

**Environment and Natural Resources Trust Fund**

# 2023 Request for Proposal

## **General Information**

**Proposal ID:** 2023-156

**Proposal Title:** Multi-Level Monitoring and Control Toward Smart Pasture Management

## **Project Manager Information**

**Name:** Ce Yang

**Organization:** U of MN - College of Food, Agricultural and Natural Resource Sciences

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**Email:** ceyang@umn.edu

## **Project Basic Information**

**Project Summary:** This project will develop new pasture management strategies using multi-level robotic monitoring and precision agricultural techniques to remove weeds in pastures and determine optimal time and location for grazing rotation.

**Funds Requested:** $1,027,000

**Proposed Project Completion:** June 30, 2026

**LCCMR Funding Category:** Foundational Natural Resource Data and Information (A)

## **Project Location**

**What is the best scale for describing where your work will take place?** Statewide

**What is the best scale to describe the area impacted by your work?** Statewide

**When will the work impact occur?** During the Project

## **Narrative**

**Describe the opportunity or problem your proposal seeks to address. Include any relevant background information.**

Dairy farms in Minnesota maintain and manage large pastures for grazing cows. Well-managed pastures with dense and healthy grass help to provide a nutrition-rich diet to livestock, prevent wind and water erosion and recharge underground water system. Weed control, rotation grazing and herding are critical actions in pasture management. Weeds can spread quickly and take over large areas if left uncontrolled. Our team has previously developed an electric mower (Cowbot) to autonomously mow the entire pasture. When operating on large acreage, mowing the entire field leads to high operating costs and energy requirements. Precision control for targeted weed removal will reduce the energy footprint of using an autonomous mower on the pasture. Another critical component of maintaining pastures is rotational grazing. It helps to maximize production and reduce sediment and nutrient runoff. The timing for rotation of livestock between paddocks is commonly determined based on satellite footage. Greenness of the grass in satellite images is the sole indicator of the readiness of an area for grazing, which is inaccurate and subjective and leads to suboptimal decisions. An energy-efficient multi-level monitoring and control system for optimized pasture management is needed to address the weed control and grazing schedule problems in pastures.

**What is your proposed solution to the problem or opportunity discussed above? Introduce us to the work you are seeking funding to do. You will be asked to expand on this proposed solution in Activities & Milestones.**

We aim to design and develop a "smart pasture" that comprises an ecosystem of ground and aerial robots and supporting infrastructure for multi-level precision control and remote sensing. A drone based spectral imaging system will be useful to detect weeds in pastures based on their morphological and spectral differences from pasture grasses. Imaging can help in detecting grass biomass in pastures (Zhou et al., 2021), which further helps decide if an area is ready for grazing. Drone flights can be flexibly scheduled to cover different areas at desired times in the pasture, which enables better monitoring of the pasture for both weed control and grazing rotation. Therefore, we propose to use a drone-based spectral imaging system to monitor the pasture. Co-PI Maini has previously developed an electric weed mowing robot (key member of ENTRF-funded Cowbot project) that uses a flail-deck for pasture weed management by autonomously mowing the entire pasture. Detecting weeds on the pasture and targeted weed control would reduce the energy footprint of the electric mower and bring down the cost of adopting electric mowers for dairy farmers. We will use multi-level imaging sensors using ground and aerial robots to detect and localize weeds for precision control.

**What are the specific project outcomes as they relate to the public purpose of protection, conservation, preservation, and enhancement of the state’s natural resources?**

The project will demonstrate a multi-level cooperative robot system for pasture management. The focus is pasture weed and grazing management based on robotic sensing, weed cutting and autonomous navigation using drones and a ground robot. The future use of the system will also include unmanned herding, in which a robot will help guide the cow herd while the drones monitor the herd and set boundaries for the herd movement. These outcomes will help preserve the state’s pasture systems and natural resources by providing more efficient management and weed control while freeing dairy producers from tedious labor and time consuming activities.

## **Activities and Milestones**

### **Activity 1: Aerial robot setup, data collection and modeling for weed detection in pasture and grazing rotation**

**Activity Budget:** $450,708

**Activity Description:**A drone based hyperspectral camera system will be used to collect data in WCROC pastures starting in the grazing season of 2023. Drone hyperspectral images provide image pixels with high definition spectral information, which have been used in weed detection in farmlands and alfalfa yield prediction in previous studies. More questions need to be answered regarding its application to pasture monitoring, including classification of grass and weeds and grass biomass estimation for grazing rotation. Manual weed identification will be conducted as ground truth for weed detection, and grass yield records will be kept closely following drone flight schedules. Collected images will be stitched and georectified to generate the field view of pasture paddocks with location information. Strategic Artificial Intelligence (AI)-based modeling and detection algorithms will be trained and validated. Advanced models improve with larger input dataset from diverse scenarios. Therefore, data collected in the years 2024-2026 will be used to greatly increase the reliability of the detection models, which is the key to its adoption for smart pasture management. The drone sensing platform also has potential use in cattle herding by cooperating with the a ground based robot.

**Activity Milestones:**

|  |  |
| --- | --- |
| **Description** | **Completion Date** |
| Drone sensing and ground truth data collection from WCROC pastures | October 31, 2023 |
| Image labeling, weed detection and pasture grass yield model training and calibration | April 30, 2024 |
| Verification and improvement of remote sensing models using multiple year’s data | October 31, 2025 |
| Drone and ground platform integration for multi-level monitoring of weed in pastures | June 30, 2026 |

### **Activity 2: Design and develop an autonomous ground vehicle system to efficiently manage pasture systems through weeding and cattle herding**

**Activity Budget:** $563,218

**Activity Description:**To operate in the rough conditions on the pasture we need a platform that is mechanically suitable for the task and can operate a mowing implement. In the initial phase of the project, we will use the Cowbot, built previously (Cowbot-1) to collect data and test individual components. While Cowbot-1 was built by custom modifying a diesel platform due to non-availability of electric mowers in the market, the availability of electric mowers has since improved significantly. We will design Cowbot-2 to be energy efficient and suitable for sensor mounting while still being mechanically robust to operate on rough terrain building on lessons learned with Cowbot-1. We will equip Cowbot-2 with sensors and design computer algorithms to allow it to intelligently traverse on the pastures. We will design artificial intelligence methods to detect weeds on the pasture using onboard sensors and design path planning algorithms that would allow the Cowbot-2 to be energy efficient by mowing only weeds instead of mowing the entire pasture. We will also develop coordination and cooperation strategies between the drone and Cowbot for multi-level monitoring and control. We will also study the cooperation between aerial and ground robots for potential use in cattle herding.

**Activity Milestones:**

|  |  |
| --- | --- |
| **Description** | **Completion Date** |
| Develop specifications for Cowbot-2 and acquire ground vehicle | December 31, 2023 |
| Software based control of Cowbot-2 | November 30, 2024 |
| Weed detection module design and evaluation and path planning methods for mowing | November 30, 2025 |
| Evaluate multi-level weed control strategies | June 30, 2026 |

### **Activity 3: Educate consumers, industry representatives, farmers and the general public about smart pasture management**

**Activity Budget:** $13,074

**Activity Description:**The results from all activities will be used to demonstrate the potential of a multi-level monitoring and control system toward smart pasture management. The knowledge and information generated will be disseminated to agricultural producers, technology providers, students, government officials, and other stakeholders through social media, University of Minnesota Extension websites, and conferences and workshops such as the Midwest Farm Energy Conference and Dairy Extension field days. Strategic information will be presented to farmers and industry representatives. Through this project we will develop the “Future Smart Pasture - manage pastures with multi-level collaborative robots” guidebook and disseminate it through a dedicated web portal and University Extension. We will publish peer-reviewed articles from project results in national journals. This will provide information to farmers, researchers and the tech companies well beyond the funding period.

**Activity Milestones:**

|  |  |
| --- | --- |
| **Description** | **Completion Date** |
| Conduct smart pasture workshops and webinars and present results at conferences | July 31, 2025 |
| Demonstrate multi-level monitoring for grazing rotation and weed control at UMN WCROC dairy field days. | August 31, 2025 |
| Submit semi-annual reports and a comprehensive final report | June 30, 2026 |
| Prepare and submit peer-review journal articles | June 30, 2026 |

## **Project Partners and Collaborators**

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Organization** | **Role** | **Receiving Funds** |
| Bradley Heins | University of Minnesota | Co-PI | Yes |
| Parikshit Maini | University of Minnesota | Co-PI | No |

## **Long-Term Implementation and Funding**

**Describe how the results will be implemented and how any ongoing effort will be funded. If not already addressed as part of the project, how will findings, results, and products developed be implemented after project completion? If additional work is needed, how will this work be funded?**The results and final products of this project will be demonstrated in state and regional conferences to show the potential of cooperative robots in smart pasture management through multi-level monitoring and control. We will publish findings in peer-reviewed journals and extension articles, and disseminate information and knowledge to farmers, educators, government officials and other stakeholders. Technology providers will be informed so that more efforts and greater progress can be made toward broader technology applications to smart pasture management, beyond the period of this funding. We will seek USDA NIFA Inter-Disciplinary Engagement in Animal Systems to support our ongoing efforts.

## **Other ENRTF Appropriations Awarded in the Last Six Years**

|  |  |  |
| --- | --- | --- |
| **Name** | **Appropriation** | **Amount Awarded** |
| Agricultural Weed Control Using Autonomous Mowers | M.L. 2018, Chp. 214, Art. 4, Sec. 2, Subd. 08d | $750,000 |
| Agrivoltaics To Improve The Environment And Farm Resiliency | M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 07c | $646,000 |

## **Project Manager and Organization Qualifications**

**Project Manager Name:** Ce Yang

**Job Title:** Assistant Professor

**Provide description of the project manager’s qualifications to manage the proposed project.**Ce Yang is a MNDrive Robotics, Sensor and Advanced Manufacturing faculty member at the University of Minnesota (UMN). Yang’s laboratory works on remote sensing and sensor applications in the area of agricultural and biological engineering. Crop monitoring and protection by various advanced sensing technologies has been the focus in Yang’s group for eight years. Yang's research focuses on drone remote sensing for efficient fertilizer management in corn field and disease monitoring in wheat fields with the aim to reduce chemical input and eliminate runoffs in farmlands. Yang also works on regenerative agriculture through novel crop physiology research using remote sensing to store carbon in the soil and address climate change. Yang's agricultural robotics lab in the College of Food, Agriculture and Nature Resource and College of Science and Engineering at UMN will manage the whole procedure from experimental design, data collection to research finding dissemination by conference/forum/field day presentations, lectures and peer-reviewed publications.

**Organization:** U of MN - College of Food, Agricultural and Natural Resource Sciences

**Organization Description:**The department of Bioproducts and Biosystems Engineering in the College of Food, Agricultural and Natural Resource Sciences (CFANS) at UMN tackle core issues in agricultural engineering, biological engineering, environmental engineering. The department has very dynamic interdisciplinary research activities and many researchers have received grant supports from the LCCMR program. WCROC from CFANS will participate as the research and demonstrate site for field experiments and showcasing the opportunities for smart pasture management, as well as generate new opportunities for the 5,000+ Minnesota dairy producers to utilize multi-level sensing/control techniques to achieve best management, reduce labor use and environmental footprint. The WCROC also hosts a Midwest Farm Energy Conference every 2 years in Morris, Minnesota where strategic information is presented to farmers and industry representatives. The University of Minnesota provides a range of facilities and sufficient laboratory space to perform each of the activities described in this proposal. UMN Sponsored Projects Administration (SPA) will be the entity authorized by the Board of Regents to manage the project agreements with LCCMR program.

## **Budget Summary**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Category / Name** | **Subcategory or Type** | **Description** | **Purpose** | **Gen. Ineli gible** | **% Bene fits** | **# FTE** | **Class ified Staff?** | **$ Amount** |
| **Personnel** |  |  |  |  |  |  |  |  |
| Project Manager |  | To manage and report the overall project progress |  |  | 33.5% | 0.12 |  | $25,490 |
| WCROC Project Coordinator |  | project coordination, field testing, ground robot modifications |  |  | 33.5% | 0.3 |  | $25,312 |
| WCROC Technician |  | Modify ground vehicle to custom needs, maintenance and minor repairs |  |  | 33.5% | 0.3 |  | $25,312 |
| 1 Postdoc |  | Path planning for Cowbot and fundamental research in cooperation between aerial and ground robots, project coordination with key personnel |  |  | 20.9% | 3 |  | $196,249 |
| Graduate Research Assistant |  | Drone remote sensing application including data collection, processing and analysis, conference presentations and publications |  |  | 23.6% | 1.5 |  | $161,231 |
| Graduate Research Assistant |  | Research and algorithm development in weed detection using the Cowbot: data collection, processing, analysis and integration |  |  | 23.6% | 1.5 |  | $161,231 |
| Undergraduate Student |  | Smart Pasture Technology for MN Farms |  |  | 0% | 0.45 |  | $12,000 |
| WCROC Researcher 3 |  | Technician for data collection, system testing, data collection and management |  |  | 28.7% | 1.05 |  | $138,998 |
| WCROC Researcher 5 |  | Engineering Technician to help with system design and placement and management |  |  | 28.7% | 0.6 |  | $32,176 |
| WCROC Farm Animal Attendent |  | Farm management to assist with labor of project, i.e. fencing, moving cattle |  |  | 7.5% | 0.24 |  | $7,524 |
|  |  |  |  |  |  |  | **Sub Total** | **$785,523** |
| **Contracts and Services** |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  | **Sub Total** | **-** |
| **Equipment, Tools, and Supplies** |  |  |  |  |  |  |  |  |
|  | Equipment | Drive-by-wire capable eletric mower from Toro or similar with a mowing implement (includes modifications to make the electric mower drive-by-wire). This is for Task 2 | This mower serves as the base model for the development of Cowbot-2 for path planning, navigation and weeding |  |  |  |  | $110,000 |
|  | Equipment | Update a drone system for drone hyperspectral imaging in Task 1 | The drone system for Task 1 will be updated in 2024 as the current drone platform was discontinued and technical support for current drone platform will be ended by 2024 |  |  |  |  | $15,000 |
|  | Equipment | Onboard sensors for gound robot | single board computer + RTK GPS + cameras + IMU + lidar + data communication equipment |  |  |  |  | $36,000 |
|  | Tools and Supplies | WCROC fence, tool and lab supplies | Fiberglass fence posts, insulators, poly wire and additional fence energizers. All objectives will require supplies that include: plot markers, sample bags, protective clothing. Seeds for cropping system objectives will also be ordered. |  |  |  |  | $15,000 |
|  | Tools and Supplies | Drone and camera maintenance | Drone imaging equipment needs to be maintained and repaired with batteries and parts |  |  |  |  | $4,500 |
|  | Tools and Supplies | Cowbot accessaries and supplies | Onboard power supplies + high data rate cables + mounting equipment + tools + field carry and storage |  |  |  |  | $7,500 |
|  | Equipment | Three high performance computers with graphic cards | Hyperspectral image and Cowbot data processing requires high performance computers with graphic cards for processing image cubes collected from the drone system and modeling as well as Cowbot navigation and path planning modeling and simulation. | X |  |  |  | $12,000 |
|  |  |  |  |  |  |  | **Sub Total** | **$200,000** |
| **Capital Expenditures** |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  | **Sub Total** | **-** |
| **Acquisitions and Stewardship** |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  | **Sub Total** | **-** |
| **Travel In Minnesota** |  |  |  |  |  |  |  |  |
|  | Miles/ Meals/ Lodging | Eight overnight trips ($750) per year to WCROC from UMN campus for three years. | Drone image collection, Cowbot system development and test in the pasture |  |  |  |  | $18,000 |
|  | Conference Registration Miles/ Meals/ Lodging | Visit and demo at Minnesota Farm Fest - space rental, lodging and travel, transportation of equipment, display signs | Outreach activities |  |  |  |  | $6,000 |
|  | Conference Registration Miles/ Meals/ Lodging | Participation in Midwest Farm Energy Conference | In-state outreach activities |  |  |  |  | $1,500 |
|  |  |  |  |  |  |  | **Sub Total** | **$25,500** |
| **Travel Outside Minnesota** |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  | **Sub Total** | **-** |
| **Printing and Publication** |  |  |  |  |  |  |  |  |
|  | Publication | Publication fees for 4 papers in total for year 2 and 3. | Publication fees for peer-reviewed journals papers and IEEE conference proceedings |  |  |  |  | $7,200 |
|  |  |  |  |  |  |  | **Sub Total** | **$7,200** |
| **Other Expenses** |  |  |  |  |  |  |  |  |
|  |  | WCROC Dairy Internal Service Fees | (Uncommon) Support for forage and crop testing. This is for WCROC dairy for services that include planting forages and crops as well as some seeds for the WCROC Dairy pastures. This is internal to the U of MN WCROC. |  |  |  |  | $8,777 |
|  |  |  |  |  |  |  | **Sub Total** | **$8,777** |
|  |  |  |  |  |  |  | **Grand Total** | **$1,027,000** |

### **Classified Staff or Generally Ineligible Expenses**

|  |  |  |  |
| --- | --- | --- | --- |
| **Category/Name** | **Subcategory or Type** | **Description** | **Justification Ineligible Expense or Classified Staff Request** |
| **Equipment, Tools, and Supplies** |  | Three high performance computers with graphic cards | Two computers are needed for data processing and analysis of large-scale hyperspectral image sets collected with the drone and multi-modal sensor data collected on the Cowbot. The third computer is needed to develop and test path planning and navigation algorithms for the Cowbot. These three computers will be used by the postdoc and two graduate research assistants to efficiently conduct the tasks in this project. |

### **Non ENRTF Funds**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Category** | **Specific Source** | **Use** | **Status** | **Amount** |
| **State** |  |  |  |  |
|  |  |  | **State Sub Total** | **-** |
| **Non-State** |  |  |  |  |
|  |  |  | **Non State Sub Total** | **-** |
|  |  |  | **Funds Total** | **-** |

## **Attachments**

### **Required Attachments**

#### ***Visual Component***

File: [5efa2ef6-e43.pdf](https://lccmrprojectmgmt.leg.mn/media/map/5efa2ef6-e43.pdf)

#### ***Alternate Text for Visual Component***

The file demonstrates the smart cattle pasture management scenario with workflow and shows the key items from the cooperative robot system....

### **Optional Attachments**

#### ***Support Letter or Other***

|  |  |
| --- | --- |
| **Title** | **File** |
| parikshit\_UNR\_support\_letter | [507deea9-6ab.pdf](https://lccmrprojectmgmt.leg.mn/media/attachments/507deea9-6ab.pdf) |
| Institutional Approval of Submission | [78b395a3-3da.pdf](https://lccmrprojectmgmt.leg.mn/media/attachments/78b395a3-3da.pdf) |
| Letter of support from Dr. Volkan Isler | [90dfb9a4-86c.pdf](https://lccmrprojectmgmt.leg.mn/media/attachments/90dfb9a4-86c.pdf) |

## **Administrative Use**

**Does your project include restoration or acquisition of land rights?**
 No

**Does your project have potential for royalties, copyrights, patents, or sale of products and assets?**
 No

**Do you understand and acknowledge IP and revenue-return and sharing requirements in 116P.10?**
 N/A

**Do you wish to request reinvestment of any revenues into your project instead of returning revenue to the ENRTF?**
 N/A

**Does your project include original, hypothesis-driven research?**
 Yes

**Does the organization have a fiscal agent for this project?**
 No