Small-scale Sustainable Agriculture as a Platform for Experiential Learning

Abstract

Background: Market pressures and the impacts of climate change are threatening the livelihoods of small-holding farmers around the world. As farmers themselves face shortages of workers and the pressures of climate change, adaptation is often required for sustainability. Solutions must be developed in collaboration with local communities to be sustainable, accessible, and equitable.
Method: These challenges provide opportunities for experiential learning within the engineering classroom. In this paper, I describe a diverse set of projects with a sustainable agriculture theme that I have used to enhance student learning through projects implemented in courses, capstone experiences, summer research programs, and independent research opportunities.
Results: The projects described here include both short-term, single-semester projects with limited scope and longer-term projects involving multiple groups of students addressing various aspects of the project over multiple semesters.
Conclusions: The projects discussed here each resulted in the successful design and construction of prototyped solutions to the challenges presented. In each case, the students have gained valuable design experience and have become better prepared to enter the engineering workforce and facilitate new product development and entrepreneurial activities. Further, students have gained new appreciation for the challenges faced by agricultural workers and communities. The students have learned the value of interdisciplinary collaboration for tackling challenging societal issues.

Introduction

Small stakeholder farmers provide a critical service to their communities through the cultivation and sale of locally produced agricultural products. While support structures such as food cooperatives, farmer's markets, and the community supported agriculture model help these farmers bring their goods to market, they also face challenges such as rising costs, shortages of workers, and limited access to the technologies that can improve operational efficiency (Kirwan, 2018). The design of appropriate technology for sustainable agriculture (Altieri, 2018) provides ample opportunity for the development of student learning experiences that can have a positive impact on local and regional farmers. Student projects can be used to explore and develop low-cost automation technology that can be deployed in small-scale farming operations to increase yields and help make up for labor shortages. Similar efforts may also be made in agriculture adjacent domains such as technologies to reduce the environmental impact of farming operations. This form of work provides opportunities for collaboration with regional farmers in partnership with undergraduate students at various levels as well as with faculty from diverse fields such as biology, environmental science, or the social sciences.

The projects described in this work follow the standard engineering design process and build on previous community development experience (Lacksonen et al., 2017; Lee et al., 2017). Further, inspiration for many of the projects came from collaboration with local community supported agriculture (CSA) and cooperative farmers where conversations and farm visits provided insight into the challenges faced during their daily operations. As a motivation for design projects, sustainable agriculture involves both technical and cultural challenges which can be solved using the principle of appropriate technology, a design methodology with a focus on people-centered, sustainable solutions (Amiolemen et al., 2012; Bauer & Brown, 2014; Kaplinsky, 2011). Solutions must be developed in collaboration with local communities to be sustainable, accessible, and equitable (Pearce, 2012; Sianipar et al., 2013; Zelenika & Pearce, 2011).

Method

Projects within the theme of this work fit within a variety of engineering courses and/or student research experiences. Those discussed in the following section include projects from senior-level engineering coursework in courses titled, Senior Design Experience I and II and Advanced Manufacturing with 3D Printing. However, similar projects not discussed here have been used in a first-year engineering course as well as in various other independent student research projects (Berg, 2019, 2018). In addition to coursework, some of the projects discussed here were a part of undergraduate research experiences, both as independent study arrangements and as part of an NSF funded Research Experiences for Undergraduates (REU) program. The venue for each particular project was selected based on timing of the course offerings and scope of the individual projects. For smaller projects, a one-semester course such as Advanced Manufacturing with 3D Printing or an independent study were more appropriate. For projects with a larger scope, the Senior Design Experience courses were more appropriate due to their longer timeline and larger student groups. In each case, the individual projects were sourced from broader research agendas including work through the NSF REU project called LAKES[1] and through a collaboration with the Department of Biology and the campus greenhouse for robotic methods in agriculture and gardening. Through these research experiences, engineering students were able to form collaborative relationships with both faculty and other students from other fields such as the social sciences and biology.

Results

As previously mentioned, the projects described here with a sustainable agriculture focus provide opportunities to integrate the work into engineering coursework, independent studies, or externally funded research programs. As such, the level of complexity within a given project must vary to accommodate the availability of student time and prerequisite skills. For a more time-constrained project with course integration, it is often necessary to have an established foundation upon which a student project may be built. One such foundation is the open-source, modular automation tool called the FarmBot (Aronson, 2013), an example of which is shown in Figure 1.

[1] NSF REU Site: LAKES Undergraduate Research Experience: Linking Applied Knowledge in Environmental Sustainability, https://www.uwstout.edu/lakes

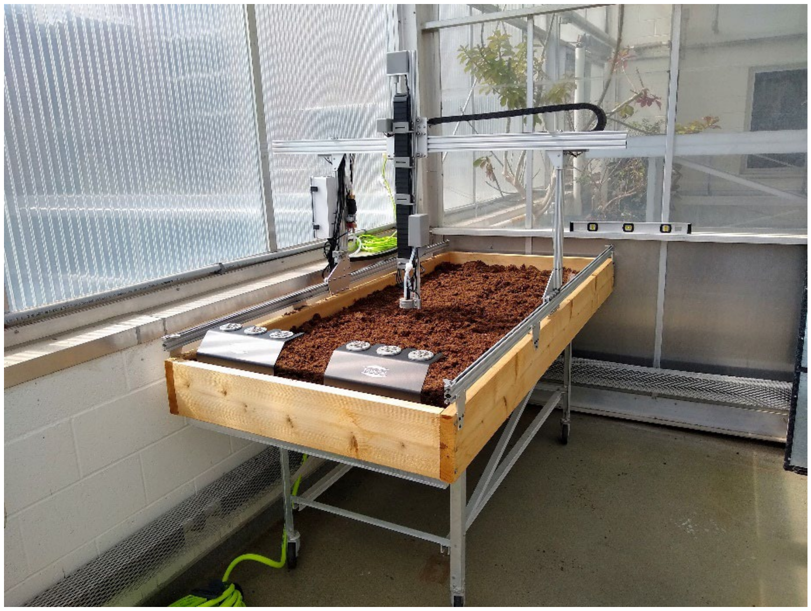

Figure 1. A FarmBot installed on a portable raised garden bed.

FarmBot End-of-Arm Tooling

The FarmBot can be purchased as a kit for assembly, or the components can be individually acquired based on the open-source hardware design available online. Once assembled, the system operates using a web-based control interface which connects to the FarmBot over an internet connection. The FarmBot system shown in Figure 1 was purchased as a kit and assembled inside the campus greenhouse. The design of the FarmBot system includes a Universal Tool Mount (UTM)[2], which allows for the attachment of various tools via magnets and provides access to electrical contacts for power and control, water, and suction. The UTM therefore allows for the design of new or unique tools with capabilities and functions not provided by the tools included with the kit. This provides a convenient starting point for student design projects. One example of such a project is shown in Figure 2 for which students design a robotic gripper to be compatible with the UTM which could be used to harvest from the FarmBot garden. This project was used in both a senior design experience course and a course focused on 3D printing. Further examples of similar student projects may be found online, with some pursuing far more ambitious outcomes (Brown et al., 2017).

[2] See: https://genesis.farm.bot/v1.6/assembly/tools/utm

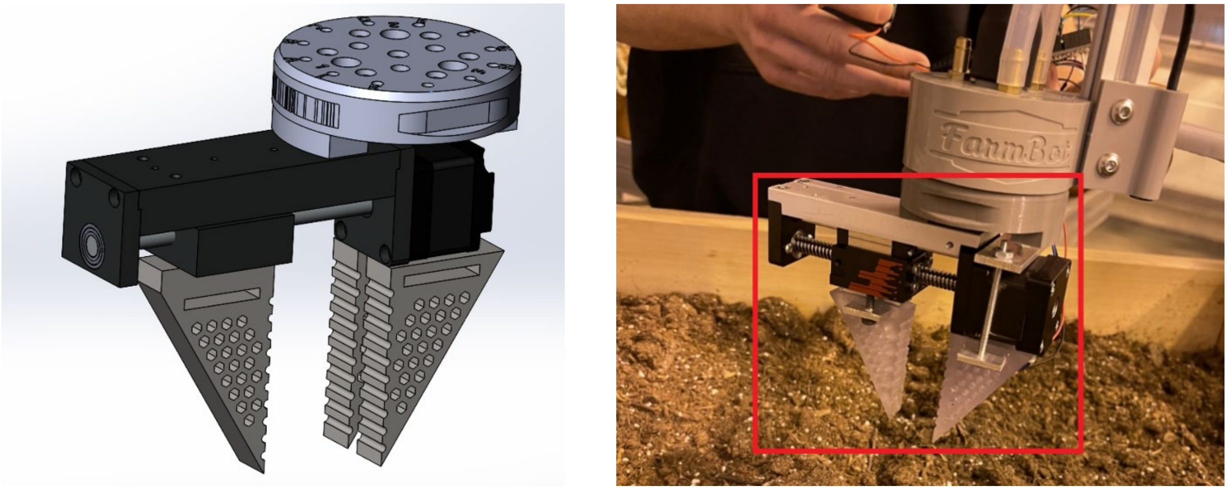

Figure 2. (left) A CAD rendering of a student designed gripper and (right) a fabricated prototype of the same gripper, with the student-designed portion highlighted by a red box.

Lake Health Monitoring

Another project which has allowed for greater flexibility in the solution space is a lake health monitoring system to assist with the development of remediation plans to combat lake eutrophication (Liu et al., 2018). Eutrophication of our waterways is due in part to runoff from upstream farms. To measure the impact of prospective remediations, it is necessary to monitor the health of the water before, during, and after any remediation would be implemented. As part of an NSF REU program, research students designed and developed a lake health monitoring system which could be deployed to monitor key metrics such as turbidity, pH, and dissolved oxygen levels (Chundu et al., 2023). The assembly of monitoring sensors were selected for interoperability and ease of use with an Arduino board providing the main control interface. This electrical system was installed in a buoy that could be deployed in a lake and provide for continuous data logging as shown in Figure 3. This project has provided additional opportunities for further student projects including in a Senior Design Experience course for Computer and Electrical Engineering and as an independent study project, both focused on building out mesh network system based on long-range radio (LoRa) transmissions which can bounce the sensor data between deployed buoys and back to a central data logging station.

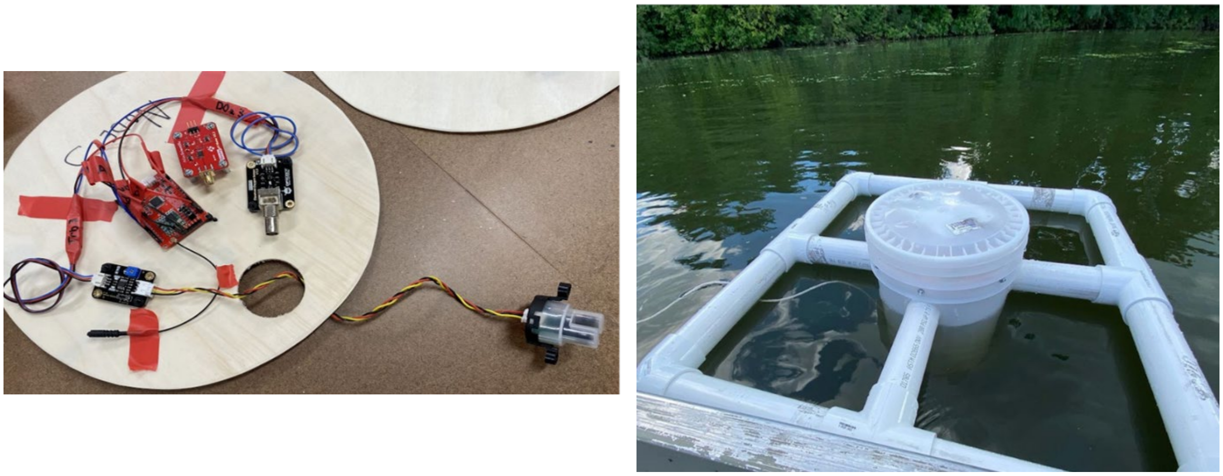

Figure 3. (left) Monitoring sensors assembled into a circuit and connected to an Arduino control board and (right) a deployed monitoring buoy.

Bioremediation

Finally, building on the theme of the last project, a third project has explored a potential bioremediation for a eutrophic waterway based on the Mesoamerican agricultural practice of the chinampa (Onofre, 2014). The chinampa is a technique in which a growing platform is constructed in a waterway. In this way, nutrients may be extracted directly from the eutrophic lake sediment and collected in the plant matter, which would then be harvested and removed from the lake. This project was proposed and initiated in a two-semester senior design experience for Mechanical Engineering students.

As part of the senior design experience, two teams of five students each started the initial design work. The teams were provided with a listing of desired outcomes for a device that could harvest lake-bed sediment and transport it to a platform for use as a growth medium. Additionally, the teams were instructed that the design should be accessible to a motivated individual such that they could purchase the components and assemble the device for a reasonable cost. These two teams spent the first semester following the engineering design process. The problem required investigation of a variety of considerations, thus drawing on the breadth of the students' prior engineering coursework. As an example, the students needed to determine how to agitate the lake-bed sediment sufficiently such that it would be drawn to the surface by a pump. To do this, the students modeled some of their design ideas and performed a computational fluid dynamics (CFD) analysis as shown in Figure 4. From this analysis, they determined that the design on the right side of the figure produced greater overall agitation of the fluid and thus would result in a higher collection rate of lake sediment.

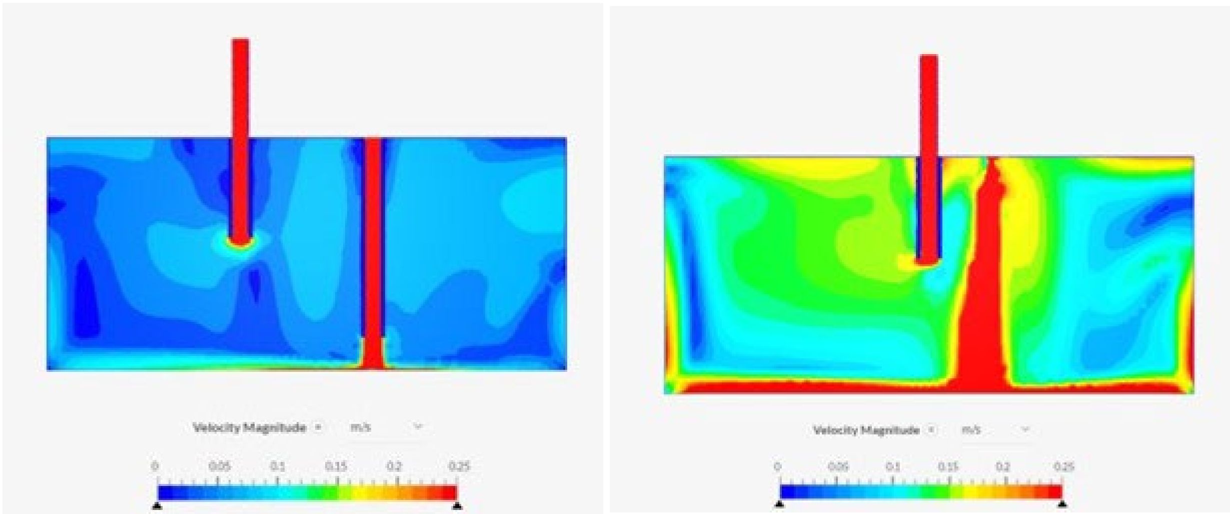

Figure 4. CFD result plots showing the fluid velocity for two different designs for a sediment agitator.

At the conclusion of the first semester, the two teams presented their designs. After a review, it was decided that only one design could move forward to the second semester and therefore, the two teams were merged, with some of the students being switched to other projects. For the second semester, a five-student team consisting of members from both of the two first-semester teams took this project forward. The final design from the second-semester team is shown in Figure 5. The design consists of a submerged box which collects sediment from the lake bottom via suction driven by a diaphragm pump. Sediment-filled water is then ejected onto a platform, which is covered in a filtration media allowing the water to pass through and retaining the sediment. The entire system is powered by a 30-Watt solar panel with a battery and solar charge controller. A timer limits the duty cycle of the pump to stay within the constraints of the solar system.


Figure 5. Final design prototype for a lake-sediment transporter (left) shown in a small pool and (right) shown deployed in a lake.

Conclusions

This work described the design and development of several tools with a common, but broadly interpreted, theme of sustainable agriculture. In each case, the result of each project was a working prototype that demonstrates the principles of the design that each student group ultimately envisioned. In some cases, the work required only one group of students over one semester, and in other cases, the work involved multiple groups of students over several semesters. While much of the impact of this work as it has been described thus far has focused on the research outcomes, this work has also demonstrated that the students involved in these projects make gains in ways both personal and professional as well. As one research student stated, "The value of interdisciplinary work is tremendous. As is especially the case for engineers such as myself, researchers have a tendency to tunnel in on their project or field." This student went on to describe how they were able to collaborate with both biologists and psychologists to better understand the root causes of the problems that they were trying to solve. By breaking out of the occasionally myopic viewpoint of engineering, the student learned how to become a more effective engineer. The experience gained by participating student researchers has better developed these students into strong contributors towards agricultural economic development. Students will be well prepared to enter the engineering workforce and facilitate new product development and entrepreneurial activities.

Another aspect of this work that has not yet been discussed is the potential for commercial applications. The development of small-scale agricultural automation equipment fills a market gap which is not currently being adequately addressed. While some automation tools such as the FarmBot (Aronson, 2013) have experienced success, there is a need for tools targeted at the challenges faced by family farming operations which operate at a scale between the home gardener and the industrial farming operation. By focusing on open-source, modular design principles and utilizing accessible fabrication techniques, the resulting technologies developed could be easily scaled to fit a range of potential users and budgets. For example, independent farmers could select the components that are most needed for their daily operations and fit within their budget constraints. Further, by this method of product development, a small business could become successful by offering the sale and production of these modular components, similar to the model of the FarmBot. This would allow the business operation to start small with little overhead costs and scale with product demand. As this market sector is largely underserved by today's available technology, this represents an opportunity for product development achieved through careful collaboration and support of the small-scale farmers.

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