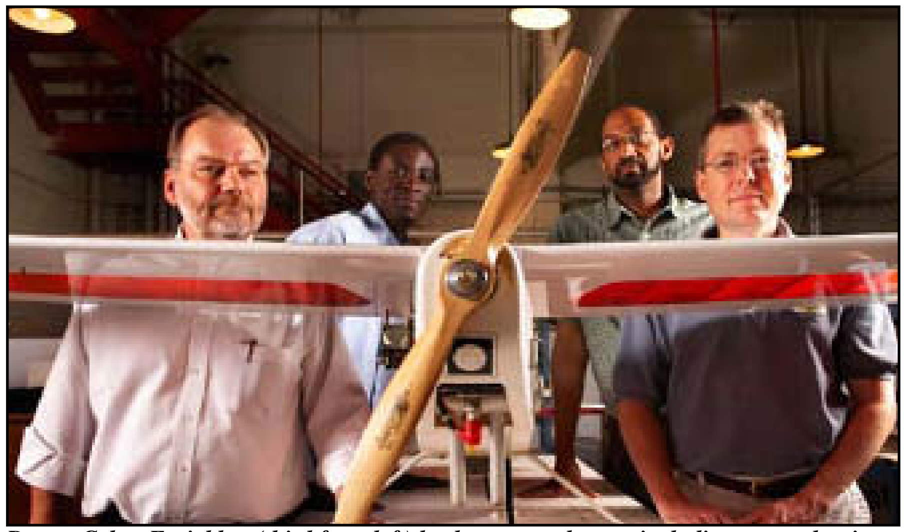
INTELLIGENT TRANSPORTATION SYSTEMS INSTITUTE
SENSOR
A periodic publication from the Intelligent Transportation Systems (ITS) Institute
2006 Volume 7, Issue 1

UNIVERSITY OF MINNESOTA
CENTER FOR TRANSPORTATION STUDIES

Remote sensing takes wing: unmanned aerial vehicle technology



Demoz Gebre-Egziabher (third from left) leads a research team including research scientist Greg K. Nelson, graduate student Romeo Ahohe, and research engineer Curt Olson.

From a few hundred feet above the ground, the video cameras have a superb view of the network of roads below. Dr. Demoz Gebre-Egziabher of the Department of Aerospace Engineering and Mechanics peers at the screen of a laptop computer displaying real-time video beamed down to the ground station via wireless video link. When he wants to move to another area, instead of radioing instructions to a pilot, Gebre-Egziabher turns to a graduate student beside him who adjusts the flight controls. The video perspective shifts as the unmanned craft banks to follow the curve of a suburban highway.

The birds-eye view afforded by an aerial platform offers many advantages for gathering data on traffic movements and general surveillance of transportation infrastructure, including a wide field of view and the capability of moving rapidly between different monitoring sites or following a single vehicle as it traverses a network. But the expense and risk associated with keeping a piloted plane in flight for hours at a time, not to mention the highly trained personnel and maintenance required, limits the effectiveness of conventional aircraft as monitoring platforms.

One solution to these limitations is to do away with the pilot—the most sensitive and expensive component in the system. Gebre-Egziabher's research group is presently developing unmanned aerial vehicles (UAVs) as monitoring platforms specifically targeted at surveillance and inspection of the surface transportation system. Through advances in navigation and guidance systems, sensors, and flight operations techniques, UAVs may play an important role in future transportation data collection and security.

Vehicle design

The potential advantages of UAVs as sensing platforms has fuelled the development of myriad designs, ranging from feather-light experimental "micro-UAVs" weighing only a few hundred grams to the imposing jet-propelled Global Hawk, operated by the U.S. Air Force, which has a wingspan of 116 feet and a takeoff weight of more than 25,000 lbs. More modest UAVs, similar to or based on hobbyist radio-controlled aircraft, have been used as airborne camera platforms, notably to assess coastal erosion and damage to structures in the aftermath of Hurricane Katrina in 2005.

Searching for a vehicle small enough to be easily transported and launched by small teams yet possessing sufficient carrying capacity to lift an array of experimental avionics and sensor payloads, Gebre-Egziabher's team decided to modify a commercially available SIG Rascal radio-controlled plane. With a wingspan of 110 inches and stable handling characteristics, this simple platform can be easily modified to suit different use scenarios.

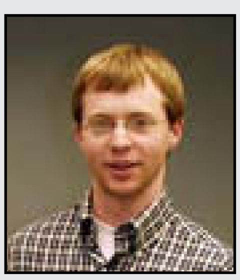
Navigation and positioning

As a remote sensing platform, the usefulness of an unmanned aerial vehicle depends on how well its position can be determined at all times. This is critical not only for the safe operation of the UAV in a complex aerial environment that includes restricted airspace and navigational obstacles such as tall structures, but also for the accurate location of events and conditions observed on the ground.

The location of a moving vehicle in the air can be described in terms of a *state vector*—a set of measurements that describe: 1) the position of the vehicle in three dimensions; 2) the orientation of the vehicle itself; 3) how fast it is moving in each direction; and, 4) the time at which these measurements were valid. Moreover, effective navigation requires the pilot or autonomous navigation system to take into account uncertainty in measurement—i.e., what are the intrinsic error margins in the position estimate (precision), and how confident can we be that the navigation system is estimating the position correctly.

These characteristics govern the operation of the navigation system under normal operating conditions. But equally important is the issue of fault toler-

Shawn Brovold is 2006 Student of the Year



Shawn Brovold

Each year, the Intelligent Transportation Systems Institute selects one graduate student for the Outstanding Student of the Year Award sponsored by the U.S. Department of Transportation's Research and Innovative Technology Administration (RITA).

This year's award winner is Shawn Brovold. He is currently pursuing a master's degree in Mechanical Engineering at the University of Minnesota. Brovold's research, entitled, In-Vehicle Technology to Correct Teen Driving Behavior, focuses on recognizing behaviors such as speeding, aggressive driving, seat belt use, and driving while intoxicated and provides mechanisms to report these behaviors to parents.

The student selected receives a $1,000 award from the ITS Institute and is presented a certificate from high ranking US DOT officials at a ceremony held in conjunction with the TRB Annual Meeting in Washington, D.C., each January. The ITS Institute also reimburses (up to $1,000) the student for his/her travel to the ceremony and TRB Annual Meeting.

Selection is based upon accomplishment in three areas: technical merit and research, academic performance, and professionalism and leadership (presentations, student professional activities).

ance—the ability to quickly detect errors in the navigation data, and automatically disregard this erroneous information.

The navigation and guidance system of the Minnesota team's UAV is based on high-accuracy Global Positioning System receivers. Basic position and velocity can be easily determined using GPS utilizing the Federal Aviation Administration's Wide-Area Augmentation System (WAAS), which enhances the accuracy of the basic GPS signal by calculating error corrections and broadcasting them to WAAS-enabled receivers. Developed specifically to improve aircraft guidance, WAAS correction results in a horizontal and vertical accuracy of a few meters, and permits velocity to be calculated to ±0.1 meter per second.

Attitude determination for the small craft is a more difficult problem, one which has led Gebre-Egziabher to develop an approach based on multiple GPS receivers. These receivers track and process the GPS carrier signal (rather than the digital information encoded within the signal) to achieve centimeter-scale range measurement accuracies. For this application, three units are modified to receive their internal timing signals from a common oscillator, and their antennas are mounted in a triangular configuration on the wings and tail of the aircraft. Monitoring the relative positions of the three antennas enables the onboard computer to calculate accurate estimates of pitch, roll, and yaw.

Guide me safely on my way

While a remotely operated vehicle has advantages over a piloted aircraft, a partially or fully autonomous craft offers even more intriguing possibilities. Designing a degree of autonomy into the UAV's guidance system would allow the vehicle to move from location to location, or around a patrol route, without requiring an operator on the ground to guide it through each turn.

The researchers began with a flight simulation software running on a personal computer. This software uses aerial photographs of the operating area to provide a realistic picture of the terrain below, in pseudo-3D perspective. By feeding the location of the UAV to the flight simulation software, the researchers succeeded in creating an artificial view from the aircraft in real time, which can be presented to the operator side-by-side with the actual camera view. The system can also display the boundaries of prohibited airspace in relation to the UAV. The artificial perspective could be immediately useful as an aid to the operator, providing a clear and unobstructed view of landmarks below. It also shows the potential for displaying augmented information such as map data. Gebre-Egziabher is now investigating the potential to build the simulator approach into a "click-to-navigate" system that would allow an operator on the ground to send the UAV over a designated point on the ground.

Safe operation is among the most difficult issues facing UAV designers. Being pilotless does not exempt UAVs from the Federal Aviation Administration's strict regulations governing all aircraft operations, including the requirement that aircraft operating in controlled airspace possess the capability to autonomously "sense and avoid" other aircraft. Currently, autonomous sensing and avoidance is beyond the capabilities of even the most advanced military UAVs. Without this ability, UAVs are restricted to operating at low altitudes, away from areas where they are likely to come near other aircraft, and within view of their operators on the ground.

Gebre-Egziabher describes the development of autonomous sense-and-avoid systems as the greatest challenge facing UAV researchers today. Such systems will make it possible for autonomous and semi-autonomous UAV sensor platforms to operate in a wide range of areas. Because highly accurate and dependable navigation is a necessity for future sense-and-avoid capability, much of the Minnesota researchers' work is directed at developing operational techniques and navigation systems that provide verifiable levels of navigation safety consistent with FAA requirements.

Sensor integration

One of the most important measures of navigation system performance is "integrity," defined as the likelihood that navigation errors are larger than computed error limits, known as protection levels. Protection levels can be visualized as invisible horizontal and vertical boundaries around aircraft that are guaranteed to contain an aircraft's true position. For most aviation applications, the threshold navigation integrity during normal operations—i.e., the likelihood that a navigation system will report a position outside the protection levels—is set at one in ten million or 10^{-7}.

Although the Global Positioning System is capable of high accuracy, the integrity of navigation devices based solely on GPS is subject to errors in the satellite-based system. Due to these inherent inaccuracies, a pure GPS system cannot guarantee positional integrity at the small scales required for safe navigation.

Because UAVs will need other sensors to augment GPS for navigation, guidance, and control in order to operate in urban areas, the researchers are also facing the technical challenges of multi-sensor integration. The design of algorithms that combine data from different types of sensors is a challenge in itself. The goal is to take advantage of the strengths of each type of sensor while minimizing their weaknesses. As different sensor types produce data at different rates and with different levels of accuracy, successful "sensor fusion" depends on factoring out a large number of possible sources of error.

The problem of integrity becomes even more challenging in systems that employ multiple sensors of different tyeps. In designing a navigation system with provable integrity, the choice of methods for overcoming these inherent limitations becomes a key issue. The nature of the error distribution, and the non-linear nature of navigation algorithms, limits the applicability of computational approaches based on common error-correction techniques such as extended Kalman filters.

The Minnesota researchers' work has important implications for all types of UAV applications. Unmanned vehicles that can operate autonomously or semi-autonomously could one day replace piloted aircraft in a wide variety of "dull, dirty, and dangerous" missions, giving researchers, emergency workers, and traffic managers a new perspective on our world.

– Peter Park Nelson

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