ALBERTA INNOVATES

CLEAN RESOURCES FINAL PUBLIC REPORT TEMPLATE

1. PROJECT INFORMATION:

Project Title:	A Systems Engineering Approach for Precision Irrigation
Alberta Innovates Project Number:	AI 2467
Submission Date:	First Draft June 10, 2021; Final Report October 8, 2021
Total Project Cost:	$409,739
Alberta Innovates Funding:	$99,768
AI Project Advisor:	Vicki Lightbown and Peggy LeSueur

2. APPLICANT INFORMATION:

Applicant (Organization):	InteliRain Inc.
Address:	3551 – 53 St NW, Calgary AB T2L 2K7
Applicant Representative Name:	Cam Cote
Title:	CEO
Phone Number:	403-660-2936
Email:	ccote@intelirain.com

Please provide an acknowledgement statement for project partners, if appropriate.

RESPOND BELOW

3. PROJECT PARTNERS

The financial support from NSERC is greatly acknowledged.

Provide a high-level description of the project, including the objective, key results, learnings, outcomes and benefits.

A. EXECUTIVE SUMMARY

In this project, InteliRain collaborated with the research team at the University of Alberta on the development of adaptive closed-loop irrigation algorithms for improved irrigation water

management that can be used in both lawn and agriculture irrigation. The primary objective includes the develop of a modeling and control system for an experimental field at Alberta Agricultures Irrigation Research farm in Lethbridge

The primary outcomes of this project from the company's perspective include the following: (a) A remote sensing algorithm for soil moisture; (b) A communication framework for smart irrigation; (c) Improved control algorithms for InteliRain's smart sprinklers.

The above outcomes have motivated our continued collaboration to further improve the technologies developed and has strengthened the competitiveness of InteliRain and the creation of a new position in InteliRain.

Please provide a narrative introducing the project using the following sub-headings.

- ☒ **Sector introduction:** Include a high-level discussion of the sector or area that the project contributes to and provide any relevant background information or context for the project.
- ☒ **Knowledge or Technology Gaps:** Explain the knowledge or technology gap that is being addressed along with the context and scope of the technical problem.

B. INTRODUCTION

Sector introduction: The increasing population and adverse climate change are escalating freshwater scarcity globally. Since irrigation consumes a large portion of fresh water, it is important to improve the efficiency in irrigation. It is well recognized that if irrigators made more efficient use of water, then there would be more water for environmental uses and for cities. According to Alberta Irrigation, in the province of Alberta even a saving of as small as 1% irrigated water would result in savings of about 23 million cubic meters of water each year.

Knowledge or Technology Gaps: There are many emerging technologies in *sensing, communication,* and *systems engineering* (e.g., soil moisture, infrared imaging, soil moisture sensors, wireless and 3G communication, dynamic optimization, model-based prediction) that can be used to improve our irrigation management and decision making. One challenge is to integrate these different technologies into one easy-to-use system.

Please provide a narrative describing the project using the following sub-headings.

- ⌧ Knowledge or Technology Description: Include a discussion of the project objectives.
- ⌧ Updates to Project Objectives: Describe any changes that have occurred compared to the original objectives of the project.
- ⌧ Performance Metrics: Discuss the project specific metrics that will be used to measure the success of the project.

C. PROJECT DESCRIPTION

Knowledge or Technology Description: In this project, we aim to develop a *solution-based* and *easy-to-use* irrigation management system. The irrigation management system has the following functionalities:

- ⌧ Connecting different devices (e.g., sensors, central pivots, central control system) together seamlessly through wireless and 3G communication.
- ⌧ Integrating information from various sources (e.g., infrared imagery, soil moisture sensor, weather station, ET gauge, precipitation gauge) to recommend the optimal irrigation solution.
- ⌧ Implementing the optimal irrigation solution automatically through *variable rate irrigation* (VRI) if the optimal irrigation solution is accepted by the irrigator.

Updates to Project Objectives: none

The project includes four primary objectives. The *first objective* is to develop a nonlinear agro-hydrological model and data-driven input-output models for the experimental field at Alberta Agricultures Irrigation Research farm in Lethbridge. The *second objective* is to design the information and communication infrastructure for the experimental field at Alberta Agricultures Irrigation Research farm in Lethbridge. The *third objective* is to develop local weather forecast algorithms including diurnal bias correction for improved irrigation performance for both agriculture and turf. The *fourth objective* is to develop adaptive and robust control algorithms that can be used to maintain the soil moisture of the entire irrigated area of a sports field or agricultural field within a desired range

Performance Metrics:

Metric	Ideal target	Minimum requirement	Achievements to date
Water savings	8% - 40% dependent on crop and soil type.	8%	achieved
Ease of use	System must be able to operate automatically without any input from the farmer and provide accurate watering prescriptions daily based on local conditions.	System requires less than 15 minutes per day of farmer input to provide accurate watering prescriptions daily based on local conditions.	achieved
Cost target	$44,000.00	$50,000.00	achieved

Please provide a narrative describing the methodology and facilities that were used to execute and complete the project. Use subheadings as appropriate.

D. METHODOLOGY

To consider the heterogeneity of soil types (which is very common for sport fields) and the geographical feature of a field, a 3D agro-hydrological model accounting for soil heterogeneity was first developed.

The first principles-based 3D agro-hydrological model provides insight into the behavior of the soil dynamics in the entire field and was very useful for sensor information fusion and was also used as a simulator to evaluate the performance of developed control algorithms.

To design a comprehensive information system architecture for closed-loop irrigation systems, including sensor networks, long-haul transmission networks, mobile control devices (based on the

App we developed), different communication protocols were tested extensively in the lab and in the field under different configurations. LoRA communication protocol was identified to be very suitable for large-scale agriculture fields.

To verify the developed algorithms, experiments were conducted in a research farm in Lethbridge, the research farm in the south campus of the University of Alberta.

Please provide a narrative describing the key results using the project's milestones as sub-headings.

- ☒ Describe the importance of the key results.
- ☒ Include a discussion of the project specific metrics and variances between expected and

D. PROJECT RESULTS

Task #	Task Description	Status	Comments on Tasks and Milestones
Task 1	A preliminary adaptive control algorithm	Completed	A preliminary control algorithm has been developed and has been tested through simulations.
Task 2	A preliminary 3D model of the experimental field	Completed	A preliminary modeling approach has been developed and verified through simulations.
Task 3	A refined model with optimal sensor information fusion	Completed	The modeling approach developed in Task 2 has been constantly refined based on simulation results and field data. From early June to mid August, two of the students involved in this project stayed in Alberta Irrigation Technology Centre and carried out many research relevant activities in a research field including field texture survey, sensor installation, remote sensing through flying a drone. We have collected lots of important data. Based on the data collected, we have further improved our model and sensor fusion algorithms.
Task 4	An improved zone MPC for model-plant mismatch	Completed	We have been constantly improving the parameter and state estimation algorithms to better handling model-plant mismatch.

Task #	Task Description	Status	Comments on Tasks and Milestones
Task 5	An integrated system including model, controller, etc.	Completed	We have put different elements together to test the closed-loop control system based on simulations.
Task 6	A refined integrated system based on extensive tests	Completed	The new PCB board has been built and testing shows greatly improved performance.

Modeling: We have developed a 3D simulation model for agro-hydrological systems including the irrigation element (i.e., center pivot). To improve the modeling, we have gone down to Lethbridge and performed extensive experiments to collect data. Figure 1 shows some simulation results.

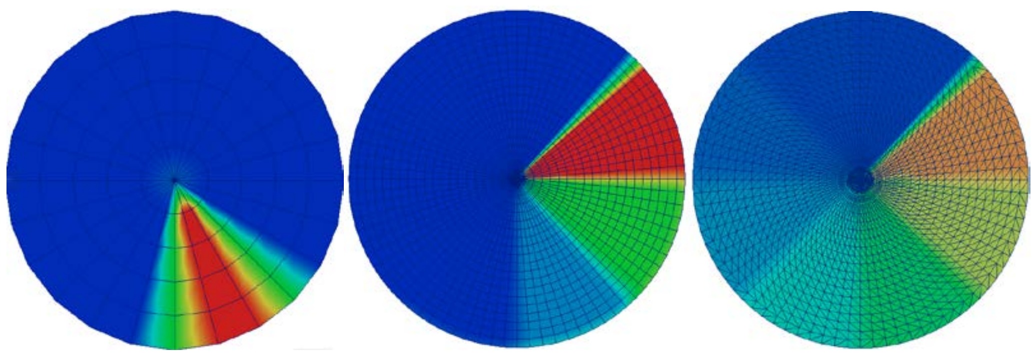
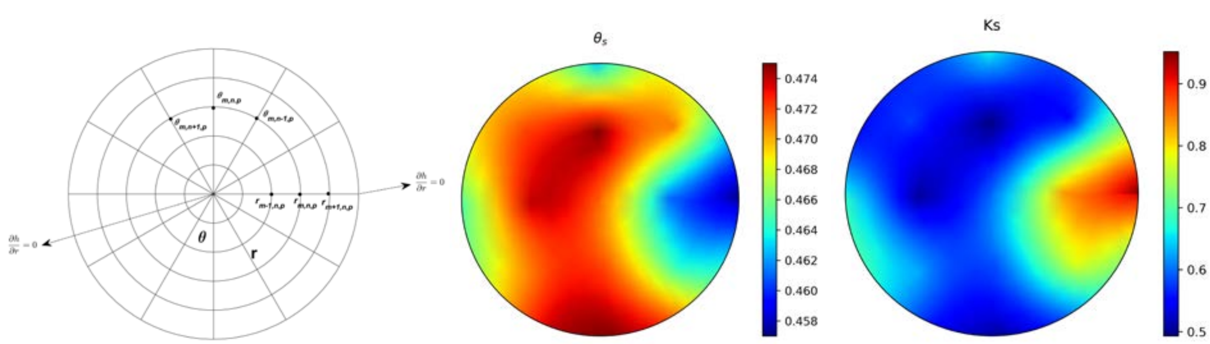


Figure 1. Irrigation of center pivot (left); surface soil moisture (middle); soil moisture at depth 10cm (right).

Based on the modeling method, we have been working on the modeling of the experimental field in the research farm in Lethbridge. In the modeling, we considered the radius of the field to be 50 meters and the depth considered is 75 cm. Based on the texture survey data we obtained last summer, we have obtained the soil properties at 40 points of the field.



(b) (c)

We have also developed an optimal sensor placement algorithm.

Parameter and state estimation. We have also worked on model parameter and state estimation algorithms. This is closely related to modeling. It is expected that the soil properties change over time. Soil texture survey can only give us an estimate of the initial soil condition. We have developed a way to estimate the soil properties (parameters) continuously using field measurements.

We have considered how to estimate the field soil moisture using the model and limited measurements from sensors. Figure 5 below shows the performance of the developed estimation algorithm. The figure shows that the state estimation algorithm works well and can converge to the actual soil moisture within 20 hours if the sensor is placed optimally. If the sensors are not optimally placed, it may take up to about 60 hours for the estimator to converge. In this set of results, the sensors are assumed to be buried in the soil and provides continuous soil moisture measurements.

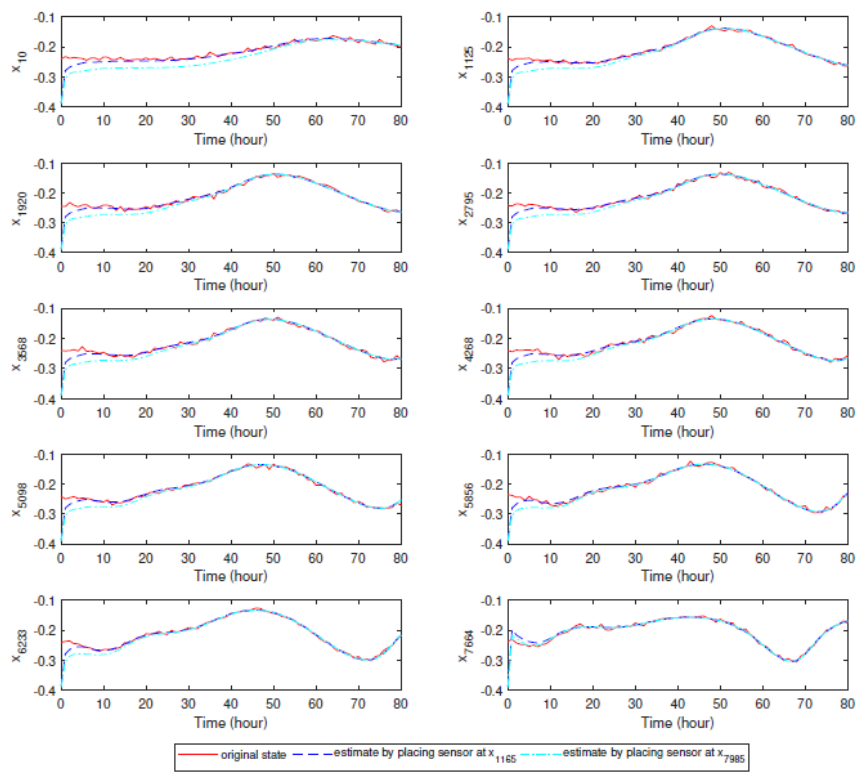


Figure 5: Performance of the developed estimation algorithm

Control system: The research team has developed a new PCB board to improve the operation of the smart sprinklers of InteliRain. The hardware cost has been reduced greatly. We have also upgraded the firmware of the irrigation system according to the various users' demand. We have also made efforts to upgrade the existing Wi-Fi communication system to LoRa to improve its robustness.

Please provide a narrative that discusses the key learnings from the project.

- ☒ Describe the project learnings and importance of those learnings within the project scope. Use milestones as headings, if appropriate.
- ☒ Discuss the broader impacts of the learnings to the industry and beyond; this may include changes to regulations, policies, and approval and permitting processes

E. KEY LEARNINGS

Through the course of the project, we learned the following:

- ☒ It is important to work closely with the end-users (e.g., farmers) to clearly understand the problem and to make sure the product is solution based so it can be used
- ☒ Wi-Fi communication is not reliable for irrigation applications. LoRa communication protocol is much more robust and reliable
- ☒ Water conservation in irrigation is possible and is achievable if technologies are integrated well so that it is easy to use

Please provide a narrative outlining the project's outcomes. Please use sub-headings as appropriate.

- ☒ **Project Outcomes and Impacts:** Describe how the outcomes of the project have impacted the technology or knowledge gap identified.
- ☒ **Clean Energy Metrics:** Describe how the project outcomes impact the Clean Energy Metrics as described in the *Work Plan, Budget and Metrics* workbook. Discuss any changes or updates to these metrics and the driving forces behind the change. Include any mitigation strategies that might be needed if the changes result in negative impacts.
- ☒ **Program Specific Metrics:** Describe how the project outcomes impact the Program Metrics as described in the *Work Plan, Budget and Metrics* workbook. Discuss any changes or updates to these metrics and the driving forces behind the change. Include any mitigation strategies that might be needed if the changes result in negative impacts.

F. OUTCOMES AND IMPACTS

Project Outcomes and Impacts:

The primary outcomes of this project from the company's perspective include the following:

1. A remote sensing algorithm for soil moisture
2. Soil moisture estimation algorithm
3. A communication framework for smart irrigation
4. Improved control algorithms for InteliRain's smart sprinklers

The above outcomes have motivated our continued collaboration to further improve the technologies developed and has strengthened the competitiveness of InteliRain and the creation of a new position in InteliRain.

Program Specific Metrics

Metric	Ideal target	Minimum requirement	Achievements to date
Water savings	8% - 21% dependent on crop and soil type.	8%	achieved
Ease of use	System must be able to operate automatically without any input from the farmer and provide accurate watering prescriptions daily based on local conditions.	System requires less than 15 minutes per day of farmer input to provide accurate watering prescriptions daily based on local conditions.	achieved
Cost target	$44,000.00	$50,000.00	achieved

Project Outputs:

- ☒ S. R. Sahoo, X. Yin, J. Liu, S. L. Shah. Dynamic model reduction and optimal sensor placement for agro-hydrological systems, IFAC World Congress, 2020. Dynamic model reduction and optimal sensor placement for agro-hydrological systems - ScienceDirect
- ☒ S. Bo, S. R. Sahoo, X. Yin, J. Liu, S. L. Shah. Simultaneous parameter and state estimation of agro-hydrological systems, IFAC World Congress, 2020. Simultaneous Parameter and State Estimation of Agro-Hydrological Systems - ScienceDirect

Please provide a narrative outline the project 's benefits. Please use the subheadings of Economic, Environmental, Social and Building Innovation Capacity.

- ☒ **Economic:** Describe the project's economic benefits such as job creation, sales, improved efficiencies, development of new commercial opportunities or economic sectors, attraction of new investment, and increased exports.
- ☒ **Environmental:** Describe the project's contribution to reducing GHG emissions (direct or indirect) and improving environmental systems (atmospheric, terrestrial, aquatic, biotic, etc.) compared to the industry benchmark. Discuss benefits, impacts and/or trade-offs.
- ☒ **Social:** Describe the project's social benefits such as augmentation of recreational value, safeguarded investments, strengthened stakeholder involvement, and entrepreneurship opportunities of value for the province.
- ☒ **Building Innovation Capacity:** Describe the project's contribution to the training of highly

G. BENEFITS

☒ Economic:

Through the project the company has added one HQP position and has hosted three engineering co-op students to enhance their education.

Intelirain has signed a national distribution agreement for its turf products which has led to greatly increased sales. Additionally, the company has had several global inquires and will start export sales in 2022.

☒ Environmental:

The developed irrigation system can save at least 8% of water compared with the ones available in the market. This also contributes to the reduction of GHG emissions about 8%.

☒ Building Innovation Capacity

The project has graduate students in the University of Alberta. The project has enriched their study experience significantly.

5.3 List students or other highly qualified personnel (HQP) being trained as part of this project.

Name	Institution	Level	Period	Thesis Title/Project	Status
Soumya Sahoo	U of A	PhD	2017-2021	State estimation and remote sensing	In progress
Song Bo	U of A	MSc	2017-2019	Parameter estimation	Completed
Erfan Orouskhani	U of A	PhD	2019-2021	State and parameter estimation	In progress
Yuan Liu	U of A	PhD	2016-2020	Sensor fusion	Completed
Wenzhou Chen	U of A	MSc	2018-2020	Control system implementation	Completed

Please provide a narrative outlining the next steps and recommendations for further development of the technology developed or knowledge generated from this project. If appropriate, include a description of potential follow-up projects. Please consider the following in the narrative:

- ☒ Describe the long-term plan for commercialization of the technology developed or implementation of the knowledge generated.
- ☒ Based on the project learnings, describe the related actions to be undertaken over the next two years to continue advancing the innovation.
- ☒ Describe the potential partnerships being developed to advance the development and

H. RECOMMENDATIONS AND NEXT STEPS

We have recently been approved by Alberta Innovates for a two year in-field study to further refine the technology and gather real world performance metrics. During this study we plan to further advance the technologies developed to make them easy to use and to improve the reliability of the entire systems.

Intelirain continues to work with the researchers at the University of Alberta to further refine the technology and improve the performance metrics.

Currently Intelirain has a national distribution agreement for its turf products and during this in-field study Intelirain will develop a sales, distribution, and service network for its agricultural products.

Please provide a narrative outlining how the knowledge gained from the project was or will be disseminated and the impact it may have on the industry.

I. KNOWLEDGE DISSEMINATION

The knowledge gained was disseminated through different approaches including the implementation of the developed technologies in InteliRain's products, the presentation of the results to different audiences, the publication of the results in academic conferences, and the presentation of the results in conferences.

- ☒ S. R. Sahoo, X. Yin, J. Liu, S. L. Shah. Dynamic model reduction and optimal sensor placement for agro-hydrological systems, IFAC World Congress, 2020. Dynamic model reduction and optimal sensor placement for agro-hydrological systems - ScienceDirect
- ☒ S. Bo, S. R. Sahoo, X. Yin, J. Liu, S. L. Shah. Simultaneous parameter and state estimation of agro-hydrological systems, IFAC World Congress, 2020.

Simultaneous Parameter and State Estimation of Agro-Hydrological Systems - ScienceDirect

Please provide a narrative outlining the project conclusions.

- ☒ Ensure this summarizes the project objective, key components, results, learnings, outcomes, benefits and next steps.

J. CONCLUSIONS

In this project, InteliRain collaborated with the research team at the University of Alberta on the development of adaptive closed-loop irrigation algorithms for improved irrigation water management that can be used in both lawn and agriculture irrigation. The primary objective was to develop a modeling and control system for an experimental field at Alberta Agricultures Irrigation Research farm in Lethbridge. Over the course of the project, we have developed modeling, sensing, control, communication algorithms. We learned that it is important to work closely with the end-users (e.g., farmers). We also discovered that LoRa communication is a promising communication protocol for irrigation applications.

Through the progression of this project, we learned how our technology could be used for agricultural irrigation and the need for new technologies in this field to increase water efficiency while improving crop quality and yield.

The outcomes of the project have motivated our continued collaboration to further improve the technologies developed and has strengthened the competitiveness of InteliRain and the creation of new positions in InteliRain.