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United States Department of Agriculture
Project Initiation

Project Data for Accession Number 1033201

Project Title

Collaborative Research: CPS: Medium: AI-driven Cyber-Physical Heterogeneous Systems for Precision Poultry Farming

Project Details

Sponsoring Institution National Institute of Food and Agriculture	**Project Status** ACTIVE
Funding Source NIFA Non Formula	**Grant Year** 2024
Grant No. 2024-67021-43694	**Cumulative Award Amt.** $874,335.00
Proposal No. 2024-07223	**Multistate No.** (N/A)
Project Start Date Sep 01, 2024	**Project End Date** Aug 31, 2027
Program Code [A7302] Cyber-Physical Systems	

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Non Technical Summary

The research addresses the challenge of optimizing bird welfare and productivity in poultry production through advanced technological solutions. Traditional methods rely heavily on manual labor and basic monitoring systems, which are not sufficient to maintain consistent health and environmental conditions for the birds. The importance of this research extends beyond the poultry industry, as it also impacts economic efficiency, community health, and environmental sustainability. By improving bird welfare, productivity is enhanced, leading to better economic outcomes for farmers. This, in turn, contributes to food security and affordability. Moreover, healthier and better-managed poultry operations can reduce the environmental footprint, promoting more sustainable agricultural practices. Therefore, this research is vital for fostering a resilient agricultural system that can adapt to growing global food demands while maintaining high standards of animal welfare.We will develop an integrated Cyber-Physical System (CPS) combining

robotics, artificial intelligence (AI), and advanced sensing technologies. Sensors will continuously monitor environmental conditions and bird health indicators within poultry houses, gathering data on temperature, humidity, air quality, and other relevant parameters. Robotics will assist in tasks such as litter aeration and egg collection, reducing physical burdens on farm workers. AI models will analyze collected data to detect patterns and anomalies, providing insights for optimizing bird welfare and environmental conditions. Through collaborative planning between the physical systems (robots and sensors) and the cyber layers (AI and data analytics), we aim to create a holistic monitoring and management system. This system will be validated in real-world commercial poultry farms, ensuring its practicality and scalability. The ultimate goal of this project is to develop a dependable and economically sustainable CPS for improving bird welfare and productivity in poultry production. Achieving this goal will have significant societal benefits, including enhanced food security and agricultural sustainability. The project aims to reduce the labor intensity and health risks associated with traditional poultry farming methods, thereby improving the quality of life for farm workers. Additionally, by promoting better animal welfare, the project supports ethical farming practices, which are increasingly valued by consumers. The research also has broader implications for the development of smart farming technologies that can be adapted to other livestock industries, fostering a more resilient and sustainable agricultural sector.

Animal Health Component

Animal Health Component: 0%

Research Effort Categories

Basic	80%
Applied	10%
Developmental	10%

Classification

Knowledge Area (KA)	Subject of Investigation (SOI)	Field of Science (FOS)	Percent
402	3299	2080	40%
402	3299	2020	40%
307	3299	2020	20%

Knowledge Area

[402] Engineering Systems and Equipment

[307] Animal Management Systems

Subject Of Investigation

[3299] Poultry, general/other

Field Of Science

[2080] Mathematics and computer sciences

[2020] Engineering

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Keywords

Phenotyping, Robotics, bird welfare, poultry houses, Cyber-Physical Systems, Autonomous systems

Goals / Objectives

We propose a new multidisciplinary CPS solution driven by Artificial Intelligence (AI) and Robotics for designing and validating an exemplar CPS for holistically monitoring and improving bird welfare, health, and productivity, and has the potential to be generalized to other poultry and livestock species. We envision precision poultry farms with high efficiency in environment and welfare management and lesser human interventions, enhanced biosecurity, and profitability by reducing high-intensity labor, ultimately resulting in healthier and sustainable poultry communities. In addition, identifying bird abnormalities and providing corresponding assistance, such as removing dead birds from the floor and early assistance to lame birds in accessing feed and water, support welfare-friendly and sustainable production. As a solution, a dependable and economic CPS to obtain heterogeneous data from the flock and the environment could provide better environmental control, improving bird performance, health, and welfare. Foundational scientific advances should be made to remove the barriers that are currently preventing a real-world deployment of CPS solutions in precision livestock environments. To this end, we identify the following critical research questions (RQ) that form the basis for the research tasks in this CPS project. These research questions are framed by leveraging our previous research results in these domains and the unique preliminary data collected from a collaborator's commercial poultry farm.RQ #1: In dynamic and dense environments such as a poultry production farm, current sensing modalities such as cameras and Lidars may fail to obtain accurate and efficient localization of robotics and sensor networks. This brings us to the research question: How novel sensing modalities and algorithms can improve the localization and navigation of mobile robots and wireless sensor nodes in dynamic environments found in precision livestock applications?RQ #2: Managing lame/dead birds on the farm is a complex issue, interconnecting the welfare aspects and the design and performance of bird-safe engineered systems. To what extent can the robots change the welfare conditions of birds by removing or transporting lame and dead birds?RQ #3: The current AI models and machine learning solutions do not scale well to bird (or animal) analytics as they typically require well-structured, feature-rich scenarios, which are not available in dense livestock environments. Also, current literature in AI-oriented welfare analytics and the availability of public datasets are significantly limited for the poultry domain. Therefore, we investigate the best AI-based approaches that we can leverage and build on to obtain welfare-oriented analyses for inferencing bird wellbeing along with predicting the environmental conditions.RQ #4: Creating a dependable CPS with multiple systems demands new principled coordination and planning frameworks, especially when tightly coupling the sensory and analytics feedback with the robot's corrective actions. What would be an ideal system-wide coordination framework that can seamlessly integrate robot control, AI-based planning, and simulation \& optimization layers?This CPS project addresses these domain-motivated research questions through the research tasks detailed below. The project integrates AI and robotics methods for achieving a dependable CPS for the poultry domain but also generalizes to precision livestock farming.To realize a dependable and cost-effective CPS in precision livestock environments, we take the perspective from three research areas that intertwine a functional Cyber-Physical Heterogeneous system: Wireless Sensor Networks, Robotics, and Machine Learning.Built on the team's prior work, we will conduct four interconnected research tasks (objectives) to address the research questions and challenges discussed above.Task #1: (CPS Physical Layer - Systems and Design Focus): Develop a distributed wireless sensor network and mobile robotic systems for sensing and monitoring the poultry house's environment and bird activities. This task focuses on building the physical systems for sensor networking and the robotic action layer of the CPS, where novel solutions for localization and navigation (addressing RQ #1) and robotic manipulation designs for bird assistance (addressing RQ #2) will be developed.Task #2: (CPS Cyber Layer - Decisions and Feedback Focus): Create welfare-oriented machine learning models and datasets. This research focuses on developing new synergistic welfare phenotyping methods (addressing RQ #3) to understand the factors impacting birds' well-being through the proposed AI-driven data and analytics tools that extract animal-based outcomes and kinematics for identifying bird abnormalities, such as lameness and mortality.Task #3: (CPS Systems/Integration Layer - Simulation and Optimization Focus): Establish a behavior-based coordination framework and a digital twin-aided simulation and

optimization of the system parameters. This research robustly integrates the systems and cyber layers (addressing RQ #4) and performs collaborative planning of sensor and robot tasks, adaptively sample environment quality, and assists birds for better behavior and productivity.Task #4: Evaluation and Validation Plan: The research approaches will be tested in the simulation tools before being evaluated with real-world prototypes. Further, the tasks will be evaluated at the poultry research facilities (model farms) at UGA and ISU in the second year. The final optimized, integrated solution and the project outcomes will be validated at a commercial farm close to UGA in the final year of this project.

Project Methods

Task #1: Develop Wireless Sensor and Robot Systems (UGA, ISU)This task will study new localization and path planning algorithms (Task 1.1) and novel robot designs (Task 1.2) for assisting, interacting, and manipulating livestock on the farm.Task 1.1 Sensing and Localization of Wireless Nodes and Mobile RobotsWe will construct low-cost wireless sensor nodes strategically placed in farms to monitor the environment and assist mobile sensing systems, as large poultry farms can't use centralized WiFi. We will study how robots in these farms can localize, navigate, and record spatiotemporal sensor data. These robots will have basic sensors, cameras for AI-driven analytics, inertial odometry, and IR-based obstacle detection for safe navigation. Optimization of sensor placement and parameters will be studied using digital twin simulations in Task 3.1. The mobile robots will be equipped with the basic sensor suite and a high-resolution camera for AI-driven real-time analytics (identification of bird abnormalities in Task 2.1 and welfare phenotyping in Task 2.2).Task 1.2 Mobile Robot Navigation for Monitoring and Livestock AssistanceIn this task, we will apply and improve on the Gaussian Process Regression (GPR)-based mapping to transform the analytics and precision data to the whole farm space, based on which regions of interest will be identified and prioritized for the robot to navigate to (e.g., to perform a fine-grained sample of temperature or gas, analyze a specific bird or flock status, etc.). The physical and chemical properties of each potential deployment location will be chosen to increase diversity and maximize the information entropy of the whole map. The Directed Coverage Path Planning (DCPP)-based navigation strategy will be paired up with autonomous charging objectives to achieve a successful and continuous navigation process with persistent CPS operations. In addition, we will develop a custom (dozer) robotic attachment for the handling and haul-away of birds on the farm.Task #2: AI-driven Synergistic Welfare Phenotyping (UGA)This task will investigate the application of machine learning and AI tools for bird welfare analytics and phenotyping the measures for bird welfare.Task 2.1 AI Tools for Monitoring of Bird State and ActivityWe will investigate lightweight Deep Learning (DL) models using RGB-Depth data tailored to the robot-centric vision data that can run on a robot's computer, as it has limited computational powers. Specifically, we plan to investigate one possible DL model for mortality detection through the "You Only Look Once" (YOLO) technique developed for object detection. We will investigate the AI tools that exploit the image sequence data combined with other sensor modalities for bird behavior analysis and indicators, detailed in Task 2.2. Moreover, six behaviors will be used to train the AI model to assess welfare: Lying, Foraging, Dust bathing, Preening, Feeding, and Drinking. Based on these developments, this research will be integrated with the coordination and integration framework (Task 3) to control the CPS to obtain better bird analytics and decrease uncertainty.Task 2.2 Phenotyping Animal-based Welfare Outcomes and KinematicsIn this task, the bird locomotive and spatio-temporal behavior metrics will be extracted and analyzed for animal-based welfare outcomes. First, we will apply AI models to project broiler locomotive behavior over time. Each RGB-Depth frame captured will be first preprocessed with common image processing algorithms such as edge detection and Hough transformations. Then, we will streamline the state-of-the-art DL toolbox called DeepLabCut for markerless pose estimation of animals performing various behaviors. The extracted features will be used to classify abnormal birds using machine learning classifiers. All the extracted animal-based outcomes and kinematics will be correlated with the results from the real-world evaluation tasks to gain more biological meaning to support precision poultry farming and welfare-oriented production.Task #3: Integration Framework for Tight CPS Coordination (UGA)This task contributes novel frameworks to perform planning and coordination for this exemplar of CPS's tightly coupled physical and cyber layers.Task 3.1 Simulation and Optimization of Poultry CPS Using Digital Twin TestbedIn this task, we will develop a realistic digital twin testbed for this poultry CPS application that can support simulation and optimization of other research tasks. As it is essential to understand and evaluate the algorithmic CPS solutions before real-world

tests, we propose a new game engine-based simulation platform built on the Unity 3D framework, which is used to create high-quality visual game scenes and virtual environments. Therefore, we will design a Poultry Robotics simulator testbed borrowing inspirations and experiences from the prior works.Task 3.2 Behavior-based CPS Coordination FrameworkIn this research task, we will study the possibilities and novelties that Behavior Trees (BT) bring to the CPS integration layer and investigate and analyze the efficacy of BTs to systematically address the integrated control and planning policies of the sensing and robot nodes, which makes it feasible to integrate with other research tasks and subsystems. First, we will design BTs for the mobile robot to take care of their robot-level logic plans, such as mobility, navigation, and autonomous recharging. Second, we will integrate this BT-based framework for handling CPS-level tasks, such as detecting and reporting bird moralities observed by multiple cameras or at multiple locations. Third, we will expand these designs with the integration of a mortality removal manipulation system, which takes care of mortality picking. The BT-based solution will be theoretically analyzed to guarantee the robustness and safety of the birds and environment. It will then be compared against state-of-the-art solutions to observe performance improvement and persistent operation capability.Evaluation and Validation PlanWe will verify the research solutions in realistic simulations and digital twins (Task 3.1) whenever possible before validating in the real-world setting at the local lab setup. All algorithms and methods proposed in this project will be evaluated against the relevant state-of-the-art methods. Partial integration of the research tasks will be evaluated at the model farms at UGA and ISU in the second year. After solid data has been collected in the lab-scale study, the system will be further improved, and the final validation with all integrated tasks will be conducted at a commercial broiler farm in Northeast Georgia towards the end of this project. The feedback and the data collected during these evaluations will determine the project's success and will provide an opportunity to improve the results.We could assert that the CPS would be successful if 1) it persistently performs sensing, monitoring, and manipulation operations (ability to move around the whole farm without collisions and transport the dead and lame bids to dedicated drop locations) in Task 1 with minimum human intervention; 2) it successfully computes the bird welfare indicators (a combination of bird state classifications, behavioral and spatio-temporal metrics), produce informative correlation results and analytics through the AI tools in Task 2; and 3) it reliably integrates the physical and cyber systems for obtaining accurate assistance with adaptable system-level behaviors and modular addition of algorithms in Task 3. We will quantify the performance of the CPS using a new Daily House Performance Score (DHS), which will be a combination of environmental measures (average air quality), bird health and well-being measures (spatio-temporal behavioral data, unassisted lame birds inside the farm), and production performance (weight, mortality rate) for multiple flocks.