# [F] PhD Extended Abstract Form

**ROBOTIC FARMING ON MARGINAL, HIGHLY SLOPED LANDS**

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**Extended Abstract**

One of the most pressing issues of our time is how to feed around 9.7 billion people by 2050. Cropland expansion is one of the leading factors in global agricultural production growth to meet the rising demands of an escalating population. Arable steep grassland, hills or uneven terrain present difficulties to farming with large conventional agriculture machinery and equipment's. The current technology is unsafe and unsuitable to operate on sloping terrain. This technological barrier to slope farming has prevented thousands of hectares of arable land from being cultivated, primarily in the United States Great Plains region. Therefore, we proposed a fleet of small Autonomous Ground Vehicles (AGVs) to expand farming to marginal, uneven, and highly sloped terrain. The proposed fleet aims to perform essential agricultural operations ranging from seeding to harvesting on sloping terrain. The research aimed to explore the potential, capabilities, and limitations of small ground vehicles to perform the sloped crop work. The dissertation consisted of four chapters, spanning over three research modules on: (1) AGV's traction, mobility, and power characteristics analysis, (2) vehicle behavior modeling on slopes, and (3) seeder prototype development. The goal of each chapter, significant findings, and conclusions are briefly discussed below.

The first chapter laid the foundation of a multi-AGV fleet by determining the single AGV's suitability and capabilities and by quantifying its physical limits for sloped crop work in a controlled soil bin setup. A standard drawbar pull test was performed in a soil bin to evaluate the AGV's performance against the varying slope (up to 18°), speed, and drawbar settings. The AGV delivered optimum power efficiency and generated enough drawbar pull with optimum travel reduction. The results found that the prototype AGV can successfully operate on slopes up to 18°, indicating that high-sloped terrain or hills could be farmed with the proposed system. Besides this, the chapter also aimed to generate an AGV's slope traction database to optimize its control variables, design optimization, and develop a mobility model for sloped terrain.

The vehicle behavior models in a sloping environment are essential for fleet operation, path planning, and developing a control algorithm. Hence, chapter two aimed to develop the AGV's behavior models from laboratory soil bin data. A series of Artificial Neural Network (ANN) models were developed with increasing complexity and different hidden layer activation functions for each response variable pertaining to traction, mobility, and power consumption. We found that shallow ANNs are the fast, accurate, and reliable tools to predict AGV behavior in a controlled laboratory setup (i.e., sloped soil bin). The predictive AGV's behavior model from a control laboratory setup proved to be an excellent starting point for optimizing the vehicle control parameters. However, these models cannot be extended to predict the AGV's behavior in a continuously varying slope environment. Therefore, chapter three aimed to develop machine learning-based models on data collected from a real field environment which included extensive drawbar pull testing in continuously varying sloped terrain. Deep learning-based models were developed from the collected experimental data to predict the AGV's behavior on slopes as a function of vehicle velocity, drawbar, and slope. A special model called the proposed model, which combined multiple deep neural networks with a mixture of Gaussians, was developed and trained with a hybrid training method. The proposed model consistently outperformed the other well-known machine learning models. The study found that the deep neural networks (DNN) model was well-suited for predicting the AGV's behavior in a sloped, real-field environment. Chapters two and three explored the capabilities of artificial intelligence methods to simulate the AGV's behavior on sloping terrain. The developed models predicted the AGV's specific dynamic response, including traction, slip, and energy from the inputs of AGV's velocity, applied load, and slope. These models would assist in vehicle path planning, route optimization, power-energy optimization, and informed decision-making.

A small and lightweight AGV was unable to provide the downforce and drawbar required for a traditional seeder. Hence, these AGVs would need a specialized robotic grain drill. The feed mechanism is the heart of the grain drill, and its design and performance influence the plant population and crop yield. Therefore, chapter four aimed to design and develop a screw

auger-type feed mechanism. Feed mechanisms with augers having three different pitches were developed as per the ASABE standards. The developed feed mechanism was investigated in a laboratory setup for flow rate and flow uniformity against speed, vibration, and slope as control variables, in accordance with ISO standards. The auger flow rate for flat slopes was a linear function of auger speed and varied from 30 g/min to 170 g/min. The coefficient of variation for the flow rate ranged from 2% to 10%. The CV was within acceptable limits, which is an excellent indicator of the bulk feed mechanism's flow uniformity. The performance of the feed mechanism was influenced by vibration and slope. The study delivered a bulk feed mechanism for wheat drilling, which can be easily scaled and adopted by small autonomous vehicles or mobile robots.

The dissertation laid the foundation for robotic farming on the sloped terrain, and the envisioned multi-AGV fleet may provide a valid solution to farm the arable uneven, highly sloped terrain. The findings provide groundwork for robotics and automation, which has the potential to solve emerging problems in the food production system by producing food, fuel, and fiber for the growing population.

Published chapter citations:


- Chapter 1: Badgujar, C, Flippo, D., Brokesh, E., & Welch, S. (2022). Experimental investigation on traction, mobility & energy usage of the tracked autonomous ground vehicle on a sloped soil bin. *Journal of the ASABE*. https://doi.org/10.13031/ja.14860 (Awarded with ASABE Superior Paper in Machinery Section, 2023)
- Chapter 2: Badgujar, C, Flippo, D., & Welch, S. (2022). Artificial neural network to predict traction performance of autonomous ground vehicle on a sloped soil bin and uncertainty analysis. *Computers and Electronics in Agriculture*, 196, 106867. https://doi.org/10.1016/j.compag.2022.106867
- Chapter 3: Badgujar, C, Das, S., Flippo, D., Martinez, D., & Welch, S. (2023). Deep neural network to predict the autonomous ground vehicle behavior on sloping terrain. *Journal of Field Robotics*. https://doi.org/10.1002/rob.22163.
- Chapter 4: Badgujar, C, Hui, W., Flippo, D., & Brokesh, E. (2022). Design, fabrication, and experimental investigation of screw auger-type feed mechanism for a robotic wheat drill. *Journal of ASABE*. https://doi.org/10.13031/ja.15199


**Final remarks concerning benchmarks and strength points of the the Pellizzi Prize 2024**

The dissertation addressed the technological barrier of large agricultural machinery to sloped land farming by proposing a novel multi-robotic fleet to expand farming to currently unsuitable marginal and sloped land. It explores and lays a foundation for small ground vehicle's traction and mobility behavior analysis on sloped land, along with robotic seeder prototype design and development. We predict that a sustainable expansion of wheat production to steep lands and uneven terrain with the help of the proposed robotic fleet would almost double the land area used for wheat crop from 4% to 7% in the Great Plains region. It would help in alleviating the 2050 food security goals. It also advances the current knowledge of robotic systems, which can be pivotal to the advancement of robotic technology in agriculture with the potential to provide a marketable solution to solve other emerging challenges not limited to crop scouting, site-specific input optimization, and so on.