Chapter 5

Detailed Design

This chapter will introduce the detailed design of Virginia Tech's NEw autonomous VehicLe, aptly named NEVEL. The detailed design attempts to meet all of the criteria set forth in Chapter 3 while adhering to the proposed design of Chapter 4. This chapter will be broken into several sections. Section one will outline the base vehicle's drive train, frame, and power systems. AutoCAD and P-Spice renderings will be used to illustrate the assembly process. Section two will focus on NEVEL's computing resources and present sensor suite. Finally, section three will describe the navigation strategy used by NEVEL during the 1998 Unmanned Ground Vehicle competition.

5.1 Base Vehicle

NEVEL's locomotion system is based on a compact, differential drive. Two drive wheels and a single passive caster are used to support the vehicle. An innovative approach has been used to minimize the number of custom-built components. CAD software has been utilized to design all custom parts and integrate the vehicle as a whole.

5.1.1 Drive Train

NEVEL uses a positive drive system, where each of the two drive wheels is independently actuated by a separate motor/gearhead set. Each drive motor and gear reducer is coupled directly to a custom hub and drive wheel. Drive power is provided by two custom-wound Kollmorgen, 24-volt brushed DC motors. The motors are rated at 34.5 amps at continuous torque and 90 amps at stall. The maximum motor speed is 3600 rpm at 1.5 HP each. A total of 3 HP can be produced, thus exceeding the 1 HP total calculated in Chapter 4. This added horsepower does come at the expense of a higher amperage requirement. To maintain a 24-volt DC bus, the desire for extremely small motor size had to be compromised due to the necessity for custom windings.

The gear reduction ratio was selected assuming 16-inch pneumatic wheels at the output. An attempt was made to limit vehicle speed to 5 MPH (the maximum wheel speed allowed during competition) using the gear reduction at maximum motor speed. This produces maximum wheel torque and hill-climbing ability. Adhering to an off-the-shelf-approach, two 90°, 20:1 Thomson Micron DuraTRUE 90 gear reducers were used, resulting in a maximum vehicle speed of 8.5 MPH. The 5-MPH speed limit is controlled by software (Section 5.2). The gear reducer output is coupled direct to the drive hubs and wheels. This results in a positive drive system that minimizes gear backlash and system "slop". The design minimizes components and eases maintenance by eliminating excess gearing, shafts, and bearing supports. NEVEL's weight is supported by the industrial gearheads' internal bearings.

Each drive assembly is equipped with a fail-safe disc brake. The brake is attached to the low-torque motor shaft. The electromagnetic braking system is disengaged while power is supplied to the vehicle. In the event of an emergency stop or loss of power, an electromagnetic solenoid will lose power and release the internal brake pad. Each fail-safe brake provides 10-ft lbs of holding torque at the motor shaft, or 200-ft lbs per wheel after reduction. This is more than sufficient to positively lock NEVEL's wheels, even on steep inclines.

5.1.2 Base Vehicle Assembly: The "T-Fame"

The base vehicle is formed by coupling the motors and gearboxes using a unique "T-Frame" design (Figure 5.1). The 90° gear reducers allow the two separate drive assemblies to be place directly beside each other. The T-Frame crossbar rigidly couples the left and right motors to their respective gear reducers. Rigid mounting helps maintain consistent steering control due to consistent alignment. A cantilever at the rear of the T-Frame provides an attachment point for the support caster. An exploded view and final assembly of NEVEL's base vehicle is shown in Figure 5.2.

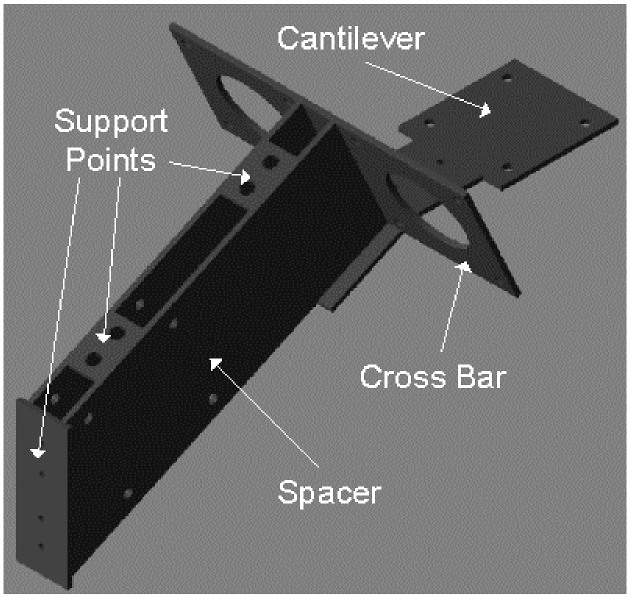


Figure 5.1: T-Frame Assembly

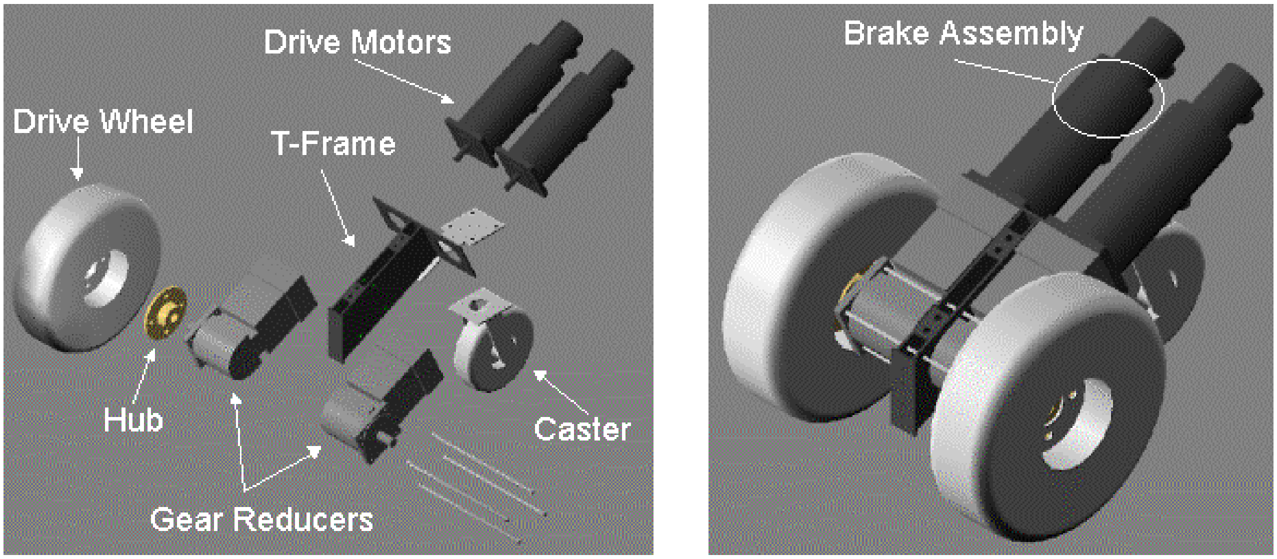


Figure 5.2: NEVEL's Base Vehicle: Exploded and Final Assembly

The T-Frame design minimizes vehicle size and weight by eliminating excess support structures. The bulk of NEVEL's superstructure is contained in the drive motors and gear reducers. The design attempts to concentrate vehicle weight on the two drive wheels. This is to aid in traction and stability. The motor/gear reducer combination is mounted at an angle to reduce vehicle length by mounting the support caster beneath the drive train. The results of this decision are discussed in Chapter 6.

The T-Frame also provides several mounting points to attach component support structures. Shelving for motor amplifiers and the computer is attached between the gear reducers. Front mounting points are used to attach a battery box and an upper computer support shelf. The upper computer shelf is detachable for easy access to lower components during maintenance. An exploded view of the support structure and shelving with the left wheel removed is shown in Figure 5.3. All of the support shelving was constructed using formed fiberglass material, resulting in a strong, nonconductive structure.

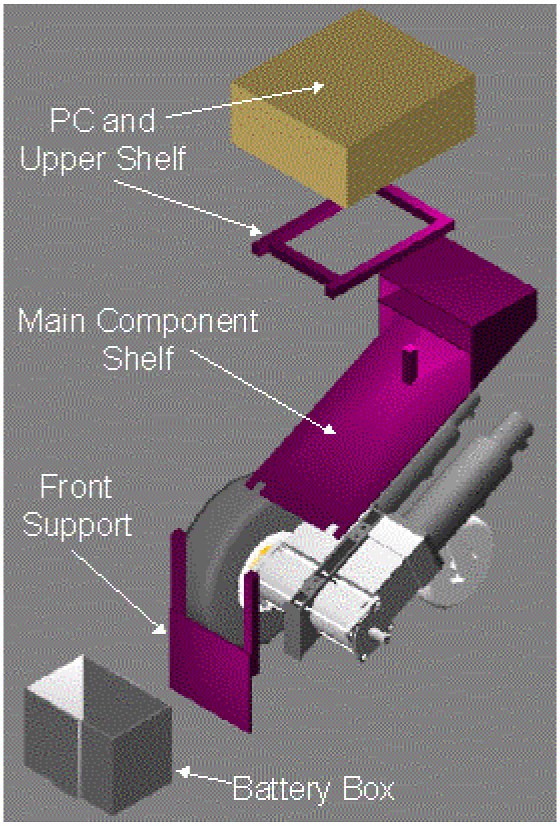


Figure 5.3: Component Support Shelving

5.1.3 Assembled Vehicle and Exterior Shell

The placement of the components described in the remainder of the chapter was optimized using CAD. This approach resulted in a minimum of vehicle dead space. Figure 5.4 shows a comparison of the final CAD and actual vehicle. NEVEL is protected from inclement weather by an exterior fiberglass shell. The shell is made from hand laid fiberglass and conforms to NEVEL’s basic shape to avoid additional vehicle size.

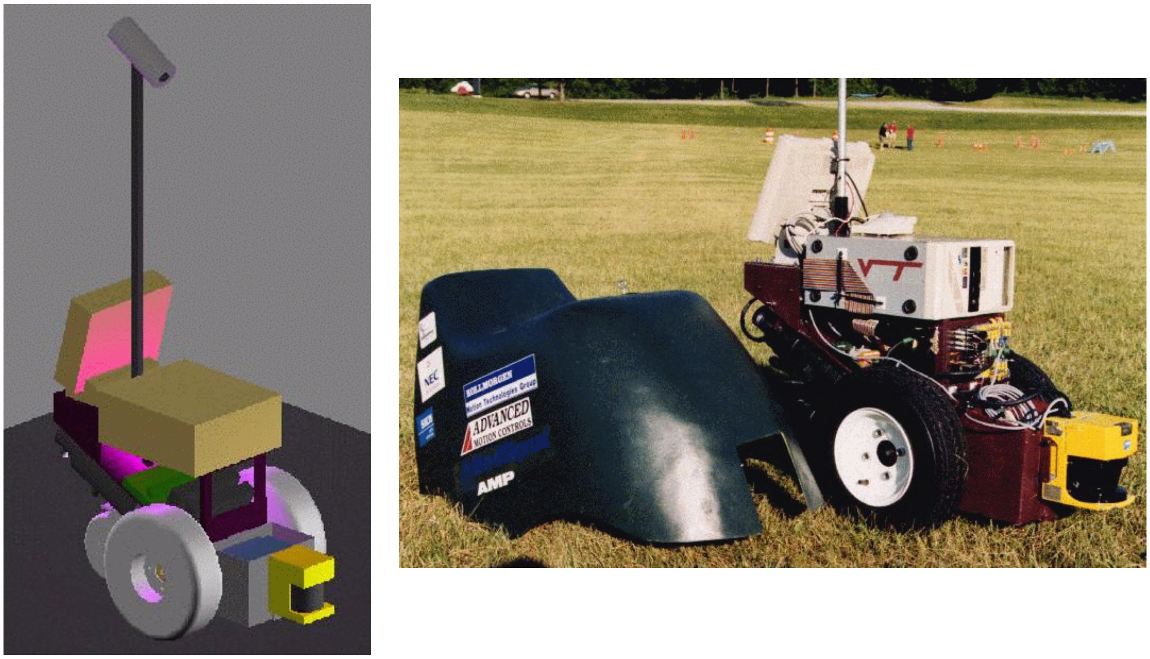


Figure 5.4: Final Vehicle Assembly

5.1.4 Power Systems

NEVEL’s power system was designed for simplicity and serviceability. The majority of parts are off-the-shelf components, which again helps to minimize custom wiring. A schematic of the entire power system is shown in Figure 5.5.

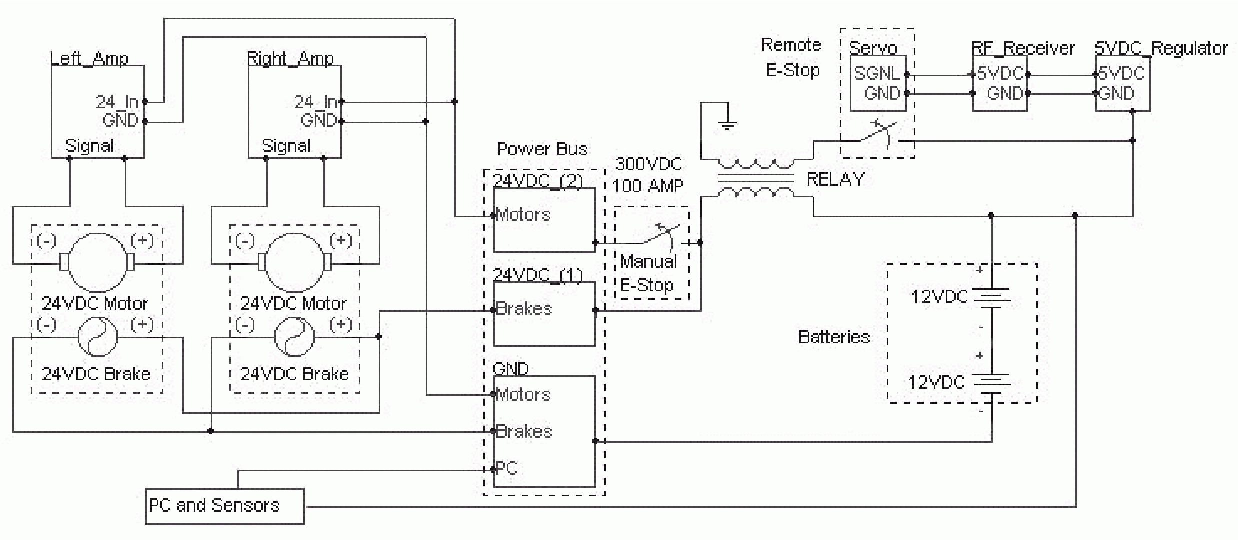


Figure 5.5: NEVEL's Power System

NEVEL's 24-volt DC bus is supplied by two, 12-volt DC deep-cycle batteries. Both batteries combined are only 7.5x11x6.5 inches and weigh 42 pounds, approximately the same size and weight as a single standard car battery. At 35 amp hours each, the batteries were estimated to power NEVEL for approximately 30 minutes. This is adequate to run a competition obstacle course twice.

The power is passed through a series of Emergency Stop switches. The remote E-stop is controlled using a standard 4-channel RF (radio frequency) remote control. A cammed servo mechanically actuates a SPST (single-pole, single-throw) lever switch that controls the coil power in a 300-volt, 100-amp continuous relay. Actuating the servo/switch assembly triggers the relay and supplies power to the brakes attached to the first bus (24VDC_(1) in Fig 5.5). A secondary Manual E-Stop must also be triggered to provide power to the drive motors on the secondary power bus (24VDC_(2)). Motor power is regulated via two 24-volt, 100-amp PWM Advanced Motion Controls servo motor amplifiers. The separation of brake and motor power allows the brakes to be disengaged while the motor holding current is off. This arrangement is useful for transporting and testing NEVEL. This system also eliminates the possibility of supplying power to the motors while the brakes are engaged. Powering the motors with the shaft locked could lead to serious motor winding and brake damage.

The computer and sensor suite are all tied directly to the batteries. Thus, the computer and sensors can be used without powering the actual base vehicle. This also eliminates computer shutdown during E-Stop situations. The computer uses a DC-DC power supply to eliminate the need for AC-DC inverters. The computer and sensor arrangement will be described in greater detail in section 5.2.

5.2 Computing Resources

NEVEL’s entire computing requirements are handled by a single 233 MHz Pentium II personal computer. A DC-DC power supply has been installed to meet the 24-volt DC requirement. The DC-DC power supply provides the computer with regulated 12 and 5-volt power sources. Also, the hard drive has been shock mounted to resist damage due to vehicle vibration. A LCD flat-screen monitor is used as the computer interface and as a vision monitor. The flat-screen monitor is lighter and smaller than standard CRT monitors. Various “plug-and-play” peripheral cards have been added to the computer for motor control and sensing. Again, this eliminates the need for custom designed and built units. The motor control board will be discussed in section 5.2.1. The remaining sensor interfaces are detailed in section 5.3.

The computer is run under the Windows 95 operating system. The system is used for ease of user interface. Numerous operations, such as manual and autonomous mode start-up, are initiated by selecting icons within the operating environment. Previous Virginia Tech vehicles required that manual and autonomous algorithms be downloaded to microprocessor units. Such arrangements required the user to be intimately familiar with microprocessor operation. NEVEL’s graphical user interface, or GUI, allows the first time user with minimal computing experience to quickly initialize the vehicle. This helps to accelerate the learning curve for first time users.

5.2.1 Motor Control

A commercially available Galil DMC-1030 motor controller is used to handle closed loop motor control. The elements of the motor control system are shown in Figure 5.6. The DMC-1030 is used to regulate the control loop between the given drive commands and motor feedback, which is provided by incremental encoders. Motor drive commands may be sent to the DMC-1030 in two modes, manual and autonomous.

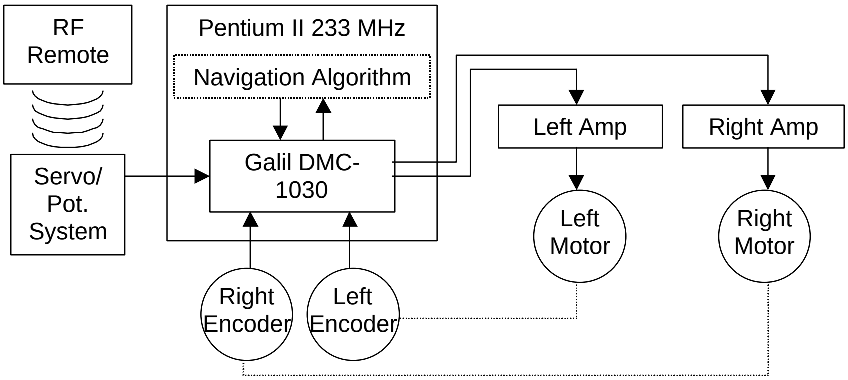


Figure 5.6: Motor Control System

In manual mode, NEVEL is driven using a RF remote control. The controller is an off-the-shelf 4-axis Futaba remote used in model airplanes. Two of the remote's channel are used to control servos that manual actuate rotary potentiometers. The potentiometers are used to send +/- 10-volt DC analog signals to the DMC-1030. The signals are then converted into proportionate motor speed commands using programming software supplied with the controller. The motor speed signal is sent to individual 24-volt, 100-amp motor amplifiers. The amplifiers have been set in a "torque mode" so that a constant 24-volts is supplied to the motors and motor torque is controlled by varying current. This allows NEVEL to maintain a constant speed by increasing motor torque when engaging inclines or variable terrain. At present, manual mode may be operated in two modes. First, the user may drive NEVEL by individually controlling the left and right wheels using separate remote levers. This mode allows true ZTR (zero-turning radius) capabilities but tends to be tricky to control. A second, pseudo-ZTR manual control mode is also available. In this mode, one remote lever controls the overall vehicle speed while the second lever controls the proportion between the wheel velocities. Although full zero radius turns are not possible in this mode, it is much easier for the inexperienced user to control. Both manual modes are initialized with a simple icon “point and click” in NEVEL’s GUI interface.

In autonomous mode, NEVEL’s motor commands are generated directly by the navigation algorithm. The method used to determine individual wheel speeds is described in section 5.4.3. Communication between the navigation algorithm and DMC-1030 is achieved using a C command library supplied with the controller. The remainder of the motor control system is the same as in the manual mode. In autonomous mode however, the DMC-1030 is used to return encoder data to the navigation algorithm to perform vehicle odometry. NEVEL’s odometry is critical to its map building algorithm (section 5.4.2).

5.3 Sensor Suite

NEVEL’s sensor suite consists of a vision system and laser range finder. The vision system is used solely for course boundary detection. The laser range finder supplements the vision system by providing obstacle location data. The sensor suite configuration is shown in Figure 5.7. Sensor suite data is processed by NEVEL’s navigation algorithm, which, in turn produces motor commands. The next two sections explain the sensor suite components in more detail.

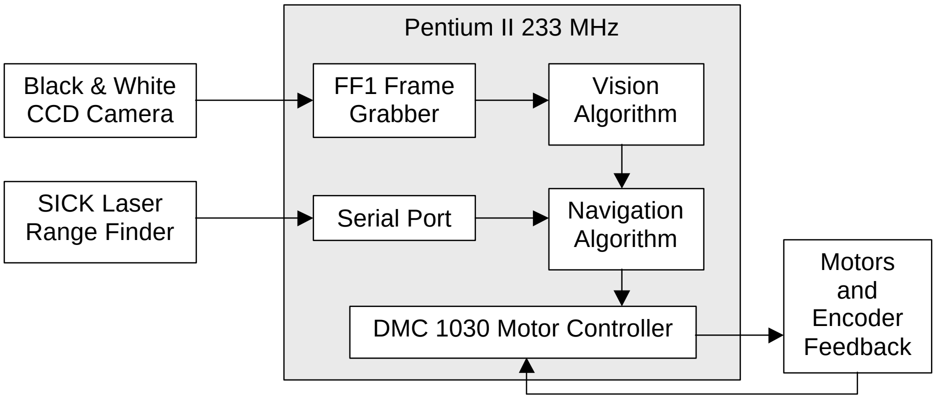
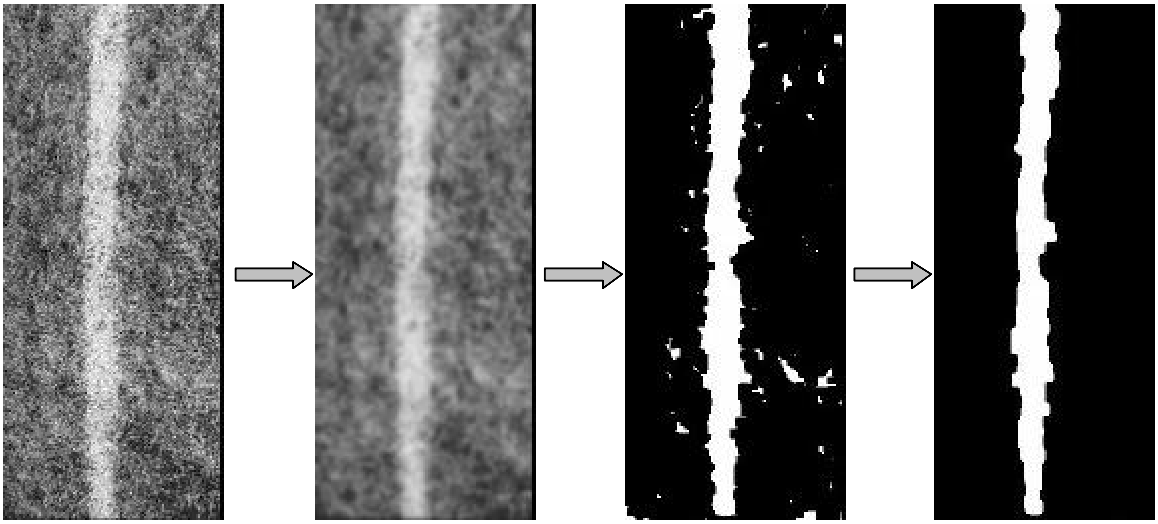


Figure 5.7: NEVEL’s Sensor Suite

5.3.1 Vision System

NEVEL uses a gray scale monocular vision system. A single high-resolution CCD camera is used to view an area that extends from zero to five meters in front of NEVEL and five meters to either side. The rather large wide viewing area accommodates curved boundary lines. The camera signal is sent to a Current Technologies FF1 DSP (digital signal processor) “frame grabber” card within NEVEL’s computer. The frame grabber is used only for image acquisition and not actual processing due to its limited processing rate. The frame grabber’s maximum processing rate is only 10 MHz, compared to the host computer’s 233MHz. The frame grabber is capable of image resolution up to 512x512 pixels. The image resolution is reduced to 128x128 pixels to decrease processing time however. Testing has shown that this resolution reduction has a negligible effect on the subsequent extraction of course boundaries. The image is then passed to the host computer as a matrix of gray scale values. The host computer then handles all image processing.

After image acquisition, several conditioning algorithms are used to prepare the data for course boundary extraction. The main steps in NEVEL’s vision process are shown in Figure 5.8. The image conditioning algorithms utilize convolution matrices. A convolution matrix is a local area computation that alters a given image pixel as a function of the values of its surrounding neighbors. Computer vision literature presents an almost endless array of convolution matrices to perform operations such as blurring, smoothing, and edge detection (Fairhurst, 1988; McKerrow, 1991).



Raw Image Blurring Thresholding Streaking

Figure 5.8: NEVEL’s Vision Algorithm

The first step in NEVEL’s vision algorithm is to normalize the image to eliminate “horizon glare”. NEVEL’s vision camera is mounted 6 feet above the ground and aimed 45° from horizontal. Pixel intensity increases towards the top of the image due to higher light intensities near the horizon. A power function is determine based on the relative increase in pixel intensity between image scan lines. This power function is then used to normalize the image. The image is then blurred to eliminate extraneous image noise in the form of glare spots and “lone pixels” caused by data noise. Blurring is achieved by replacing each pixel with the average value of its surrounding neighbors (typically the nearest 8 pixels). Thus lone white pixels are averaged to black and smaller clusters of bright pixels are dimmed.

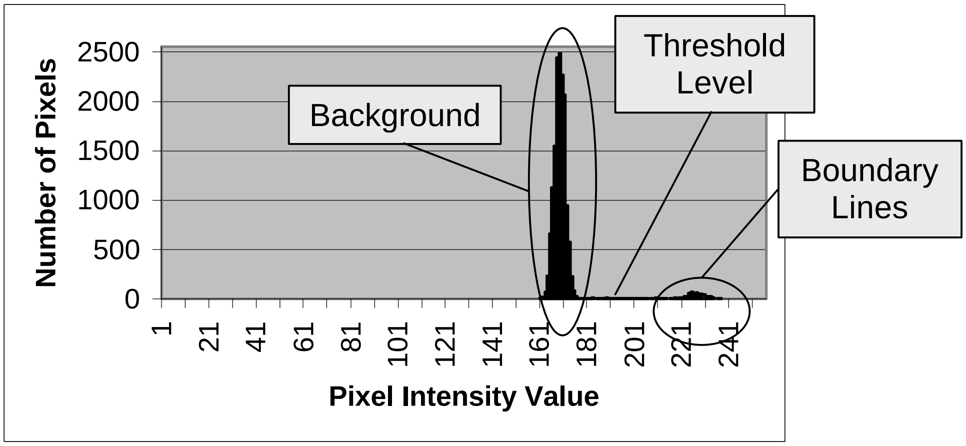


Figure 5.9: Pixel Intensity vs. Number of Pixels

The next step, thresholding, is the most critical step in NEVEL's course boundary extraction. Course boundaries are typically bright (white or yellow lines) compared with their background (turf or asphalt). Course boundaries also comprise a relatively small portion of the overall image. The histogram in Figure 5.9 indicates the number of pixels at each grayscale intensity level for the image of Figure 5.8. The histogram shows two distinct intensity clusters. The lower cluster is the large collection of lower intensity background pixels. The significantly smaller upper cluster is comprised of the distinctly higher intensity pixels of the course boundary lines.

NEVEL's thresholding procedure calculates the arithmetic mean and the standard deviation for all pixel intensities within each image. The mean intensity is typically near the center of the lower cluster. The image threshold is set at a scale factor of the standard deviation above the mean intensity level. This moves the threshold above the cluster of background pixels. In Figure 5.9 the mean and standard deviation are 171.6 and 11.9 respectively. Using a standard deviation factor of 1.5, the threshold limit for the image of Figure 5.8 was set at an intensity level of 190. The scale factor of the standard deviation offset is adjustable for indoor and outdoor conditions and is based upon testing results. This standard deviation algorithm allows the vision system to actively threshold each image and thereby adjusts to changing lighting and background conditions.

The final step in NEVEL's vision algorithm is designed to remove the "noise" which remains in the image. Noise is considered to be extraneous high-intensity pixels that do not lie on the course boundary lines. Competition boundaries are required to be 3 to 4 inches in width. Thus, lines will appear in the vision image within a known pixel width. Based on camera height and angle, lines are typically 4 to 6 pixels wide. Thus, cluster of pixels smaller than this preset limit is assumed to be residual image noise. The image is then scanned with a custom "streaking" algorithm. The streaking algorithm searches for these "noise clusters" and removes them from the image. Any clusters of pixels above the preset line width most likely constitute an obstacle. These large clusters are also removed since obstacle detection will be handled by the range finder.

Once the boundary lines have been extracted from the image, they must be adjusted to compensate for distortion due to the camera's perspective view. The camera's height and angle cause straight lines to appear as converging lines (Figure 5.10). The effect upon curved lines is even more dramatic. If the vision is to be used in a mapping algorithm, the lines must be transformed back to ground plane. The image transformation described below has been used on several of Virginia Tech's previous vehicles.

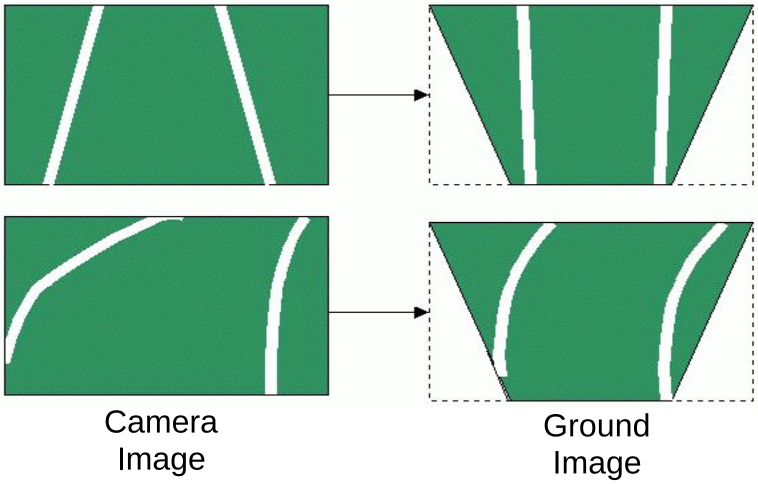
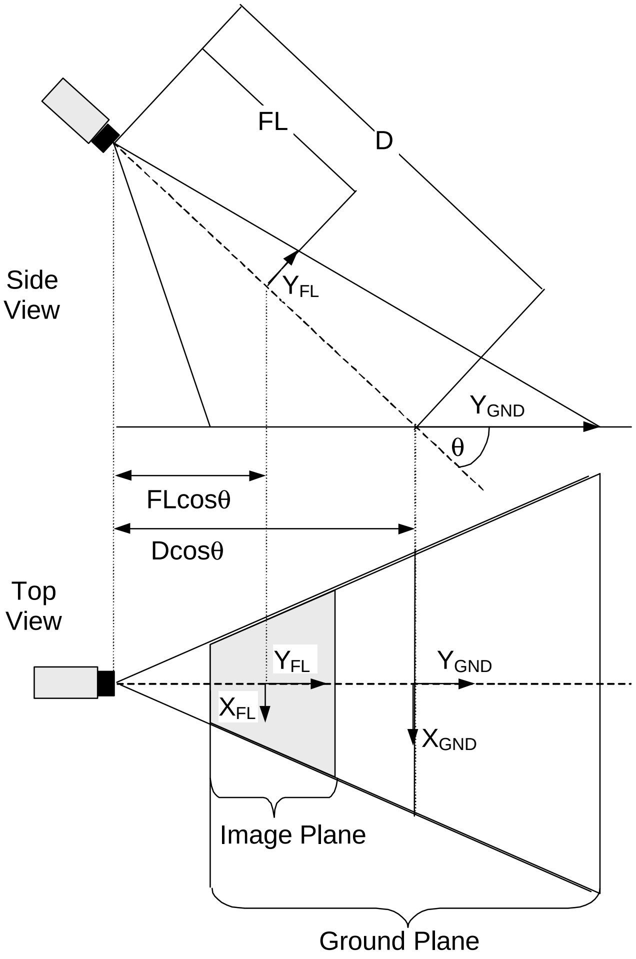


Figure 5.10: Perspective View Distortion

The transformation begins by recognizing that two distinct coordinate planes exist, the image plane and the ground plane. The image plane is located at the camera's focal point and rotated by an angle theta from the ground plane, thus producing the perspective distortion. The transformation of boundary line pixel locations to the ground plane is a relatively simple geometric relationship (Figure 5.11). The resulting coordinates distinctly locate each image pixel relative to NEVEL's center point (also the camera mounting point). This produces the first half of the sensor data needed to complete NEVEL's worldview.

X_{FL},Y_{FL} : Image Coordinates
X_{GND},Y_{GND} : Ground Coordinates
θ : Camera Elevation Angle
FL : Camera Focal Length
D : Distance from Camera's Optical Center to the Ground



$$X_{GND} = X_{FL}\left(\frac{\left(D + Y_{FL}\cos\theta\right)}{FL}\right)$$

$$Y_{GND} = \frac{DY_{FL}}{\left(FL\sin\theta - Y_{FL}\cos\theta\right)}$$

Figure 5.11: Vision Image Transformation

5.3.2 Laser Range Finder

The final selection of a range finding sensor was based upon the donation of a laser range finding unit by SICK Optic Electronics. The use of a laser helps eliminate the errors in obstacle detection caused by ultrasonic systems previously used by Virginia Tech AVT. The unit is capable of scanning 180° at a maximum resolution of 0.5°. The laser is mounted at the front of NEVEL at a height of 5 inches. This allows NEVEL to detect obstacles very low to the ground while avoiding false reading caused by long grass. The region of interest limits laser data collection to a region 10 meters wide and 5 meters in front of NEVEL. The laser itself is “eye-safe” which prevents possible hazards to users.

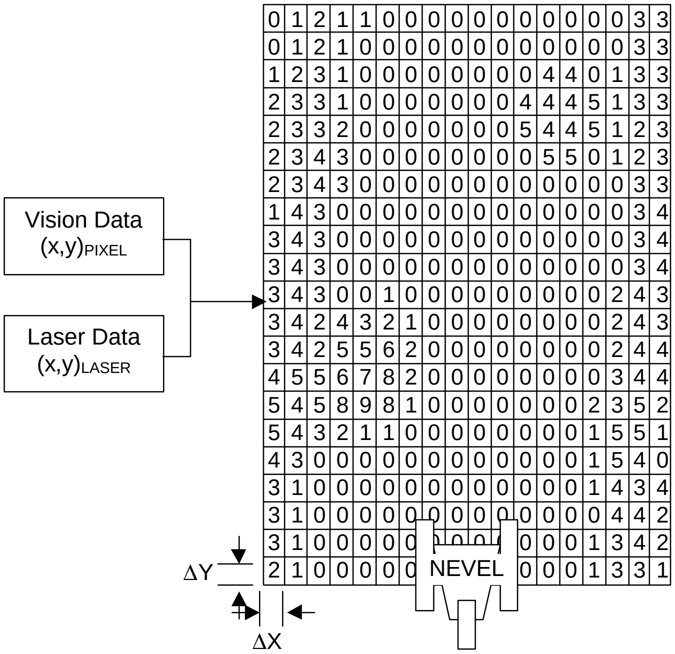
The laser communicates with NEVEL’s host computer via a serial port connection. The laser is capable of baud rates up to 58,000 BPS. Data is sent to the computer as a series of angle and distance measurements. While the laser is set to constantly deliver data to the host computer, the navigation algorithm regulates when laser data is actually incorporated into the navigation map. The actual operation of the laser is controlled using software supplied with the unit. Laser data is collected via a calling function within the main navigation algorithm.

5.4 Navigation Strategy

NEVEL’s navigation strategy incorporates both certainty and occupancy grids and potential field models. The navigation strategy was designed to use a planning rather than reactive algorithm to make optimal use of NEVEL’s long range sensing capabilities. An attempt was made to keep the fusion, mapping, and navigation algorithms reasonably simple while incorporating planning abilities. The navigation strategy presented here was used at the Sixth Annual International Ground Robotics Competition. It was also designed to be adaptable and thus act as a starting point for further navigation research.

5.4.1 Data Fusion

NEVEL’s data fusion technique is simple. Vision and laser range finder data are collected as a series of grid elements that locate either a point on the course boundary or the profile of an obstacle. Data coordinates for the grid elements are then transformed with NEVEL acting as the coordinate origin. Data fusion occurs in a *Data In-Data Out* I/O mode (Dasarathy, 1997). Data fusion is accomplished by placing vision and laser data points into a grid such as the one shown in Figure 5.12. Each grid cell specifies a Δx and Δy coordinate group relative to NEVEL. The resolution (size) of the grid cells is adjustable. Lower resolutions can lead to faster refresh rates but decreases map accuracy. Realistic grid resolutions are function of sensor resolution and accuracy. The default resolution uses 0.1x0.1 meter grid cells. Data fusion currently assumes that the data from both the vision and laser range finder is equally accurate and relevant. The number in each grid cell indicates the number of sensor data points within the coordinate group. In turn, this indicates the confidence that an obstacle or boundary line is located within that region. NEVEL's data fusion approach provides the basis for the map building algorithm.



0	1	2	1	1	0	0	0	0	0	0	0	0	0	0	0	3	3
0	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	3	3
1	2	3	1	0	0	0	0	0	0	0	0	4	4	0	1	3	3
2	3	3	1	0	0	0	0	0	0	0	4	4	4	5	1	3	3
2	3	3	2	0	0	0	0	0	0	0	5	4	4	5	1	2	3
2	3	4	3	0	0	0	0	0	0	0	0	5	5	0	1	2	3
2	3	4	3	0	0	0	0	0	0	0	0	0	0	0	0	3	3
1	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	3	4
3	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	3	4
3	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	3	4
3	4	3	0	0	1	0	0	0	0	0	0	0	0	0	2	4	3
3	4	2	4	3	2	1	0	0	0	0	0	0	0	0	2	4	3
3	4	2	5	5	6	2	0	0	0	0	0	0	0	0	2	4	4
4	5	5	6	7	8	2	0	0	0	0	0	0	0	0	3	4	4
5	4	5	8	9	8	1	0	0	0	0	0	0	0	2	3	5	2
5	4	3	2	1	1	0	0	0	0	0	0	0	0	1	5	5	1
4	3	0	0	0	0	0	0	0	0	0	0	0	0	1	5	4	0
3	1	0	0	0	0	0	0	0	0	0	0	0	0	1	4	3	4
3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	2
3	1	0	0	0	0	0	0	0	0	0	0	0	0	1	3	4	2
2	1	0	0	0	0	0					0	0	0	1	3	3	1

Figure 5.12: Confidence Grid Data Fusion

5.4.2 Map Building

NEVEL's map building is based directly on his data fusion. The map building algorithm consists of five steps:

1. New sensor data is collected and fused into the confidence grid
2. The old confidence gird cells are transformed relative to NEVEL's new coordinates
3. The old and new confidence grids are fused into a single master confidence grid
4. A threshold operation is applied to the master confidence grid to produce an occupancy grid
5. The master confidence grid is stored as the "old confidence grid"

The first step of the process was described in section 5.4.1. Step two demonstrates a key element in NEVEL's mapping and navigation algorithms. As NEVEL proceeds through the environment, multiple sensor data sets are collected and fused. This aids in reducing sensor error by averaging multiple data sets over time (Hall, 1997; Kam et al., 1997). As NEVEL moves, however, the old data coordinates must be continually realigned to match NEVEL's new position and orientation within the world. NEVEL is always assumed to be the origin of the confidence grid (Figure 5.13). Thus, NEVEL's encoder readings are tracked between sensor readings and used to determine transformation and rotation values. Areas within the transformed grid that do not contain previously stored data are considered as "unknown regions" with a confidence level of zero. Unknown regions within the transformed old data map will later be updated with confidence levels based upon newly collected sensor data. At this point, however, unknown regions are assumed to be unoccupied.

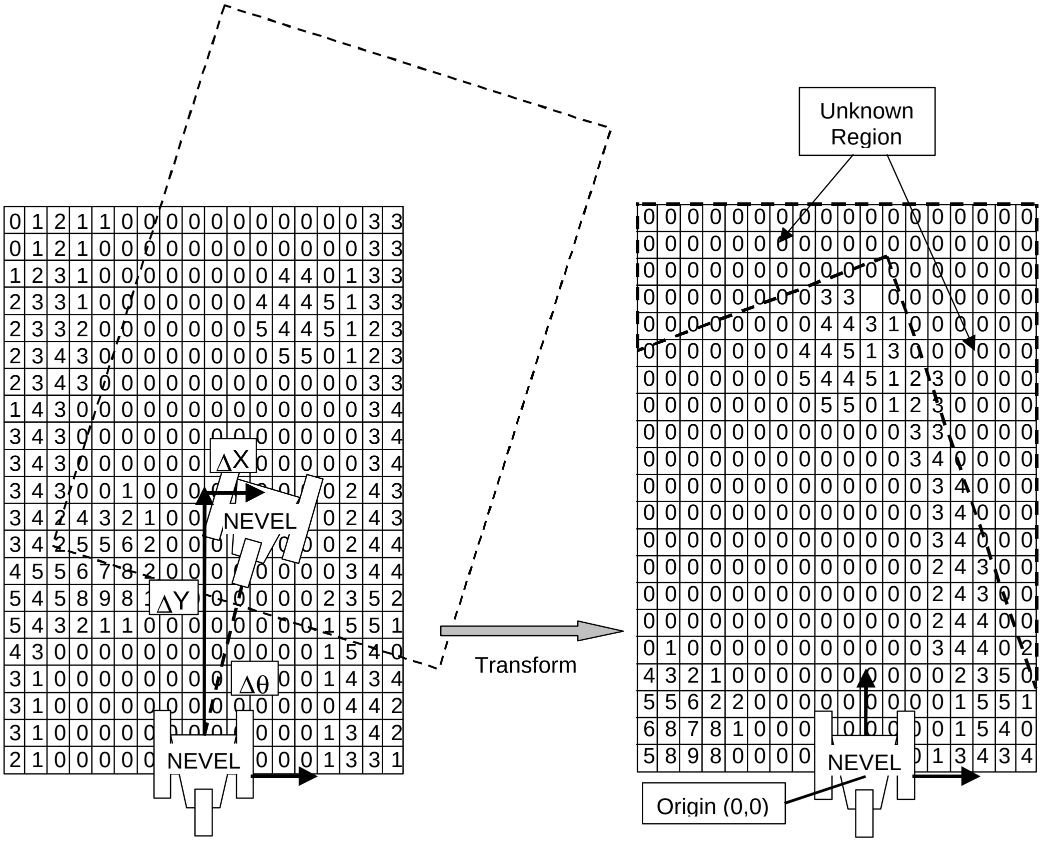


Figure 5.13: Old Confidence Grid Transformation

Once the old confidence grid coordinates have been transformed to match NEVEL's new position, the *old* and *new* grids may be fused into a *master confidence grid* (Figure 5.14). This is NEVEL's second *Data In-Data Out* sensor fusion process before navigation occurs. The combination of old and new data helps NEVEL reduce sensor errors by averaging multiple sets of data. Presently, the old and new data are combined with equal weighting. Thus, the confidence level in each *master grid* cell is the arithmetic mean of the *old* and *new* grids. Areas in the *master grid* that coincide with "unknown regions" of the *old grid* are assigned the value contained in the *new grid.*

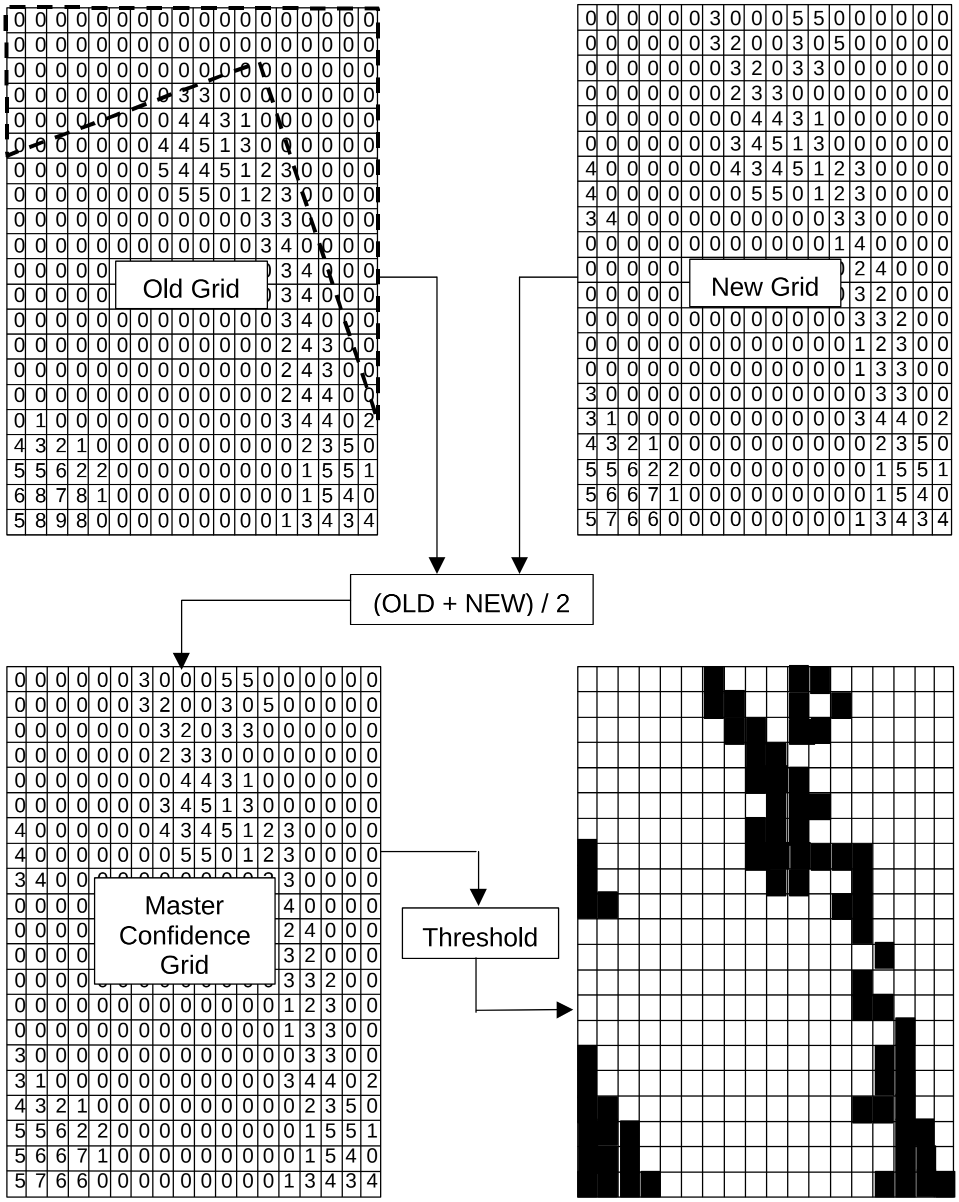


Figure 5.14: Master Confidence Grid Formation

A threshold operation is then applied to the master confidence grid to produce and occupancy grid. The threshold level is variable to adjust to changing environments and sensor accuracy. A typical occupancy result is shown in the final stage of Figure 5.14. The final stage of the map-building process is to replace the stored "old confidence grid" with the newest master confidence grid. With the incorporation of new sensor data into NEVEL's memory the map building process is completed. The navigation algorithm will then use the occupancy grid to vehicle path planning.

5.4.3 Navigation Strategy

NEVEL's navigation strategy uses a potential field model to accomplish path planning. The navigation algorithm utilizes the final occupancy grid from section 5.4.2. Each occupied grid cell is assigned a potential charge mask as shown in Figure 5.15. The mask specifies how the potential charge varies with distance from occupied cells. NEVEL's potential field mask presently consists of two parts, a repulsive core and attractive perimeter. The repulsive core of the mask is used to direct NEVEL's trajectory away from obstacles and course boundaries. The core achieves maximum potential at the cell center and decreases according to the inverse of distance squared proceeding from the cell center.

The attractive perimeter is primarily used to guide NEVEL down the course. The attractive perimeter has another function, however. In sections with dashed-lines, or no lines at all, the repulsive core alone could force NEVEL's trajectory out of the course. The attractive perimeter restrains NEVEL within a safe following distance of boundary lines by balancing the repulsive force at distances over 1.5 meters. Thus, NEVEL will follow lines and obstacles without colliding with them. The navigation algorithm allows the mask to be altered for testing.

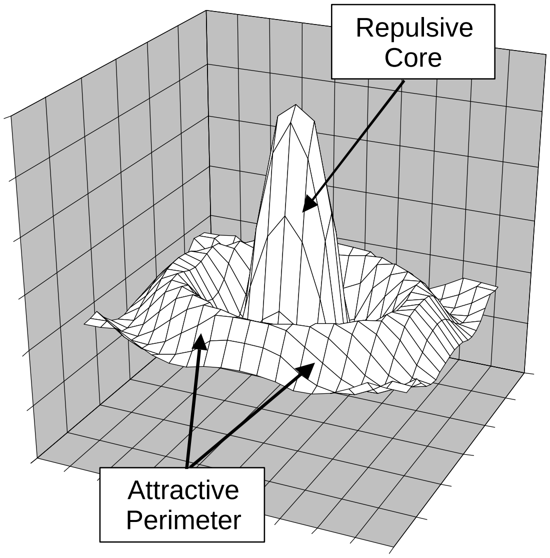


Figure 5.15: Potential Field Mask

A complete potential field map is produced by replacing all occupied cells within the occupancy map with the desired potential mask (Figure 5.16). Since the potential field map is built upon an occupancy grid, each individual potential field is located at a discrete grid location. Starting at NEVEL's current location, the navigation algorithm searches each horizontal line of grid cells for the minimum potential location (Figure 5.17). Each map line minimum is the result of the total potential field created by surrounding lines. Minimum locations are specific locations in space and are not necessarily the center of any grid cell. The collection of minimum potential locations represents an approximate path plan.

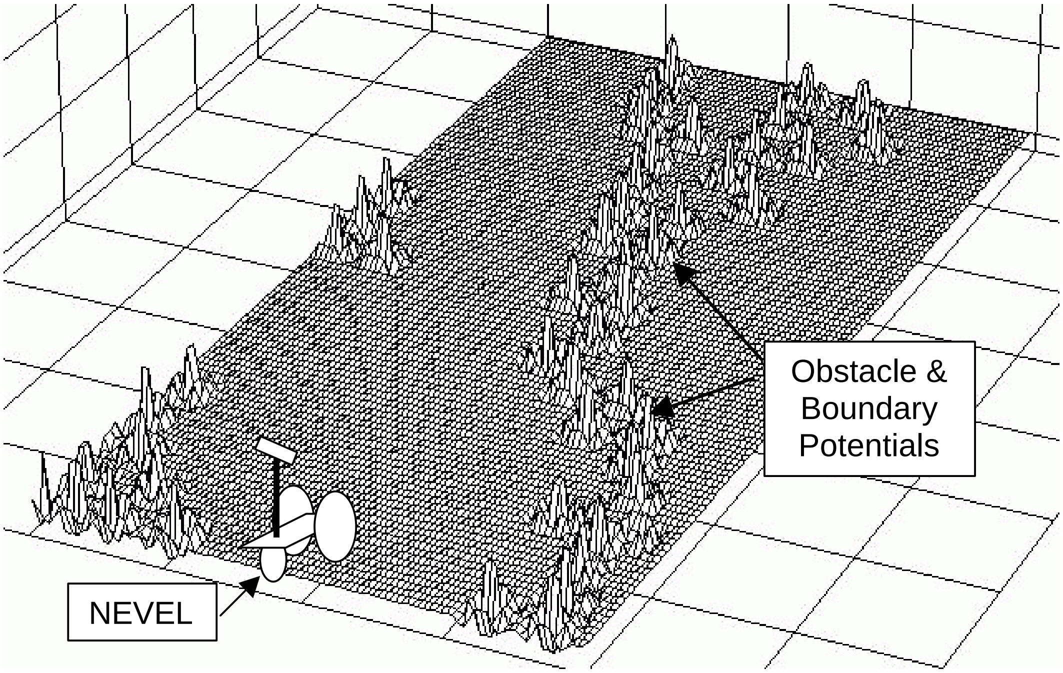


Figure 5.16: Potential Field Map

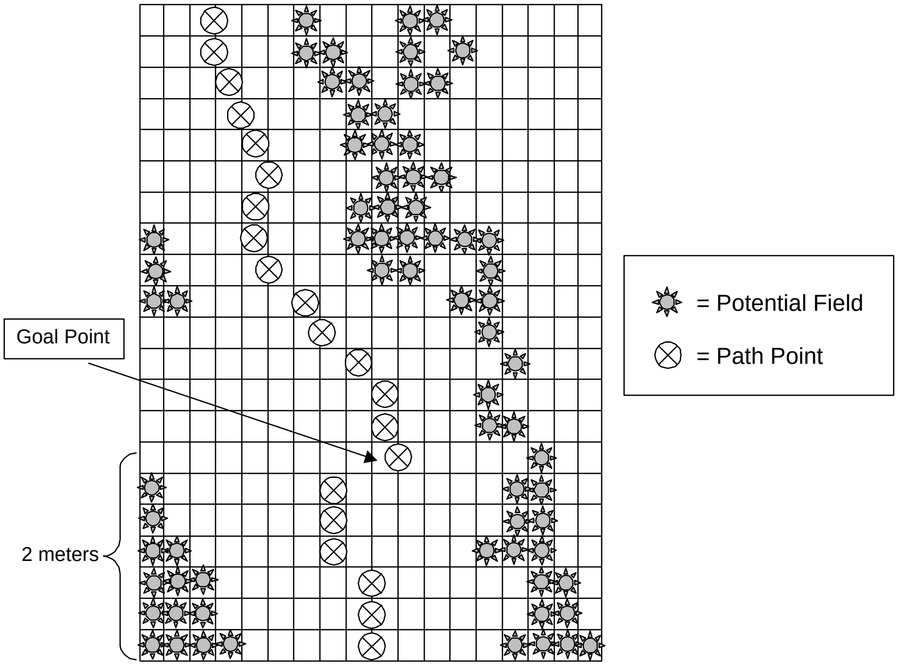


Figure 5.17: Potential Field Path Plan Points

NEVEL's instantaneous trajectory is derived from the rough path found in the potential field map. The path point two meters in front of NEVEL is selected as the desired goal. It is assumed that data within 2 meters of NEVEL has been sufficiently tempered with numerous data sets to make it reliable for path planning. NEVEL's present location and this goal point are then used to compute an arc for NEVEL to follow (Figure 5.18). A perpendicular bisector is found for the line connecting NEVEL and the goal point. The intersection of the perpendicular bisector with the coordinate axis (with NEVEL acting as the origin) specifies the center of the path arc, (X_{CENTER}, Y_{CENTER}). This information is used to determine the radius of curvature, ρ, and the angle the arc subtends, θ. This path is then used to compute NEVEL's differential wheel speeds.

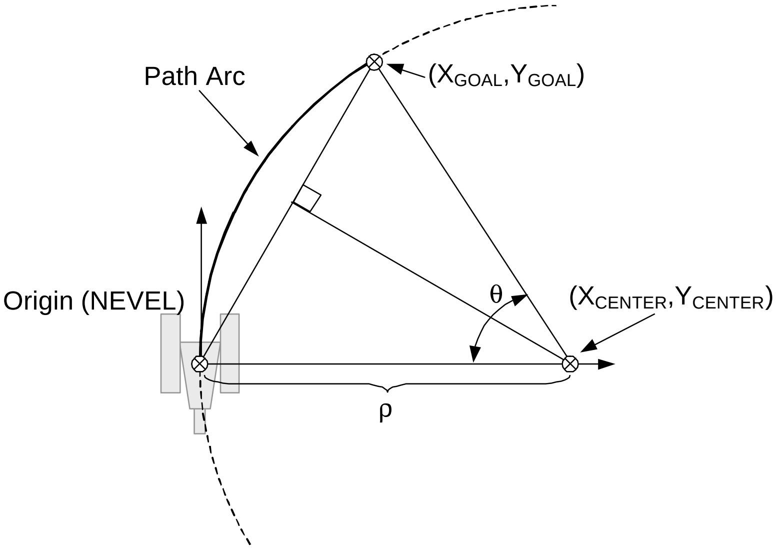


Figure 5.18: Path Arc Calculation

Given the path arc radius of curvature, ρ, and the angle it subtends, θ, NEVEL's drive loop begins (Figure 5.19). First, wheel speeds are computed as functions of the desired total vehicle velocity and NEVEL's wheelbase, L. If ρ is smaller than 0.01 meters, the wheel velocities are set equal to each other and NEVEL drives straight. The desired wheel velocities are then sent to the DMC-1030 for closed loop processing. NEVEL moves forward and collects data for the next navigation loop. During this time, NEVEL tracks encoder readings and passes them back to the map building algorithm for use in the *old data* transform (section 5.4.2).

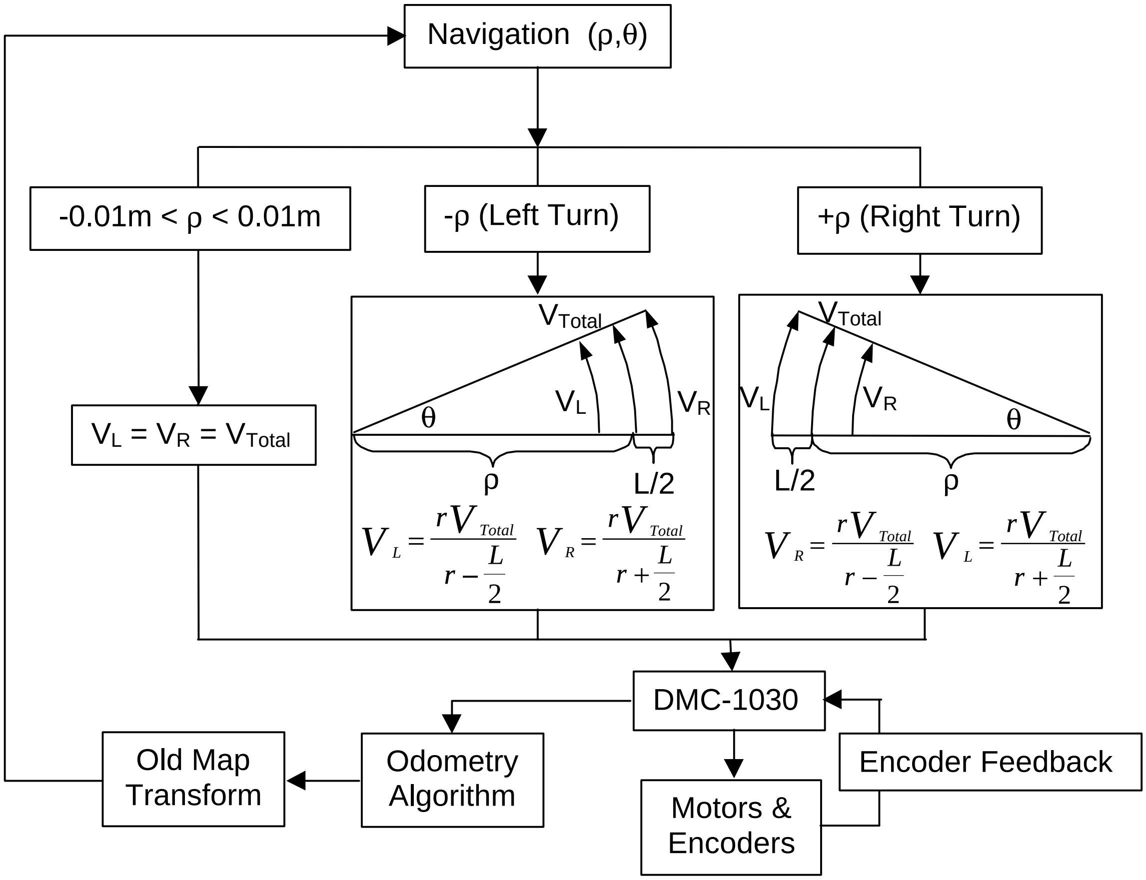


Figure 5.19: NEVEL’s Drive Loop

NEVEL’s path plan is updated twice per second. Thus, a single erroneous segment of the path will be corrected by subsequent navigation loops. Since each path arc is at least 2 meters long, NEVEL never actually completes an entire path segment before the navigation is updated with a new path. However, the odometry feedback can be used to record the portion of each path arc that is completed. The individual path segments may be assembled in a piecewise manner to track NEVEL’s global path. This could be advantageous during testing to determine the accuracy of NEVEL’s actual path compared to the path computed by the navigation algorithm.

5.5 Summary

This chapter describes the detailed design of NEVEL, Virginia Tech's newest autonomous vehicle. The design meets three key goals: integration of existing technology, simplicity, and robust design. The design requires that only four parts had to be custom manufactured: the "T-Frame", support shelving, wheel hubs, and protective shell. The remainder of NEVEL's drive train, sensor suite, and computer system are industrially available components.

The mechanical and electrical systems are simple in design. NEVEL's drive train consists of motors, gear reducers, hubs, and wheels in a positive drive configuration. This reduces the chance of mechanical failure and simplifies maintenance. The electrical system uses a minimum of wiring and yet efficiently provides power to all necessary components. The electrical system also incorporates several E-Stop systems for user safety. The sensor suite uses a single camera and laser range finder to provide all necessary environmental information. The sensor fusion and navigation systems are concentrated within a single personal computer system. This eliminates the need for custom-made microcontrollers and excessive wiring. Both manual and autonomous modes have been developed in a user-friendly GUI environment.

The navigation strategy incorporates planning abilities without being overly complex. The use of certainty and occupancy grids also provides flexible sensor fusion through adjustable weighting, resolution, and potential field masks. The use of grids also provides a framework for testing other navigation strategies.