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Agricultural Automation and Bioenergy

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Abstract: Building on the success of agricultural mechanization, progresses have been made in automating agricultural operations. Automation involves the addition of human like intelligence (including perception, reasoning/learning, communication, task planning/execution) to mechanized devices and processes. Mechanical and electronic components are integrated to operate in concert with the situations of cultural practices and environmental conditions encountered in agriculture. Many agricultural automation capabilities are being developed and implemented in practicing precision agriculture and assuring quality of agricultural produce. Bioenergy has become increasingly important in solving the challenging energy supply situation. The underlying value chain of biomass based energy systems starts with sunlight and results in providing fuel, power, and materials as usable end-products. The key components of this value chain include feedstock production, physical, chemical, and/or biological conversion of biomass, and synthesis/utilization of biofuels. Biomass is considered a key source of bioenergy. Large-scale biomass feedstock production is likely to add a new future dimension to the current agricultural system.
Key words: perception, reasoning & learning, communication, task planning & exceution, biomass feedstock production, biomass coversion to energy, systems informatics & analysis

INTRODUCTION

Agriculture is understandably a complex system; especially when it is broadly defined to include plant and animal production, food, environment, energy, society, etc. It is a very large economic engine. The sustainability and competitiveness of this economic engine are of paramount importance to the mankind. It is critical that capabilities exist for effective planning, management, and operation of all aspects of agriculture. Since factors, such as technologies, environment, social acceptance, policy, etc., that influence parts and/or the whole of the agricultural system are mostly time-varying, site-specific, and interdependent, many tasks and processes will require assistance from machines with certain level of intelligence. Mechanization has made an invaluable impact to agriculture. The objective of automation is to add intelligence to mechanized devices and systems.

Energy has become an issue of heightened global interest and concern for many obvious reasons. Bioenergy, especially biomass based, is expected to be part of the solutions for future energy supply and demand. The underlying value chain of biomass based energy systems starts with sunlight and results in providing fuel, power, and materials as usable end-products. The key components of this value chain include feedstock production, physical, chemical, and/or biological conversion of biomass, and synthesis/utilization of biofuels. The production of bioenergy will likely, to a significant extent, build on the success of the existing technologies and infrastructures that are used in the agricultural system. However, there are also many issues, specific to crop production, conversion processes, and energy utilization, that will require new considerations and/or methodologies.

In order to successfully provide engineering solutions to solving the problems associated with agriculture and bioenergy operations, core competencies of automation, culture, environment, and systems (i.e. the ACESys concept) are required. The culture (i.e. biosciences and biotechnologies) and environment set the governing conditions under which agricultural and bioenergy operations take place. Automation deals with information processing and task execution. It often plays the role of integrator for a functional system. Automation adds to machines the human like capabilities of perception, reasoning & planning, communication, and task planning & execution. Computers, with their vast storage capacities for data and algorithms and high speed for information processing, have brought about ever increasing possibilities for effective automation in agricultural systems.

This presentation highlights a number of current agricultural automation and bioenergy research activities conducted by the University of Illinois and its partners.

AGRICULTURAL AUTOMATION

It is well recognized that mechanization has made an invaluable impact to the modernization of agricultural production. It has significantly substituted and extended human labour, enabled effective task execution, and improved the quality of processes and products. In recent years, a substantial amount of research effort has been made to enhance machine performance through automation, i.e. the adoption and incorporation of human-like capabilities of perception, reasoning and learning, communication, and task planning and execution. Excellent examples of agricultural automation may be seen in the practice of precision agriculture. Precision agriculture is an intelligence empowered production system that requires capability for information collection/processing and decision making, mechatronics devices for controls and actions, and ability to synergistically integrate components into functional systems.

The above-mentioned machine intelligence that enables automation is further decribed as follows:

Perception involves obtaining the awareness of surroundings; i.e. gathering, processing, and interpretation of information about situations. Example devices that provide perception capabilities include direct and indirect sensors, machine vision systems, etc.

Reasoning and Learning is the process of logical deduction, mathematical analysis, heuristic inference, and experiential adaptation used to derive conclusions, make decisions, and issue instructions/commands. Commonly seen machine reasoning and learning software forms are computer models, expert systems, decision support systems, and artificial neural network.

Communication function coordinates and delivers information between various entities. The key consideration is what information needs to be made available to what unit at what time. Computers that are originally developed for data storage and processing have become increasingly more important for communication.

Task planning and execution is to effect device operations for control activation and physical work. Environmental control algorithms, automated watering systems, and robots are the examples.

Faculty members in the Department of Agricultural and Biological Engineering, University of Illinois, ***Tony Grift, Alan Hansen, Luis Rodriguez, Lei Tian, Qin Zhang,*** and their cooperators have been working on various aspects of agricultural automation with main applications to precision agriculture for many years. Some of their research activities are described here (http://www.engr.uiuc.edu/communications/engineering_research/current/pdf/AgBio.Sum.07.pdf):

A system was developed to efficiently image a large number of corn roots. Fractal dimension and entropy were used to charaterize the stored images for distinguishing corn genotypes grown under diverse field conditions (Grift, Bohn and Novais).

A yield monitor for citrus fruits is being developed, in cooperation with the Citrus Reearch and Education Center, University of Florida, to provide a precise indication of the performance of a per tree basis so that the growers may better manage their groves (Grift, Ehsani and Nishiwaki).

In cooperation with CEMAGREF at Montoldre, France, a Smart Spreader System is being developed to control both rate and uniformity of fertilizer applications. The fundamental flow of particles during spreading and material properties are also being studied (Grift, Kweon, Piron and Rioual).

An infotronic platform has been developed by integrating information and electronics technologies to provide farmers a holistic data collection/processing, decision support, and impementation computational environment (Q. Zhang).

A study is being conducted to investigate what the future data set might be and how researchers could best plan to analyze it (Tian, Schnitkey and Welge). The research team has been using state-of-the-art technologies in the development of sensing systems for future farms. The value of information is being evaluated in the context of site-specific farming.

A preliminary model is being developed to study the complex interations of cattle-corn rotation operation (Rodriguez, Li, Hansen and Q. Zhang).

Automatic tuning and adaptive control technologies have been investigated for intelligently tracking vehicle paths (Zhang). The purposes of this project are to identify candidate technologies and recommend construct guidelines for vehicle controller in order to achieve high maneuvering performance on ground vehicles.

A flexible weeding system that is capable of identifying weeds and treating them according to their response to glyphosate (roundup) is being developed (Grift, Bohn, Tian, Rodriguez and Hager). Autonomous robots will be used to treat weeds that are responsive to glyphosate chemically and those that are resistant to glyphosate mechanically.

BIOENERGY

Bioenergy is expected to play an important part in solving the current and future energy problems. It is believed by many researchers and policy makers that bioenergy will provide fuel for competitiveness and sustainability. To ensure biomass feedstock availability, the large-scale crop production systems as practiced in today's agriculture will serve as a model and foundation for producing energy crops. In producing energy crops, efforts need to be continued in improving its effectiveness and competitiveness, minimizing its impact on environmental quality, optimizing its economic return, providing management capabilities, monitoring and ensuring intelligent use of resources, understanding the governing constraints, enabling creative productivity, interfacing with other economic sectors, identifying value-added opportunities, and creating new economic activities for wealth and job generation. The holistic integration of knowledge bases (in energy sources/feedstock, material processes/conversion, products utiliation, economics, envrionment/natural resources, systems informatics/analysis, and policy) and applications (in fuel or thermal energy, electric or mechanical power, and co-products or by-products) will be essential for developing successful bioenergy solutions. This is likely to be accomplished through cross-cutting research, development, demonstration, and implementation of components, subsystems, and the entire system.

The Center for Advanced BioEnergy Research (CABER), University of Illinois at Urbana-Champaign (UIUC) has been established to focus on "sustainable bioenergy systems, including plant, microbial, downstream processing and economics and policy issues as they relate to bio-based products" (www.bioenergy.uiuc.edu). The Center "provides a platform for promoting national and international visibility of all UIUC faculty involved with bioenergy research, teaching and outreach" and "is partnered with a variety of scientists from a host of different disciplines, including faculty in the UIUC Colleges of Agricultural, Consumer and Environmental Sciences, Liberal Arts and Sciences, and Engineering, as well as the Institute of Genomic Biology." The current and future projects of the Center include (1) partnering in the multi-state project NC506: Sustainable Biorefining Systems for Corn in the North Central Region (of U.S.), (2) conducted seminar series in Bioenergy Research (11 seminars in Spring 2008), (3) developed a graduate student curriculum (Professional Science Master in Bioenergy), (4) building the Integrated Bioprocessing Research Laboratory, and (5) cosponsored the Environmental Horizons Summit.

An Energy Biosciences Institute (EBI) has been established, with support from BP, on the campuses of the University of Berkeley, Lawrence Berkeley National Laboratory, and the University of Illinois (www.energybiosciencesinstitute.org). Five areas of research (with programs and projects in each area) are being conducted: Feedstock Development; Biomass Depolymerization; Biofuels Production; Environmental, Social and Economic Dimensions; and Fossil Fuel Bioprocessing.

Faculty members in the Department of Agricultural and Biological Engineering, University of Illinois, ***Steven Eckhoff, Ted Funk, Tony Grift, Alan Hansen, Kent Rausch, Luis Rodriguez, Vijay Singh, Lei Tian, K.C. Ting, Xinlei Wang, Qin Zhang, Yuanhui Zhang***, and their cooperators have been working on various aspects of bioenergy including:

Ethanol – corn dry-grind processes and co-product improvement,

Biobased Crude Oil – thermochemical conversion (TCC) of waste and biomass to crude oil,

Biodiesel – fuel properties, engine performance and emission,

Feedstocks – engineering solutions for biomass feedstock production, and

Systems Informatics and Analysis – information, modeling, simulation, and decision support.

Some of their research activities are described here (http://www.engr.uiuc.edu/communications/engineering_research/current/pdf/AgBio.Sum.07.pdf):

The fuel ethanol industry is rapidly growing and becoming more competitive. As a result, more value needs to be extracted from coproducts made with ethanol. A collaborative project was conducted to understand the role of raw material (corn) in optimally producing ethanol and other bioproducts and to identify process methods that generate multiple coproducts with increased value. A small-scale (25g) dry grind procedure is being developed and evaluated to serve as a reference for the fuel ethanol and corn gnentics industries. As new sources of genetic material are developed, the procedure will determine ethanol yields accurately (Rausch, Dien and Singh).

Distillers dried grains with soluables (DDGS) is a coproduct of dry grind process used to produce fuel ehtanol from corn. Knowledge is limited on thin stillage and wet grains that are used to produce DDGS. Effects of process modifications on these process streams is unknown. Compositions of the thin stillage streams from modified processes will be affected. Membrane filtration and heat transfer fouling characteristics are expected to be different. Research is being conducted to determine membrane filtration and heat transfer fouling characteristics to identify potential for increasing water recycle and reducing energy requirements during ethanol production (Rausch, Singh and Belyea).

A transgenic corn that produces high levels of endogenous amylase is being evaluated for dry grind corn processing. The enzyme is activated in the presence of water and high temperature. In a conventional process, exogenous alpha amylase enzymes are added during liquefaction to break down starch into dextrins. In this study, liquefaction and fermentation properties of transgenic corn are being tested using a small-scale laboratory dry grind procedure and compared to the fermentaion properties of a control sample of isogenic corn (Singh and Rausch).

New or modified existing corn milling technologies that allow value-added processing and lower the capital and operating costs of ethanol production facilities have been developed. The project involves recovering multiple coproducts and improving the efficiency of dry-grind corn processing. Economic assessment of process improvements has been done by process simulation and economic modeling (Singh, Rausch and Johnston).

A study on evaluation and development of enzymes for modified corn dry grind processes has been conducted. The use of amylases and proteases in dry grind corn fractionation processes to improve rate of fermentation and increase ethanol yield has been evaluated. Use of corn fiber as feedstock for ethanol production has also been evaluated (Singh, Wenger and Lindergaard).

Concern over the use of corn for fuel at the expense of animal feed can be partially mitigated by harvesting the corn near physiological maturity (35-40% moisture w.b.), where the stover has higher digestibility than in field dried corn. A study is being conducted to compare ruminant digestibility corn stover harvested at different corn moistures and evaluate methods to dry or preserve the high moisture corn (Berger and Eckhoff).

A continuous thermochemical conversion (TCC) process is being developed. This technology involves major changes in conventional waste handling process, and there are no manufacturers currently supplying the systems needed for the process. It is envisioned that a single unit continuous TCC (CTCC) system being able to process manure of a 2000 hog farm or an equivalent amount, and the unit should be no larger than a hot-water boiler in a residential house. The crude oil produced on the farm can be trucked to a central refinery for further process (Y. Zhang, Morgenroth, Funk, Chen, Wang and Hansen).

A project on hydrothermal process for fiber stream is being conducted to develop and pilot-test the continuous thermal hydrolysis process and operating parameters to convert the fiber stream from corn milling and miscanthus into value-added products, or products that can be easily further processed, such as fermentation or thermochemical conversion (Zhang, Wang and Dong).

There is considerable interest in reducing U.S. reliance on imported petroleum. Biodiesel manufactured from vegetable oil is seen as a viable alternative to regular diesel. A research project is being conducted to investigate a novel low-temperature combustion (LTC) strategy with biodiesel that is able to simultaneously reduce regulated NOx and particulate emissions while achieving high combustion efficiency. LTC combustion with biodiesel has been investigated via laser diagnostic and multidimensional modeling techniques. Experiments are conducted in both optical and metal engines. Optimum strategies for reducing exhaust emissions and increasing the efficiency of biodiesel LTC engines are also being investigated (Lee and Hansen).

Emissions reducing strategies and technologies are at the forefront of research and development efforts of all major diesel engine manufacturers in order to meet future U.S. Environmental Protection Agency regulations. Very littel work has been done to investigate the use of these technologies in conjunction with biofuels such as biodiesel and E-diesel (ethanol-diesel blended) fuels. A study is being conducted to evaluate the impact of biofuels on both present and emerging emissions reducing technologies for diesel engines. Preliminary results with the exhaust gas recirculation Nox emissions reducing strategy show that a greater rate of emissions reduction occurs with biodiesel fuel (Hansen).

Biomass feedstock production is a critical subsystem within the overall bio-based energy production and utilization system. It provides necessary materials input to the conversion process of biomass into fuel, power, and value-added materails. This subsystem includes the oeprations of agronomic production of energy crops and physical handling/delivery of biomass, as well as other enabling logistics. On the technical side, biological, physical, and chemical seciences need to be integrated with engineering and technology to ensure effective and efficient production of biomass feedstock. The entire bio-based energy system is understandably complex. A research program has been initiated within the BP funded Energy Biosciences Institute (EBI) to focuss on the engineering solutions for biomass feedstock production while keeping in mind the “external” interactions and influencing factors, such as social/economic consideration, environmental impact, and policy/regulatory issues. The overall objective of this program is to develop effective and efficient engineering solutions and machinery for successful production of biomass feedstock. This program objective is being accomplished through five interrelated tasks of (1) Pre-harvest Crop Production; (2) Harvesting; (3) Transportation; (4) Storage; and (5) Systems Informatics and Analysis. For each task, systematic approaches are taken to evaluate existing technologies, charaterize task features, identify information needs and researchable questions, develop prototypes and computer models, conduct experiments and computer simulations, analyze experimental data and simulation output, and deliver results in the forms of operational machinery design/prototype and decision support information/tools (Resource – Engineering & Technology for a Sustaninable World, April 2008, P25; Ting, Hansen, Q. Zhang, Grift, Tian, Eckhoff and Rodriguez).

The rural economy in parts of the U.S. is bolstered by the explosion of small dry grind ethanol facilities. However, following the rapid increase in the number of these small-sized dry grind facilities, there has been a flurry of announcements of expansions and new plants by major commercial entities. A model is being developed that captures each of these aspects at the facility level and integrates them in a package capable of assisting decision making at two key levels: technology decisions for cooperative board members; and tax incentive decisions at the legislature for handling of potential pollutants (Rodriguez, Li, Eckhoff, Khanna, Spaulding).

CONCLUDING REMARKS

Agriculture has returned to the center stage in a world that has heightened concerns for the sustainability of energy, environment, and food. Sustainability may be simply described as "continuing to do well." The definition of "wellness" is expected to be different by different people depending on the objectives of the system under study. Examples of system level wellness include technical workability, economic viability, social acceptability, energy efficiency, environmental friendliness, ecological harmony, optimization ability, operation and management capability, etc. Systems thinking and approach are essential in addressing complex issues. Agriculture is a complex system that will continue to be a critical part of the solutions to the world problems. Agricultural automation and bioenergy are among the key areas of capacity enhancement in agriculture.

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