Proposal for the Development of Innovative Low-cost Air Quality and Soil Sensors to Support Research and Operations

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1. Participants

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2. Overview

The successful development and deployment of the 3D-Printed Automatic Weather Station (3D-PAWS) platform has resulted in a great deal of interest in additional sensors using similar technology. Specifically, the developers have received requests for air quality and soil moisture/temperature sensors. While interest in these sensors has been high, paying for development of prototypes has been difficult to secure. Most groups would like to see tested prototypes before funding projects to build and deploy this instrumentation.

The 3D-PAWS system provides sensors to measure temperature, relative humidity, station pressure, solar light, wind speed, wind direction, and rainfall. This effort would expand 3D-PAWS capability to include a new instrumentation package for environmental monitoring that includes an integrated air quality package. The air quality package would provide sensors to monitor atmospheric conditions along with common pollutants (ozone (O_3), particulate matter (PM2.5; PM10), nitrous oxides (NOX), sulfur oxides (SOX), and volatile organic compounds (VOCs). A second package would also be developed to observe soil moisture and temperature for agricultural and hydrologic applications.

Throughout the development of 3D-PAWS, collaborators have expressed interest in expanding 3D-PAWS capabilities for air quality monitoring and for soil moisture monitoring for urban and agricultural applications, respectively. The initial development of 3D-PAWS has been supported by USAID to provide early warning capabilities for high-impact weather events as flash floods, severe storms, and extreme temperature. USAID priorities have not focused on the development of air quality and/or soil moisture and temperature sensors. We have been exploring options to expand sensor capabilities. This initiative would help accelerate the development of these new sensors.

This work would greatly impact a wide variety of community members and would attract new sponsors in the private sector, international donor agencies, and national meteorological and hydrological services including but not limited to:

- Kingdom of Saudi Arabia
- SkyMet in India
- World Bank

- USAID
- Smart City Initiative (Comcast in Denver, Philadelphia, Houston)

In addition to prototyping these sensors, the funding would support a data assimilation (DA) demonstration that would utilize these new datasets in a Weather Research and Forecasting (WRF) modeling simulation. These new sensors would support new observation and modeling initiatives especially in data sparse regions of the world (e.g., Africa, Asia, etc.).

3. Scientific Merit

There are several scientific merits identified with this initiative. The development of a new soil moisture and temperature sensor could support Constellation Observing System for Meteorology Ionosphere and Climate (COSMIC) program (https://www.cosmic.ucar.edu). The COSMIC community has developed a remote sensing technique that uses GPS measurements to estimate environmental conditions over ocean, land, and sea ice. In particular, the satellite retrievals are able to estimate near-surface soil moisture on a global scale. Verification of the soil moisture retrievals is an important component in assessing the data quality and uncertainty of the observations. In developed regions such as the US and Europe, soil moisture sensors are relatively plentiful. In data sparse regions such as Africa, soil moisture datasets are limited to non-existent. However, soil moisture observations are important for a variety of agricultural, health, and water resource applications. The development of a low-cost soil moisture (and temperature) sensor could provide significant potential benefits. With support for USAID, World Bank, and/or other government/private agencies, the sensors could be built and distributed to local communities to expand local monitoring networks. This effort would also provide scientific merit in extending surface datasets to data sparse regions to provide observations to improve satellite-based soil moisture retrievals. The improved satellite retrievals could then provide additional spatial and temporal soil moisture information around the surface based measurements. In a no-cost collaboration, we will work directly with the COSMIC program to assess priorities and locations where the sensors could be tested and validated.

Monitoring of air quality has become of the key environmental topic for many communities. Commercial air quality sensors are expensive and difficult to maintain. Therefore, the number of monitoring stations around the world are relatively small. Recently, there has been significant interest in finding a low-cost, easily deployable air quality sensor package. There is an ongoing effort to develop smart-city technology that integrate small, low-cost devices using the internet of things (IoT). These IoT devices would be used to develop applications to monitor real-time conditions down to a city block level. The scientific merit of the air quality sensors is not only in improved monitoring, but the data could also be assimilated into air quality modeling and regional forecast systems (e.g., WRF-Chem) to provide short-term prediction of hazardous conditions (e.g., PM 2.5, surface ozone, etc.) within urban communities. We will work with RAL staff to develop and test the framework of assimilating the 3D-PAWS data into a WRF modeling simulation case study. Education and outreach is another potential benefit. Schools have reached out and asked about air quality monitoring for classroom learning, but for monitoring of air quality around the school (e.g., VOC's from a nearby by gas well). The GLOBE program in UCP has expressed interest in developing protocols for air quality monitoring. Through a no-cost collaboration with the GLOBE, we will identify opportunities where we could implement the air quality sensors at schools and also development new education protocols.

4. Approach

With this initiative, we will design and develop the fabrication process of the 3D-printed sensor housing, mounting design, integration of the sensor and associated electronics of the air quality sensors and soil moisture/temperature sensors into 3D-PAWS. The sensors will be tested and evaluated with commercial reference sensors to document data quality. This information will be used to support further business development with potential sponsors that will allow UCP to expand to new areas of data delivery, monitoring capabilities, and training activities. During the project period of performance (PoP), we will collaboration with COSMIC and GLOBE to identify scientific and educational opportunities for additional agencies. In the final period of the project, we will visit several sponsors (supported by UCP program development funds) and support proposal for external funding. The anticipated PoP will be over a one-year period. The following is a summary of the planned timeline to complete the initiative:

<u>Months 1-3:</u> Design the 3D-PAWS air quality and soil moisture/temperature system design and fabrication of a prototype system
<u>Months 4-6:</u> Laboratory testing and development of software for the new sensors and develop data assimilation methodology to ingest data into WRF; identify new opportunities science and educations opportunities with our COSMIC and GLOBE partners
<u>Months 7-8:</u> Conduct an assessment study to evaluate the new sensors; prepare document to support proposals.
<u>Month 9-12:</u> Visit sponsor(s) and prepare proposal(s) to obtain external funding to expand the opportunities using the new prototype air quality and soil moisture/temperature sensor systems

4. Anticipated Outcome

The project will provide opportunities to expand partnerships with international organizations, universities, and private sector through the expansion of monitoring capabilities of 3D-PAWS. The funding will allow is to prototype new technology that will support research to operations to address societal needs in both developed and under-developed regions of the world. An additional beneficial outcome from the project will be new education and outreach opportunities for K-12 and universities for the next generation of scientists and engineers.

New sensors prototypes will have been developed and tested. The proof of concept of using 3D-PAWS observations in DA system and tested with a regional forecast system (e.g., WRF-Chem) will be tested. Data from the sensor networks will be accessible by the meteorological community. In the future, developing and developed nations have access to new, regional observation datasets using 3D-PAWS systems for monitoring and warning and use in research. New applications could be developed for air quality forecasting, agricultural sector and hydro applications (water availability, water security). With this initiative, we anticipate widespread opportunities in supporting operations, research to operations, research. With these widespread opportunities come a wide range of business development potential. For example, real-time data access in areas where data observations are limited. We anticipate new opportunities with government, private, and university partners.

The new technology would provide new monitoring solutions for early warning decision support systems for high-impact air quality events in larger metropolitan areas or for regional dust events. For example, organizations in Saudi Arabia, India, and in the US (e.g., Smart City Initiative) have expressed interest in supporting the deployment and educational activities using our air quality sensors if the technology was available. Communities in Africa and regional farming communities in the US are interested in low-cost soil moisture/temperature sensor capabilities to improve monitoring of field conditions and optimization of water usage through irrigation.

5. Budget

5.1 Required Resources

The funding will provide support to accelerate the development of new innovative low cost sensors. The project have a focused technical effort to build new sensor capability for air quality and soil moisture/temperature sampling. There has been initial investigation of air quality sensors for measuring dust (PM 2.5 and PM 10), ozone, and volatile organic compounds (VOC). These sensors are available for cost of 25 to 75 USD. These air quality sensors will be compared to commercial research sensors to ensure data quality, sensitivity, and reliability. Research has been conducted in soil sensor technology and several prototype low-cost solutions are available. The COSMIC program has also been interested in soil moisture sensors. We plan to leverage their efforts to accelerate and/or adapt the technology that they have been developing and testing into the 3D-PAWS system. There is interest in the community to demonstrate the usefulness of using 3D-PAWS observations into a DA system. We plan to work with the DA group in RAL to demonstrate the viability of using 3D-PAWS for a regional modeling case study. Finally, we will work with the GLOBE program to identify new educational opportunities. In summary, the initiative will provide opportunities to obtain external funding for applications that address societal issues both domestically and internationally.

<u>Budget Summary</u>
Table 1 provides a summary of the budget to support the initiative.

Table 1: Budget summary.

Item	Cost
Salaries	$26,046
Benefits	$14,305
Materials and Supplies	$2,500
Overhead (15.9%)	$6,815
Total	**$49,676**

<u>Budget Justification</u>
Salaries

Paul Kucera (COMET: 120 hours): He will conduct the sensor research, oversee the sensor evaluation, and lead meeting/prepare proposal for potential sponsors
Martin Steinson (COMET: 160 hours): He will lead the development of the sensor design including the 3D-printing fabrication and electronic integration
Joey Rener (COMET: 120 hours): He will the development of the data acquisition software and testing of the new sensors
Lorrie Alberta (COMET: 40 hours): She will support the preparation and submission of the proposals to external sponsors
Kathryn Newman (RAL: 60 hours): She will support the setup and testing of the DA system using 3D-PAWS observations.

Materials and supplies
This cost will cover the purchase of the prototype air quality and soil sensors, Raspberry Pi single board computers, electronic components, 3D-printing materials, and supplies to build the prototype sensors.

Overhead
Overhead has been included at a G&A rate of 15.9%.

7. Narrative

7.1 Why is this transformational?

The project is innovative in that it expands 3D-PAWS capabilities to address additional environmental monitoring needs and applications. The new technology will provide additional funding opportunities to expand 3D-PAWS, associated applications, and training opportunities to other regions of the world.

7.2 Why is this interdisciplinary?

The initiative will expand over observing, modeling, technology transfer, educational development, and potential partnerships with government, private, and university institutions.

7.3 How will this promote collaboration across the greater NCAR, UCP, university and/or private sector community?

The initiative has collaboration between UCP programs (COSMIC and GLOBE) and to NCAR (RAL). With the new sensors, there is opportunity to expand partnerships with the private sector that would be able to transfer the technology on a large scale with universities that could integrate the sensors into the classroom (e.g., instrumentation courses).

7.4 What are expectations that this will lead to future, ongoing funding?

As with the initial development of 3D-PAWS, the goal is to seek funding to transfer the technology with the support of donors and partners. We envision the business development would lead to several funding opportunities. New initiatives would range from customization of sensors to meet the needs of stakeholders (National Meteorological and Hydrological Services, private industry, universities), support the development of new observations networks, and training to teach end-users to fabricate and implement their local-built sensors. External funding as a result of the business development project could range from 250K to 1000K per year depending on the number of new initiatives. The goal is to submit proposals to further develop and deploy air quality and soil moisture/temperature technology within nine months of the project start with the possibility of acquiring external funding within a year of the project start.

There are several possible partnerships and funding sources for external funding for both the air quality system and soil moisture sensors. Larger sources of funding could be obtained from donor agencies such as World Bank and Green Climate Fund. These agencies have expressed interest in low-cost sustainable solutions in least developed regions of the world. We have also been in discussion with private partners to support the implementation of technology. For example, a company called mFactor Engineering located in Boulder have expressed interest in partnering to address the Smart City initiatives that are being developed in major cities like Denver, Houston, and Philadelphia to monitor air quality conditions at the city block level. Another partnership has recently developed with a company called Opus Insights from the Netherlands. They focus on implementing solutions for agricultural applications in least developed nations. We have also been successful in implementing 3D-PAWS in partnership with GLOBE. We could leverage this partnership to expand educational opportunities for monitoring air quality and soil conditions at schools. These are just a few examples of new opportunities.

7.5 What are your metrics and success criteria to demonstrate achievement?

The metrics for the project are developing and demonstrating the usefulness of the new sensors for observations, modeling (DA), applications, and education opportunities. A successful outcome would be to have a new low-cost air quality sensor and soil moisture package available as part of 3D-PAWS to the community. The ultimate success to have several new externally funded projects through the support of the initiative.

7.6 What are your milestones for when these metrics will be achieved?

<u>Months 3:</u> A prototype air-quality and soil moisture/temperature working
<u>Months 6:</u> Completion of initial data collection; successful DA test using WRF in a case study; outline of new research and educational opportunities with COSMIC and GLOBE
<u>Months 8:</u> A completed document assessing the new sensors
<u>Month 12:</u> Several new potential sponsors identified and one to two proposals submitted or being prepared for external funding