Chapter 6

Testing and Performance

This chapter summarizes the performance of NEVEL during testing and competition. Attention is given to the design goals set forth in chapter 3. Numerous challenges encountered during testing are also discussed. The mechanical, sensor and navigation issues will be covered in order.

6.1 Mechanical Performance

NEVEL's mechanical construction proved to be quite robust. The "T-Frame" was fabricated from 3/16-inch steel and was more than adequate to support vehicle loads. The rigid frame also provides the accurate wheel shaft alignment necessary in a differential drive system. The shelving material, though somewhat difficult to machine and fasten, resulted in a strong, nonconductive support structure. The final assembled vehicle weighs 220 lbs. The use of CAD also provided an overall design that efficiently utilized space and required minimal rework.

NEVEL is capable of achieving a top speed of 8.5 MPH but is limited to 5 MPH through software. NEVEL's drive train supplies approximately 600 ft-lbs of torque to each wheel at stall speed. The differential design proved to be extremely maneuverable even in cluttered environments. NEVEL is capable of performing zero-radius-turn maneuvers within a 3.5-foot diameter envelope.

Several challenges were encountered during NEVEL's initial testing. The first challenge deals with vehicle stability. The majority of NEVEL's weight was centered about the two main drive wheels in an attempt to increase traction and lower NEVEL's center of gravity. The final design carries only 45 pounds on the rear support caster. While NEVEL is statically stable it was found that the vehicle could run dangerously close to rollover (tipping) conditions while moving. NEVEL's instability can be partly accounted for by the inclined motor mounting and rather high computer and monitor. The motor and computer weight were heavier than expected and shifted NEVEL's center of gravity above the drive wheel axis. NEVEL tended to tip forward when stopping quickly or operating on downward slopes. The stability issue became very evident during competition. During a near-zero-radius maneuver at finite velocity, NEVEL toppled over and shattered a portion of the shelving system. When turned upright however, the vehicle started back up and operated perfectly, a testament to NEVEL's mechanical robustness. The stability problem was partially solved through the addition of acceleration and deceleration ramp functions in NEVEL's drive algorithm. Coding was also modified to decrease NEVEL's total velocity in proportion to the radius of curvature when entering a turn. Both of these modifications helped to reduce NEVEL's inertia while maneuvering and eliminated subsequent rollovers.

NEVEL's initial drive loop also proved under-powered when running on rough terrain or steep inclines. Both situations require high starting torque. The inability to move caused NEVEL's motor controller to enter a "position error state". The DMC-1030's error state reflected the difference between the controller's position commands and actual encoder readings. This error state resulted in vehicle shut down and required the system to be reinitialized. Numerous PID adjustments were made to the control loop within the DMC-1030. All efforts to optimize this system proved futile however and the motor controller was reset to its factory default settings. Increasing the torque limit and the gain on the motor amplifiers finally solved the problem. Motor power is now more than sufficient to handle the necessary competition terrain.

NEVEL's operation time also varied during testing. The batteries that were initially selected proved to provide insufficient capacity to operate the vehicle for any reasonable amount of time. Larger deep-cycle batteries were added to the power system. Subsequent testing demonstrated that NEVEL's run time could still vary from 15 minutes to more than 40 minutes. The greatest factor in this variation is obviously the current draw by the motors. The use of lead-acid batteries also complicates the ability to predict run time. The constant recharging and heavy current draws placed on the batteries has resulted in a decrease in overall performance.

The use of pneumatic tires with the differential drive configuration also provided testing challenges. The variation in tire pressure affected NEVEL's ability to drive perfectly straight. The difference in tire pressure affected tire diameter and often caused NEVEL to veer left or right over long distances on smooth surfaces. This had a minimal affect during autonomous operation. The constant updating of NEVEL trajectory was able to compensate for vehicle drift. The effect of tire variation compared to the variation of terrain on vehicle odometry is debatable. Since NEVEL has no suspension system, it was hoped that the pneumatic tires would absorb the brunt of shock caused by rough terrain. However, tire stiffness coupled with NEVEL's small wheelbase resulted in significant vehicle "bounce." The uneven terrain coupled with vehicle bounce led to errors in trajectory following. The effects were most evident during straight-line motion. Reducing NEVEL's speed allowed much more accurate path following.

Overall, NEVEL meets the design goals set forth in chapter 3. The base vehicle meets dimensional requirements for competition and is significantly smaller than other Virginia Tech vehicles. The differential design has eliminated the maneuverability and "scrubbing" problems of Virginia Tech's previous four-wheel designs. NEVEL's mechanical design adhered to an off-the-shelf approach for all major components. The use of the gear reducer's output shaft as the actual drive axle eliminated extra chains, gears, and support bearings present in many designs. The final result is a highly maneuverable, direct drive, low maintenance package. Suggested solutions to NEVEL's shortcomings are suggested in Chapter 7.

6.2 Computing and Sensing

An off-the-shelf approach proved to be quite beneficial to the final design. The integration of motor control and sensor was simple due to plug-and-play peripheral cards. The use of the DMC-1030 eliminated the need to design a custom motor control loop. The use of the included software and motor control command library resulted in highly accurate motor control. The DMC-1030 also simplified the differential control scheme. Losses in position accuracy can be attributed to variations in tire size and vehicle “bounce“ (section 6.1).

Computer vision data acquisition was simplified using a plug-and-play peripheral also. Challenges associated with the computer vision system are tied almost exclusively to lighting conditions. Glare continued to produce “wash-out” by blinding the camera with intense light. The addition of a “hot mirror” filter partially eliminated this problem. The laser range finder was quite reliable at accurately detecting obstacles within a range or +/- 3-cm. Communications with the range finder were handle over a single computer serial port. Thus, the integration of the laser into the computing system was mechanically simple.

NEVEL’s sensing and controls group coded the navigation algorithm. Work on the actual coding was started late in the development process. The subsequent code received minimal testing prior competition. While the sensor fusion and map building was completed, the actual path planning underwent numerous redesigns. The results of this are discussed in the next section.

The personal computer itself was reliable. The integration of sensing and motor control was convenient and simple. Having the computer onboard the vehicle also allowed for easy modification of sensing and navigation algorithms in the field. The computer did experience some minor difficulties associate with loose internal connection. This repeatedly caused the system to lock up or fail during cold boots. The selection of a more ruggedized industrial computer could solve this problem.

6.3 Competition Results

NEVEL and two other Virginia Tech vehicles were entered in the Sixth Annual International Ground Robotics Competition. Fifteen teams entered and eleven actually qualified to run the obstacle course. NEVEL received the first place award for vehicle design and static judging. NEVEL received eighth place in the actual obstacle course run and sixth during the bonus course competition.

Several problems were encountered during competition. Initially, NEVEL's motors were not supplying the torque necessary to climb the course inclines or even traverse thicker field grass. Increasing the amplifier current gain to "stiffen" the control loop solved the problem. NEVEL's stability problem also became more apparent when the vehicle drove over competition inclines. At the peak of incline ramp, NEVEL's inertia caused the vehicle to tip forward. NEVEL's vision system had difficulties adjusting to the glare of the course. This made course boundary detection somewhat difficult. The majority or problems encountered during competition stemmed from minimal testing of the navigation algorithm. The potential field model caused NEVEL to "ride" course boundary lines and collide with obstacles. Two of NEVEL's three course attempts were aborted due to this problem. The final run was actually performed using code from a previous year's vehicle. This again demonstrates NEVEL's value as a testbed for numerous navigation strategies.

Chapter 7
Conclusion and Recommendations

7.1 Recommendations for Future Work

NEVEL's current design is adequate to fulfill its task as a sensor and navigation test-bed. However, if NEVEL is to become more competitive in upcoming years, several design changes need to be implemented. This is especially true in the area of algorithm coding. Any changes should be carefully considered, however, since a single change, mechanically or computationally, could drastically alter the performance of all remaining systems. This chapter will summarize the author's recommendations for the direction of future work in the areas of mechanical, electrical and computational, sensor and navigation design. The key points of the thesis will then be summarized.

7.1.1 Mechanical Design

NEVEL's present base vehicle is quite robust in design. The integration of components into the frame, such as motors and gear reducers, and the lack of available space limits the potential for easy modifications. Still, the design leaves room for improvement. The main mechanical priority is improvement of vehicle stability. Reducing the angle of the drive train and lowering heavy components would result in a lower center of gravity. A modification such as this will require fabrication of a new "T-Frame" or alterations to the existing component layout. Increasing the wheelbase could also provide better vehicle stability and possibly reduce vehicle "bounce". Any other improvements in vehicle stability might come at the cost of an added suspension system. The present drive train, however, does not easily facilitate such an addition. This is one cost of the simplistic drive train design. Due to the high level of integration and support among mechanical components, any mechanical modification will most likely require the complete overhaul of every system. This requires significant vehicle downtime and reduces testing time. This has proven a critical failing point during previous years' competitions.

The use of improved drive code presents the most attractive stability solution with a minimum of physical modification. The derivation of an accurate dynamic model of NEVEL would greatly facilitate this process. The ability to accurately vary speed according to turning radius and vehicle incline would reduce the risk of rollover.

7.1.2 Electrical and Computing Improvements

NEVEL's present all-DC power bus provides sufficient capability to handle future additions of sensors or computer components. The main shortcoming, however, is the short run time during full operation. Further research needs to be conducted into alternative batteries such as gel-cells, Nickel-Cadmium, and other rechargeable power sources. A reduction in battery weight would also aid in lowering NEVEL's center of gravity and moving it toward the rear of the vehicle.

Improvements could also be made to NEVEL's manual control system. The present servo/potentiometer system (section 5.2.1) is not precise. Variations between the two potentiometers and inherent non-linearity results in control signal fluctuation that makes true ZTR control difficult. The present system could be upgraded to a PWM or digital system. The use of a solid state receiver will most likely reduce the space required by the present manual mode system. A more advanced remote system could also be used to transfer motion code and receive odometry and other system data via the DMC-1030's numerous I/O ports. The possibility of tracking system functions remotely could prove beneficial during testing.

It is the author's opinion that the use of a commercially available personal computer was beneficial to vehicle design. The centralization of sensing, navigation, and motor control seems natural. This also resulted in the elimination of separate custom units and the associated communication and maintenance problems. The use of a standard desktop PC was unwise however. The present unit should be replaced with a more ruggedized industrial system. Although such systems come at considerable cost, their ability to handle rougher environments and deal with moderate impacts make them a sound investment.

7.1.3 Sensors and Navigation

NEVEL's present sensor suite provides sufficient facilities for line and obstacle detection. The capabilities of the sensor suite are currently under utilized. The vision system could be modified to include obstacle detection. The comparison of vision and range finder data could be used not only to detect, but also identify and classify various types of known obstacles. This could be extremely advantageous in a competition environment. While Virginia Tech's vision algorithms have advanced in recent years, the challenge of working in an unstructured outdoor environment still proves to be a difficult hurdle. The need to develop a robust vision system capable of dynamically adjusting to radically varying lighting conditions must be met. The main difficulty is not line extraction, but rather dealing with glare and normalizing each image before line and obstacle extraction can begin. The combination of various lighting filters and glare reduction algorithms has met with some success but still requires intense research.

The main shortcomings of NEVEL's overall system are the sensor fusion and navigation algorithms. NEVEL's present sensor fusion algorithm equally weights the data from the vision and range finding systems. An effort must be made to measure the true accuracy and reliability of each system's data if intelligent sensor fusion is to be achieved. This is extremely important if the both vision and range finding systems are to be used for redundant obstacle detection. The same logic applies to the fusion of old and new sensor data. It would seem appropriate that older data be more heavily weighted due to the averaging of multiple data sets. However, what confidence level should be applied to regions where only new data is available? The determination of these weighting factors relies heavily on experimental data. The role of large amounts of testing time can not be over stressed in this area.

NEVEL's navigation algorithm also requires research. While the grid-based representation is adequate in its environmental representation, the use of potential field models proved somewhat difficult. The present potential charge mask tended to generate incorrect potential fields and caused NEVEL to steer towards lines and obstacles. This could be remedied by modifying the potential charge mask or eliminating the use of the potential field model altogether. The implementation of another path finding algorithm, such as the classic A* (McKerrow, 1991) path planner, could solve this problem.

It should be recalled that one of NEVEL's functions is as a testbed for further research. Thus, the failure of a single navigation strategy does not diminish the value of the system as a whole. The experience gained by the team should be used when improving or designing subsequent fusion and navigation strategies. Energy should be focus on developing robust algorithms for the present mechanical system. The value of thorough testing in a variety of conditions is again stressed.

7.2 Conclusion

This thesis has presented the full design cycle of NEVEL, Virginia Tech's newest autonomous vehicle. The preliminary and detailed designs are meant to fulfill the goals set forth by the Sixth Annual International Ground Robotics Competition and the need for a robust autonomous vehicle testbed. The final zero-radius-turn differential vehicle was designed and fabricated in approximately 10 months. The resulting vehicle, however, provides the basis for numerous years of subsequent research. Several key ideas can be drawn from the overall process. The tasks and goals for any given application may be met using numerous vehicle designs. The final design selection should be based upon experience as much as quantitative knowledge of each design's advantages and shortcomings. The simplest solution is often the best solution. Overly complex mechanical systems and sensor fusion and navigation strategies can lead to a system that is difficult to fine tune and trouble shoot. Simple systems, such as NEVEL's basic sensor suite and minimal drive train, should be perfected to act as the basis for more complex systems. Most importantly, sufficient time must be allotted for testing. Only through extensive testing in varying environments can a system be made truly robust.

NEVEL's design focuses on the integration of existing technology rather than custom-built systems. Thus, the design team was able to concentrate on the operation of the system as a whole rather than the detailed design of each specific component. This approach has resulted in a mechanically and electrically robust system. The vehicle is easy to control, accurate, and highly maneuverable. This provides a good basis for testing experimental navigation strategies. It is hoped that the use of this testbed for further research will help contribute to the field of autonomous robotics.

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