Hawk-Eye an Autonomous Ground Vehicle

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***Abstract*-- An autonomous ground vehicle designed for the purpose of competing in the 20th Annual Intelligent Vehicle Competition (IGVC) at Oakland University, Rochester, MI. The qualifying specifications for this vehicle cover a wide spectrum of topics in the electrical engineering discipline. The objective is to produce an autonomous vehicle which, upon its completion, will succeed through theory-based simulation, team implementation, system integration, periodical product assessment, and product realization through a design process. In competition the vehicle is to autonomously negotiate a predetermined obstacle course. The vehicle must demonstrate the capability to detect and follow lanes, avoid obstacles, and navigate to waypoints via GPS.**

***Index Terms*-- autonomous vehicle, unmanned ground vehicle, intelligent vehicle, robot, obstacle avoidance, GPS waypoint navigation, array integration.**

I. NOMENCLATURE

Course-Over-Ground (COG) - The actual direction the vehicle is traveling, relative to north, determined by the GPS.

AGV – Autonomous Ground Vehicle
UGV – Unmanned Ground Vehicle
IGVC – Intelligent Ground Vehicle Competition
GPS – Global Positioning System
LIDAR – Light Detecting and Ranging (also LADAR)

II. INTRODUCTION

THIS document discusses the design progression, integration, and completion of the autonomous ground vehicle (AGV) Hawk-Eye. Also discussed are details of the IGVC competition, as well as background information on the field of robotics and autonomy. Hawk-Eye succeeds CLETIS (CitadeL Engineered Traversing Intelligent System) which was a project in The Citadel's 2010-2011 senior design courses. The basic frame design and drive power configurations were recycled from the previous design project, with a few significant mechanical upgrades and repairs, however Team Hawk-Eye approached the 2012 design project with a new respect to autonomous logic design and sensor integration.

III. COMPETITION

The IGVC is an annual event held at Oakland University, Rochester, MI. The competition encompasses a multidisciplinary engineering structure which includes electrical engineering, computer science, and mechanical engineering. These aspects allow for three areas of participation in the competition: Auto-Nav Challenge, design competition, and Joint Architecture for Unmanned Systems (JAUS) Challenge. Hawk-Eye is only competing in the Auto-Nav Challenge and the design competition. Specific design requirements and detailed information regarding each challenge can be found in the official IGVC details, rules, and format guide at http://www.igvc.org/rules.html. Vehicles must meet parameters and design specifications in order to qualify for competition.

The vehicle must be designed as a small semi-rugged outdoor unit. It must measure between three and seven feet in length, two and five feet in width, and no taller than six feet. The vehicle must be capable of maintaining a speed of 1 mile per hour (mph) or greater but, not exceed 10 mph. The vehicle is also required to carry a 20 pound payload during each progression of the competition.

The design competition judges strategy and innovation without regard to vehicle performance during competition. Design will be scored as a combinative score of the: written report, oral presentation, and physical examination of the vehicle. The written report must describe the concept of the vehicle design and its components. In further detail the detection/avoidance systems as well as the GPS must be specifically defined. The oral presentation is a brief summarization of the written report [1].

During the Auto-Nav Challenge the vehicle navigates towards multiple GPS waypoints as it traverses across varying terrain types, while simultaneously detecting and avoiding a variety of obstacles, ground lines, and boundaries along the way. An example of the course layout is shown in Fig. 1.

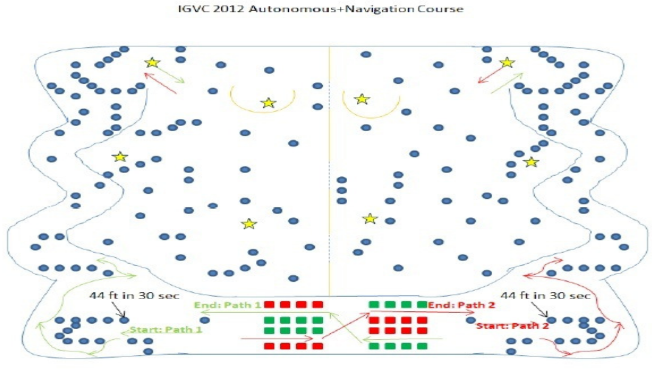

Fig. 1. Auto-Nav course layout.

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IV. PERCEPTION

For Hawk-Eye to negotiate an obstacle course it must perceive information about its surroundings. This information includes, but is not limited to, a) accurate sensing of obstacles and ground lines, b) the vehicle's position in respect to these obstacles, c) the physical location of the vehicle in the field, and, d) an efficient formulation of the distance and direction to sequential waypoints [2]. This was accomplished by integrating three primary sensors into the system: a LIDAR (Light Detection and Ranging), a video camera, and a GPS receiver.

A. *Obstacle and Line Detection*

The LIDAR and video camera are the visual input components. The camera takes an image and filters out colors in order to produce a black and white image; this technique is used to sense white ground lines. Once a line is recognized on the ground, a distance and angle from the vehicle is calculated. The values found were used to determine the robot orientation with respect to the line and programmed to turn accordingly in order to avoid the line.

Through LabVIEW programming, colors were extracted from the image seen so that dark objects appeared as black, and light objects appeared as white. With adjustments to the sensitivity of the applied filter, white lines became the only images that were visible on the screen. A straight edge detection filter was used to decipher and clean up the image of the lines. Viewing the front panel indicator, the screen was divided into four horizontal sections and four vertical sections. The horizontal lines assisted in determining depth, while the vertical lines determined if the line fell left or right of the vehicle. When a line was detected, LabVIEW output two sets of (x, y) coordinates for the location where it recognized the line; one set for the top and one set for the bottom sections of each horizontal zone. By adding the x coordinates from the top of each zone and subtracting them from the x coordinates at the bottom of each zone, the slope of the line was able to be calculated. Using the max and min x and y coordinates, the magnitude and angle to the line was also computed. Since the magnitude was shown in pixels and that the images at the bottom of the screen were close to the vehicle and images at the top were furthest away, a ratio of direct measurements were taken to calculate a vector, both distance and direction, from the vehicle to the line.

Hawk-Eye employs a Hokuyo URG-04LX-UG01 LIDAR which is a scanning laser rangefinder. The Hokuyo LIDAR is a relatively versatile and inexpensive sensor which returns an array of distance readings above ground level in the horizontal plane with a field of view of +/- 120 degrees. The LIDAR is used in competition to identify both the existence and location of obstacles, mainly traffic barrels and fencing, with respect to the AGV. The LIDAR scans a horizontal plane from its mount on the vehicle approximately 3.5 feet above ground level. The filtering process consisted of effectively managing and modifying the array of values produced by the LIDAR each time it scanned its environment. For example, through vigorous testing of the unit, false near-field reflections, or echoes, created the appearance of non-existent obstacles, and, subsequently, erroneous steering reactions by the AGV. The issue was resolved by applying filter techniques of the LIDAR array using LabVIEW code and the component parameters.

Compiling and evaluating the data from the LIDAR array was important to several key functions of the vehicle. The array was separated into thirds; each sub-array represented the three areas in front of the vehicle. For example, obstacles in the left and right arrays did not require immediate action by the vehicle; thus identifying the location of non-critical obstacles which had no immediate impact on navigation decisions. Conversely, obstacles directly in front of the vehicle required immediate action to avoid obstacles.

Choosing a best fit path is another critical function of the LIDAR array. By using a vector-field histogram (VFH), the decision to change direction towards the widest opening was calculated by identifying sub-groups of array indices containing sequential far-field values. The vector to center index of the largest sub-group is defined as the best path vector. This function is especially useful when multiple objects lie in the vehicles path. Boolean logic was developed based on the existence of obstacles in a particular region of the vehicle's field of view; this helped to organize and implement top level navigation. Shown in Fig. 2, is the integrated logic of the video camera and the LIDAR.

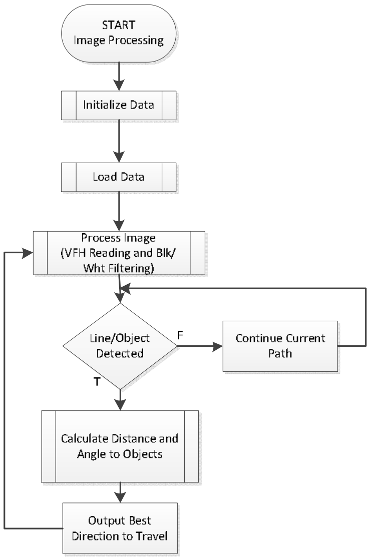

Fig. 2. Integrated flowchart of video camera and LIDAR

B. *Positioning and Navigation*

The GPS is used for waypoint navigation during the IGVC's Auto-Nav challenge. In order to determine the vehicle's position on the surface of the earth relative to the pre-determined waypoint, a U-Blox 5 Series GPS is used to acquire relevant position data. The data collected via the GPS receiver is compared to the waypoint coordinates in order to calculate a distance and bearing to the destination. The following formulas demonstrate the process of the algorithm; note that R is the earth's radius at 6,371 km and all angles must be converted to radians:

$$a = \sin^2\left(\frac{\Delta Lat}{2}\right) + \cos(Lat1) * \cos(Lat2) * \sin^2\left(\frac{\Delta Lon}{2}\right) \quad (1)$$

$$c = 2 * \tan^{-1}\left(2 * \left(\sqrt{a}, \sqrt{1-a}\right)\right) \quad (2)$$

$$distance = R * c \tag{3}$$

Once found the calculated distance is compared with a set parameter (approximately one meter), in order to determine whether or not the vehicle has arrived at the waypoint. As the distance calculation reads within the set parameter, it is determined that the vehicle has reached the waypoint. When the calculated distance reaches the target parameter of one meter (set by the competition rules), the UGV stops and signifies the waypoint has been reached.

The bearing for the vehicle is calculated with the following logic [4]:

$$A = \sin(Lat) - \sin(Lat1) * \cos(distance) \tag{4}$$

$$B = \cos(Lat1) * \sin(distance) \tag{5}$$

$$C = A/B \tag{6}$$

If

$$\sin(Lon2 - Lon1) < 0 \tag{7}$$

$$Bearing = \tan^{-1}\left(\frac{-C}{\sqrt{-C*C+1}}\right) + 2 * \tan^{-1}(1) \tag{8}$$

Else

$$Bearing = \tan^{-1}\left(\frac{-C}{\sqrt{-C*C+1}}\right) + 2 * \tan^{-1}(1) \tag{9}$$

Once calculated, the bearing for the vehicle is compared to the course-over-ground. Based on the difference in angles, the vehicle is programmed to turn in the correct direction in order to travel towards the waypoint.

A second GPS unit installed onto Hawk-Eye is a Garmin GPS 76. The second GPS acts as a speedometer and is a contingency in case the first option fails. Both units were considered for primary use, field tests were conducted in order to determine the accuracy of position, speed, and bearing and how fast data was read. From the results in shown in Table I, the U-Blox 5 Series was able to reach a waypoint more consistently and with more accuracy than the Garmin GPS 76. The results are due to the programming of the U-Blox 5 series which is more efficient due to the pre-defined blocks available in LabVIEW's robotics module. These blocks allow data to be collected at a faster rate than the Garmin GPS 76.

The Garmin GPS 76 did have one advantage over the U-Blox 5 Series, speed accuracy. When the vehicle is not in motion The U-Blox 5 Series has unstable readings. While stopped, the coordinates continue to reflect change, which, in turn, reflects false changes in position. This perception of movement triggers a speed reading and erroneous movement by the UGV. However, with the Garmin, when the vehicle is stopped the Garmin reflects zero speed. This is an important feature because if the situation arises that the vehicle is no longer in motion, such as the case when the UGV approaches inclined terrain, more power can temporarily be applied to the motors to create the necessary extra torque.

TABLE I
U-BLOX 5 AND GARMIN GPS 76 COMPARISON CHART

Unit	U–Blox 5 Series	Garmin GPS 76
Position Accuracy	X	
Bearing Accuracy	X	
Speed Accuracy		X
Refresh Rate	X	

V. SYSTEM MAINTENANCE AND ADJUSTMENTS

In its original construction Hawk-Eye was built with a six step design methodology. The process consisted of: 1) Identifying environmental variables to measure 2) Identifying sensor requirements and making selection 3) Designing in virtual environment 4) Developing and prototyping subsystems 5) Validating subsystems 6) Integrating subsystems and field testing [2]. Steps one and two were reevaluated due to changes in the competition rules and course layout. The improvements to the structure, hardware, and software were made to make sure each component of the vehicle ran as efficiently as possible.

A. Frame and Structure

Several additions were made to the frame of the vehicle to improve functionality and ergonomics. The previous design used a flat panel display placed low in the base of the vehicle, and problems with outside visibility in sunlight were hindering during field testing. Instead, a laptop shelf was built above the emergency stop to bring the screen to eye level. The LIDAR, designed by the manufacture for indoor use, overheated and malfunctioned when exposed to continuous sunlight. Last year's team CLETIS remedied by affixing a paper plate atop the unit. Enclosing the sensor in an aluminum mounted shelf was a quick fix for both functionality and cosmetic appeal.

B. Hardware Components

One of the primary complaints by last year's team was a speed versus torque problem with the drive train. The competition required the vehicle to traverse terrain with a maximum gradient of 15%. Two solutions were investigated: 1) increase vehicle speed as it reached the incline and 2) adjust sprocket sizes to increase torque. To increase vehicular speed, there would be an inclusion in the main VI in LabVIEW that would indicate if the wheels quit moving, then increase the voltage to the pulse-width-modulators (PWM). In turn this increase would speed all four motors up; but consequently if the incline were too steep the motors would stall and burn out. The decision was made that changing the sprockets size would be safer and more effective. The middle set of sprockets was decreased from a 13 tooth gear to a 9 tooth gear, which effectively increased the torque. The difference in sprockets is shown in Fig. 2.

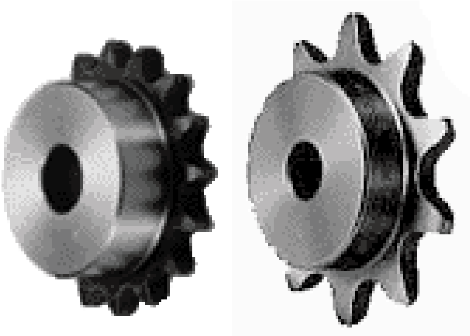

Fig. 2. 13 tooth sprocket (right), 9 tooth sprocket (left).

Finally, in order to control the AGV in command mode, a remote control was incorporated into the system. A wireless Xbox 360 controller was acquired to operate the vehicle; and a LabVIEW VI was created with a similar interface to ease operation. In order for the controller to communicate with the processing computer, an Xbox 360 wireless gaming receiver was attached to the computer so it could pick up the controller's signal.

C. Software

LabVIEW programming with external device drivers was determined to be the best choice due to National Instruments long-term commitment to robotics. All of the input and output devices were easily integrated, as were the debugging and filtering solutions throughout the project.

Each team member was assigned a sensor and tasked with the necessary research, developing application techniques, and integrating the sensor with the UGV resulting in successful stand-alone field trials. Once individual successes were fulfilled, the team met the daunting task of integrating all the sensor inputs and producing a final product ready for competition. This system-of-systems (SOS) approach proved to be quite challenging, requiring significant bench- and field-testing. Once basic autonomous vehicle operation occurred, the team studied the top-level behavior of the operating vehicle and continues, at this time, to reach a level of operation which can be considered 'intelligent', as the name of the competition implies.

VI. CONCLUSION

With increasing demand for product production, personnel safety, and new innovative ideas, the field of robotics is being explored extensively. Autonomy is at the head of this movement because the machines and devices needed are required to carry a certain conceptual level of human perception. An example of this is the AGV Hawk-Eye. For Hawk-Eye to function as it does, the system required a variety of sensors to simulate human responses in specific situations. The video camera, LIDAR, and GPS were integrated into a vehicle that will make intelligent navigational decisions.

VII. ACKNOWLEDGMENT

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References

[1] IGVC Official Competition Details, Rules and Format, Dec. 2011. [Online]. Available: http://www.igvc.org/IGVC%20Rules%202012_19%20Dec%202011.pdf

[2] N. Lett, L. McBee, K. Nowocin, and M. Player, "CitadeL Engineered Traversing Intelligent System an Intelligent Ground Vehicle," The Citadel, Charleston, SC, CEEDS. Apr. 2011.

[3] C. Veness. (2002, Aug.). Calculate distance, bearing and more between Latitude/Longitude points. [Online]. Available: http://www.movable-type.co.uk/scripts/latlong.html

[4] Drexel University. (1994, Jan.). The Math Forum. [Online]. Available: http://mathforum.org/library/drmath/view/55417.html

Biographies

Jason McLemore was born in Newport News, VA on May 13, 1969. He served in the Navy aboard the USS Sellers DDG-11 based in Charleston, SC. After 18 years in the shipping industry performing in various technical and managerial roles, he decided to pursue an Electrical Engineering undergraduate degree from The Citadel and begin a small business surveying marine cargo equipment for steamship lines. He excelled in his college coursework, earning membership in Tau Beta Pi Engineering Honor Society and the Bernard Gordon Scholarship, Jason is excited to begin a second career as a member of a vibrant engineering team. Jason and his wife of 25 years currently reside near Summerville, SC with their two daughters.

Russell Bramlett was born in Charleston, South Carolina on April 10, 1986. He completed the 2+2 program and graduated from The Citadel in May 2012 with a Bachelor of Science in Electrical Engineering. While enrolled as a full-time student and employed full time with ManTech International as an Electronic Cable Fabricator, he became a member of Tau Beta Pi Engineering Honor Society and received the Santee Cooper Scholarship. Russell is currently waiting to begin a career with Santee Cooper as an Associate Engineer.

Kelly Oliver was born in Charleston, South Carolina on August 29, 1989. She obtained her B.S. in Electrical Engineer, May 2012 from The Citadel. She completed her coursework in the corps of cadets and evening program at The Citadel. Her specialties include communications and digital signal processing. She will be attending the 20th Annual Intelligent Vehicle Competition at Oakland University, Rochester, MI on June 8, 2012. She is currently seeking employment in the Charleston, SC tri-county area.

Mark Kaspar was born in David City, Nebraska on December 14, 1986. A cadet with the class of 2009, he earned 4 letters on the school's football team. He will graduate from The Citadel with a Bachelor of Science in Electrical Engineering.