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Development of an inexpensive guidance system for agricultural purposes

Goutam Jagannadha Nistala

Louisiana State University and Agricultural and Mechanical College, gnista1@lsu.edu

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DEVELOPMENT OF AN INEXPENSIVE GUIDANCE SYSTEM FOR AGRICULTURAL PURPOSES

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science in Biological and Agricultural Engineering

in

The Department of Biological and Agricultural Engineering

by

Goutam Jagannadha Nistala
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ABSTRACT

Robotics is a rapidly growing technology and robots have pervaded into most of the industries. Robotics and automation are designed to remove the human factor from the labor intensive and monotonous work and thereby decrease the associated costs. The application of robotics to agriculture is fairly recent. Robotic applications in agriculture vary from autonomous row-guidance tractors to fruit picking robots. Similarly, soil testing and soil sampling is one area in agriculture where automation of tasks and the employment of an autonomous robot would be of great use to consultants and farmers employing site specific farming techniques.

Soil testing is an important part of farming used to determine the average nutrient status in a field and to obtain a measure of nutrient availability in the field. Fertilizers and other nutrients are applied to the fields based on different soil tests. Site specific farming is greatly dependent on soil testing and can result in increased yield, reduced cost and reduced water pollution. Soil testing requires a lot of soil samples and soil sampling is a time consuming, laborious process and expensive process. Most of the consultants employing site specific techniques use ATVs to get around large fields when sampling. The development of an autonomous guidance system for an ATV to perform soil sampling would be greatly beneficial to them. Labor costs would be significantly reduced and the operators would be subjected to fewer environmental elements. The use of ATVs ensures that no extra capital is needed to buy a vehicle. The use of a small vehicle like an ATV also causes less soil compaction.

A WAAS enabled Differential GPS with accuracies to within 9.84 feet was used as the position sensor. Pocket PCs are more portable than a laptop computer and are more suitable for farm conditions. Shape files were used to provide the sampling points as input to the guidance program. A guidance program was made to operate on a PDA and provide guidance instructions.
A microprocessor was programmed to read the guidance instructions and actuate the different components like throttle and steering.

Tests were conducted to test the accuracy and consistency of the system. The offsets of each stop point from the test point were documented and analyzed. The results indicated that the system was as accurate as the GPS used for guidance. They also indicated that a guidance system can be realized with the use of very few components and an accuracy needed for soil sampling can be achieved. Avoidance routines for obstacles within the field were indicated as future developments.
CHAPTER 1. INTRODUCTION

Robotics is a rapidly growing technology and robots have pervaded into most of the industries. Robotics and automation are designed to remove the human factor from the labor intensive and monotonous work and thereby decrease the associated costs. The application of robotics to agriculture is fairly recent. Robotic applications in agriculture vary from autonomous row-guidance tractors to fruit picking robots. Similarly, soil testing and soil sampling is one area in agriculture where automation of tasks and the employment of an autonomous robot would be of great use to consultants and farmers employing site specific farming techniques.

Soil testing is a very important part of farming. Soil testing is usually done to determine the average nutrient status in a field and to obtain a measure of nutrient availability in the field. Application of fertilizers and other nutrient sources is based on the results of soil tests like soil pH, electrical conductivity, organic matter, nitrate, phosphorus, and potassium. The variability of the soil can be used to adjust the fertilizer application to closely match the supplemental nutrient needs of a crop for specific sites in the field. Site specific farming techniques have the potential to increase yields, reduce costs, reduce the chemicals being applied which can make less chemicals available for water pollution. A soil core is an individual boring or coring at one spot in the field. Soil cores are usually collected at random in the sample area or in a grid pattern.

A variety of sensor techniques have been used to sense different soil properties. Soil conductivity has been correlated with soil moisture (Waine, 1999; Waine et al., 2000). Near-Infra-Red reflectance in real time was used to measure soil nitrates, organic matter, and Charged-ion Exchange Capacity (CEC), pH and soil moisture at different depths (Shibusawa, et al., 2000). Ion Selective Field Effect Transistors (ISFETs) have been used to sense soil nitrates in real time (Price, 2000). Many soil samples may be required and the process is often laborious. Some of
these sensor techniques are not used commercially because of the labor and cost involved in employing an operator to perform the task repeatedly all over the field. Automation of selected systems and usage of an autonomous vehicle would significantly decrease the labor costs.

With falling prices of food products and reduction of production subsidies, modern day farmers are under increasing financial strain. As such, there has been a trend towards decrease in capital costs and input and increase in efficiency and output. This is being achieved by farmers through increased field size, and bigger tractors, which decrease the labor costs per unit area (Blackmore, 2004).

Larger agricultural machines are favored over smaller machines so that more area can be covered and more work can be done per unit time. However, this may result in higher costs of owning, operating and maintaining these machines. Manual guidance of these large vehicles has become tougher with the operator concentrating on multiple tasks like row navigation and variable inputs for site specific farming. The automatic guidance systems would allow the operator to concentrate more on other tasks like variable rate inputs (Stombaugh et al., 1999).

The majority of operations performed in agriculture fields are based on either parallel swathing or switchback patterns (Grovum and Zoerb, 1970). The operator in charge of the agricultural machine may find these patterns monotonous and stressful. Due to the large size of the farm machinery, human operators tend to overlap previous paths while performing field operations (Niemenin and Sampo, 1993).

To avoid the high maintenance and capital costs of a few larger machines and the high costs of human labor involved in using numerous smaller machines, much research is being done on the development of unmanned and autonomous small size agricultural equipment. The advantages of using smaller vehicles with better guidance abilities, higher accuracy, and less
hazardous failure outcomes instead of bigger vehicles for autonomous guidance have been elucidated by Blackmore et al., (2002).

Autonomous guidance of vehicles can be achieved by using microprocessors and computers with real time computing capabilities. Therefore the cost involved in using these computers has also to be considered. Rapid advances have been made in technology and its applications over the past century in all fields including agriculture. According to Moore’s law, the processing power of computers aided by information technology would double every 18 months for the same price (Moore, 1965). Therefore achieving autonomous guidance would not be an expensive process.

Automation of the laborious process of soil sampling, and the use of autonomously operating ATV to perform the soil sampling would greatly help farmers employing site specific farming. The farmer can utilize the man hours saved to attend to other tasks. Farmers employing site specific farming techniques are usually equipped with small size farm vehicles like ATVs. So, the farmers need not invest extra capital to buy an autonomous vehicle. Their existing ATVs can be retrofitted to operate in autonomous mode. The objectives of this project were determined keeping the above factors in view.

1.1 Objectives

The objective of this research is to develop an inexpensive guidance system for use on a small agricultural vehicle suitable for soil testing purposes. The guidance system should provide sufficient accuracy to meet soil sampling or penetrometer needs in a field. The system should incorporate the use of Global Positioning System (GPS) receivers for use as the position sensors and a software module to provide the guidance instructions. The integrated system would be capable of point-to-point guidance in an open field. The principal aspects of this project include
• Investigation and selection of an optimum test vehicle

• Development of the actuation and automation hardware to retrofit the test vehicle to act as an autonomous vehicle

• Investigation and selection of a portable computer to run the software

• Development of software to provide the navigation and guidance signals

• Development of an interface between the software and the test vehicle

• Testing of the system

• Analysis of the results to determine accuracy
CHAPTER 2. LITERATURE REVIEW

2.1 Guidance Used in Agriculture

Traditionally animals were used to provide power for agricultural tasks like plowing. The advent of engines and self propelled vehicles has led to the replacements of animals by engine driven vehicles. Engines have themselves transitioned from steam powered to gasoline driven. Gasoline powered tractors can be traced back to 1892 when they were first made by a blacksmith from Iowa, John Froehlich (http://www.froelichtractor.com/tractor.htm).

Large vehicles cause soil compaction. Soil compaction increases soil density and detrimental affects root growth and nutrient absorption. Soil compaction also may encourage denitrification of the soil due to a decrease in soil porosity. According to Wolkolski (1990) potassium uptake may be reduced with the reduction of respiration within the root. It was found that an overall increase in yield can be observed when a tracked gantry system applies no wheel pressure instead of conventional methods that apply wheel pressure (Chamen et al, 1992).

Larger farm vehicles and respective implements can cover more area and do more work per unit time when compared to smaller farm vehicles and their implements. The number of operator man hours can also be noticeably decreased resulting in decreased labor costs. To avoid the high maintenance and capital costs of a few larger machines as well as the high costs of human labor involved in using numerous smaller machines, research is being to develop unmanned and autonomous small size agricultural equipment. Blackmore et al., (2002) discuss the use of smaller vehicles with better guidance abilities, higher accuracy and less hazardous failure outcomes when compared to bigger vehicles for autonomous guidance. Three different vehicles have been evaluated for automation: a commonly available small tractor, a specialized tractor and a high end small vehicle. He noted that a small tractor though generally available in
all farm environments, uses standard implements, low in cost, causes soil compaction and is not suitable for the addition of autonomous control systems due to its mobility. Some advantages of a small tractor are its maneuverability, and adaptability to be retrofitted with control systems. The shortcomings about these tractors are that they are not commercially available and have to be completely fabricated, would be less robust and would not suit the agricultural environment.

Therefore, the possibility of an autonomous machine that is robust and suitable for farm environments, which cause less soil compaction than a tractor, which can be inexpensively retrofitted with control systems and has high maneuverability, was explored.

### 2.2 Background of Autonomous Guidance

Attempts to replace human labor with automated machines can be traced back to as early as 1924 (Wilrodt, 1924). A tractor was controlled along a furrow by linking the steering of the front axle of the tractor to a previously formed row (Fig 1). Sissons (1939) made an attempt to guide a tractor in a field along gradually decreasing circles by the use of a large spool of wire. Another important attempt at autonomous guidance of tractors was done by Rushing (1971). Powered wires buried underneath the ground were used for guiding the driverless tractor. An electric motor was used to achieve actuation of the steering.

Further improvements were made to the system and an electro hydraulic valve was used in place of the electric motor for automatic steering. The relative position of the vehicle to the buried wire was sensed by measuring the magnetic fields with two identical coils. Turning movement at the end of the rows was achieved through programmed routines. The convergence to the straight line was up to around 1 inch at a maximum speed of six mph. The other functions like throttle and clutch were actuated through the use of electrical servos. Rushing noted that autonomous control of up to six tractors can be achieved by a single operator.
A similar tactic was used by Schafer and Young (1979) to develop an autonomous tractor. A logic circuit was developed to address the steering control and correction. They noted that the required steering force was not developed when the tractor was rear loaded. They achieved accuracies of up to 1.97 inches at a speed of 6.21 mph and 2.76 inches at higher speeds with no implement loads.

The development of electronics and the resulting decrease in size of computers and the simultaneous development of smarter chips and microprocessors greatly affected the agricultural industry. Improvement in data acquisition methods, improvement in transfer of data, improvement in processing power of the computers and their ability to process huge quantities of data in very little time contributed to the increase in autonomous vehicle research. Research is also being done on various types of sensors. Guidance systems can be traditionally classified into two types: autonomous systems, that do not need an operator and guidance aids (assisted guidance systems) that need an operator to drive the vehicle.
A method for navigation of autonomous vehicles was developed using angular measurement between fixed beacon pairs (McGillem and Rappaport 1989). The study indicates that very accurate position information can be obtained over a large area with simple trigonometric and geometric calculations. A worst case error of 3.94 inches within a 0.62 acres workspace was obtained. An experimental position measuring system that demonstrated the feasibility for use a method for navigation of autonomous vehicles was developed. The results indicate that the technique could be used to enhance dead reckoning systems or could serve as a stand alone navigating system.

Ima and Mann, (2004) point out that operators working with automated systems are less prone to detect system errors and react to the errors or automation failure when compared to operators who manually perform the same tasks. Autonomous guidance systems would have to overcome a number of shortcomings in terms of precision, accuracy and safety due to the complex field environment before they can be seen commonly in North American farms.

2.3 Guidance Aids

Guidance aids, as their name suggests while assisting the operator, do not replace him/her and aim at reducing operator stress due to the redundancy of the task. They present information to the operator through visual display and the operator takes the necessary action like adjusting the steering position. The most commonly used guidance aids use global positioning systems to obtain position information and display the error on the lightbar screen. The lightbar is a device consisting of different colored Light Emitting Diodes (LEDs) in a row of single LEDs. These LEDs glow to the right or left of the center indicating the steering correction required in the corresponding direction in terms of left, right and straight. Ergonomic factors should be considered in the design of commercial lightbars including increasing the size of the lightbar,
usage of blue LEDs instead of red ones, avoidance of flashing LEDs, positioning of the lightbar below eye level and between 1.64 feet and 3.28 feet from the operator (Ima et al., 2004).

Farmers have tested guidance technologies by owning or renting them and they are concerned about the accuracy of the Guidance systems (Ehsani et al., 2002). Six different lightbar guidance systems (assisted guidance) have been compared by calculating the error of the actual position and the desired position of the field vehicle. These light bar systems guide and assist the driver through his route around the field and could be used as a replacement to visual techniques like foam markers. They have concluded that, with the exception of two guidance systems the rest were not significantly different from each other when converging to a straight line.

Automatic guidance systems provide promising prospects for implementation in agricultural systems according to an economic analysis study conducted on Differential Global Positioning System (DGPS)-based guidance systems (Gan-Mor and Clark, 2001). The study concluded that centimeter scale accuracy DGPS guidance systems would have immediate commercial applications. However, a long return period should be expected when the system is used for improving conventional field operations. The study suggests the integration of precision agricultural technologies with automated guidance systems for increasing the profits and that acreage of 25000 is required to return the cost of the automatic guidance system. Lightbar systems can be used with a marginal benefit of $ 0.3/acre and a break even occurs at acreage of 5000-15000 acres (Lowenberg-DeBoer, 2000).

2.4 Autonomous Guidance Systems

The reduction of capital input has always been a critical issue for agriculture. A lot of the commercially available guidance systems are very expensive to be of practical use and
implementation, and are mostly suited to particular needs. Global Positioning System (GPS) based guidance is showing promise and efforts are being made to reduce the cost of these guidance systems. The use of Differential GPS for guidance of agricultural vehicles is being evaluated by a number of groups.

Stombaugh et al., (1999) developed an automated agricultural vehicle guidance system capable of controlling the vehicle at high speed field operations. A Novatel RT-20 Kinematic Differential GPS was used as the position sensor. An electro hydraulic proportional valve was used to achieve automatic steering. A dual-coil valve driver was used to convert an analog DC voltage to the required Pulse Width Modulated (PWM) signal. A 150 MHz Pentium-based guidance computer was responsible for reading posture sensor outputs, computing and sending the appropriate steering commands to the steering controller, and logging data. RS232 Serial communication was used to interface the GPS receiver and the steering controller to the guidance computer. The analog output from the microcontroller or a Data Acquisition (DAQ) card could actuate the PWM Valve Driver. A wheel angle sensor was also used for feedback. Experimental frequency response tests were used to develop models of steering equipment and vehicle dynamics. Classical feedback control was developed based on these models. Guidance controller effectiveness was evaluated with experimental step response tests. The vehicle and steering equipment dynamics were compensated by the guidance controller design. The GPS sensor position also affected the guidance control. Guidance control to within 0.5 feet of the desired path was demonstrated at a speed of 15.2 mph.

An autonomous crawler was developed by Suguri et al., (2004). An RTK GPS was used for position sensing and wheel angle was determined by the use of rotary encoders. Kalman Filter was used for estimating the orientation based on kinematic modeling. Most of the
trajectories required for field operations were covered through a combination of straight line and arc line tracing models that were developed. Results were verified through simulation. The control of the autonomous vehicle without the use of an Inertial Mass Unit was also discussed.

Stombaugh and Shearer (2001) developed an automatic guidance system on a high clearance field sprayer using DGPS technology and it was tested for its straight line steering accuracy, convergence and stability. An SLX DGPS receiver, a Pentium based light bar computer equipped with a digital to analog converter, and a Data Acquisition Card to read the analog steering valve were used for achieving the automatic guidance. Inexpensive solenoid valves were used as the steering valves. The algorithm used for guidance considered the heading and offset to the desired path. Visual Basic was used to program the guidance algorithm to calculate the steering command based on the steering signal. A pair of relays was used to control the steering valve coils. The position feedback was obtained only from the DGPS receiver. The hydraulic flow rate and the feedback gain were found to be the critical tuning parameters having considerable effect on the system performance. If the gain was too low, the system would not converge to the desired path. If the gain was too high, any noise in the system was amplified. If the flow rate was too high, the system tended to oscillate about the desired path. If the flow rate was too low, the steering could not respond quickly enough to converge to the desired path. There were significant steady state errors but the system was found to have good convergence and tracking abilities.

Guo and Zhang, (2004) developed a low cost navigation system for autonomous off-road vehicles. The navigation system consists of a Garmin N17 GPS and an inertial sensor unit consisting of three single-axis MicroElectroMechanical Systems (MEMS) gyros and one triaxial MEMS accelerometer. This navigation system employed a position-velocity-attitude (PVA)
based fusion algorithm to integrate the data sensed by the GPS and inertial sensor unit to provide accurate vehicle navigation information. The system was evaluated at three different test sites. A highly accurate Real Time Kinematic (RTK-DGPS), with a dynamic positioning accuracy of 0.06 feet, was used as the reference. The maximum errors of the GPS inertial unit fusion system were 0.98 feet at one test site and 1.64 feet at the other test site. The fusion system could effectively estimate the trajectory of the vehicle during the GPS signal outage for more than 30 seconds without large accuracy degradation.

Mizushima et al., (2004) demonstrated automatic navigation of an agricultural vehicle using a low cost attitude sensor. The sensor unit composed of three vibratory gyroscopes and two inclinometers. A H8S2612 (manufactured by Hitachi®) microcomputer was installed to measure the sensor data, calculate the corrected position, corrected heading and corrected inclination without the use of a laptop computer and high resolution Analog to Digital converter. Three microcomputers were used for different purposes. The first one was used for heading estimation calculated from a gyroscope and a DGPS. The second one measured the DGPS position and converted the Latitude/Longitude coordinate system to the Universal Transverse Mercator (UTM) coordinate system. It then gave out the corrected DGPS position, roll, pitch and heading angles. The third one was utilized to measure the roll and pitch angle of gyroscopes and inclinometers and estimate the corrected roll and pitch angle. CAN bus communication was used instead of serial communication. The developed sensor unit could estimate the heading angle with 1.59° and roll angle with 0.41° and pitch angle with 0.65°. This accuracy was equivalent to that obtained with a RTK-GPS and IMU system using high resolution A/D converter and a laptop computer.
Burcham and Lee (1999) developed an autonomous robot for locating and eradicating pests in agricultural systems. An ATRV-Jr (manufactured by iRobot®) robot was equipped with orientation sensors and a DGPS for autonomous guidance. It is capable of autonomous point-to-point guidance within a geo-referenced perimeter. A magnetometer/inclinometer was used for obtaining orientation data. A base computer superimposes a systematic search grid within the geo-referenced perimeter and transmits the grid to the onboard computer. Navigational software was developed by the authors using C++. The system uses DGPS and magnetometer input data to steer and propel the vehicle to each subsequent point defined in the search grid.

In a study conducted by Ehsani et al., (2003), the dynamic accuracy of five commonly used DGPS receivers was compared and evaluated on a straight path in field conditions. Wide Area Augmentation system (WAAS) was used as the form of differential signal. An RTK GPS was used to determine the exact locations in the field and the driver used lightbar guidance system to drive through the fields. Cross track error was calculated from differences in readings of RTK GPS and DGPS. The cross track error was found to be higher in N-S direction than in E-W direction. Their study found that the results are similar to that given by the manufacturers.

As mentioned before, the WAAS (Wide Area Augmentation System) is a source of differential signals that improves the accuracy of the GPS receivers significantly. WAAS enabled GPS receivers are currently being used for precision agricultural purposes (Sullivan et al., 2001). Their popularity lies in their accuracy and that they require no subscription fee. Lightbar guidance systems have increased in quality and have decreased in price. As such, the combination of a free and accurate GPS signals with inexpensive lightbar guidance systems has made them more affordable to farmers (Ehsani et al., 2002).
A field robot was developed for agricultural purposes by Noguchi et al. (1999, and 2002). An RTK GPS was used for position information, a fiber optic gyroscope (FOG) and inertial measurement units (IMU) were together used for navigation. They rightly pointed out that all the previous attempts made at autonomous guidance of agricultural vehicles were solution specific and cannot manage all types of field operations. The robotic tractor operated in mission planner and autonomous operation mode. The robot was able to mimic the path that was previously made by a human operator under the mission planner mode. The management operations like engine speed set and hitch functions can all be created in the mission planner mode. Input maps can be made for the mission planner modes by use of Geographical Information System (GIS) software. A sensor fusion algorithm was developed for identifying Fiber Optic Gyroscope bias and compensating location error in real time for navigation purposes. Guidance of straight and curved paths up to a speed of 5.59 mph was achieved. An offset error of less than 0.16 feet was also achieved. This method depended on backing up the tractor until the required position calculated is reached. However, this caused a lateral error of up to 1.64 feet due to variability in the tire-soil interaction.

Kise et al. (2002) developed a turning path algorithm using a third order spline function. Tractor characteristics like minimum turning radius and maximum steering speeds were included in the calculation of a feasible turning path. Turning was done both in forward turning and switch back turning methods. They achieved better results with a lateral deviation of 0.66 feet by the use of this algorithm.

Autonomous control of farm vehicles requires control of tractor functions along with steering commands. Tractor functions like engine throttle, transmission speed and three-point hitch position should be supplied to the navigation computer along with guidance instructions. In
a research conducted at University of Illinois, a procedure for creating autonomous field
operation maps was developed (Han and Zhang, 2001). GIS was used for the development of the
field map. The study indicates that, due to the lack of real time sensors and their control in
agriculture, real time sensing and updating of field operations will not happen in the near future.
Map-based autonomous operations would be the primary format for autonomous tractors. Raster
GIS data models were used for the representation of the maps. The combination of field
operation maps, real time sensing and updating of field operation maps was suggested for
autonomous guidance of tractors.

Most of these studies have shown that higher accuracies can be reached by usage of
expensive RTK GPS as compared to relatively less expensive DGPS as the position sensors.
Higher accuracies can be achieved by the use of sensor fusion technologies where more than one
sensor has been used to obtain the position information of the vehicles.

New platforms for autonomous guidance and agricultural applications are being
developed and tested due to reasons like soil compaction, less control and the difficulty of adding
actuation systems to the existing tractor platform. Researchers at North Carolina State University
developed a zero turning radius machine for agricultural purposes (Powell and Boyette, 2004). A
commercially available John Deere Quik-Trak 647 mower was retrofitted with sensors and
computers to serve as the autonomous test vehicle. A Z-World SmartStar SR 9000 was used as
the control computer. Integration of other sensors, machine vision, GPS and a digital compass
are expected as future developments.

A software framework has been developed for the purpose of agricultural vehicle
navigation by Hamada et al, (2004). A software framework can perform various vehicle
navigation tasks for autonomous vehicles and it can be used as a class library of software running
on a personal computer (PC). Various elements that are involved in precision farming like PC interfaces, devices, implements and geographical data were modeled as objects of the software. The software was written in Microsoft ® C# (Microsoft Inc.) language and it required Microsoft.NET Framework 1.1 for operation. The software consisted of a module viewer and a module controller that is analogous to an operating system for a PC. These features and their performance were evaluated by conducting tests. Practical testing in the future was mentioned.

Safety of autonomous vehicles has always been a concern. These systems should be thoroughly tested for safety issues to avoid collision to prevent loss of life and property. Techniques like machine vision can provide for both guidance and obstacle avoidance features.

A shock absorbing bumper system was developed by Rude (1996) for robots traveling and operating in a multi-robot environment. The bumper system avoided damages from collisions, reduced the wheel slip during collision and also had a limited touch sensing capability and simple human push interface.

A low cost autonomous vehicle was built by modifying the chassis of a radio controlled car (Wall et al, 2002). It was equipped with GPS for position information and an ultra sonic range finder was used for obstacle detection. A Rabbit 2000 (manufactured by Rabbit Semiconductor ®) processor was used to process the information from the sensors. Lack of braking capabilities of the RC car led to the car coasting past the desired point and circling back to reach the point. The ultrasonic sensors were working effectively for most objects but faced problems with seeing the objects in time to make the turn. It was suggested that these results can be made better by the use of fine tuning the ultrasonic sensors. The results suggested that low cost autonomous guidance of vehicles can be achieved but were not implemented on a real vehicle.
2.5 Soil Sampling

Jacobsen (1999), a soil scientist explains that fields used for crop production are best sampled at any time after harvest and before planting and that a representative soil sample gives an average estimate of the whole area sampled. He has given an example where a range of 40 individual soil sample cores were taken from a fairly uniform, 80-acre field. He also notes that specialized areas such as dead or back furrows, manure piles, fences, roads, wet spots or other variable areas should be avoided and areas within the field with a different crop rotation and fertilizer treatments should be separately sampled.

According to a report by Franzen (1999), research on soil sampling and variable rate applications done in many states concluded that a good sampling grid density to use is one sample per acre. He noted that this density was selected because it consistently recognized fertility boundaries and reproduced soil levels similar to greater density grids. The report also indicates that many growers are reluctant to use this dense sampling grid and instead use a less dense grid with about one sample per 3-5 acre. This less dense sampling rate compromises the correctness of values and the boundary definition. Irrespective of the sampling method, multiple cores around 8-10 should be taken from each sampling area. They suggest that the samples must be taken in a point sampling technique, with all the cores obtained from a 10-20 foot radius circle.

The following are criteria for choosing grid sampling over zone approach:

• The field history is unknown

• Fertility levels are high due to high rates of fertilizer application

• There is a history of manure application
• Small fields have been merged into large fields

• Non-mobile nutrient levels are of primary importance (P, K, Zn)

The following are criteria for choosing zone sampling methods over grid sampling

• Yield monitor data or remote imaging shows a relationship with topography

• There is no history of manure application

• Relatively low fertility levels are present, or low fertilizer rates of non-mobile nutrients (less than maintenance) have been applied over the most recent years

• Mobile nutrients, especially N, are important to map

Ferguson et al., (1998) developed a guide that states fields must be divided into uniform areas before soil samples are collected. These divisions should be based on soil type, slope, degree of erosion and any other factors that may influence the nutrient levels in the soil. They clarify that proper random sampling provides an accurate picture of the average nutrient level in the field. Grid sampling allows for obtaining more information. Individual samples from grids can be used to make nutrient level maps on the fields that can be used as a database for fine-tuning fertilizer application across a field when a computerized fertilizer applicator is used. The guide points out that this equipment has limited availability, but would soon be widely available. They also point out that grid sampling would cost more when individual samples are analyzed, but this information should help customize fertilizer application. They suggest the collection of one sample for every 20 acres to give a good measure of the average nutrient status in the field. A collection of 15-20 cores of surface sample and 6-8 cores of subsurface samples per 20 acres would give reliable mean values for sampled areas.
The number of sub samples needed to obtain a representative composite sample depends on the uniformity and size of the sampling unit. A table (Table 1) that indicates the number of sub samples for a representative composite sample based on field size is shown (Mahler et al., 1994).

Table 1. Field Size and Number of soil samples required

<table>
<thead>
<tr>
<th>Field Size (acres)</th>
<th>Number of subsamples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fewer than 5</td>
<td>15</td>
</tr>
<tr>
<td>5-10</td>
<td>18</td>
</tr>
<tr>
<td>10-25</td>
<td>20</td>
</tr>
<tr>
<td>25-50</td>
<td>25</td>
</tr>
<tr>
<td>More than 50</td>
<td>30</td>
</tr>
</tbody>
</table>

A study was conducted to compare the accuracy of spatially continuous pH and lime requirement (LR) maps derived from commercially used approaches to sampling and LR prediction at unsampled locations (Brouder et al., 2005). Point sampling was evaluated on 0.1, 0.4 and 1.0 hectare grids and area composite sampling was evaluated by 1 hectare, soil types and whole field. For intensive point sampling (0.1 or 0.4 hectare grids), kriging was occasionally found to be more accurate than ID weighting but the mean absolute error differences were small suggesting little practical consequence to prediction method selection. One-hectare point data were found to be too sparse to produce variograms and the use of ID weighting found small advantages over whole field compositing.

Various soil sampling techniques and methods are employed based on purpose of sampling. Thus, the autonomous vehicle should be adaptable to various sampling methods.
 CHAPTER 3. CHARACTERISTICS AND SELECTION OF COMPONENTS

3.1 Selection of DGPS

It can be inferred from the literature review that a maximum of 1 soil sample per acre was sufficient to represent the variability of most agricultural soils. Soil sampling is usually done under fallow conditions either before the crop is planted or anytime after the crop is harvested, therefore is usually done in open fields. Because of this reason, obstacle avoidance and obstacle detection systems are not as critical as in some situations. However, they can be installed in the future work for safety concerns.

Considering a soil sampling grid of one sampling point per acre, an autonomous vehicle based on the DGPS would be considered at the specific location when it is anywhere within the arrival circle with GPS error as radius. A typical WAAS enabled GPS gives an error of 10 feet. If an error of 10 feet is considered then the arrival circle has an area of 314 square feet. One acre is equal to 43,560 square feet. So the error percentage was calculated to be 0.72 %.

Due to the above reasons, the autonomous soil sampling vehicle did not require guidance with sub-inch accuracy and convergence to straight line ability. These reasons facilitate the use of a low cost GPS providing lesser accuracy. Therefore, a low cost differential GPS receiver unit was used for autonomous guidance of the soil sampler vehicle instead of a highly expensive RTK GPS receiver unit.

3.2 Usage of PDA

Most of the studies done on the development of autonomous vehicles for agricultural purposes have included the use of full scale computers on board the vehicle. The use of an on board computer and its functionality can be chosen according to the number of sensors used and the complexity of the task involved. A faster computer with higher processing power and higher
cost can be used to monitor a number of different sensors, coordinate the communication between them and output the corrections needed to the hardware or the controller. As demonstrated by Mizushima et al., (2004) the same can be achieved with more than one microcomputer. This approach would result in the portability of the application and eliminate the unnecessary capital costs associated with a high scale computer. A limitation was observed with the use of microprocessors for navigation and guidance tasks. A user input interface cannot be created as a part of the microprocessor and also the lack of display options is obvious. A separate control unit for user application of inputs and a separate display unit like an LCD screen should be programmed separately.

Another interesting observation regarding the use of computers in agriculture was made by the U.S.Congress, Office of technology Assessment, and New Technological Era for American Agriculture, OTA-F474 (Washington, DC: U.S.Government Printing Office, 1992). “By and large, computers have had little impact on production agriculture to date. Predictions that every farmer would own a computer by 1990 have not come true. Few farmers have computers and those that do use them primarily for book keeping and general calculations”.

It can be inferred that an easy to use interface, which a farmer can carry around in his pocket much similar to a pocket diary might be a feasible option to replace a full scale computer for agricultural purposes.

This interface should have the following characteristics:

- Provide necessary functionalities of a full scale computer
- Be less expensive than a laptop computer
- Be more portable and easy to use than a laptop computer
- Have the availability of standard software and operating systems available for its working
• Provide a means for storage and retrieval of data in compatible formats

• Be capable of providing standard communication methods

Therefore the feasibility of a cheaper, display capable computer with optimum processing capacities for the task was investigated. A Personal Digital Assistant (PDA) or a hand held PC was found to have all the necessary characteristics. Even though the cost of computers has decreased dramatically due to recent technological advancements in electronics and globalization of the market, the difference in the price of a computer and a hand held pc can be clearly seen. The average price of a PDA is about 25 percent the cost of full scale laptop computer and its size can be estimated to be about 12 percent of the size of the laptop computer.

The PDAs have slowly become a part of precision agriculture techniques because of their portability and adaptability. A high speed wireless networking system has been developed to allow farmers to download aerial images via the internet onto their PDAs (Flores, 2003). Previously, aerial images were printed and then given to the farmers in a hard copy format. They had to wait 2-3 days to get the photographs of their fields after the flight. With the help of their PDAs and internet they can now look at the photographs within minutes of the plane landing. Aerial photographs with rectified GPS coordinates can then be used to identify the problem areas immediately.

A great advantage of using a PDA is the graphical user environment where the user can give inputs to the program through the use of a stylus instead of a keyboard. The touch screen is better input technology than a keyboard while operating in a farm environment or onboard a vehicle. As such, a software program has been developed for PDA-based autonomous guidance of an agricultural vehicle.
3.3 Usage of Shapefiles

Shapefiles (See Appendix A) can also be used as input maps for point to point guidance. Agricultural fields can be reduced to sampling maps. GPS data streams can be used for creating shapefiles. Some commercially available software allows the creation of shapefiles that can be used for variable rate applications and farm scouting applications. They can be used for various agricultural applications like site specific mapping, scouting, soil sampling and variable rate applications. The farmers can easily create maps of field boundaries, weed area, tile lines, spray paths and soil sample locations. These maps can then be exported to a standard shape format like ESRI ArcGIS shapefile and could be subsequently used in most GIS programs.

The portability of a pocket PC and the availability of such software can be a handy tool for the farmers. Farmers can navigate around their fields in a farm vehicle equipped with their pocket PC enabled with a GPS receiver and create maps of the sampling, spraying or problem areas. These GPS coordinates can also be exported into conventional files like Microsoft Excel (Microsoft Inc.) and notepad and can be used for programming applications. The ease of creating shapefiles and the option of being able to view the coordinates in text based format has prompted the use of text files as input for the guidance program.

3.4 Usage of Microprocessor

The actuation of the various components of the hardware can be achieved with the use of various inexpensive electronics. The PDA outputs turning instructions. However, these turning instructions in the serial text output cannot serve as control instructions for the electronics. Electronics can be controlled through the supply of various voltage levels, as the case seems fit, for their operation in terms of “highs” and “lows”. A “high” signifies the presence of a required voltage for their working and a “low” signifies an absence of the required voltage for working.
So, there is a need for a Central Processing Unit that reads the commands from the PDA and supplies the necessary voltage manipulation instructions to the electronic components with the following characteristics.

- The microprocessor should be inexpensive
- The microprocessor should have an easy user interface for programming it
- The microprocessor should be capable of processing instructions as fast as the GPS information is updated for controlling autonomous operations of the ATV
- The microprocessor should have sufficient capacity for storing data from an entire field

A GPS acting as the position sensor and continuously updating position information, a PDA reading the GPS and determining the guidance instructions, and a microprocessor achieving actuation of various components as instructed by the PDA, were integrated (fig 2.) for achieving autonomous guidance of the test vehicle.

Figure 2. Guidance flow chart
3.5 Choice of Test Vehicle

As elucidated by Blackmore (2000) a number of smaller autonomous guidance vehicles are ideal for farm operations compared to one huge autonomous vehicle. Therefore the size, length, type of steering, ruggedness and ultimately the price have been considered as the principal factors in considering the vehicle:

- **Size:** The autonomous vehicle was developed as a pilot project for field operations like soil sampling and penetrometer tests. So it need not be a huge vehicle like a tractor. A size smaller than a conventional tractor would be optimum.

- **Length:** The vehicle should have a small turning radius; in effect it should not be very long. This would be essential for point-to-point guidance of locations near to each other and a sharp angle to each other.

- **Steering:** The vehicle should be easy to steer. The torque required to turn the steering should not be very high.

- **Durability:** The vehicle should be rugged for infield operations and should have sturdy wheels and a good suspension system, able to withstand the shocks of the rugged terrain.

- **Price and purpose:** The vehicle should not be very expensive and should not be a burden for the farmer. It should cost less than $5000. It should be an all purpose vehicle and should be gasoline driven.

3.6 Custom Vehicle vs. Retrofitting an Existing Vehicle

Designing a custom vehicle like those used in many research applications was considered. There was a choice between building a custom vehicle and modifying a commercially available vehicle. Building a custom vehicle from scratch would require significant design considerations. Moreover a custom vehicle would have many incidental
expenses that are inherent to a commercially available vehicle. A commercially available vehicle would have an entirely different set of performance criteria suited to manual operation rather than autonomous operation. The time required to build a custom vehicle would far exceed the time limits of the project. Building multiple custom vehicles would be harder than retrofitting multiple commercially available vehicles.

A custom built vehicle had its own advantages, in the sense it could be designed to meet the criterion of the software. With proper research and design consideration, sufficient manpower and time, a custom vehicle could be built with expenses much less than buying a manufactured vehicle.

Based on the available funding, the opportunity to retrofit vehicles that may already be available on a farm and the inherent problems with creating a unique new vehicle, application to a commercially available vehicle was chosen.

Many small sized vehicles that are used in the farm environment satisfy either some or most of the required characteristics. For example, a Bobcat ® offers skid steering and a John Deere Quicktrak® commercial lawn mower offers differential steering. These types of steering work very well with autonomous operation. Differential steering provides the operator with easy left and right movements and forward or backward movements by the operation of two levers either simultaneously or in a sequence. One more advantage is the zero turning radiiuses of skid steer vehicles. The vehicles with a zero turning radii can be programmed to turn in any direction and head straight to the desired location from the current location. As such, the operator need not worry about the turning radius and corrections needed in order to reach a particular position. If considered in perspective of autonomous guidance, the autonomous solution could be mostly independent of vehicle characteristics.
On the other hand there are a lot of small farm vehicles like a John Deere Gator® that are small in size and all wheel drive. The most difficult task for guidance of a wheeled vehicle is that they do not turn with a zero radius. There is look ahead distance required that is based on the radius of turning of the vehicle. Since, an autonomous guidance solution independent of the characteristics of the vehicle was the objective of this project, it was decided that a wheeled vehicle would be used instead of a tracked or hydraulics enabled vehicle.

Most of the farmers and consultants usually own and use ATVs for obtaining soil samples and for crop scouting. ATVs are popular because they are inexpensive, usually less than $5000, robust, and can be easily transported in the bed of a pickup truck or a small trailer. Thus, an ATV was chosen as the test vehicle.
CHAPTER 4. DEVELOPMENT OF SOFTWARE FOR AUTONOMOUS GUIDANCE

4.1 Interface Development

Microsoft .NET (Microsoft Inc.) was used for the development of the software program for autonomous guidance. It is software that connects information, people, systems and devices. It connects a range of personal and business technologies, enabling the user to access information, whenever and wherever it is needed. Built on Extensible Markup Language (XML) Web service standards, .NET enables both new and existing applications to connect with software and services across platforms, applications and programming languages.

The .NET framework is a component of Windows® that provides a programming model and runtime for XML Web services, Web applications and rich-client applications. The two main components of the .NET framework are:

1) Common language runtime: It is the.NET framework engine at the core of the managed code execution.

2) .NET framework class library: It includes classes, interfaces and value types that expedite and optimize the development process and provide access to system functionality.

4.2 Visual Studio .NET

Microsoft Visual Studio.NET is a commonly used development environment for .NET software and services. It provides a complete set of integrated designers, editors and other development tools for creating ASP.NET (Active Server Pages) web applications, XML web services, Windows based applications and mobile applications.

4.2.1 Smart Device Applications

Visual Studio.NET provides tools for creating applications for smart devices, such as the Pocket PC. These applications run on the .NET compact framework in personal digital assistants.
(PDAs), mobile phones, and other resource constrained devices. The interface was developed as a part of the program. The PDA user interface that was created can be seen in the figure (fig. 3).

Figure 3. Visual Studio.NET Smart Device Application Environment-Designer window

The development of a user input interface involved use of the following Visual Studio components:

References: A .dll (dynamic link library) file for acquiring the NMEA code and parsing it to obtain the latitude and longitude was used. Another .dll file was used for serial RS232 communication. These references were added using the Add Reference button in Project Menu.

Form Components: A Form is a Visual studio .NET template on which the windows are based. The form Layout window allowed positioning the forms as to appear on the screen. The Toolbox is used to add controls to the project. By clicking it and placing it on the form. The Toolbox is loaded with controls such as text boxes, labels, picture boxes and other image controls, and timers. The form designer displays the current form under design and the code window is where the code for the components is added to perform various functions.
The Visual Studio.NET Smart Device Project Development environment on a PC can be seen in fig. 4.

![Visual Studio.NET Smart Device Application Environment-Code window](image)

**Figure 4.** Visual Studio.NET Smart Device Application Environment-Code window

### 4.3 User Interface

The following buttons associated with the following events have been developed as a part of the user interface.

#### 4.3.1 Start /Stop Button

When the form is first loaded this button has “Start” label on it and when clicked starts the GPS stream. The NMEA code can be seen on the PDA screen (fig. 5). The label changes to “Stop”. The NMEA code keeps updating every one second. If clicked when the label is “Stop” (fig. 6) the GPS stream is cut off and the program is stopped. Guidance cannot be done when the button is stopped. The purpose of this screen and this button is to let the user watch the GPS signal. When indoors or when the program was just started, and the GPS does not yet have a fix many consecutive commas”, can be seen within the NMEA code sentences. The user can wait...
until the NMEA sentences do not show consecutive commas within them. The NMEA data stream is displayed when the Start Button is clicked which then turns to Stop.

![NMEA Data Stream](image)

Figure 5. NMEA data streams displays when Start is clicked (“Start” changed to “Stop” when clicked)

### 4.3.2 NMEA Data/Decoded Data Button

This button allows the user to switch between NMEA coded data and decoded data (fig. 6). The button label alternates between “NMEA Data” and “Decoded Data” and so does the data displayed and serially outputted. This button works only when the Guidance button is not in operation. It outputs most of the GPS data on the screen as well as outputs it serially through a com port available on the PDA. When the button is clicked when in the “Decoded Data” mode, it outputs Current Latitude, Current Longitude, Local Time, Local Date, Course Over the ground, Speed Over the Ground, Altitude, and Number of satellites in use. In the “NMEA Data” mode it just displays the NMEA data. The button allows for ordinary GPS functionality when there is no need for Guidance.
4.3.3 Browse Button and ContentsDisplay Box

This button allows the user to navigate to any file on the PDA including its detachable memory (fig.7). The user can just click the “Browse” button and navigate his way through the various pull down menus containing different folders until he reaches the specified file. This button serves as the input to the Guidance system.

The program accepts only text files with a list of Latitude and Longitudes of the GPS points. The program accesses all the GPS locations (latitude and longitude values) consecutively and stores them in two different arrays; the “Latitude array” and the “Longitude array”. As soon as the file is selected the program browses rapidly through all the GPS points and displays them in the ContentsDisplay box (fig.8).

After going through all the GPS points in the text file, the ContentsDisplay box shows the last GPS point until the guidance system has guided through all the points until the last one. The program doesn’t give any error if a file of format other than a text file format is shown. The user
can clearly distinguish between the right file and a wrong file by looking at the ContentsDisplay box. If it is file of unknown format then the ContentsDisplay box is left blank. The user can then navigate to another file.

4.3.4 Navigation Box

This text box displays the latitude and longitude of the GPS location that the guidance system is currently guiding to (fig.8). The guidance starts with the first GPS location and displays it in the Navigation Box. As soon as the location is reached, the program accesses the next GPS location based on the indexes of the arrays.

4.3.5 Display Box

This is a text box that serves as the display for the user. All the data is shown in this box (fig.8). It displays the NMEA data and the decoded data when the guidance system is not started. When the guidance system is started it displays extra guidance information along with all the standard GPS data as mentioned above.

4.3.6 Guidance Button

This button when clicked displays the guidance instructions on the screen as well as outputs them through serial port available on the PDA (fig.9). The guidance instructions include the following:

- “Angle to turn” - the angle (degrees) required of the vehicle to turn to head exactly towards the destination location”
- “Distance to go” - the distance between current position and destination position in feet.
- “Left Right” - the turn movement of the vehicle in terms of left, right, straight and arrived. They are displayed as a numeric code: left-0, right-1, straight-2, and stop-3. This numeric format is used since it is easy to program integers using a microprocessor instead of strings.
These variables are updated once every second along with the GPS data and serve as the
guidance instructions and serve as inputs to the microcontroller.

4.4 Guidance Methodology

The following are the variables that are obtained from the GPS:

Longitude1 = Current Longitude
Latitude1 = Current Latitude
Latitudedest = Destination Latitude from Latitude array
Longitudedest = Destination Longitude from Longitude array
COG1 = Current Course Over ground from GPS

(Course over the ground is the direction, reported in true or magnetic north values, in which a
GPS receiver and the person operating it are moving with respect to the earth).

The current latitude and Longitude are obtained in the Degrees Minutes Seconds format.
They are converted into Decimal Latitude and Decimal Longitude formats by using

Decimal Degrees = Degrees + (minutes/60) + (seconds/3600)

Figure 7. The Browse button allows the user to navigate through files on the PDA
Figure 8. Navigation box, Contents Display box and Display box during typical display of PDA in guidance mode

Figure 9. Guidance instructions shown on the screen
The values of different variables are calculated as follows:

Y21 (Difference in latitudes in feet) = Current Latitude – Destination Latitude = Absolute Value
(Latitude\text{dest} - \text{Latitude}1) * 3600.0 * 101.25
(1 second of latitude = 101.25 ft)

X21 (Difference in longitudes) = Current Longitude-Destination Longitude = Absolute Value
(Longitude\text{dest} - \text{Longitude}1) * 3600.0 * 88
(1 sec of longitude =88 ft)

\text{angle}21 = \text{Arc Tan} \left( \frac{Y21}{X21} \right) * 180.0 / \pi

Distance (between the Current GPS location and Destination GPS location) = \text{Square Root} \left((Y21 * Y21) + (X21 * X21)\right)

COG2 is a variable that is calculated in the program according to the quadrant the vehicle is in. The conversion of latitude and longitude to feet were considered for the 91 degree longitude and 30 degree latitude and would vary with change in geographical location.

4.4.1 Turning Instructions as Outputs

Angle to turn: It is the angle required to turn from the current heading to head straight to the destination point. The software calculates the minimum turn that is required.

LR: The direction in which the autonomous vehicle should turn. It outputs four values that comprise left, right, straight and stop.

4.4.2 Quadrant Conditions

If the current location of the vehicle is considered as the origin in the XY plane then the destination location can be anywhere around the origin in the XY plane. When the destination location overlaps the origin then the vehicle has arrived in the destination circle. The radius of the destination circle is given as a user input.
The entire range of different positions of the destination location relative to the origin (current location) have been identified and distinguished into 7 cases. Four of the cases represent the destination location position relative to the current location of the autonomous vehicle in 4 different quadrants of the XY-plane, they being the first, second, third, and fourth quadrants. The next two cases are the ones when the destination location and the current location share the same latitude or longitude. The last one is the “Arrived” condition, when the destination location and the current location are the same.

In each quadrant the position of the vehicle is again determined based on the values of the course over ground obtained from the GPS, COG1, and a value COG2 that is determined based on the Quadrant the vehicle is in.

If the destination latitude is north of current latitude and the destination longitude is east of current longitude then destination location can be best described as Quadrant 1 position. COG2 is calculated in this quadrant as

\[ COG2 = 90.0 - \text{angle21} \]

Based on the difference between the COG1 and COG2 it is determined if the vehicle is to the right or left, heading towards or away from the destination location. If COG2 is greater than the Course Over Ground obtained from the GPS i.e. COG1, then the vehicle is heading towards the destination point and it lies to the right of the vehicle (fig.10). Similarly if COG2 < COG1, then the vehicle is heading away from the destination point and it lies to the left of the vehicle (fig.11). If COG2 = COG1, then vehicle is heading exactly towards the destination point and the vehicle need not turn (fig.12).

In a similar way the turning instructions are calculated based on the quadrant the vehicle is in. The cases where the destination location and the current location have the same latitudes or
longitudes and the calculation of turning instructions in the other three quadrants can be found in the Appendix A.

Figure 10. Quadrant 1 COG2 > COG1

Figure 11. Quadrant 1 COG2 < COG1
The outputs given by the PDA are in the form of a string in the form of RS232 asynchronous serial data. The following is a piece of VB.NET code from the software program developed for the PDA.

```vbnet
com1.Output ("A," & angletoturn & "," & distance & "," & leftright & vbCrLf)
```

This code outputs the following serial strings at the rate of 1 Hz. The serial strings were all designed to start with a character “A”. Every sentence begins with an “A” and ends with a carriage return and line feed. It can be understood by looking at the code annotation that com1 port of the PDA was used for serial communication. The “angle to turn”, “distance”, and “leftright” are the variables that continuously change in value.

The microprocessor was programmed to recognize “A” as the beginning of the string sentence and the carriage return and line feed as the end of the sentence. It was mentioned before that the range of values of leftright are 0,1,2,3 denoting left, right, straight and stop respectively.

The corresponding code snippet that the microprocessor uses to read the serial data is shown as SERIN 11, baud1, 3010, nodata, [WAIT ("A,"), DEC turn, DEC dist, DEC lr]
The microprocessor places the values received from the PDA in the variables “turn”, “dist”, and “lr” respectively. The different actions to be performed by the various actuators are programmed based on the values of these variables. For example, if the value of “lr” is 0 then it implies that the total desired movement of the vehicle should be “left” of the normal in the direction of travel of the ATV. So the steering is actuated to left. But this also depends on the current position of the steering. This has been discussed in detail in the steering section. If the “lr” value is 3, it indicates that the vehicle should stop, so the brake is actuated.
CHAPTER 5. HARDWARE AND AUTOMATION

5.1 GPS Receiver

A Fortuna Pocket Xtrack® GPS (Fortuna Electronic Corp, Taiwan) receiver with CF card plug-in (fig 13) was chosen. The Differential GPS provides position accuracies of up to 32.8 feet, 2D RMS accuracy of 22.9 feet, WAAS corrected accuracy of 3.28 - 16.41 feet.

Figure 13. A Fortuna XTrack DGPS receiver

5.2 PDA

A Dell AximX50-v (Dell Inc, Roundrock, TX) was chosen as the PDA (fig. 14). It has an Intel ® PXA270 type processor with a speed of 624 MHz and has Windows Mobile™ 2003 Second Edition Version 4.21.1088 (Build 14260.2.0.5) as its operating system. It is equipped with a 64 MB RAM and a 128 MB ROM.

5.3 Microprocessor

A Basic Stamp® 2p (Parallax Inc, Rocklin, California) was used as the microprocessor for controlling the electronics and the actuators. It acts as the interconnection between the hardware and the software. A Basic Stamp microcontroller is a single-board computer (chip) and it runs a
custom PBASIC language interpreter. A BASIC Stamp microcontroller is a single-board computer that runs the Parallax PBASIC language interpreter in its microcontroller. Although it is a microprocessor, it has a set of prewritten library commands that can be used directly. A lot of factors were considered for selecting the microprocessor.

- The current price of the Basic Stamp 2p is $79 (Accessed from www.parallax.com 10/03/05)
- The advantage of using a BASIC Stamp is its Windows® based Editor and the microprocessor can directly be programmed through a PC. Programs can be written in PBASIC and downloaded to the microcontroller through RS232 serial communication. After downloading the program the serial cable can be removed and the microcontroller holds the program until a new program is downloaded to it.
- The Basic Stamp 2p has a program execution speed of ~12000 instructions per second. The serial communication can be achieved at different baud rates. Usually a baud (bits per second) rate of 9600 is used.
- The Basic Stamp has an onboard memory of 38 Bytes. A maximum of 26 variables can be stored in the RAM. An EEPROM (Electrically Erasable Programmable Read Only Memory) is also available for storage of data.

The Basic Stamp 2p (fig. 15) technical specifications as reproduced from the www.Parallax.com can be found in Appendix A. A program was developed in PBasic for the Basic Stamp Microcontroller.

5.4 Test Vehicle

An ATV (fig 16) possessing all the required characteristics, was chosen as the platform for testing the autonomous vehicle guidance software. An ATV is a rugged vehicle suitable for farm environment.
A medium size ATV is smaller than a small size tractor, about 3.2 feet long and is of conventional steering (not differential or skid steering). A Suzuki ATV powered by an electric start, single cylinder, and a gasoline powered four stroke engine was chosen as the test vehicle. It had a reverse, selectable 2 Wheel-Drive/4 Wheel-Drive via a lever on the right side of the fuel
tank. It was decided that the ATV would be operated in the 2 wheel-drive mode for autonomous guidance.

The 4 wheel-drive was not selected for testing, because the steering was being directly manipulated for direction change and 4 wheel-drives would have more tire slippage than 2 wheel-drives. It has a standard throttle with finger push operation and leg brakes. The vehicle can be driven in low, super low and high speeds with a total range of 0-30 mph selectable via a switch beside the wheel drive option switch. The throttle button on being pushed provides more fuel to the engine resulting in the increase in acceleration. However, the total amount of throttle that can be given to the ATV is limited by the speed mode that it is in. High throttle at super low speed would cause problems to the engine.

As such, for initial experimentation a super low speed with a range of 2 mph to 5 mph was chosen. The autonomous operation also depended a lot on the type of steering controller that was used.

The vehicle forward speed can be only as high as the rate of change of steering. For example, if the steering controller was slow and it is in the process of making a turn, higher speed on the ATV would result in the ATV trying to travel faster than the rate at which it can turn. This would result in the ATV getting caught in a full circuitous turn. By the time the steering controller reaches the desired position the ATV may no longer be heading towards the desired location. Therefore a lot of care was taken in setting up the speed range for the operation of the ATV. The ATV weighed approximately 500 pounds with a wheel base of about 50 inches. The total forward speed range varied from 0-25 mph and the reverse speed range varied from 0-12 mph.
5.5 Automation of the ATV

Figure 16. Test vehicle ATV retrofitted and automated

Figure 17. Circuit diagram of the system
5.5.1 Power

The automation was achieved from electromechanical components. A standard power source was needed on the ATV for the actuation of brakes, throttle, steering and various electronic components. Both A.C. And D.C. power sources were needed. A standard 12 V car battery was used as the power source. A 6000 W inverter (fig 18) was used for the A.C. power needs. The usage of a car battery as the power source was suitable for the portable application. In case of a depletion of charge, the battery could be charged from any standard farm vehicle.

Figure 18. PDAs, microcontroller and inverter

5.5.2 Steering

The steering was the most important component of the automation system. Most of the guidance systems that were previously developed depended on controlling the hydraulics of the system. Hydraulics is commonly available on conventional farm vehicles like tractors and high clearance sprayers. Lack of standard hydraulic systems characterizes small scale farm vehicles.
The ATV had no hydraulics on it. Automatic steering can be achieved by actually moving the steering unit from one direction to other just like imitating a human driving the ATV.

The torque need to turn the steering was measured to be 55 ft-lb while it was stationary. It was described before that the navigational steering commands calculated by the PDA were given as the amount of turning needed and the direction of turn. If the “left/right” given by the PDA is 1 then the net turn is to the right of the normal in the direction of motion of the ATV. However this depends on the current position of the steering. If the steering is currently situated to the extreme right and the steering command says the turn required is a relatively lesser right, then the steering actuator should turn left instead of right.

Thus the whole process of steering is based on the current position of the actuator and the error in position of the actuator to the desired position of the actuator. So, in effect the need for a wheel angle sensor is eliminated. As such, left, right and neutral positions of the steering can be programmatically achieved only by knowing the current position of the steering.

Many different systems were considered for actuation. Pneumatics were also considered for the actuation of the brakes, steering and throttle. The main disadvantage found with pneumatics as compared with hydraulic and electrical actuation is that the fluid used is air and it is compressible. As such, precise speed control and position control is tough to achieve. They often need accessory systems to eliminate this disadvantage.

A commercially available electric linear actuator (fig. 19) with position feedback was used to achieve the actuation of the steering. Electric linear actuators provide linear motion via a motor driven ball screw, lead screw or acme screw assembly. The load is attached to the end of the screw and is unsupported. The most important factors that were considered when selecting the linear actuator were the stroke, rated load, rated speed and the backlash. The stroke of the
linear actuator is the maximum distance that the shaft travels from a fully extended position to a fully retracted position. The backlash is the positional error due to the change in direction from forward to reverse. The linear actuators are available with several mounting options. Some cylinders are equipped with a clevis or eye attachment that connects to the extended end of the piston. Others are equipped with a mounting flange or bracket. Lugs are short blocks with holes that allow mounting to another surface. A 115 V AC, 60 Hz, 1.6A linear actuator with an intended duty ratio of 153:1 was used for achieving actuation of the steering. One end of the linear actuator was rigidly mounted on an arm welded to the front of the ATV to move the steering. The other end of the linear actuator was mounted at the front of the ATV on a metal bar. Thus, when the actuator is switched on, the steering moves left and right based on the position of the piston and the cylinder.

Figure 19. Linear actuator for steering
Since both the ends of the actuator are rigidly mounted, there is a dead limit for the actuator position at the fully extended position and the fully retracted position where the actuator should be powered no more in that direction. In the event of crossing the limit, the actuator would get bent and might also break. So, the microprocessor had also been programmed to limit the actuator movement to these dead limits. The linear actuator was also equipped with a position feedback sensor that gives the value of resistance as a continuous output. The values range from maximum on one extreme to a minimum on another extreme. So the maximum and minimum of the position feedback had to be calculated and scaled according to our use.

The RCTIME command in the Basic stamp library can be used to measure the charge or discharge time of a resistor/capacitor circuit. This functionality can be used to respond to some other event or user input through a potentiometer.

The output from the position feedback potentiometer was used to calculate the current position of the actuator based on the RCTIME. In a broader sense, RCTIME was used to serve as timer circuit or a stopwatch. When RCTIME executes, a counter is started. The counter is stopped as soon as the specified pin of the Basic Stamp is no longer in the state that is previously mentioned. The RCTIME circuit was shown in fig. 20. The output is in the form of a number. This number was used for determining the safe operating lengths of the actuator.

Steering Connections: The left and right movements of the actuator have been controlled through Pins 4 and 5 of the Basic Stamp connected through a pair of solid state relays and a common ground. The Basic Stamp also gets position feedback through the RCTIME circuit on Pin 0. The state “0” or the “low “ state of the Pin was monitored. The power for the linear actuator was supplied through the inverter.
Setting up of limits and neutral: The Basic Stamp was programmed to control the power to the relays, and start the linear actuator. The output from the RCTIME circuit was monitored as a serial output on a PC through the Windows HyperTerminal® program. The HyperTerminal (Hilgraeve Inc., Monroe, Michigan) is software provided along with Windows through which we can monitor the serial communication through various com ports. The limits were observed to be ranging from 7000 on left to 35000 on right. However, these limits were turning the steering to extreme turn positions that would not normally be used by human drivers. A limits range of 8000-34000 was suitable for the operation.

The actuator had to be set to a neutral position so that there is equal swing on extension and contraction. The cylinder and screw arrangement of the linear actuator was manually screwed and unscrewed to various positions and a position range of less than 1 inch was identified where there is equal swing on either side. This 1 inch limit was identified as ranging from 19500 to 21500 on the RC time reading. Exact number limits were not considered because the RCTIME readings were calculated in ms and vary very fast. The chances of overshooting the limit were very high. This 2000 number range offered a buffer of less than 1 inch that can be taken as the “neutral” or “straight” position of the steering.

Steering Tests: Preliminary tests conducted on the ATV gave the following data. The actuator was repeatedly moved from left to right and back from right to left and the operation was timed with a digital stop watch.

The average of 10 tests yielded 35.5 s for the time required to move from one extreme position to the other. The total turn movement of the actuator was measured using a HMR digital compass (Honeywell International, Plymouth, Minnesota, (fig. 21). The angle turn of the ATV steering was found to be 38.1 degrees from extreme left to extreme right.
The steering actuator was put in various offsets from the centre and the radius of curvature of the circular motion was recorded and the time taken to complete each circle at constant speed was noted. To ensure uniform speed the vehicle was first allowed to accelerate and then after completing two or three circles, the throttle position was held constant by the driver. The turning radii of the circles ranged from 14 feet to 27 at different speeds of the ATV. The ATV can be driven at speeds between 2.3 mph to 6.3 mph without considerable slippage on the wheels.

5.5.3 Throttle

Several design considerations were made for the throttle. At the onset of the project it was decided that the main focus of the project would be that all the sensors and electronics used in it would be inexpensive. The main purpose of the project was to build an autonomous vehicle for point to point guidance in open fields. This would serve as an initial step towards forming a base for future research on guidance and control of the autonomous vehicle. Therefore the control systems that were available on the market were evaluated.

There were many embedded control systems that could have been used, in the price range of $200-300 including all the boards and electronics. For example a Z-World Smart sensor system along with the Rabbit 2000 microprocessor costs about $300. However, the guidance system need not hold the autonomous vehicle at a constant speed. The guidance was based on the
PDA program in which the output is measured as a function of distance from the desired location, and the program continuously gives instructions until the desired location is reached.

Figure 21. Output of the HMR Digital Compass

There is a relation between the linear actuator that provides the left-right steering and the throttle that accounts for the vehicle speed. Considering the situation in which the steering is too slow and the throttle is too fast then the vehicle forward movement is much higher and it cannot make a turn in time to head for the desired location. Thus the steering would be continuously making turns while trying to compensate for the error caused by going forward. Thus, an optimum range of speeds should be identified in which the steering speed matches the vehicle forward speed. To monitor the speed, a Melexis 90217 Hall Effect sensor (available at www.parallax.com) was used that monitors the drive shaft of the ATV. The Melexis 90217 is designed to be used with a bias magnet “south” facing the back of the integrated circuit(IC). The drive shaft has bolts on it that are spaced equidistantly from each other around the shaft. As the drive shaft rotates and every time a bolt passes by there is pulse that is detected by the Hall
Effect sensor. Extra gear teeth have been added to the wheel axle to increase the sensitivity of the sensor. This sensor was programmed with micro processor to output the number of pulses it read per second. This quantity was used as the indication of the speed. The throttle (fig. 22) was connected to a bicycle-brake cable that tugged at the throttle button with the movement of a bicycle- brake. A servo was mounted such that it actuated the bicycle-brake with its motion.

Figure 22. Throttle control

Many tests were done by driving the ATV at different speeds and actuating the steering. It was found that autonomous control can be obtained only when the speed of actuation of the steering can match the vehicle forward speed. The Hall Effect sensor reading ranged from 5000 to 14000 as the speed of the ATV was varied from 2-5 mph.

The guidance program was tried at different speeds and it was clearly evident that at higher speeds the steering could not match the throttle and in effect the vehicle was caught in circuitous routes with large radii of curvature ranging from 20-25 feet. The performance
improved with slower speeds of the ATV. It was also noticed that very slow speeds gave too much time to turn for the ATV resulting in circuitous routes with smaller radii of curvature ranging from 12-14 feet. A range of readings of the Hall Effect sensor ranging from 9000 to 11000 was found to be appropriate where both speeds matched.

The servo was programmed to maintain the speed between the predetermined Hall Effect sensor values. The ATV was started at some arbitrary value. The throttle is proportionally stepped up until the higher Hall Effect sensor reading is matched. As soon as the higher limit is matched the throttle is proportionally stepped down until the lower limit is matched. Thus the throttle was made to oscillate between the maximum speed and minimum speed. The flow chart can be seen in fig. 23.

This type of speed control is not entirely dependent on the vehicle characteristics but mostly dependent on the characteristics of the linear actuator. The principal emphasis is that the guidance system does not depend on the speed control to achieve point to point guidance; the guidance system would work irrespective of the speed control. This speed control would aid in reaching the desired location faster.

If \( P \) the plant represents the autonomous vehicle, \( H \) represents the Hall Effect sensor, \( K \) represents the Microcontroller processor, \( r \) represents the initial moderate throttle supplied to the system, \( u \) represents the input given to the plant \( P \), the control system representation is shown in fig. 24.

If \( K_p \) represents the proportional constant of the control system, then \( K_p \) is given by the ratio of output to input. At the two speed limits that are given to the microcontroller the output is the desired speed and the input is the amount of throttle given to get the desired speed, so \( K_p \) is
equal to one. At the maximum speed limit when the desired speed is exceeds the input given then \( K_p \) is greater than one. Immediately the servo is adjusted to reduce the speed.

![Speed Control Flow chart](image)

**Figure 23. Speed Control Flow chart**

### 5.5.4 Brake System

A DC motor (fig. 25) was mounted at the brake at the leg position. Two NC/NO switches were mounted on the circular plate on the shaft of the DC motor. Two gear cams were also bolted on the circular plate such that when the motor turns they contact the NC/NO switches and switch them off or on. As a result the DC motor had only limited rotation in either direction.

One of the gear cams was extended with a bolt that presses onto the brake just like the human operator does. The brake is let off when the DC motor turns in the opposite directions. The brake motor is switched on and off with two relays. The motor is made to rotate in both
directions by reversing the polarity. The brake is switched on as soon as the PDA outputs the value “3” for “leftright”.

Figure 24. Speed Control representation of the ATV with feedback and controller

Figure 25. Brake system
CHAPTER 6. RESULTS AND DISCUSSIONS

Different types of tests were conducted on the ATV to determine its guidance capabilities. Preliminary tests were conducted to test the guidance abilities of the system to one single geographical location (Price and Nistala, 2005). Tests were conducted to test the ability of the vehicle to reach a destination location “D”. The PDA was programmed to guide the ATV to the destination location D (3024.2990 E, 9110.6376 W). The ATV was started in different locations with different orientations relative to the destination location. The tracks made by the ATV were plotted using Farmworks® software (CTN Data Service Inc, Hamilton, Indiana) and can be seen in fig. 26.

A total of five tests were conducted. The tracks for the five tests can be seen as 1, 2, 3, 4 and 5 in fig. 26. Tests 1 and 2 show that the ATV has the capability to autonomously guide itself to the destination point. Tests 4 and 5 were conducted from the same starting point and “D” as the destination point. The tracks of the ATV in the tests 4 and 5 were identical to each other. The maximum offset between the two tracks was 2 feet.

Figure 26. A Farmworks® plot of the preliminary single point guidance tests
The ATV had an offset of 12 feet from the destination. The results showed that the system was feasible. It was noted that the vehicle needed some fine tuning regarding the amount of turn and the speed limits that allow for guidance.

6.1 Test Points Layout

The autonomous ATV was designed to operate in open field conditions primarily for soil sample and penetrometer applications. These applications do not require row guidance. However, the need to guide through a set of points that lie in a straight line may commonly arise in field conditions. A grid of 4 X 4 points was laid out in an open field at Louisiana Agricultural Experiment Station Benhur Research Farm, Baton Rouge, Louisiana with points equidistant from each other. The layouts of the test points can be seen in fig. 27. Flags were planted in the ground for identification as the test points. The GPS points were plotted in ArcGIS ArcMap® software. Each location was marked at a distance of 100 feet from the other immediate locations surrounding it.

Figure. 27. The Arc GIS layout of the GPS locations of the test grid
A measuring tape was used to mark out the points each at a distance of 100 feet from the surrounding points. However there was error of less than one foot in the laying out of points manually using just a measuring tape and no other laser positioning devices. It was noted that when the test points were marked using the GPS they were not exactly lying in straight lines. These errors can be attributed to the GPS error. The GPS error was 10 meters. These points were then marked using flags. A serpentine route was used because it comprises of straight lines and steep curves at the end of the rows.

A Garmin® GPS 16 (fig 28) receiver whose WAAS enabled accuracy is less than 9.84 feet was connected to a different PDA with a serial card and was used to capture the track log of the ATV.

Figure 28. Garmin GPS

A shape file was created using Farmworks TracSitemate® software(fig. 29). This is commercially available software that has the capability of creating shape files and text files with GPS stream.

It was described before that the input to the PDA guidance program can be a text file with the GPS locations of the destination points. All the destination locations can be logged into the text files. The PDA guides from one location to the other based on the order of the GPS points in the file. After the flags were planted, the guidance program containing PDA was used to log
these points in serpentine route and make a shapefile. This shapefile was used as the input map for the guidance program.

![Image of FarmWorks ® shapefile of test grid](image)

**Figure 29. FarmWorks ® shapefile of test grid**

### 6.2 Preliminary Test

The serpentine route grid file was given to the ATV for guidance. The ATV was able to guide to the first four points correctly. At the end of the row, a sharp turn was required to go to the next leg of the serpentine route.

It can be seen in fig. 30 that the ATV was caught in a continuous circuitous route because the forward speed was more than the steering actuator movement. So, the desired turning movement could not be achieved before the vehicle changed position and then a new turning movement and a new position of the steering actuator was required. Initially the ATV was not programmed to stop after it reached a location. It was clear from the ATV behavior that the steering actuator needed to match the vehicle forward speed in order to make a steep turning.

Since the autonomous ATV was meant to be used for soil sampling and penetrometer
applications, it needs some time for running those applications when it has reached the desired location. This required a pause time at the destination points. So, the pause time was programmed into the microprocessor. During the pause, the throttle actuation would be cut off and the brake would be actuated.

Figure 30. ATV stuck in circuitous routes at the end of the row

Thus the ATV was programmed to stop at the destination location for a brief interval of time before it started again towards the next location. The introduction of this pause time was helpful in two ways. First, it gave time for soil sample collection and penetrometer application and next it gave time for the linear actuator to turn enough or have enough heading for going to the next location. Different pause times were tried out and it was found that a minimum of 5 seconds was found to be sufficient for the ATV to avoid circuitous tracks.
6.3 Testing

Five tests were conducted with a serpentine route. The tracks made by the ATV were plotted in ArcGIS ArcMAP® software (fig. 31). The five tracks of the ATV can be seen in five different colors and the test grid can be seen in black squares. The test points were laid out manually on a 100 foot grid. When these points were marked by the GPS and plotted in ArcGIS, it can be seen that the rows were not absolutely straight. This can be attributed to the DGPS error. This error can be reduced by the use of an RTK GPS and the readings from RTK GPS could be used as a reference but it is more expensive. However the current study uses only DGPS receivers.

Figure 31. Arc GIS ArcMAP® plot for ATV routes Tests 1, 2, 3, 4 and 5

It can be seen at test point 7 that the ATV went exactly through the point with minimum offset error in all the tests. The ATV continued to go with the same heading and then
compensated to reach the next test point 8. Thus in all the tests the point 7 had less offset error and point 8 had higher offset errors.

The ArcGIS plot doesn’t show the stop points of the ATV. The stop points of the ATV were marked with flags and these flags were plotted with the same DGPS as used by the guidance PDA. The stop points of the ATV were plotted in Microsoft Excel® along with the test points in all the five tests. The plot obtained for test 1 is shown in fig.32. The plots obtained for other tests can be seen in Appendix A. These graphs give an indication of how much the stop points were offset by the original test points. The units in the graph are in terms of Latitude (degree) and Longitude (degree).

Figure 32. Grid vs. ATV Stop points Test 1

These graphs can be used to obtain the offset of stop points from the test grid points but the offset would be in latitude and longitude inches. So the distance of each flag dropped at the stop point, from the test grid point was measured with a measuring tape and rounded off to the nearest
inch and the offset was noted. Table 2 gives the Offsets O1, O2 … O16 of all the 16 points from the test grid points for all the five tests.

It was described earlier that the offsets of each stop point from the destination point were measured with a measuring tape to the nearest inch. The standard deviation indicates how tightly all the various offsets are clustered around the mean in the set of test points. Therefore, the standard deviations and averages of all offsets in feet of each individual test were calculated and tabulated (Table 2). The standard deviation of offsets of each replicated test ranged from 2 feet to 3 feet and the average of offsets ranged from 5 to 8 feet and they can be observed along the columns. If the error of the WAAS enabled DGPS was considered to be 10 feet then the maximum error of offsets ranged from 15 to 18 feet within the actual destination point. Thus the arrival circle had an average radius ranging from 15 -18 feet. This standard deviation and average of the stop point from the test points is less than the error of the GPS.

Table 2. Offsets of test points

<table>
<thead>
<tr>
<th>Offsets (feet)</th>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
<th>Test 4</th>
<th>Test 5</th>
<th>stdev</th>
<th>average</th>
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Table 2 continued

| Offset15 | 4.33 | 9.33 | 3.25 | 8.17 | 3.50 | 2.82 | 5.71 |
| Offset16 | 5.16 | 4.16 | 4.08 | 7.75 | 7.66 | 1.82 | 5.76 |
| stdev    | 2.35 | 2.19 | 3.47 | 2.74 | 2.54 |      |      |
| average  | 5.38 | 7.27 | 7.58 | 8.81 | 6.77 |      |      |

The results were also analyzed with respect to offsets at each test point and variability of offsets at the same point in different tests. The standard deviation and average of offsets at each stop point from all the five tests were tabulated and they can be observed along the rows in Table 2. It was found that the standard deviation ranged from 1 to 3 feet and the average ranged from 3 to 11 feet. The minimum offset observed in all the tests was 1.25 feet and the maximum offset was observed to be 13.5 feet. If the error of the WAAS enabled DGPS was considered to be 10 feet then the maximum error of offsets ranged from 13 to 20 feet within the actual destination point. Thus the arrival circle had an average radius ranging from 13-20 feet.

Thus, the results were analyzed both test wise and point wise. These results indicate that the vehicle was fairly consistent in all of the tests and the deviation lies within the GPS error. These test results were within the acceptable error.

The total expenses involved in creating the autonomous guidance system for soil sampling purposes are given below:

- PDA- $ 250.00  
- Fortuna Xtrack CFGPS- $ 168.00  
- Basic Stamp- $ 79.00  
- Electronics and Electromechanical components
  - Linear Actuator & Solid State Relays & DC Motors - $ 250.00  
  - Inverter- $ 60.00
- Hall effect Sensor- $ 4.25
- Total expenses- $ 811.25

Thus, the total expenses incurred in making the autonomous system were around $800.00.

The desired objective of achieving a guidance system enabled with an inexpensive DGPS and acceptable results was achieved.

### 6.4 Commercially Available Guidance System

Table 3 gives the price of the Autotrac Steering package as obtained from a quote given by an authorized dealer on 11/30/05. Table 4 shows the price of Autotrac® John Deere 8020 Series Wheel Tractors (accessed http://www.deere.com/en_CA/jdc/special_offers/ag/ 8000_at.html 11/14/05).

It can be seen that the commercially available guidance systems that are enabled with sub inch accuracy GPS systems are very expensive to be owned individually by the farmers. It can also be seen from Table 4 that they are very expensive to rent. So, these autonomous guidance systems may not be used for soil sampling purposes because of their high price. There is also a lack of commercial systems solely for the purpose of soil testing and sampling purposes.

It was described earlier that a Garmin GPS with an accuracy of less than 10 feet was used to track the route of the ATV on the tracking PDA. The stop points were recorded on the guidance PDA after the test. Theoretically, the stop points recorded on the guidance PDA would lie on the track of the ATV recorded by the tracking PDA. But it was seen that when the same points were plotted using the guidance GPS and the tracking GPS there was a discrepancy in both of them. They were both obtained with different DGPS. The RC time circuit that was used for obtaining
the position feedback may slowly lose accuracy with passage of time. An analog to digital converter would be more accurate and better than a RC time circuit.

Table 3. Price of John Deere Autotrac® system

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<th>Description</th>
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<td>AutoTrac SF2</td>
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<td>0.00</td>
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<tr>
<td>0970</td>
<td>AutoTrac for Original GreenStar System with KeyCard</td>
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<td>1000</td>
<td>Original GreenStar Display and Mobile Processor</td>
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Table 4. Price of Auto trac® John Deere 8020 Series Wheel Tractors

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</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>6</td>
<td>$18491.60</td>
<td>$110,949.60</td>
<td>4.00%</td>
<td>$8238.43</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
<td>$14324.85</td>
<td>$114,598.80</td>
<td>5.00%</td>
<td>$11,887.63</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>$11887.76</td>
<td>$118,877.60</td>
<td>5.50%</td>
<td>$16,166.43</td>
</tr>
</tbody>
</table>

The linear actuator had to be unplugged every time the mode was changed from manual to autonomous guidance. This would cause trouble if the ATV was frequently used for manual
and autonomous modes of operation. If the linear actuator changed position due to these reasons, it had to be tested for the limits before use.

The following conversions have been used in the guidance program:

1 second of latitude = 101.25 feet.

1 second of longitude = 88 feet.

These approximations are true only in Louisiana and are not valid all over the world. The longitudes converge as they move away from the equator. So, these conversions should be changed according to the place the guidance program is being used.
CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

An autonomous guidance system was successfully constructed for the purpose of use on an ATV. This system can be used as an autonomously operating soil sampler or a penetrometer test vehicle with a robotic penetrometer (fig .33) developed at Biological and Agricultural Engineering, Louisiana State University. This system was built with a minimum number of components and the total expense of building it remained around $ 800 including the PDA and the GPS.

Figure 33. Robotic penetrometer

The autonomous guidance system was tested for accuracy for guidance to predetermined sampling points. The system was found to be accurate with average offset errors between 5.4 and 8.8 feet and standard deviation of 2.19 and 3.47 feet from the desired sampling points within a test. The total maximum error of the system was estimated to be ± 18.8 feet including the Differential GPS error.
The repeatability of the results was tested by determining the average and standard deviation offset errors of each test point over 5 tests. The average offset error was found to be in the range of 3.73-10.71 feet and the standard deviation was in the range of 1.24-3.78 feet.

These offset errors are within the accuracy range of the DGPS. These results prove that a WAAS enabled differential GPS with accuracy of about 10 feet is sufficient for guidance of autonomous vehicles used for soil testing and soil sampling purposes in open fields.

7.2 Recommendations

A faster linear actuator could be used for steering. This would ensure that the steering speed can match the PDA instruction speed and the speed of the autonomous guidance system need not be compromised. The PDA can be programmed to create an auto grid by giving the number of sampling points and distance between each point as the user inputs. Commercially available farm management softwares also have auto-grid functions that make shapefiles. These shapefiles can be used as the input maps for the autonomous system. The conversion factors containing the number of feet in a second of latitude and longitude could be taken as a user input or can be accesses from a preprogrammed database. Thus the guidance program need not be altered according to the place. Machine vision can be included for obstacle detection and avoidance routines. A more efficient speed control method could be built using proportional control.
REFERENCES


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APPENDIX A: HARD WARE AND SOFTWARE

Quadrant Conditions

If destination latitude is more south of the current latitude and the destination longitude is less west of current longitude then destination location can be best described as Quadrant2 position.

COG2 is defined as $\text{COG2} = 90 + \text{angle 21}$

If COG2 is greater than the course over ground obtained from the GPS then the vehicle is heading towards the destination location and it lies to the right of the vehicle.

If COG2 is less than the course over ground obtained from the GPS then the vehicle is heading towards the destination location and it lies to the left of the vehicle.
If COG2 is exactly equal to the course over ground obtained from the GPS (COG1) then the vehicle is heading exactly towards the destination location and then vehicle need not turn.

If destination latitude is more south of current latitude and the destination longitude is more west of current longitude then destination location can be best described as Quadrant3 position.

COG2 is defined as $COG2 = 270.0 - \text{angle21}$

If COG2 is greater than the course over ground obtained from the GPS then the vehicle is heading away from the destination location and it lies to the right of the vehicle.
If COG2 is less than the course over ground obtained from the GPS then the vehicle is heading towards the destination location and it lies to the left of the vehicle.

If COG2 is equal to the course over ground (COG1) obtained from the GPS then the vehicle is heading exactly towards the destination location and it need not turn.
Quadrant 4 conditions

If destination latitude is more north of current latitude and the destination longitude is more west of current longitude then destination location can be best described as Quadrant 4 position.

The variable COG2 is defined as COG2 = 270° + angle 21

If COG2 is more than the course over ground obtained from the GPS then the vehicle is heading towards the destination location and it lies to the right of the vehicle.
If COG2 is less than the course over ground obtained from the GPS then the vehicle is heading towards the destination location and it lies to the left of the vehicle.

If COG2 is equal to the course over ground obtained from the GPS then the vehicle is heading exactly towards the destination location and it need not turn.

Same latitude conditions
If the latitude of the current location and the destination location are same and the
destination longitude is less west of current longitude the variable COG2 is determined to be 90
degrees. The same three conditions as before apply.

If COG2 > COG1 then the vehicle is heading towards the destination point and it lies to
the right of the vehicle.

If COG2 < COG1 then the vehicle is heading away from the destination point and it lies
to the left of the vehicle.

If the Course Over Ground obtained from the GPS is 90 degrees then it indicates that the
vehicle is heading exactly towards the destination point.
Similarly if the latitude of the current location and the destination location are same and the destination longitude is more west of current longitude the variable COG2 is determined to be 270 degrees.

If COG2 > COG1 then the vehicle is heading towards the destination point and it lies to the right of the vehicle.

If COG2 < COG1 then the vehicle is heading towards the destination point and it lies to the left of the vehicle.
If the Course over ground obtained from the GPS is 270 degrees then it indicates that the vehicle is heading exactly towards the destination point (Fig. 21)

**Same longitude conditions**

If the destination GPS location and the current GPs location are on the same longitude and if the destination latitude is more south of the current latitude then COG2 is defined to be 180 degrees. There are three situations that need to be considered.

If the Course over ground obtained from the GPS is less than COG2 then the vehicle is heading away from the destination point and it lies to its right.
If the Course over ground obtained from the GPS is more than COG2, then the vehicle is heading towards the destination point and it lies to its left.

If the Course over ground obtained from the GPS is equal to COG2, then the vehicle is heading exactly towards the destination point and it need not turn.
If the destination GPS location and the current GPS location are on the same longitude and if the destination latitude is more north of the current latitude then COG2 is defined to be 360 degrees.

The position of the destination location relative to the vehicle can be determined by using the same condition as above. Similarly the position of the vehicle relative to the destination location can be determined and the necessary turning instructions calculated.

The various positions of the current location of the vehicle and the destination location have been illustrated below.

**Basic Stamp 2p Technical Specifications**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processor Speed</td>
<td>20 MHz Turbo</td>
</tr>
<tr>
<td>Program Execution Speed</td>
<td>~12,000 instructions/sec.</td>
</tr>
<tr>
<td>RAM Size</td>
<td>38 Bytes (12 I/O, 26 Variable)</td>
</tr>
<tr>
<td>Scratch Pad RAM</td>
<td>128 Bytes</td>
</tr>
</tbody>
</table>
Shapefiles

A shapefile stores nontopological geometry and attribute information for the spatial features in a dataset (An ESRI White paper, 1998). The geometry of a feature is stored as a shape comprising of a set of vector coordinates. Shapefiles are being used more and more as a part of the Geographical Information System and their applications. Their popularity lies in their advantage over other topographical data structures in that they can be drawn faster and that they occupy less computer memory. Shapefiles support point, line and area features. ESRI shapefiles are a very popular type of shapefiles. They consist of a main file, and index file and a dBASE table file. In some cases a main file is a direct access, variable-record-length file in which each record describes a shape with a list of its vertices (ESRI, 1998). In the index file, each record contains the offset of the corresponding main file record from the beginning of the main file. The dBASE table file contains feature attributes with one record per feature.

Shapefiles can be created as follows:

- By exporting any data source to a shapefile using software like ARC/INFO®, PC ARC/INFO®, Spatial Database Engine® and ArcView®GIS
• By digitizing shapes using software like ArcView® GIS
• Can be directly programmed by using software like MapObjects®, ARC Macro Language (AML) etc.

Visual Studio.NET Form Components

Buttons

These are also called event handlers or event driven controls (fig. 7). They are an easy way of user interaction with the application. The Buttons perform various actions based on the user interaction. Some typical actions of the buttons are Button Click events and Button Loose Focus events. The Buttons are given names in the Properties Window and these names are used to perform actions depending on the events. The Buttons can be captioned from the Properties window. The most typical Button event is the Click event. The code written within the event handler gets executed when the event occurs i.e. the Button is clicked.

TextBox

The TextBox is another control that is used to display text or accept user input. The textbox cannot display a continuous stream of text like the GPS data. The effect of the textbox displaying a continuous stream of data was created by clearing the TextBox and writing the updated GPS information into it every second.

Timer

A Timer repeats the code written within it at the end of the specified period of time. A Timer component was used to update GPS information everyone second.
Smart Device User Interface

**Types of Guidance Systems**

**Long Range Navigation (LORAN)**

This guidance technique existed before the GPS and was used in commercial sea transportation and aircrafts located within 600 miles of the American Coast (http://www.britannica.com/eb/article-9048944). It was first developed in at the Massachusetts Institute of Technology during World War II. The next version was LORAN-C and it operates in the frequency range 90-110 kHz developed during the 1950s with arrange of 2000 miles. This type of guidance is limited obsolete and not much used any longer due to its low range.

**Laser Designation**

This guidance technique is used exclusively for military munitions. It is a form of semiactive guidance that involved illumination or designating the target with energy emitted
from a source extraneous to the missile (http://www.britannica.com/eb/article-57324). A seeker in the projectile that is sensitive to the reflected energy is then homed onto the target. This type of guidance is limited with regards to the fact that it needs a line of sight to the target from the munition as well as to the designator. Advanced systems use GPS target data to provide the designator thus allowing targets to be designated long before operations commence as well as eliminating the line-of-sight requirement for the munition. This type of guidance system is not suitable for agriculture and landbased vehicle guidance.

**Machine Vision**

It is a popular technique used for autonomous vehicle guidance and is used a lot in agriculture. It is used in a variety of applications like automation, recognition, counting objects, reading serial numbers etc. Machine or computer vision is used to extract specific information from images and use it to achieve a specific task. As pertinent to agriculture, machine vision is being used in a variety of applications including guidance and crop row navigation of agricultural vehicles, fruit grading, fruit picking and any more such applications.

**Global Positioning System (GPS)**

This is a satellite navigation system used to determine the precise location and a highly accurate time reference anywhere on the earth. It uses an Intermediate Circular Orbit (ICO) satellite constellation of at least 24 satellites. The GPS system was designed by and is controlled by the United States Department of Defense and can be used by anyone free of charge. This is one of the reasons why this form of guidance is very popular and widely used in various industries like aviation, agriculture, and transport. The GPS system consists of three segments: space, control and user. The space segment comprises of the satellites. The control segment consists of the ground stations that monitor the satellites path of flight, synchronizing the
satellites atomic clocks and uploading the data for transmission by the satellites. The user segment comprises of the GPS receivers being used for a variety of military and civil purposes. A GPS receiver decodes the time signal transmissions from multiple satellites and calculates the position by trilateration. The US spends reportedly millions of dollars per year including maintenance expenses (http://www.rand.org/publications/MR/MR614/MR614.appb.pdf). The first satellite to be used for positioning purposes was launched in the February of 1978 and the latest one was launched in September 2005 (http://en.wikipedia.org/wiki/Gps). The idea for GPS first originated when the Soviets launched the first Sputnik in 1957. A team of U.S. scientists who were monitoring the Sputnik discovered that frequency of the radio signal transmitted by the Sputnik was higher as the Sputnik approached and lower as it went away from them and that they could pinpoint the satellite from their position and vice versa.

GPS data is not accurate. It has many errors in it caused due to a lot of factors like the satellite clocks, errors due to ionosphere, reflections caused by other signals like radio waves.

The accuracy of GPS can be improved in a number of ways. A few of them are discussed below as pertinent to their application in agriculture.

**Improvement of GPS accuracy**

**Differential GPS (DGPS):** A network of fixed ground based reference stations broadcast the difference between the measured satellite pseudoranges and the actual internally computed pseudo ranges. The receiver stations could correct their pseudo ranges by the same amount. This method is called Differential GPS or DGPS.

**Wide Area Augmentation System (WAAS):** An additional set of satellites in the geosynchronous orbit are uploaded with GPS correction data by ground stations. This data includes ionospheric delays and satellite clock drift. This data is then transmitted by the these
satellites for receiving by the GPS receivers. The WAAS system currently works only in North America. The European and Japanese counterparts of WAAS are EGNOS (EuroGeoStationaryNavigation Overlay Service) and MSAS (Multifunctional Satellite Augmentation System) respectively.

**Local Area Augmentation System (LAAS):** This system is similar to WAAS and similar correction data is used. But it is transmitted from a local source like an airport station instead of geosynchronous satellite. These signals are available up to 30-50 km range from the transmitter.

**Relative Kinematic Positioning (RKP):** This is the most accurate and the most expensive form of correction of GPS signals with accuracies of up to 10 cm. This is done by resolving the number of cycles in which the signal is transmitted and received by the receiver. This is done by using a combination of differential GPS (DGPS) correction data, transmitting GPS signal phase information and ambiguity resolution techniques via statistical tests, possibly with processing in real-time (real time kinematic positioning, RTK GPS).

**Navigation**

There are several different methods of navigation. Some common types of navigation are dead reckoning and position fixing.

**Dead Reckoning**

It is the process of navigation by determining the global position of a vehicle by advancing a known position using course, speed, time and distance to be traveled. It is a means of figuring out the current position or the future position at a particular time by holding the speed time and course.
**Position Fixing**

It is the navigation based on determining the position by means of various visual and electronic methods. Different types of position fixing are radio navigation, satellite navigation and celestial navigation.

**NMEA 0183 Code**

The National Marine Electronics Association (NMEA) (http://www.nmea.org/pub/0183/index.html) has developed a specification that defines the interface between various pieces of marine electronic equipment. GPS receiver communications are defined within the NMEA 0183 specifications. A line of data or a sentence is sent that is entirely independent of the other sentences. It is widely used format and most of the computer programs that provide real time position information work with the NMEA format. There are different standard sentences based on the device category. The GPS receiver manufacturing company can make up its own proprietary sentences for use by its devices. The standard sentences have a two letter prefix that denotes the device that uses those sentences. Thus all the GPS receivers have a prefix of GP (for GPS). This prefix is followed by the three letters that differ with the sentence type and its data. The hardware manufacturers can also define their own proprietary sentences. All the proprietary sentences start with P and are followed by 3 letters that identify the manufacturer’s name. A Garmin® sentence would begin with PGRM and a Magellan® sentence with a PMGN. Usually each sentence begins with a “$” and ends with a carriage return and line feed and is a maximum of 80 characters of visible text. Commas are used as the delimiters (http://vancouver-webpages.com/peter/).

Many GPS receivers output a fixed set of sentences that cannot be tampered by the user. The first word of the sentence is called a data type and its interpretation is defined in the NMEA
standard. Some information may be repeated in various sentences but they all have different data. The devices that read the data wait for the required sentence and ignore the other sentences. The receiver ignores corrupted data based on the checksum. Some GPS sentences that are pertinent to the present study are

- GPAAM-Waypoint Arrival Alarm
- GPALM-Almanac Data
- GPBOD-Bearing Origin to Distance
- GPBWC-Bearing Using Greater Circle route
- GPDTM-Datum Being Used
- GPGGA-Fix information
- GPGLL-Latitude, Longitude data
- GPGSA-Overall satellite data
- GPGSV-Detailed Satellite Data
- GPMSS-Beacon Receiver Status information
- GPRMA-Recommended Loran Data
- GPRMB-Recommended Navigation data for GPS
- GPRMC-Recommended Minimum data for GPS
- GPVTG-Vector Track and Speed over the ground
- GPWCV-Waypoint closure velocity
- GPWPL-Waypoint information
- GPTXC-Cross Track Error
- GPTXE-Measured Cross Track Error
- GPZDA-Date and Time

Grid vs ATV Stop points Tests 2, 3, 4 and 5

Grid vs ATV Stop points Test 2

Grid vs. ATV Stop points Test 2
Grid vs. ATV Stop points Test3

Grid vs. ATV Stop points Test4
Grid vs. ATV Stop points Test 5
APPENDIX B: SMART DEVICE APPLICATION FOR GUIDANCE PROGRAM IN VB.NET FOR PDA

Imports RS232Class.SerialIO
Imports Decoder
Imports System.Text
Imports System.Collections
Imports Microsoft.VisualBasic

Public Class Form1
    Inherits System.Windows.Forms.Form
    Friend WithEvents cmdStartStop As System.Windows.Forms.Button
    Friend WithEvents MainMenu2 As System.Windows.Forms.MainMenu
    Friend WithEvents MainMenu1 As System.Windows.Forms.MainMenu
    'Friend WithEvents OpenFileDialog1 As System.Windows.Forms.OpenFileDialog
    Public p As String
    Public s As String
    Private WithEvents GPSSerial As New SerialPort
    Public WithEvents com1 As New SerialPort
    Public latitude As New Double
    Public longitude As New Double
    Public latitude1 As New Double
    Public longitude1 As New Double
    Public latitudedest As New Double
    Public longitudedest As New Double
    Public latdest As String
    Public longdest As String
    Public x21 As New Double
    Public y21 As New Double
    Public angle21 As New Double
    Public angletoturn As New Double
    Public distance As New Double
    Public leftright As Double
    Dim pi As Double = 3.14285
    Public cog As String
    Public cog1 As New Double
    Public cog2 As New Double
    Private WithEvents Decoder As New DecodeGPS.DecodeGPS
    Public i As Integer
    Public j As Integer
    Public arraylatitude(70) As Double
    Public arraylongitude(70) As Double

   #Region " Windows Form Designer generated code "
    Public Sub New()
        MyBase.New()
        'This call is required by the Windows Form Designer.
        InitializeComponent()
        'Add any initialization after the InitializeComponent() call
    End Sub

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'Form overrides dispose to clean up the component list.
Protected Overloads Overrides Sub Dispose(ByVal disposing As Boolean)
    MyBase.Dispose(disposing)
End Sub

'NOTE: The following procedure is required by the Windows Form Designer
'It can be modified using the Windows Form Designer.
'Do not modify it using the code editor.
Friend WithEvents textbox1 As System.Windows.Forms.TextBox
Friend WithEvents Timer1 As System.Windows.Forms.Timer
Friend WithEvents cmdStartandStop As System.Windows.Forms.Button
Friend WithEvents Button1 As System.Windows.Forms.Button
Friend WithEvents TextBox2 As System.Windows.Forms.TextBox
Friend WithEvents OpenFileDialog2 As System.Windows.Forms.OpenFileDialog
Friend WithEvents TextBox3 As System.Windows.Forms.TextBox
Friend WithEvents cmdDisplay As System.Windows.Forms.Button
Friend WithEvents cmdguidance As System.Windows.Forms.Button
Private Sub InitializeComponent()
    Me.MainMenu1 = New System.Windows.Forms.MainMenu
    Me.textbox1 = New System.Windows.Forms.TextBox
    Me.Timer1 = New System.Windows.Forms.Timer
    Me.TextBox2 = New System.Windows.Forms.TextBox
    Me.TextBox3 = New System.Windows.Forms.TextBox
    Me.serialpoll = New System.Windows.Forms.Timer
    Me.cmdStartandStop.Location = New System.Drawing.Point(8, 232)
    Me.cmdStartandStop.Size = New System.Drawing.Size(104, 16)
    Me.cmdStartandStop.Text = "Start"
    Me.textbox1.Location = New System.Drawing.Point(8, 8)
    Me.textbox1.Multiline = True
    Me.textbox1.Size = New System.Drawing.Size(224, 144)
    Me.textbox1.Text = ""
    Me.Timer1.Interval = 1000
    Me.Button1.Location = New System.Drawing.Point(8, 248)
    Me.Button1.Text = "Browse"
    Me.TextBox2.Location = New System.Drawing.Point(8, 192)
Me.TextBox2.Multiline = True
Me.TextBox2.Size = New System.Drawing.Size(224, 40)
Me.TextBox2.Text = ""
'
'TextBox3
'
Me.TextBox3.Location = New System.Drawing.Point(8, 152)
Me.TextBox3.Multiline = True
Me.TextBox3.Size = New System.Drawing.Size(224, 40)
Me.TextBox3.Text = ""
'
'serialpoll
'
Me.serialpoll.Interval = 1000
'
'cmdDisplay
'
Me.cmdDisplay.Location = New System.Drawing.Point(112, 232)
Me.cmdDisplay.Size = New System.Drawing.Size(120, 16)
Me.cmdDisplay.Text = "Decoded Data"
'
'cmdguidance
'
Me.cmdguidance.Location = New System.Drawing.Point(112, 248)
Me.cmdguidance.Size = New System.Drawing.Size(120, 16)
Me.cmdguidance.Text = "Guidance"
'
'Form1
'
Me.Controls.Add(Me.cmdguidance)
Me.Controls.Add(Me.cmdDisplay)
Me.Controls.Add(Me.TextBox3)
Me.Controls.Add(Me.TextBox2)
Me.Controls.Add(Me.Button1)
Me.Controls.Add(Me.textbox1)
Me.Controls.Add(Me.cmdStartandStop)
Me.Menu = Me.MainMenu1
Me.Text = "straight line"

End Sub

#End Region

Private Sub Form1_Load(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles MyBase.Load
With GPSSerial
    .BitRate = 4800
    .RTSEnable = True
    .DTREnable = True
    .EnableOnComm = False
    Try
        .CommPort = 4
        .PortOpen = True
    Catch
        End Try
    End If
End If
MessageBox.Show("Could not open Com4.")
End If
End With
With com1
  .BitRate = 4800
  .RTSEnable = False
  .DTREnable = False
  .EnableOnComm = False
Try
  .CommPort = 1
  .PortOpen = True
Catch
  End Try
If .PortOpen = False Then
  MessageBox.Show("Could not open Com1.")
End If
End With
End Sub

Private Sub Decoder_GPSDecoded(ByVal Status As Boolean) Handles Decoder.GPSDecoded
  With Decoder
    If Status = False Then
      'TextBuffer.Remove(0, TextBuffer.Length)
      textbox1.Text = ("GPS Status: Violation. A valid navigation solution is not possible."
      & vbCrLf & "Current Date: " & .CreateDate & vbCrLf & "Current Time: " & .CreateTime)
      'TextBuffer.Append("GPS Status: Violation. A valid navigation solution is not possible."
      & vbCrLf & "Current Date: " & .CreateDate & vbCrLf & "Current Time: " & .CreateTime)
    Else
      'textbox1.Text = ("Latitude: " & Decoder.Latitude & vbCrLf & 
      "Longitude: " & Decoder.Longitude & vbCrLf & vbCrLf & "Local Time: " 
      & Decoder.LocalTime & vbCrLf & vbCrLf & "OrNull: " & Decoder.NotNull & 
      vbCrLf & "Course over Ground: " & Decoder.COG & vbCrLf & vbCrLf & "Speed over 
      Ground: " & Decoder.Speed & vbCrLf & vbCrLf & "Dec Latitude: " & 
      Decoder.DecimalLatitude & vbCrLf & vbCrLf & "Dec Longitude: " & 
      Decoder.DecimalLongitude & vbCrLf & vbCrLf & "Number of Satellites in Use: 
      " & Decoder.NumberOfSatellites & vbCrLf)
      'Textbox1.Text = ("Latitude: " & .Latitude & vbCrLf & 
      "Longitude: " & .Longitude & vbCrLf & vbCrLf & "Local Time: " & 
      .LocalTime & vbCrLf & 
      "Local Date: " & .LocalDate & vbCrLf & vbCrLf & "Course over Ground: " & 
      .CourseOverGround & vbCrLf & 
      "Speed over Ground: " & .SpeedOverGround & vbCrLf & 
      "Dec Latitude: " & .DecimalLatitude & vbCrLf & 
      "Dec Longitude: " & -(DecimalLongitude & vbCrLf & "Number of Satellites in Use: 
      " & NumberOfSatellites & vbCrLf & "cog2: " & cog2 & vbCrLf & 
      "Angle to turn: " & angle & vbCrLf & "Distance to go: " & distance & vbCrLf & 
      "Left Right: " & leftright & vbCrLf)
"
' textbox1.Text = "Course Over Ground: " & .CourseOverGround & vbCrLf
' textbox1.Text = "Speed Over Ground: " & .SpeedOverGround & vbCrLf
' textbox1.Text = "Decimal Latitude: " & .DecimalLatitude.ToString & vbCrLf
' textbox1.Text = "Decimal Longitude: " & .DecimalLongitude.ToString & vbCrLf
latitude = .DecimalLatitude
longitude = -(.DecimalLongitude)
cog = .CourseOverGround
' TextBox1.Text.Append("Altitude (meters): " & .Altitude & vbCrLf)
' textbox1.Text = "Number of Satellites in Use: " & .NumberOfSatellites & vbCrLf
' textbox1.Text = "cog2: " & cog2 & vbCrLf
' textbox1.Text = "Angle to turn: " & angletoturn & vbCrLf
' textbox1.Text = "Distance to go: " & distance & vbCrLf
' textbox1.Text = "Left Right: " & leftright & vbCrLf
' textbox1.Text.Remove(1, 300)
End If
End With
End Sub
Private Sub Form1_Closing(ByVal sender As Object, ByVal e As System.ComponentModel.CancelEventArgs) Handles MyBase.Closing
If GPSSerial.PortOpen = True Then GPSSerial.PortOpen = False
If com1.PortOpen = True Then com1.PortOpen = False
End Sub
Private Sub guidance()
TextBox3.Text = "Nav to Lat: " & arraylatitude(i) & vbCrLf & "Long: " & arraylongitude(j) & vbCrLf
Try
cog1 = Convert.ToDouble(cog)
Catch
End Try
' latitudedest = 30.40845
' longitudedest = 91.17885
latitudedest = arraylatitude(i)
longitudedest = -(arraylongitude(j))
latitude1 = latitude
longitude1 = longitude
' Try
y21 = (Math.Abs(latitudedest - latitude1)) * 3600.0 * 100
x21 = (Math.Abs(longitudedest - longitude1)) * 3600.0 * 88
If x21 <> 0 Then
  angle21 = Math.Atan(y21 / x21) * 180.0 / pi
End If
distance = Math.Sqrt(((y21 * y21) + (x21 * x21))
'textbox1.Text = (longitudedest & vbCrLf & longitudedest & angle21 & vbCrLf & distance & vbCrLf)
'com1.Output(latitudedest & vbCrLf & latitude1 & longitudedest & y21 & vbCrLf & x21 & vbCrLf & angle21 & vbCrLf & distance & vbCrLf)
If Math.Round(longitudedest, 6) = Math.Round(longitude1, 6) And Math.Round(latitudedest, 6) = Math.Round(latitude1, 6) Then
  'Timer1.Enabled = False
  leftright = 3
i = i + 1
j = j + 1
com1.Output("A," & "0," & "0," & "3" & vbCrLf)
Exit Sub
End If
If distance <= 20.0 Then
lefright = 3
i = i + 1
j = j + 1
'Timer1.Enabled = False
com1.Output("A," & "0," & "0," & "3" & vbCrLf)
Exit Sub
End If
If latitudedest > latitude1 And longitudedest = longitude1 Then
If cog1 > 0.0 And cog1 <= 180.0 Then
angletoturn = Math.Round(cog1, 4)
lefright = 0
GoTo output
ElseIf cog1 > 180 Then
angletoturn = Math.Round(360.0 - cog1, 4)
lefright = 1
GoTo output
ElseIf cog1 = 0.0 Then
angletoturn = Math.Round(0.0, 4)
lefright = 2
cm1.Output("A," & "0," & Convert.ToInt16(distance) & "," & "2" & vbCrLf)
Exit Sub
End If
End If
If latitudedest > latitude1 And longitudedest < longitude1 Then
cog2 = 90.0 - angle21
GoTo output
ElseIf latitudedest = latitude1 And longitudedest < longitude1 Then
cog2 = 90.0
ElseIf latitudedest < latitude1 And longitudedest < longitudedest Then
  cog2 = 90.0 + angle21
  GoTo output
End If
ElseIf latitudedest < latitude1 And longitudedest = longitudedest Then
  cog2 = 180.0
  GoTo output
End If
ElseIf latitudedest < latitude1 And longitudedest > longitudedest Then
  cog2 = 270.0 - angle21
  GoTo output
ElseIf latitudedest = latitude1 And longitudedest > longitudedest Then
  cog2 = 270.0
  GoTo output
ElseIf latitudedest > latitude1 And longitudedest > longitudedest Then
  cog2 = 270.0 + angle21
  GoTo output
End If
End If

output:

If cog2 > cog1 Then
  angletoturn = Math.Round(cog2 - cog1, 4)
  leftright = 1
  GoTo outputangle
ElseIf cog2 < cog1 Then
  angletoturn = Math.Round(cog1 - cog2, 4)
  leftright = 0
  GoTo outputangle
ElseIf cog2 = cog1 Then
  angletoturn = Math.Round(0.0, 4)
  leftright = 2
  com1.Output("A," & "0," & Convert.ToInt16(distance) & "," & "2" & vbCrLf)
  Exit Sub
End If

outputangle:

If angletoturn <= 5.0 Then
  com1.Output("A," & "0," & Convert.ToInt16(distance) & "," & "2" & vbCrLf)
  Exit Sub
End If
ElseIf latitudedest > longitudedest Then
  angletoturn = Math.Round(360.0 - angletoturn, 4)
  GoTo outputangle
ElseIf latitudedest < longitudedest Then
  angletoturn = Math.Round(360.0 - latitudedest, 4)
  GoTo outputangle
ElseIf latitudedest = longitudedest Then
  angletoturn = Math.Round(0.0, 4)
  GoTo outputangle
End If
leftright = 1
ElseIf angletoturn > 180.0 And leftright = 1 Then
    angletoturn = Math.Round(360.0 - angletoturn, 4)
    leftright = 0
End If
com1.Output("A," & Convert.ToInt16(angletoturn) & "," & Convert.ToInt16(distance) & "," & leftright & vbCrLf)
textbox1.Text = ("Local Time: " & Decoder.LocalTime & vbCrLf & 
    "Course Over Ground: " & Decoder.CourseOverGround & vbCrLf & 
    "Speed Over Ground: " & Decoder.SpeedOverGround & vbCrLf & 
    "Dec Latitude: " & Decoder.DecimalLatitude & vbCrLf & 
    "Dec Longitude: " & Decoder.DecimalLongitude & vbCrLf & 
    "Angle to turn: " & angletoturn & vbCrLf & 
    "Distance to go: " & distance & vbCrLf & 
    "Left Right: " & leftright & vbCrLf)
Exit Sub
End Sub

Private Sub cmdStartandStop_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles cmdStartandStop.Click
    If cmdStartandStop.Text = "Stop" Then
        cmdStartandStop.Text = "Start"
        'serialpoll.Enabled = False
        Timer1.Enabled = False
    Else
        cmdStartandStop.Text = "Stop"
        'serialpoll.Enabled = True
        Timer1.Enabled = True
    End If
End Sub

Private Sub Timer1_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles Timer1.Tick
    textbox1.Text = ""
    Dim Buffer1 As String = GPSSerial.InputString
    If Buffer1.Length > 0 Then
        Try
            If cmdguidance.Text = "Guidance" Then
                textbox1.Text = Buffer1
            Else
                Decoder.GPSStream(Buffer1)
                Call guidance()
            End If
        Catch
            End Try
    End If
End Sub

Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles Button1.Click
    If OpenFileDialog2.ShowDialog() = DialogResult.OK Then
        Dim sr As New System.IO.StreamReader(OpenFileDialog2.FileName)
        Try
            Dim line As String
            line = sr.ReadLine()
            line = sr.ReadLine()
            line = sr.ReadLine()
            line = sr.ReadLine()
        Catch
            End Try
    End Sub
i = 0
j = 0
Do
    line = sr.ReadLine()
    latdest = Microsoft.VisualBasic.Right(Microsoft.VisualBasic.Left(line, 22), 11)
    longdest = Microsoft.VisualBasic.Right(Microsoft.VisualBasic.Left(line, 34), 11)
    arraylatitude(i) = Convert.ToDouble(latdest)
    arraylongitude(j) = Convert.ToDouble(longdest)
    TextBox2.Text = ("Reading File: Latitude: " & latdest & vbCrLf & "Longitude: " & longdest & vbCrLf)
    TextBox3.Text = (arraylatitude(i) & vbCrLf & arraylongitude(j) & vbCrLf)
    i = i + 1
    j = j + 1
Loop Until line Is Nothing
TextBox2.Text = ("File Read Complete" & vbCrLf)
sr.Close()
Catch 'To let the user know what went wrong.
    'TextBox2.Text = ("This file cannot be opened" & vbCrLf)
End Try
End If
End Sub
Private Sub GPSSerial_OnComm() Handles GPSSerial.OnComm
    Dim Buffer As String = GPSSerial.InputString
    Try
        Decoder.GPSStream(Buffer)
    Catch
    End Try
End Sub
Private Sub cmdDisplay_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles cmdDisplay.Click
    With cmdDisplay
        If .Text = "Raw Data" Then
            .Text = "Decoded Data"
        Else
            .Text = "Raw Data"
        End If
    End With
textbox1.Text = ""
End Sub
Private Sub SerialPoll_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles serialpoll.Tick
    Dim Buffer As String = GPSSerial.InputString
    If Buffer.Length > 0 Then
        Try
            If cmdDisplay.Text = "Decoded Data" Then
                textbox1.Text = Buffer
            Else
                Decoder.GPSStream(Buffer)
(Decoder.DecimalLongitude.ToString) & vbCrLf & "Number of Satellites in Use: " & Decoder.NumberOfSatellites & vbCrLf)
    End If
    Catch
    End Try
    End If
      End Sub
  Private Sub cmdguidance_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles cmdguidance.Click
    If cmdguidance.Text = "Stop Guidance" Then
      cmdguidance.Text = "Guidance"
    Else
      i = 0
      j = 0
      cmdguidance.Text = "Stop Guidance"
      textbox1.Text = " "
    End If
  End Sub
End Class
APPENDIX C: BASIC STAMP PROGRAMS FOR MICROPROCESSOR CONTROL OF ACTUATORS

Basic Stamp to read serial output from PDA

' {STAMP BS2p}
' {PBASIC 2.5}
angle VAR Byte
A VAR Byte
F VAR Byte
turn VAR Word
dist VAR Byte
lr VAR Byte
'5 makes it go right 4 makes it go left
baud1 CON 16884' i4800
anvol VAR Word
deadband CON 1000
right VAR Word
left VAR Word

'neutral 22900,right 6000,left 34900 difference
'20 atv deg -180 pda deg
'1 atv deg = 20 pda degrees
'left- 12000
'right- 17000

'SEROUT 16,baud,["starting",10,13]
DEBUG "starting"
PAUSE 1000

main:
'PAUSE 100
SERIN 11,baud1,3010,nodata,[WAIT("",),DEC turn,DEC dist,DEC lr]
DEBUG ? turn ,? dist,? lr,10,13
HIGH 10 'throttle on
LOW 14' brake off
IF lr=0 THEN
GOSUB leftt
ELSEIF lr=1 THEN
GOSUB rightt
ELSEIF lr=2 THEN
GOSUB neutral
ELSEIF lr=3 THEN
    GOSUB brakethrottlestop
ENDIF
GOTO main

nodata:
DEBUG "no data 
GOTO main

left:
IF turn>=130 THEN
    turn=130
ELSE
    turn=turn
ENDIF
left= 21000+(100*turn)  '90*133=11970~12000
HIGH 14  'brake on
LOW 10  'throttle off
DO  WHILE (anvol)<left
    GOSUB rctimer
    IF (anvol+deadband)>34000 THEN
        LOW 4
        LOW 5
    ENDIF
    IF (anvol<34000)AND (anvol<left) THEN  ' present position is  right of desired position
        LOW 5
        HIGH 4
    ENDIF
    IF (anvol < 34000) AND (anvol> left) THEN   'present position left of desired position
        LOW 4
        HIGH 5
    ENDIF
    LOOP
    LOW 14  'brake off
    HIGH 10  'throttle on
    PAUSE 4000
    HIGH 14  'brake on
    LOW 10  'throttle off
    GOSUB neutral
    GOTO main

'PAUSE 100
'LOOP UNTIL (anvol+100)>left AND (anvol-100)<left
'GOSUB neutral
right:
IF turn>=130 THEN
  turn=130
ELSE
  turn=turn
ENDIF
right=21000-(100*turn)
HIGH 14 'brake on
LOW 10 'throttle off
DO WHILE anvol<>right
  GOSUB rctimer ' 
  IF (anvol-deadband<8000) THEN
    LOW 4
    LOW 5
  ENDIF
  IF (anvol>8000) AND (anvol>right) THEN
    "desired position is left of current position
    LOW 4
    HIGH 5
  ENDIF
  IF (anvol>8000) AND (anvol<right) THEN
    "desired position right of current position
    LOW 5
    HIGH 4
  ENDIF
  LOOP
LOW 14 'brake off
HIGH 10 'throttle on
PAUSE 4000
HIGH 14 'brake on
LOW 10 'throttle off
GOSUB neutral
GOTO main
neutral:
DO WHILE anvol<19500 OR anvol>21500
  GOSUB rctimer
  IF (anvol > 19500) AND (anvol < 21500) THEN
    LOW 4
    LOW 5
  ENDIF
  IF (anvol>19500) THEN
    HIGH 5
    LOW 4
    PAUSE 100
  ENDIF
  IF (anvol<19500) THEN
    HIGH 4
    LOW 4
    PAUSE 100
  ENDIF
  IF (anvol<21500) THEN
    HIGH 4
    LOW 4
    PAUSE 100
  ENDIF
  IF (anvol<21500) THEN
    HIGH 4
  ENDIF

LOW 5
ENDIF
LOOP
RETURN

brakethrottlestop:
HIGH 14
LOW 10
PAUSE 5000
GOTO main

rctimer:
HIGH 0
PAUSE 1
RCTIME 0, 1, anvol
RETURN

Basic Stamp to set steering position for testing

' {$STAMP BS2p}
' {$PBASIC 2.5}
angle VAR Byte
A VAR Byte
F VAR Byte
turn VAR Word
dist VAR Byte
lr VAR Byte
'5 makes it go right 4 makes it go left
baud1 CON 16884' i4800
anvol VAR Word
deadband CON 1000
right VAR Word
left VAR Word

main:
PAUSE 100
LOW 4
LOW 5
turn= 20
GOTO neutral

END
left:
IF turn>=20 THEN
  turn=20
ELSE
  turn=turn
ENDIF
left= 21000+(600*turn)  '600* 20 makes 12000 we dont want 12000 so deadband of 2000
DEBUG?left
GOSUB rctimer
IF (anvol+deadband)>34000 THEN
DEBUG "main",CR
GOTO main
ENDIF
IF (anvol<34000)AND (anvol<left) THEN  ' present position is right of desired position
  LOW 5
  HIGH 4
ELSEIF (anvol < 34000) AND (anvol> left) THEN  'present position left of desired position
  LOW 4
  HIGH 5
ENDIF
GOTO main
'PAUSE 100
'LOOP UNTIL (anvol+100)>left AND (anvol-100)<left
'GOSUB neutral

right:
IF turn>=20 THEN
  turn=20
ELSE
  turn=turn
ENDIF
right= 21000-(600*turn)  'we need 17000 so 800 * 20 but dead band 2000 so 750 * 20 gives 15000
GOSUB rctimer
IF (anvol-deadband<8000) THEN
DEBUG "main",CR
GOTO main
ENDIF
IF (anvol> 8000) AND (anvol>right)THEN  "desired position left of right
  LOW 4
  HIGH 5
ELSEIF(anvol>8000)AND (anvol < right)  THEN  'desired position right of right
  LOW 5
  HIGH 4
ENDIF
GOTO main
'PAUSE 100
'LOOP UNTIL (anvol+100)>right AND (anvol-100)<right
'GOSUB neutral

neutral:
LOW 4
LOW 5
'DO
GOSUB rctimer
IF (anvol > 19500) AND (anvol < 21500)  THEN
  LOW 4
  LOW 5
ELSEIF (anvol>19500) THEN
  HIGH 5
  LOW 4
  PAUSE 100
ELSEIF (anvol <21500) THEN
  HIGH 4
  LOW 5
ENDIF
'PAUSE 100
'LOOP UNTIL (anvol > 19000) AND (anvol < 22000)
GOTO main

brakethrottlestop:
HIGH 14
LOW 10
PAUSE 5000
GOTO main
'GOTO brakethrottlestop

rctimer:
HIGH 0
PAUSE 1
RCTIME 0,1,anvol
DEBUG CLS,DEC anvol
RETURN
VITA

Goutam Jagannadha Nistala was born on March 7, 1982, in Visakhapatnam, Andhra Pradesh, India. He graduated from High School in April 1998. He received a degree in Bachelor of Technology in Electrical and Electronics Engineering from Jawaharlal Nehru Technological University, Hyderabad, India, in April 2002. He started his graduate studies at Louisiana State University, Baton Rouge, Louisiana, in January 2003. As a master’s student he served as a research assistant to Dr. Randy R. Price. His research interests are robotics, and sensors.