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A Stanford University research team has developed a satellite-based control system to automatically navigate a tractor in the field

by David Oltman

While the wheels have been turning for these Stanford University graduate students, it's been a hands off approach that has led to their success in creating a tractor that can literally steer itself.

The work done at Stanford is the latest development in an effort to automate what is seen as one of the most tedious jobs in American agriculture -- driving a tractor or other piece of farm equipment for long periods over large expanses of land.

"This technology offers an opportunity to create a minor revolution in farming," says Bradford Parkinson, a Stanford professor who has supervised work on the automatically controlled tractor. "We are now working to ensure that all of the safety and reliability issues surrounding it are fully addressed."

Parkinson, a professor in the Aeronautics and Astronautics Department at Stanford, has overseen a team of graduate students who have been perfecting an automated tractor for the past three years.

The project has been funded in part by Deere and Company, which has also donated one of its mid-sized tractors, a model 7800, to the Stanford research team. The John Deere tractor is equipped with a satellite-based automatic control system that can guide it more precisely than a human driver.

The technology relies on signals from a series of 24 earth-orbiting satellites operated by the U.S. Department of Defense to pinpoint exact locations on the ground. The satellites, originally designed for military purposes, are now part of a Global Positioning System (GPS) network available for civilian use.

The Stanford University team is utilizing what is known as carrier-phase differential GPS, a sophisticated signal processing technique that requires a local base station placed in the field to receive satellite signals and transmit them to an on-board computer in the tractor. The carrier-phase differential GPS program offers accuracy down to the centimeter level for a tractor moving through a field.

"I would like nothing more than to see this technology become a useful tool for farmers, both in terms of improving the efficiency of their farms and in the job they are required to do," says Michael O'Connor, a Stanford graduate student who worked on the project. "Following rows for 16 hours a day is just the ideal thing that computers were designed to do."

The creation of a tractor that can steer itself is an outgrowth of an automatic aircraft landing system developed in 1994 by Stanford researchers working in the Gravity Probe B program. That program, funded by the National Aeronautics and Space Administration, is the largest satellite research project ever delegated to a university by that agency, says Parkinson, who serves as program director.

After demonstrating that a receiver placed on board the aircraft could successfully measure its attitude in the sky, Stanford researchers obtained Federal Aviation Administration (FAA) funding to develop an automatic landing system. That system utilized an integrity beacon, a GPS transmitter on the ground, to determine an aircraft's location within about a centimeter, Parkinson says.

"The next thing we knew we were on a Boeing 737 and we landed it automatically 110 times," Parkinson says. "It was a United Airlines airplane that was fully automatic all the way to touchdown using a GPS receiver on the ground and in the airplane plus a pair of transmitters."

"With the success of that program behind us, I said the next area I would like to see this technology used would be with farm and construction equipment, " Parkinson says. "I knew, however, that getting anyone to believe we could do this with farm equipment would be very difficult."

In the meantime, O'Connor joined the researcher team and decided that the GPS technology could be adapted to a smaller piece of equipment -- an electric golf cart. With the installation of a GPS receiver and a yacht steering mechanism, the Stanford research team created a golf cart that could be driven in a straight line without anyone in it.

After proving that a golf cart could be equipped with an on-board GPS receiver to steer itself, the Stanford research team decided to approach John Deere officials with a proposal to adapt the technology to agricultural uses. The goal was to develop system that could automatically control the tractor with centimeter-level precision at all speeds while pulling a variety of implements.

"We came to a mutual agreement with Deere that there would be a good research opportunity for Stanford University," O'Connor says. "The impression we got from Deere was that they were looking for someone who could develop a GPS application for a tractor rather than just a theoretical discussion of what could be done with the technology."

The ongoing research to further enhance the ability of GPS technology to automatically control a variety of functions on the tractor is being conducted by graduate students Thomas Bell and Andy Rekow. O'Connor has since been involved in the formation of a company, IntegriNautics, to adapt the GPS technology for use in automatic landing of tactical unmanned aerial vehicles (TUAVs), small fixed-wing aircraft.

"As far as we know, nobody else is doing centimeter level control of the tractor using carrier phase differential GPS technology," Bell says. "There has been other research done on the automatic guidance of tractors, but that work relies on other technology such as vision or laser systems, all of which have significant disadvantages."

The tractor being used for the project is equipped with a GPS positioning program developed by IntegriNautics and a receiver built by Trimble Navigation. A desktop computer keyboard and screen are placed in the tractor cab to receive and display the GPS data.

"The first piece of the puzzle is knowing where you are in the field and the second piece is knowing where you want to go," Bell says. The technology can be used to automatically steer the tractor in a straight line or in a spiral pattern, which can be beneficial when using the tractor in fields that are under a center pivot irrigation system, he adds.

Antennas placed on top of the tractor cab receive GPS signals from the in-field reference station to obtain the tractor's exact position and the attitude (roll, pitch and yaw) of the tractor. All of that information is delivered to the onboard computer in the tractor cab.

"We also have a potentiometer to measure the front wheel angle and that goes into the computer as well," Bell says. "So now the computer knows where it is at, which way the wheels are oriented and knows where it wants to go -- it uses the algorithms that we have created to steer the tractor to get there."

While the steering wheel of the automated tractor developed by the Stanford University research team is disconnected, other controls, such as the brakes, the clutch and the throttle are still manually controlled. As a result, one person remains in the cab of the tractor, even though it can be driven down a row without the need of anyone to actually steer it.

"We keep someone in the cab first of all for safety reasons -- this is still a research project that is not yet what we call 'robust,' we are here to demonstrate that it is possible to automatically steer a tractor," Bell says. "The second reason is that we are not yet able to tap into those other manual controls -- the clutch, brakes and throttle."

Parkinson says the tractor developed by the Stanford research team is actually a "pre prototype" that will continue to be tested for safety and reliability while evolving into a piece of machinery that will offer additional capabilities in the field.

"We don't think you leap all the way to a full robotic tractor in one step -- the correct role for the university is to implement this technology and prove that such things can be done," Parkinson says. "It is not the university's job to be producing something commercially -- the exact timing of how a company would do that depends on what they think the market acceptance will be."

Stanford researchers have successfully completed the first two phases of a process that will eventually lead to a fully automated tractor that can be operated without an onboard operator, Parkinson says. They have also been able to demonstrate the third phase, which is the actual fully automated tractor itself, he adds.

"The first step is that you simply give the farmer guidance -- he steers the tractor himself but you provide a guidance system that allows him to operate when there is obscured visibility or when the operator is doing offsets from the previous row," Parkinson says.

"Step two is you hook that guidance system directly into the tractor steering -- the farmer is still in the tractor but he is just watching it go along," Parkinson says. "That step involves getting into the hydraulic valve system of the tractor and commanding the automatic steering while compensating for any variations in the field."

Step three is a fully robotic machine in which the operator is out of the tractor -- sitting at home or in an office -- and controlling all its functions by way of a two-way radio link, Parkinson says.

"With that type of system in place, the tractor could communicate to the farmer when it has stopped and for what reason -- whether it is out of gas or fertilizer or because the navigation system is broken," Parkinson says. Stanford researchers have successfully demonstrated that two-way communication link and have established system parameters of what problems an automated tractor might face in the field, he adds.

Taking the next step to a fully automated tractor involves the relatively simple task of inputting the necessary requirements into the tractor's on-board computer, Rekow says. By adding a series of actuators to control the throttle, brake, clutch and gears that level of automation could be achieved, although it is not required of the research currently being conducted, he adds.

As part of the ongoing research under way at Stanford, Rekow is working on an "adaptive control" program that will allow an automated tractor to adjust for various conditions that it might encounter in the field.

"With traditional control methods, you have to do a calibration of the whole system to figure out what is called a dynamic model -- you decide if I do this to it, this is going to happen," Rekow says. "Once you put that in a computer with a traditional control scheme, it is set in stone and if you make any changes you essentially have to recalibrate the vehicle and build a new model."

With an adaptive control system, a prediction is made of what is expected to happen based on the model that is input into the computer, Rekow says. The program is then able to compare what was predicted to happen under a certain set of circumstances with what actually occurred, he adds.

"The vehicle will behave differently based on the conditions it is experiencing in the field -- any farmer will tell you that driving in a muddy field is a lot different than driving in a dry field," Rekow says. "This system is able to notice when conditions are not the same as they were the day before, for example, and make the appropriate adjustment to maintain a level of accuracy in the field."

The ultimate goal of a program designed to implement full robotic control of a tractor would be to actually memorize the field over which it is passing and use that information in future operations, Parkinson says.

"I can see at one level the farmer doing the master plowing or the master cultivation job on a field that is adjusted to the contour lines and the tractor just memorizes what he did," Parkinson says. "That is possible with this technology."

One of the biggest challenges that an automated tractor will help a farmer overcome is in the creation of vegetable or melon beds that contain buried drip irrigation tape, Parkinson says. "It will offer a big advantage because you can go back year after year in those beds and not disturb those tapes, you will know exactly where they are."

As a further enhancement to the technology, Bell is working to improve the tractor's ability to perform tasks on sloped terrain and also to automatically control any piece of equipment that it is pulling through the field.

"The research has successfully demonstrated the automatic control of the tractor along a straight row," Bell says. "What we are trying to do now is extend the envelope of capability to include sloped terrain and automatic control of an implement through the tractor itself."

The continuing work on the GPS tractor guidance system will parallel research being funded by the FAA at Stanford for fine tuning of the automatic landing system, Parkinson says. "It turns out the FAA's problem is identical in concept to a farmer's problem except that the farmer has never thought of it that way," he adds.

In the development of an automated control system, the FAA is first of all concerned with accuracy, which is exactly the concern that any farmer would have, Parkinson says. The second concern is availability -- whether there are a sufficient number of GPS satellites to get the job done or whether there are obstacles that would prevent the signals from reaching the transmitters, he adds.

The third concern is continuity -- in the case of an aircraft that includes an assurance for the pilot that a landing pattern will not be interrupted once it is started, Parkinson says. In agriculture, it is an assurance that once farmers start an operation in the field, they will be able to finish it, he adds.

"The fourth concern, which is the most important one of all, is integrity -- being assured that the system is not lying," Parkinson says. Since the system is supposed to have a certain accuracy, integrity is achieved when it operates within a specified parameter that has been established set for its safe and reliable operation, he adds.

"However you define integrity, it is exactly the same for a tractor as it is for an aircraft, although the risks are different," Parkinson says. "Obviously if I crash an airliner it will kill a lot of people -- if I run a tractor into a fence, I will probably have done some damage to it. We want to ensure that it doesn't happen."

When those assurances are finally realized, the result will be a technological system that should have enormous benefits for agricultural users who want to improve efficiency and accuracy in their field work, according to the Stanford researchers.

"I do know that there is a lot more research to do but at the same time we think that what we have now is in a form that could be very useful to farmers," O'Connor says. "The technology will work at night, in the rain or in very thick fog -- in many conditions that wouldn't be possible for a human driver."

Bell says he recently learned that European farmers who use below a certain amount of chemicals on their crop are given a marketing label to show they are being environmentally friendly and are able to obtain a higher market price for their product. The technology developed at Stanford could help attain that goal, he says.

"With this system you can eliminate a lot of overlap in your spray program, which has been estimated to be about 10%," Bell says. "A farmer can be more precise in applying those materials -- you know where you are at all times in the field within centimeters."

The ongoing research will now focus on improving the "robustness" of the automated tractor project and assuring that its reliability, Parkinson says. "By robust I mean that it works in the an acceptable manner in face of the unexpected events that happen in farming."

The biggest benefit that agricultural can realize with the technology is all-weather operation, Parkinson says. A second benefit is the reduction in the overlap between rows that often occurs with manually operated field equipment and a subsequent improvement in productivity, he adds.

"You are also able to reduce operator fatigue if there is an operator in the tractor," Parkinson says. In the final step of the process, with a full automation, an operator could sit in a farm office and manage tractors working in a number of fields, he adds.

Parkinson says the Stanford research garnered a lot of attention when it was presented to an agricultural audience attending a recent precision farming conference in the Midwest. When he started a videotape on the technology, the room where it was being presented was only half full, but by the time it was over, there was standing room only, he adds.

"I don't think they had a clue that somebody could take these satellite signals and guide a tractor to an accuracy factor that is two or three times better than the best operator," Parkinson says. "We have been successful in making that comparison."