRC).**Indirect Costs:** Indirect Costs (F&A) are calculated using the University’s current federal negotiated pre-determined rate for on-campus research which is 55% of modified total direct costs (MTDC), per agreement with DHHS dated 06/04/2018. The MTDC base excludes equipment costing $5,000 or more, tuition remission, and subaward amounts in excess of $25,000.   Indirect costs represent research support costs incurred by the University of Oklahoma. These costs include laboratories and facilities usage, building maintenance, utilities, general grant administration and accounting, and other University services.  Cognizant agency and contact:  DHHS, Arif Karim, 214.767.3261. <https://ors.ou.edu/about/rateagr.html> |
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