Aircraft Instrumentation Based On GPS

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May 7, 1999

Abstract

This project involves implementing a backup instrumentation system for civil aircraft based on the Global Positioning System (GPS). The project interfaces a laptop computer and a GPS receiver in order to provide a pilot with 6 virtual instruments: an altimeter, an airspeed indicator, a VOR receiver, an ADF receiver, a DME receiver, and a compass. The project also includes a course tracker. Labview 4.0 Professional Edition is used to implement the instruments on the laptop.

Introduction

Aircraft pilots currently use a variety of navigational systems during the course of their flight. Each navigational system is comprised of a ground station and a receiver installed in the aircraft. Pilots rely on the accuracy of their navigation equipment to safely fly from their departure point to their destination. These navigational aids allow them to plan their flight routes and to maintain the planned route, therefore preserving safety in the air. With the aid of these navigational systems, pilots can fly safely in adverse weather conditions.

Navigation Systems

Though pilots have a wide range of navigational systems to employ, most pilots tend to rely on following primary navigational instruments systems: Very high frequency Omnidirectional Radio (VOR), Distance Measuring Equipment (DME), and Non Directional Beacon (NDB). During Instrument Flight Rules (IFR), in which pilots navigate completely using instruments, pilots depend on the accuracy of the functionality of these navigational systems. Each system operates independently, with its strengths and weaknesses. Using a combination of all three systems allows pilots to navigate with precision.

However, partial or total failures of these systems can result in severe consequences for the pilot, including becoming disoriented or accidents. The systems can fail if either the on-board receiver in the aircraft fails or if the ground station component fails.

To reduce the risk of flying during instrument system failures, many pilots prefer to install secondary navigation systems. With the evolution of the Global Positioning System (GPS), many pilots have begun to use GPS receivers as secondary navigation instruments. Current Federal Aviation Administration regulations prohibit the use of GPS receivers as primary navigation instruments.[i] However, GPS receivers are approved only as supplemental navigation instruments provided that at least one other instrument flight approved instrument is available and operational in the aircraft.

Aviation applications of GPS are currently under in-depth studies by the FAA. The FAA has already approved the use of GPS for non-precision approaches.[ii] GPS, which is operated by the Department of Defense (DOD), is being explored as a possible replacement for current navigational systems including VOR, NDB, DME, and a few others. It is feasible that GPS will become a primary navigation method by 2010. Before comparing GPS with traditional systems, a brief description of VOR, NDB, and DME necessary.

VOR is a ground-based navigational system. It operates by transmitting two very high frequency signals. The first signal is used as a reference signal towards magnetic north. The second signal rotates 360 degrees around the VOR station, producing 360 radials separated by 1 degree. VOR receivers use both signals to determine which radial the aircraft is on. One of the advantages of using VOR is that the transmitting and receiving equipment is inexpensive. VOR is also a passive system, therefore allowing an unlimited number of simultaneous users. However, VOR has the following limitations:

- 100 nm range above 5000 ft[iii]
- 200 nm range above 20,000 ft[iv]
- line of sight[v]
- requires 2 VORs to determine position[vi]
- +/- 4 degree accuracy for radial on ground[vii]
- +/- 6 degree accuracy for radial in air – 20 nm error possible[viii]

Therefore, VOR is not accurate when used alone.

To increase the accuracy of navigation with VOR, DME is often used in conjunction with VOR. DME requires a transmitter and receiver in both the aircraft and the ground station. It is an active system that operates on ultra-high frequency (UHF) signals. The system operates by transmitting paired pulses from the airborne transmitter/receiver. The ground station responds with by transmitting paired pulses. Comparing the time interval between the two pairs of pulses, the DME unit is able to calculate the slant range from the airborne unit to the ground station. DME is quite popular because it is simple and accurate to within 3%.[ix] DME also has a line of sight requirement.[x] Finally, DME has engineered integrity that causes the signal to be disabled within 10 seconds of detecting an out-of-tolerance condition.[xi]

The final system often relied upon by pilots is NDB. The NDB system operates on low frequencies and medium frequencies. It is composed of a ground transmitter and an airborne receiver. The ground transmitter transmits signals in all directions from the station. The airborne receiver determines the bearing to the transmitting station. This system is severely affected by atmosphere conditions, including ionosphere conditions and atmosphere degradations.[xii] Though not as accurate as VOR, the ground based equip is inexpensive to install, operate, and maintain.[xiii]

VOR, NDB, and DME all rely on ground based stations. GPS, however, relies on a network of satellites. The GPS system is comprised of 24 satellites in orbit, with an additional 3 spare.[xiv] In order to determine position accurately, the GPS receiver uses 4 satellites to “triangulate” the position of the receiver in reference to latitude and longitude.[xv]

GPS has several disadvantages that must be considered. A major disadvantage is that GPS satellite signals are affected by forests, behind rocks, in buildings, therefore limiting the accuracy of the receiver in these situations.[xvi] Aircraft, however, usually fly at altitudes above these situations so this is a minimal problem. A main disadvantage of GPS is that it could fail without warning since it does not have integrity testing.[xvii] The DOD, however, is considering revising its design of GPS to allow a warning for out-of-tolerance conditions. Another problem is that it is possible for GPS to be jammed. The Air Force is conducting studies for anti-jamming devices for GPS, so GPS jamming is currently not a problem.[xviii] Finally, GPS is the only navigation system that the United States President can suspend at any time for national security concerns.[xix]

GPS, however, has several advantages over the other navigational systems. The military mode of GPS is accurate to 1 meter while the civilian mode is accurate to 15 meters-100 meters.[xx] An additional supplementary system to GPS, Differential Global Positioning System (DGPS), allows the civilian mode to be accurate from 2cm-5m (0.79 in-16.4 in).[xxi] GPS is a passive system, therefore allowing any number of simultaneous users. The accuracy of GPS is not affected by weather or other atmospheric conditions. GPS receivers are relatively inexpensive compared to the costs of other navigational equipment. Also, GPS removes the restriction of navigating using established ground stations since "pseudo-stations", or waypoints, could be created. This permits transoceanic navigation and cross-country flying.

Currently, there are a number of GPS receivers designed for aviation applications. Expensive GPS receivers targeted toward aviation have virtual VOR trackers, virtual Vertical Navigation (VNAV), virtual Auto-Direction Finders (ADF), virtual Horizontal Situation Indicators (HSI), maps, airport/facility directories, trip planners, trip simulators, and weight and balance planners. These receivers, however, have several limiting disadvantages:

- No built in position tracking
- Display only one function at a time
- Expensive
- Menu driven
- Limited number of waypoints
- Complexity of use during flight
- Limited size display screen

General Project Requirements

Pilots place a great emphasis on instruments for instrument flight. There are several vital instruments that a pilot needs during instrument flight. From these vital instruments, a pilot is able to derive all necessary information for navigating safely under instrument flight conditions. The goal of the project is to provide secondary systems for all vital instruments.

To provide the pilot with adequate information for instrument flight navigation, it is necessary to replicate at least one instrument from the three major navigation systems that pilots usually rely upon. Therefore, VOR receivers and DME receivers would need to be implemented for the VOR and DME systems. For the NDB system, it is necessary to implement an Automatic Direction Finder (ADF) receiver. To further aid the pilot in instrument flight, it is necessary to replicate three other vital flight attitude instruments: an altimeter, a compass, and an airspeed indicator. An altimeter displays altitude, a compass displays heading, and an airspeed indicator would indicate the airspeed. Therefore, a total of six virtual instruments are required. Failure of any of these vital components results in degraded flight performance since the pilot lacks crucial flight information.

There are a number of ways that navigation instruments can fail. Electrical situations, including fires, short circuits, and blown fuses can cripple all of an aircraft's navigation instruments simultaneously. The weather and nature (ionosphere changes) can affect the performance of certain instruments. Finally, ground station transmitter/receiver failures can temporarily cripple certain instruments.

Most civil aircraft counter on-board instrument failure by implementing dual vital instruments. However, this does not address the problem of weather and natural effects on navigation instruments. Further, failure of ground stations cannot be circumvented.

Due to dependence on navigation systems by pilots, a suitable independent backup navigation system is required. To enhance the portability of such a system, it should operate completely independent of all other primary navigation systems on-board the aircraft. The solution should target civil aviation, with a possible application in commercial aviation. Since pilots operate under time constraining conditions, the backup system needs to be user friendly and simple to use. The backup system also should be portable, with easy installation, therefore allowing pilots to quickly and easily change aircraft. The system should allow the pilot to assimilate easily, without requiring extensive training. Therefore, it is necessary to design the system so that it reflects current navigation instruments, resembling those that the pilot relies on traditionally.

Since this system is targeted towards civil aviation, the overall weight of the system should be minimized due to the strict weight restrictions for civil aircraft. The size of the system is also a factor since most civil aircraft have strict limitations on available space.

The system also needs to be durable and reliable. It would be preferred if the system operates completely independently, even with its own power supply, therefore not to have any impact or to be impacted by current avionic equipment in the aircraft.

The system should also have a built in mechanism for testing it on the ground and for simulation. This allows pilots to verify their flight plans and to acquaint themselves with the system before flights.

Finally, the system should be designed so that it can be updated while minimizing the amount of hardware replaced. The system should also allow pilots to customize its various aspects. This includes the display methods as well as the navigation information such as waypoints, frequency changes, new navigation stations, deletion of navigation stations.

Theoretically, the pilot should be able use the backup instrument system to fly completely using the virtual instruments, without any reliance on traditional cockpit instruments.

Design Solutions

There are several solutions that can be employed for this project.

One possible solution involves altering current aircraft navigation instruments so that they are fully independent. This solution involves installing clones of existing navigation instruments. The clones would be powered by batteries and have their own antennas, making them completely independent of the aircraft's systems. An advantage is that the pilot will be using instruments exactly the same as the aircraft's primary navigation instruments. However, this solution has several limitations. It requires purchasing dual instruments, each of which costs thousands of dollars. Also, this system provides no backup if the VOR, NDB, or ADF ground systems fail. The small size of civil aviation aircraft is also a limiting factor since these clones would occupy considerable amount of space. Installing these clones would lead to a substantial increase in the aircraft's weight, therefore reducing the amount of passenger/cargo weight the aircraft can carry. Further, the clones would not enhance the aircraft's current navigation since waypoints and course tracking would still be unavailable.

Another solution would be to rely on a handheld GPS receiver which has all the built in requirements. This solution relies on existing equipment and involves no design. These units are approximately $600, therefore quite inexpensive compared to the previous solution. However, each unit can only display one function or virtual instrument at a time. This unit relies solely on GPS and therefore is not affected by ground system failures. Pilots require various navigation data to be presented simultaneously. Further, the concentration levels required for safe instrument flights limit the amount of time pilots can be distracted while they configure and adjust virtual instruments. This solution would require too much time and complexity for a pilot to use. In order for a pilot to simultaneously view navigation data, it would be necessary to use one GPS receiver unit to display each virtual instrument. There are approximately six vital navigation units, therefore costing approximately $3600. This solution is not economical or space conservative for the typical civil aviation pilot.

Final Design Solution

The final design solution is to interface a standard laptop computer with a GPS receiver. Using Labview Professional Edition 4.0 software, the virtual navigation instruments can be created. Labview is used to create an environment which can simulate the necessary instruments even though the GPS receiver may not have the built in virtual instruments.

After reviewing the advantages and disadvantages of each system, it was decided to implement the laptop and GPS receiver configuration.

Advantages

Preliminary analysis of this solution indicates that it has several advantages. This backup system does not require much training for the pilot. Its fully independent backup ability gives the pilot confidence in instrument flying. The system can be extremely useful in conditions where other ground-based navigation systems are scarce such as cross country flying, transoceanic flying, Alaska. Further, the system could be quickly activated in an emergency situation with very little configuration needed. This system will also allow pilots to accurately locate areas which have no other navigation beacons including airports without VORs and private runways. With this system available, precision flight is available at all times. Further, the system will minimize the amount of time required for setting and changing the GPS unit, allowing the pilot to concentrate on flying the aircraft. The combination of the GPS unit and a laptop will be far more superior than a stand alone GPS unit since it will allow the pilot to view all instruments at once. The system will not require in-flight instrument calibration which traditional instruments required due to their sensitivity to temperature, air pressure, and magnetic drift. Finally, the system will allow easy upgrading of the GPS interface with minimal changes to the overall system.

A laptop can also be used for other non-navigation tasks, including administrative tasks. This further increases the usefulness of the project outside the cockpit.

Disadvantages

This implementation has a few disadvantages that must be considered. The laptop may require several minutes to power up and initialize itself. However, this could be minimized if the laptop is constantly operated in "standby" mode. Further, the laptop's battery and the GPS receiver's battery will require charging before use.

Some of the disadvantages are not specific to this implementation, but rather to the GPS navigation system. GPS signals are difficult to receive in forests, behind mountains, or inside buildings. Aircraft, however, do not normally fly under such conditions so this is a minor problem.

During a national emergency, the President of the United States has the power to disable the GPS system. Further, the reliance on the Department of Defense (DOD) can also be considered a disadvantage since it involves adhering to standards set by the DOD. Satellite failure is not a common problem, but should be able to be corrected by most GPS receivers since they usually have 5 satellites in view at a time. The dependency on GPS standards would require only the receiver of the laptop to be updated, not the laptop component. Finally, there is some concern over the possibility of GPS jamming. Hardware is currently in its final developmental stage for anti-GPS jamming.

Project Methodology

The main purpose of the project is to develop an independent backup system for vital navigation instruments. This can be accomplished by interfacing a laptop computer to a GPS receiver. This combination will reduce the disadvantages of current GPS receivers with the aid of software on the laptop. This design will also create a fully independent backup system for pilots since the laptop and GPS receiver are completely separate from all other avionics equipment and rely only on GPS. To allow portability and installation ease, the laptop computer will be used to display the virtual instruments. Therefore, GPS data will be used to update the virtual instruments, resulting in a virtual representation of all three major navigation systems.

Project Overview

The project can be separated into three main components:

GPS receiver unit
GPS receiver interface to the laptop
Virtual instrument representation on the laptop

The GPS receiver is a battery operated device that uses GPS to determine the latitude and longitude position of the receiver. The GPS receiver must have the capability to transfer data from the unit to a PC interface.

The GPS receiver interface allows the GPS unit to communicate with the laptop. Kits exist for this component, therefore no design is required.

The final component is the virtual instrument representation on the laptop. This is implemented using software and is the main design component of the entire project.

Virtual Instrument Implementation

For this project, the virtual instruments will be implemented using software. There are several ways to implement these instruments. It is possible to create a C or C++ program to display each instrument. However, this method is quite extensive and would be considerably difficult and time consuming.

A more efficient solution would be to use an existing software package. After reviewing a number of software packages, it was decided that National Instruments' Labview would be the best platform for this project.

Labview is a Windows based program that is often used by scientists. It allows modeling of scientific instruments for experiments. The program allows the user to create virtual instruments using modular designs, including an extensive library of functions. These virtual instruments can be used to collect, monitor, analyze, store, and retrieve data. The program also allows data to be transferred using a standard, RS-232 serial connection found on most PCs. Therefore, the program allows complete control of an experiment through Labview.

Since Labview supports modular design, it was decided to employ modular design for implementing the virtual instruments. In order to allow a quick visual transition from the aircraft's instruments to the virtual cockpit, it was decided to setup the virtual instrument panel so that it resembled the instrument panel in most civilian aircraft. Therefore, the following instruments would be implemented:

- 2 VORs
- ADF
- DME
- Altitude
- Compass
- Airspeed Indicator

To aid the pilot in in-flight and post-flight analyses, it was decided to implement an aircraft position tracker which would display the path the aircraft has flown.

To aid in testing purposes, the project should have two modes: simulation mode and GPS mode. In simulation mode, the project will use data inputted from the keyboard to simulate operation of the project. Therefore, the project can be tested extensively on the ground to verify that all components are behaving correctly. This allows simulation of the project. This simulation mode can be used by pilots to verify the accuracy of their flight plans. Pilots can also use the simulation mode to get acquainted with the system.

The GPS mode will be used when the system is used in flight since this mode relies on the GPS receiver unit to provide position data.

Therefore, the project can be broken down into the following modules:

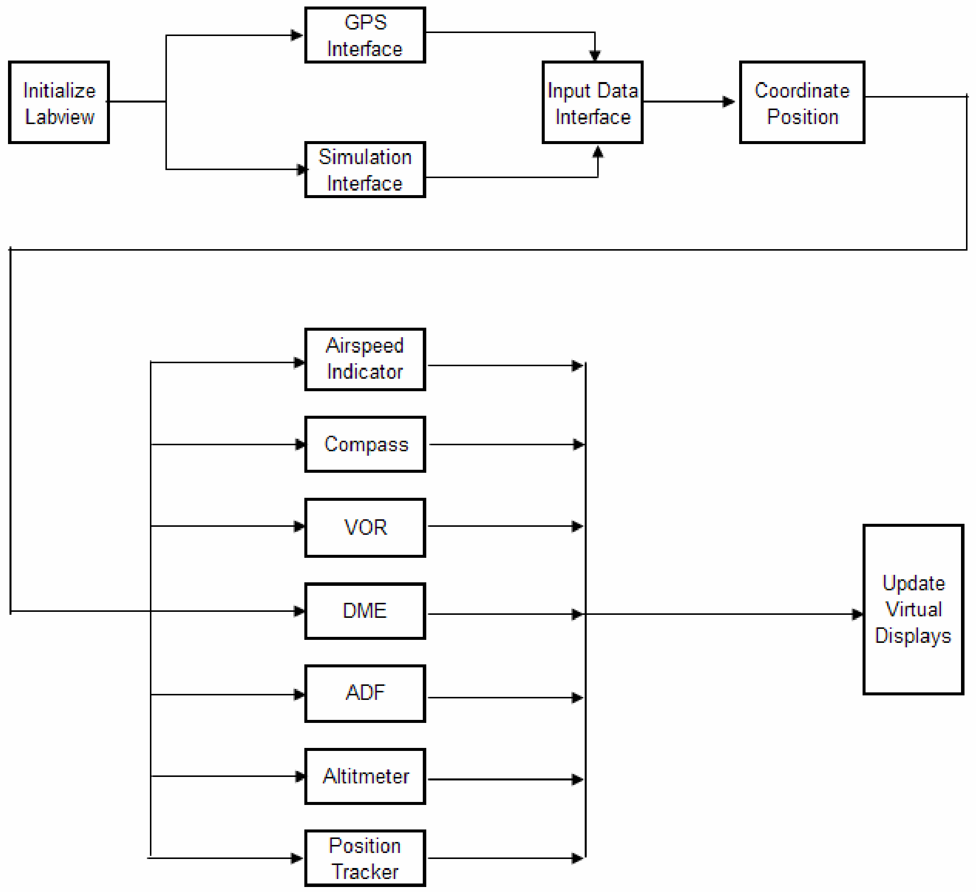
- Initialize Labview
- GPS Mode Interface
- Simulation Mode Interface
- Input Data Interface
- Coordinate Conversion (from latitude/longitude to Cartesian)
- 2 VORs
- ADF
- DME
- Altimeter
- Compass
- Airspeed Indicator
- Position Tracker

- Virtual instrument display
- Database files

Using a modular design allows better testing, debugging, and troubleshooting technique. Also, this modular design makes division of the project more feasible among the team members. Figure 1 contains a diagram for the data flow of all modules.

It was decided to implement the virtual instruments separately into subpanels. Each subpanel will operate independently of the other instrument subpanels. This allows testing and optimization of each sub panel. Further, depending on future pilot needs, instruments can be added or subtracted as necessary. Finally, after all the subpanels have been tested, they will be interfaced together.

Figure 1 - System Level Data Flow Diagram



Module Description

Initialize Labview

This module performs all necessary initializations for Labview. This includes setting variables to initial values and ensuring that the system is ready.

GPS Mode Interface

This module is enabled when the system is operated in GPS mode. This module gathers data from the laptop's RS-232 serial port and converts the aircraft's position obtained from the GPS receiver to a longitude, latitude, altitude, and time format that Labview will be able to interpret. This module will also determine the effects of a null connection to the RS-232 port in order to simulate a disabled/disconnected GPS receiver.

Simulation Mode Interface

This module is enabled when the system is operated in Simulation mode. This module allows the user to fly a simulated flight. The user is then able to verify the accuracy of flight plans as well as to practice navigation techniques. The mode requires the user to input initial aircraft position, initial airspeed, and initial altitude to establish the initial conditions. Once these initial conditions have been set, the system is ready for simulation. The module then allows the user to vary throttle levels (fast/slow), bank angles (left/right), and elevator angles (up/down) to simulate an actual flight. The module uses this data to calculate the aircraft's position in terms of longitude, latitude, altitude, and time. This information can be used by the other modules.

Input Data Interface

The module allows the user to choose the desired operation mode: Simulation or GPS. If the user chooses the Simulation Mode, the module then enables the Simulation Mode Interface module while disabling the GPS Mode Interface module. If the user chooses the GPS Mode, the module then enables the GPS Mode Interface module while disabling the Simulation Mode Interface module.

Coordinate Conversion

This module converts latitude and longitude coordinates into 3-D Cartesian coordinates. This allows other Labview modules to use 3-D Cartesian coordinates. The module accomplishes this by using translation equations based on the Earth's shape and geodetic equations.

VOR

This module determines all necessary information concerning VOR navigation. This module allows the user to select the frequency for a VOR station from the VOR Database File. It also allows the user to input the desired OBS setting, which indicates the radial to be tracked. It then searches the database file for the selected VOR and extracts all necessary information. It then uses this information in conjunction with coordinate information to determine the VOR indicator information for the VOR needle displacement. It also determines whether the OBS setting indicates a radial TO or FROM the VOR station.

ADF

This module uses the same inputs as the VOR module. This module allows the user to select the frequency of a NDB station from the ADF Database File. The module then searches the database file and retrieves all necessary information. This module then determines the bearing toward the NDB.

DME

This module also uses the same inputs as the VOR module. Using the VOR frequency, this module uses the VOR station information to determine the distance from the aircraft to the VOR station. This module can display the distance in nautical miles, statute miles, or kilometers.

Altimeter

This module uses the altitude from the Input Data module to calculate the altitude in feet. This information is then displayed to the pilot. This module relies on the altitude data from the GPS receiver. Note that GPS receiver manufacturers do not advise use of the GPS receiver’s altitude data because of the lack of its accuracy. However, since this system is for use in navigation, where altitude accuracy is not as crucial as landing requirements, it is permissible to use the GPS receiver’s altitude data since its accuracy is tolerable to the FAA’s vertical separation requirements.

Compass

This module requires data for two positions of the aircraft and the time that elapsed between the two positions. This data is obtained from the Input Data module. Using the two positions, the module then computes the aircraft's heading according to true North. However, to calculate magnetic heading, the module uses the true North heading and factors in a magnetic deviation factor, which varies depending on the location on the earth.

Airspeed Indicator

This module also uses two positions and the time elapsed between them. This data is then used to determine the distance traveled during the time interval. This speed is then converted to nautical miles.

Position Tracker

This module requires the aircraft's position and time in order to create a graph indicating the aircraft's track. The module also stores all collected data in a tracking file.

Virtual instrument display

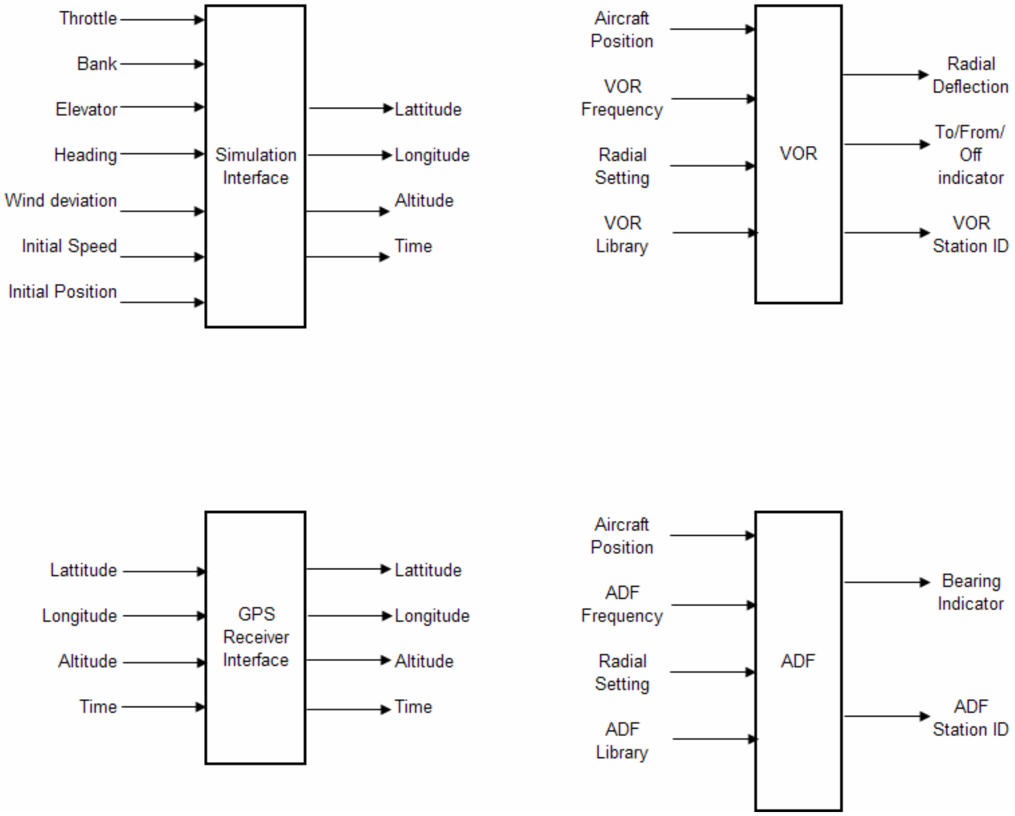
The goal of this module is to create virtual representations of the vital instruments. This module relies on data from the other modules. No calculations are carried out in this module. Only organization and formatting of data is performed.

Database Files

The simulation will require the use of several database files: ADF database and VOR database. Both database files will contain information concerning ground stations. Both file will contain the following information about the ground stations: station name, frequency, latitude, longitude, and magnetic deviation. Since VOR and ADF stations are parts of different systems, it was decided to keep these two files separate. Also, using separate files will allow faster searching and loading since the files will be smaller.

Figures 2a and 2b illustrate the input and output requirements for each module.

Figure 2a - Module Diagrams



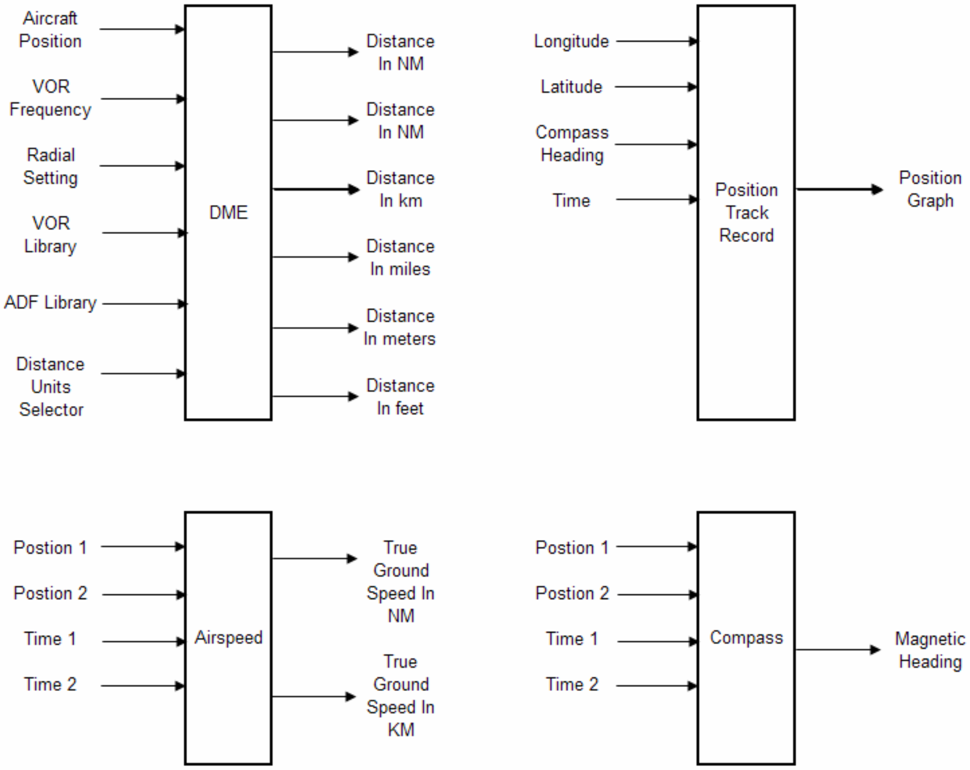


Figure 2b - Module Diagrams

Implementation Overview

To ensure completion of the project by the target date, the implementation portion of the project was begun in the beginning of December 1998, almost two months ahead of the timeline specified in the proposal. The team's first task was to gain a basic understanding of Labview's tools and methods. Once a basic understanding of Labview was achieved, the team implemented simple functions for coordinate conversions and metric conversions as practical examples in Labview. Full-scale implementation of the project began on December 15, 1998.

Implementation Methodology

Initially, a design review was conducted on the project to reevaluate the original implementation suggested by the project proposal. Analysis revealed that implementation of the project could be partitioned into three components:

<u>Input Data Interface</u>
Instrument Calculations/Processing
Instrument Output Displays

The Input Data Interface would contain the GPS Interface and the Simulation Interface. The Instrument Calculations/Processing would perform all necessary calculations for each of the instruments. Finally, the Instrument Output Display would display the information.

All three portions were ranked according to feasibility and dependence. It was decided to implement the Instrument Calculations/Processing first due to its estimated complexity and since it will be the basis of the project.

Further analysis revealed that all the instruments had two main calculations in common: the distance between two points and the course between two points (in reference to magnetic North). The various data presented by each instrument involves using these two calculations. Therefore, the accuracy of these instruments would depend on the accuracy of these two calculations.

It was decided to prototype possible equations for these two calculations in Microsoft Excel before implementing in them in Labview. Excel was used as the prototyping mechanism since we were more familiar with it than Labview. Also, the results generated by using Excel could be used as a benchmark for verifying the equations in Labview. Our familiarity with Excel would reduce the amount of error and time spent attempting to implement prototypes. Once we had obtained working equations, we were then able to begin implementing the instruments.

The six instruments to be implemented were divided into two groups:

Static - VOR, DME, ADF, Track Record
Dynamic – Airspeed Indicator, Compass, Altimeter

Static instruments represented instruments whose data could be calculated using two static positions. VOR, DME, and ADF required the position of the station and the aircraft's current position. The Track Record is simply a record of the aircraft's current position over time.

Dynamic instruments, however, required two positions to calculate their data. Airspeed, Compass, and Altimeter are dependent on the aircraft's current position and on the aircraft's previous position, which will be used as a reference. In reality, the Compass depends on magnetic fields to detect Magnetic North. In reality, the Airspeed Indicator and Altimeter use pressure and motion for their measurements. However, emulating these instruments on a computer requires two position measurements.

DME was the first instrument to be implemented since it was a direct application of the distance calculations. Though usually found only in conjunction with VOR stations, it was decided to also allow DME to be used in conjunction with ADF stations.

The team then decided to implement the VOR instrument since it contained many features and appeared to be the most complex instrument. The VOR instrument was built incrementally, adding one feature at a time and testing that feature completely. Many of the functions created for the VOR instrument would be reused for other instruments. Therefore, each function required extensive testing to prevent migration of any problems to other instruments. During the testing of the VOR instrument, the Simulation Mode module emerged as a necessity for verifying the correct operation of the instrument during flight. Eventually, data file capabilities were added to the VOR instrument to simplify the amount of data entry required for testing the VOR instrument.

The Simulation Mode module, which began as a test platform for the VOR instrument, gradually grew as more features were implemented. The module initially began as a simple module capable of calculating a new position at a specified distance along a course. The Track Record was implemented to verify the correct operation of the Simulation Mode module. The Track Record was instrumental in debugging the Simulation Mode module since the Track Record presented a visual, graphical representation of the calculations performed by the Simulation Mode module. The Simulation Mode module was then altered to simulate the aircraft's position based on data provided by the user.

The Track Record was implemented as an x-y graph for the aircraft's position. Longitude was graphed on the x-axis and latitude was graphed on the y-axis.
The ADF instrument was then implemented to complete all the static instruments. The ADF instrument was originally designed to use the same calculations as the VOR instrument representing the course from the aircraft to the station. However, this

assumption was later proved to be invalid. The ADF instrument had to be reclassified as a dynamic instrument since it depended on the aircraft's heading, which is displayed by the Compass.

With the completion of the static instruments, the dynamic instruments were then implemented. The Compass was implemented next since it was a direct application of the calculations for the aircraft's course between two positions. The Airspeed Indicator was implemented as a direct application of the distance between two reported positions of the aircraft.

The Altimeter was the last instrument to be implemented. Though easily implemented for Simulation Mode, the GPS Mode implementation was delayed until implementation of the GPS interface was complete.

The GPS interface was initially to be constructed using third-party software capable of reading the data from the GPS unit. Research on the Internet provided a number of different utilities for reading data from the GPS unit. However, none of these would allow transferring the data in real-time from the GPS unit to Labview. All the utilities could read data from the GPS unit and store it in a file. Additional research was necessary to find a method for designing an interface that could read data directly from the GPS unit.

Once the GPS interface was attached to the rest of the project, the project was now ready for final testing.

Testing Methodology

The project's testing strategy could be separated into several classes:

Simulation - stationary
Simulation - moving
GPS Mode - stationary
GPS Mode - moving (on-ground)
GPS Mode - moving (flight)

Simulation testing in stationary positions was conducted by setting only the initial position of the Simulation Controls. All other controls were set to 0. Measurements would then be taken for various different stations along specified flight routes. These measurements were then compared to measurements on high altitude flight maps. To reduce the amount of error introduced by distance and course calculations on the flight maps, only routes that were documented on the maps were used for testing. Simulation testing in moving positions was conducted in a similar manner.

To test the GPS Mode in stationary positions, the project was tested with the GPS unit active and at rest. The GPS unit and project were set to track various VOR stations in order to establish a correlation. A tape recorder was used to data log the measurements from both sources. The GPS Mode was then tested on the ground with moving positions by activating it in an automobile. The automobile was driven at various speeds on roads with varying curvatures and grades. The data produced by the project was directly compared to the data displayed by the GPS unit. Theoretically, all faults in the project should have been discovered before the completion of this stage.

The final testing of the project in GPS Mode was scheduled to be performed in a civilian aircraft departing from Palo Alto regional airport. Due to unforeseen circumstances regarding obtaining the aircraft, the flight testing of the project had to be cancelled and could not be completed.

Problems Experienced

Throughout the implementation of the project, it was necessary to develop methods to overcome a number of problems. Two major problems that were apparent from the onset of the implementation phase were the derivation of the equations for Geodetic calculations and the interfacing of the GPS unit to the computer.

Geodetic Calculations

The implementation of the project required many different calculations. However, all the navigational functions of the project could be derived using two fundamental calculations. These calculations involved using Geodetic coordinates, latitude and longitude, to calculate the distance and course between two positions. An additional consideration was that aircraft navigational instruments reference Magnetic North, not True North.

Initially, the project was implemented by converting Geodetic coordinates to Cartesian coordinates. Cartesian formulas, though simple and easily available, proved to be highly inaccurate for this application with percent errors well above the 10% target level.
An alternative to converting to Cartesian coordinates was to convert from Geodetic coordinates to spherical coordinates. This alternative would allow use of previously derived equations in the spherical coordinate system since more extensive mathematics research has been done the spherical coordinate system that the Geodetic system. However, the equations of the spherical coordinate system can be complex and valid only for certain conditions due to their complexity and reliance on the sine, cosine, and tangent trigonometric functions. Prototypes for spherical coordinate equations also resulted in highly inaccurate values. It appeared necessary to derive equations that would be specific to this application.

Another possibility seemed to be to derive new equations. However, deriving new equations tends to introduce further experimental errors. Also, extensive testing of newly derived equations would be required before they could safely be used.

In an attempt to avoid deriving new equations, research was conducted on the Internet. An article on Geodetic systems and Geodetic equations was discovered, written by Ed Williams. The article explained the basics of the Geodetic coordinate system as well as the Great Circle Navigation, the method used in aviation for navigating. The article also included the necessary equations for calculating distance and the course between two points. Verification of Williams' equations using Excel indicated that solutions for the two fundamental formulas had been found. Williams' equations were implemented and verified to be accurate.

However, using Williams' equations forced us to follow Williams' orientation for latitude and longitude representations. Latitude was represented as the North-South angle of a position in relation to the Equator. Latitude could only have a range of ±90 degrees. Positive latitude referred to the Northern Hemisphere and negative latitude referred to the Southern Hemisphere. Longitude was represented as the East-West angle of a position in relation to the Prime Meridian. Longitude could only have a range of ±180 degrees. Positive longitude referred to the Western Hemisphere while negative longitude referred to the Eastern Hemisphere.

GPS Interface

Another major problem faced was interfacing the GPS unit to the laptop. It did not appear necessary to design any hardware for interfacing the Garmin GPSMAP195 to the laptop since the GPS unit has an accessory to interface it to an RS-232 serial port. However, retrieving the position information from the unit was the challenge.

Previous student projects at San Jose State University had utilized third-party software to download the position data from the GPS unit. The program used, PCX5AVD, was a utility program developed by the GPS unit's manufacturer, Garmin. This utility is capable of reading data previously saved on the GPS or real-time data. The data can then be stored in a file. Previous projects used this utility to save data to a text file. The text file could later be opened and used by their programs. However, the goal of this project is to provide a pilot with a real-time instrument panel backup system. Therefore, it is necessary to obtain the current position data from the GPS in real time. Using this utility, it was attempted to simultaneously write data to the file and have the GPS project access the file. This method failed since the nature of the operating system makes this virtually impossible.

One possibility investigated was to read the position data directly from the GPS unit via the serial port, without the intervention of a third party software. We were able to obtain a copy of the Garmin Interface Specification. Examination of this specification indicated that the Garmin Interface is focused on data transfers by sending commands and retrieving responses. Also, the data is transferred using the Garmin format, not ASCII. Though this method appeared to be feasible, the Garmin Protocol's complexity was intimidating due to the strict requirements for timing of commands for reading and writing to the GPS unit.

Further research on the Internet resulted in the discovery of a document by Peter Bennett on the National Marine Electronics Associations (NMEA) standards. The NMEA has created several standards for the communication of data between various types of electronic equipment. Several NMEA standards have been created for data communication and protocol between navigational devices, including GPS units. NMEA-0183 is a common stand supported by most GPS units. In his document, Bennett outlines the standard protocol. The standard transfers data in ASCII continuously, without any commands necessary to initiate the data transfer. Bennett also includes a section on testing the data transfer from the GPS unit to a computer by using a modem program. Windows 95's HyperTerminal was used to verify that the GPSMAP195's data could be read in ASCII from the serial port. HyperTerminal was also used to verify that the GPS unit conformed to the NMEA-0183 standard.

The NMEA method was chosen for implementation since it appears to be a standard feature on most GPS units, regardless of the GPS unit model or manufacturer. An additional advantage is that all data transfers are in ASCII, simplifying the task of reading the data and reducing the complexity of data conversions to a number format. The ASCII format would be beneficial in debugging the interface. Further, the NMEA operation of the GPS unit could be verified using a modem program, or any program that can read the data from a serial port.

Also, the NMEA standard made it possible for the project to be interfaced to any device that supported NMEA data transfers to a RS-232 serial port. The only disadvantage of using the NMEA protocol instead of the Garmin Protocol is the data transfer speed from the GPSMAP195 to the RS-232. The Garmin Protocol can transfer data at a rate of

9600bps, while the NMEA protocol is limited to 4800bps. However, it was concluded that a data transfer of 4800bps would satisfy the speed and accuracy requirements of the project.

ADF

The ADF instrument had been incorrectly implemented as a static instrument displaying the magnetic course to the station. The ADF instrument should have been implemented so that it displayed the bearing of the ADF station relative to the aircraft's nose. This would require that the ADF instrument know the aircraft's heading. Since the aircraft's heading was dynamic, the ADF instrument was reclassified to be a dynamic instrument. Many of the VOR instrument equations were still used with an additional calculation to accurately emulate an ADF instrument.

Magnetic Variation

During the Simulation testing of the VOR instrument, it was noted that many of the VOR stations tested indicated headings that were approximately sixteen degrees different than that annotated on the high altitude charts. The error appeared to be a failure to implement magnetic variation, the difference between the Magnetic Heading and the True North Heading. Since magnetic variation varies throughout the world, no equations could be found that accurately predicted the variation. Therefore the magnetic variation was implemented as a manual control that the user must periodically set.

Altimeter

Analysis of the altimeter revealed that there are no equations to determine the altitude using just latitude and longitude data. After reviewing the NMEA-0183 protocol, it was determined that altitude could be retrieved from the GPS unit directly. Therefore, in Simulated Mode, the altitude is calculated directly from the Simulation Module. In GPS Mode, the altitude is retried directly from the GPS unit, requiring no calculations. This results in a restriction that the GPS unit must be capable of providing altitude data. Most inexpensive GPS units have the altitude as a standard feature.

Miscellaneous Problems

There were many other miscellaneous problems that were detected. All the problems have been noted in the Implementation Log, which can be found in the Appendices.

Module Implementation

The main module of the project was implemented in GPSProject.vi. The vi must be loaded by Labview Professional Edition 4.0 or higher. Once loaded, the vi must be “run” from Labview. GPSProject.vi begins by calling Initialize Module. The vi then transfers control to the Main Module, in which all calculations, processing, and display updates is conducted. This Main Module contains calls to all the other modules necessary for the program. The only way to terminate the loop is to “stop” the vi from Labview.
It is important to note that Labview behaves very similar to hardware, not software. Therefore, all operations in a vi are carried out in parallel, unless specifically implemented as sequential. Further, registers must be used to preserve data values from one cycle for user in another cycle.

Initialize Labview (Initialization Module)

This module performs all tasks that are required before the Main Module assumes control. The values in the global array necessary for implementing the Track Record are initialized to 0. The computer’s serial port is also initialized for the possibility that the GPS Input Mode will be used later. The module also reads all the data from the VOR and ADF data files. This ensures that the data is only read once, at the beginning of the program, therefore reducing the amount of time spent rereading the same file from the hard drive. The module will also clear all registers, setting them to 0. Finally, the module is responsible for reading the data to initialize the Simulation Mode.

Main Module

The Main Module will assume total control of the program until Labview stops it. The purpose of this module is to interface and synchronize the user interface, the position input interface, the instrument calculations/processing, and the instrument display components.

DME (NMBetTwoPts.vi)

The DME Module was easily implemented since it involves calculating the distance between two points. Since DME Module is coupled with the ADF Module and VOR Module, it was decided to implement the DME Module as a function that could be accessed by VOR and ADF. Aviation standards rely on horizontal distances in nautical miles (NM), therefore DME was implemented as the function NMBetTwoPts.vi. This simple function would take the coordinates of two positions and calculate the distance between them, returning the distance in nautical miles.

VOR (VOR.vi)

VOR was implemented as VOR.vi. This vi performs all necessary calculations for the VOR instruments. The vi allows the user to select a VOR frequency, a station from that frequency, and the desired heading to be tracked (OBS). The vi then calculates the course, distance, needle deflection, and status for the VOR station. Implementing the VOR was the one of the most complex tasks due to the complexity of the information it presents to the pilot.

ADF (altered form of VOR.vi)

Analysis of the ADF instrument revealed that it requires many of the same calculations as the VOR insturment. The primary difference is the way the information is presented to the pilot. Promoting code reuse, VOR.vi was altered to additionally return the magnetic course to the station. Therefore, ADF was implemented using VOR.vi, setting the OBS to 0, and performing an external calculation to determine the bearing of from the aircraft to the ADF station. Note that the course output of VOR.vi is not used in the VOR instrument.

Input Data Interface Module

Due to Labview's design capabilities, this module was implemented as a case data structure. The module contains the Simulation Interface Modules and GPS Interface Modules. For both modes, the module outputs the current latitude, longitude, altitude, and time. Depending on the mode, the appropriate module is called. In Simulation Mode, the Simulated Airspeed and Simulated Heading are outputted to registers to preserve their values since these values are needed as inputs on the next cycle.

Coordinate Conversion

The Coordinate Conversion Module specified in the proposal was not implemented since all calculations using latitude and longitude were based on the equations in Ed Williams' *Aviation Formulary*. These equations require the inputs to be in latitude and longitude, not the Cartesian coordinates.

Altimeter

The altimeter was implemented as an output from the Data Interface Module. In GPS Mode, the altitude is retrieved from the GPS unit. In Simulation Mode, the altitude is calculated by SimFlight.vi.

Compass

The Compass Module was simplified to CourseBetTwoPts.vi and a conversion.

Airspeed Indicator, Position Tracker, and Virtual Instrument Display

Due to the nature of Labview, these modules were implemented in the main module.

Database Files

The operations for reading and writing to the various files were implemented as InputFileIO.vi and OutputFileIO.vi. InputFileIO.vi reads all the data from any ASCII file and returns the data as a string to the calling module. OutputFileIO.vi writes data from a string to an ASCII file. Both functions require the calling modules to perform formatting the data to a string or from a string. It should be noted that correct operation of the ADF and VOR instruments requires that the data in their respective files be sorted in ascending order by frequency.

Advantages

A major implementation of the DME instrument is that the calculations used in this program are independent of altitude. Traditional DME instruments account for altitude in their calculations, which can mislead a pilot since a flight at 10,000 feet over a station will cause the DME instrument that the aircraft is approximately 2 NM from the staion. For the same example, the implementation used in this program would indicate that the aircraft is 0 NM from the station.

Disadvantages

A disadvantage of the implementation of this project is that none of the dynamic instruments will show accurate values if the aircraft is not moving. In reality, ADF and the magnetic compass are still able to display accurate readings when the aircraft is stationary since the two instruments rely on radio frequencies and magnetism, respectively. Since the dynamic instruments use calculations between two positions, an aircraft at rest will cause the same position to be used for both positions, resulting in an inaccurate value. However, the only time an aircraft is stationary is when it is parked on the ground, therefore, this backup system would not be necessary since navigation would not be necessary.

Quantitative Performance Analysis

The project was initially tested for its accuracy using the Simulation Mode. Several VOR stations were chosen for testing. A high altitude aviation map was used for choosing these VOR stations. Stations and routes were chosen that were already marked on the map to prevent any errors introduced by generating our own measurements on the map. Since the basis of the project involves calculating distance and course between two points, the testing targeted these two measurements.

Our initial measurements in Simulation Mode indicated the following percent errors:

Table 1 - Simulation Mode Test Results

	Average Difference	Average Percent Error	Difference Range	Percent Error Range
Heading (Degs)	2.45	2.09%	0.57 - 13.78	0.17% - 11.88%
Distance (NM)	0.78	1.26%	0.01 - 11.42	0.0% - 22.84%

The average percent errors indicated that we had met our goal of a maximum error of 10 percent for all measurements. However, inspection of the data revealed that there were several routes with percent errors close to 10% for either heading. One route for the distance was considerably higher than 10% with a value of 22.8%.

Investigation into the root cause of the high percent errors for heading revealed that an error had been made in calculating the percent errors. For the distance outlier, the high percent error was determined to be an inaccurate observation from the high altitude map. Therefore, once both problems were rectified, the simulation data was recalculated with the following results:

Table 2 - Simulation Mode Corrected Test Results

	Average Difference	Average Percent Error	Difference Range	Percent Error Range
Heading (Degs)	2.45	0.68%	0.57 - 13.78	0.0% - 3.83%
Distance (NM)	0.40	0.47%	0.01 - 1.58	0.0% - 3.0%

The implementations of ADF, VOR, and DME confirmed the above measurements in Labview.

The next phase involved testing the project in GPS Mode. Testing was conducted by utilizing an automobile as the mobile platform. This would allow both stationary and mobile testing, therefore permitting testing of all the instruments. Stationary testing indicated percent errors as high as 10%. This did not correlate with Simulation testing. Mobile testing also experienced high percent errors. An error in the GPS interface data translation was determined as the root cause for the high percent errors. Correction of this fault and retesting resulted in the following:

Table 3 - GPS Mode Test Results

VOR/DME Percent Errors

Stationary Heading	0.00%
Stationary Distance	0.12%
OBS	0.00%
Needle Deflection	3.40%
Moving Heading	0.00%
Moving Distance	0.19%

Moving Instruments Percent Errors

Airspeed	3.91%
Compass	1.66%
ADF Heading	0.78%
Altitude	
Moving Altitude	2.96%
Stationary Altitude	1.00%

Overall, test data indicates that the project is considerably more accurate than the maximum percent error of 10%.

Resources Used/Cost

There were a number of components used in this project. Since there is no hardware design, all major components are pre-manufactured and supplied by various vendors. However, there are several hardware and software products were needed to be obtained.

Hardware

Implementation of the project did not require the purchase of any hardware. The GPS unit, Garmin GPSMAP 195, was loaned from the San Jose State University's Electrical Engineering Department, under the supervision of Professor U. Strasilla. The Garmin unit is an advanced GPS unit, which supports the NMEA data interface standard. The unit also has many built in functions including a VOR tracker, a position tracker, and a DME instrument.

The laptop was also loaned from San Jose State University's Instructional Resource Center. The laptop, containing an Intel Pentium processor, was pre-loaded with the Windows 95 operating system. Both items were loaned without incurring any expenses.

Software

Initial studying of Labview was conducted using the Labview Student Edition 4.0, which was purchased by the team. Professor U. Strasilla and San Jose State University's Electrical Engineering Department provided National Instrument's Labview 4.0 Professional Edition for the project. This was permitted since the project was to be conducted under the authority of the Electrical Engineering Department.

Labor Used

The project consisted of 2 team members. Though accurate logs were not maintained of the exact number of hours spent each week, an estimated total of 200 hours was spent implementing, testing, and documenting the project.

Final Timeline

The final time line does not appear to be as sequential as indicated by the proposed timeline. The reason for this is that implementing the design revealed that it would be beneficial and necessary to implement certain components earlier than anticipated.
The project was initially begun in the beginning of December 1998 with the study of Labview 4.0 Student Edition. The time indicated for learning Labview includes learning the basics of both the Student Edition and Professional Editions of Labview. Though only four weeks of familiarization with Labview, it is important to remember that the entire duration of the project was spent learning Labview since implementing each instrument introduced many new challenges.

Studying the instruments only required one week since a considerable amount of research had been conducting during the proposal phase of the project.

Only one week was necessary for studying the spherical coordinates. The discovery of Aviation Formulary v1.22 By Ed Williams eliminated the need to derive equations for the various calculations needed.

Reviewing the operation of the Garmin GPS receiver required four weeks. It was necessary to allocate this amount of time in order to fully understand the receiver since the receiver would be the “ideal” model of which the project was to follow. Also, time spent reviewing the receiver’s operation in this stage resulted in a faster testing process.

Only two weeks were allocated specifically for developing the algorithms for implementing the instruments. Our lack of knowledge with Labview promoted a design-implement-test cycle strategy for the implementing the instruments.

The majority of the time was spent designing, implementing, and testing the Sub Panels in the Simulation Mode. Fourteen weeks were spent on this phase which included implementing all the instruments. The beginning of this phase occurred during the team’s vacation from college, so it was decided to implement as many instruments as possible. It was necessary to ensure correct operation of all the instruments in order to obtain accurate data when testing in GPS Mode.

Since all the instruments were based on two calculations, distance and course, it was decided to implement the easier of the two calculations, distance. Distance correlates directly to DME and therefore DME was the first instrument to be implemented.

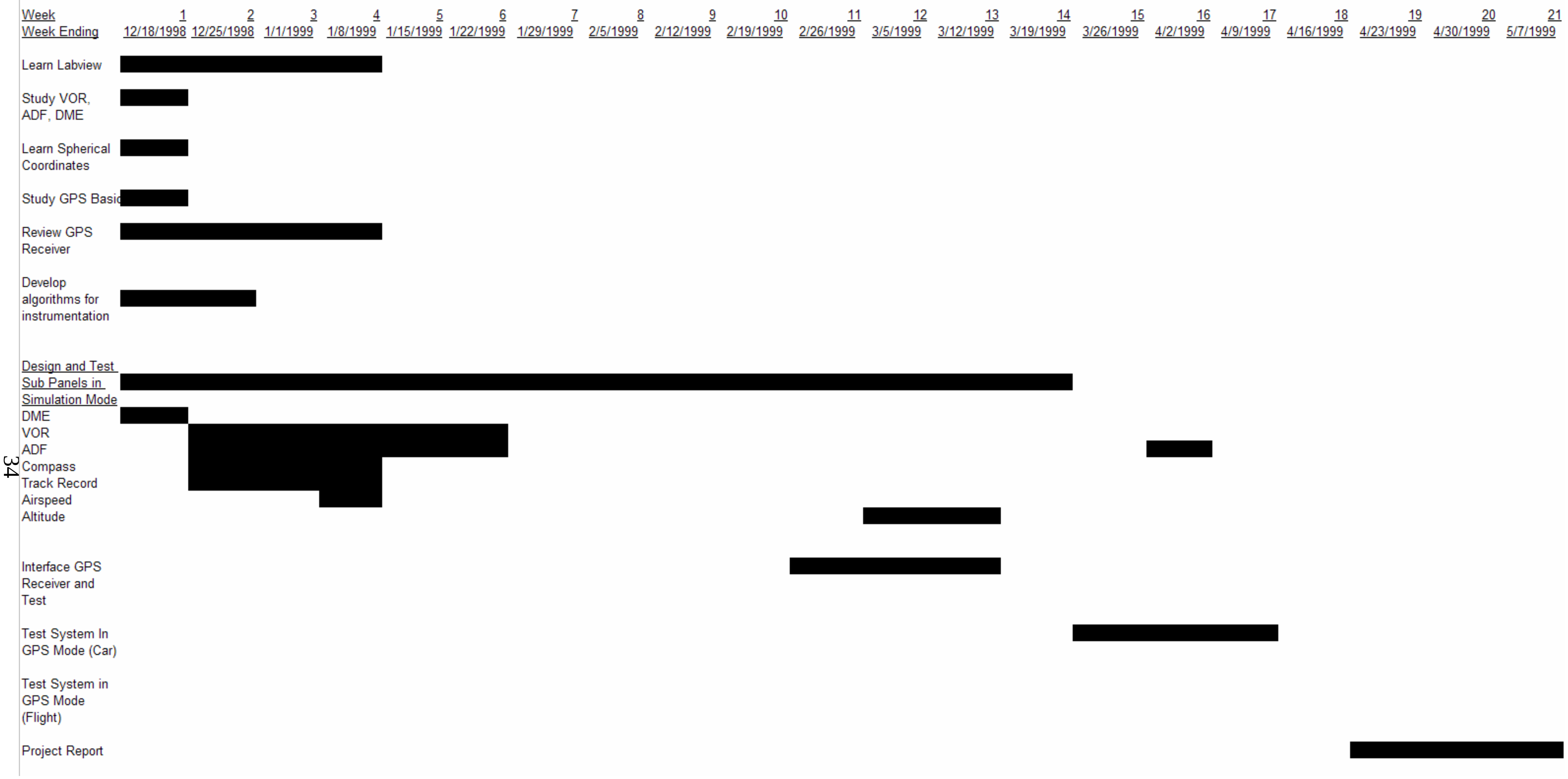
Observing that ADF is a simpler, altered form of VOR, it was decided to implement VOR and ADF in parallel. Further testing of the instruments required implementing the Simulation Mode. The Track Record was also implemented to verify the correct operation of the Simulation Mode. Though Altitude could be easily implemented in Simulation Mode, the information necessary for implementing in GPS Mode only became available when the GPS unit interface was being created.

Interfacing the GPS receiver required three weeks. The majority of this time was spent investigating interfacing the GPS unit to the computer using a variety of third-party software utilities.

Testing of the project in GPS mode required three weeks. Three weeks was required since the GPS unit had to be shared with another team and the laptop had to be shared with the San Jose State University faculty.

Flight testing of the project was not possible due to the inability to obtain an aircraft for testing purposes. However, the project will be tested in-flight after the presentation.

Figure 3 - Final Timeline



Clarification of Results

The performance data for testing conduced in GPS Mode indicates that the project successfully met the goal of a percent error less than 10% for all implemented instruments. This accomplishment is valid for the average percent error for measurements for each individual instrument.

However, further testing is still required to determine the maximum and minimum specifications for safe operation using this program. Extensive testing for reliability and accuracy under various conditions is highly recommended. Testing the system in the Easter Hemisphere and the Southern Hemisphere would ensures that the system operations correctly globally.

A significant observation during testing in GPS Mode is that the project suffers from an approximately one second delay, due to its polling for data from the GPS unit. This delay could be reduced by implementing the GPS interface using the Garmin Protocol, which is capable of data transfers at a higher rate then the NMEA-0183 protocol. However, this delay will not impact the pilot severely since the aircraft has a much slower response rate than one second. Therefore, a one-second delay is not catastrophic under most conditions.

Project Requirements Compliance

One of the main design goals was to successfully emulate the six instruments considered vital to the navigation of the aircraft. The six instruments were implemented and tested as specified in the proposal for the project. The implemented instruments resemble the aircraft instruments that the pilot is familiar with. Improvements were also made to provide the pilot with information that current instruments lack.

The implementation of the VOR depicts a VOR receiver used in aircraft. However, the project’s VOR has a few additional features. These features include the ability to use the VOR to track stations further than 200 NM by activating the Override feature. Also, the project’s VOR deflection needle was designed to indicate the unbounded deflection from the course, which surpasses the ± 10 degree limit on most aircraft VORs.

The ADF implemented physically depicts an aircraft’s ADF instrument. The emulated ADF instrument also has the same Override feature implemented as the VOR implementation to allow a pilot to track stations further than 200 NM.

The Compass has a digital display to permit the user to easily identify the actual magnetic direction. Magnetic variation was also implemented.

The Track Record was implemented as proposed. This navigational tool has the additional feature to save the user’s data into a text file. This requirement was not specified in the original design, but evolved from the testing phase.

The altimeter was implemented as a digital display, making it easer to observe than traditional instruments. The Airspeed indicator was implemented in a similar manner.

The Simulation Mode was implemented as specified. An additional feature is the ability to retrieve data from a file and fly the simulated course for that data. An audible warning was also added to signify that the system is in Simulation Mode or File Mode, therefore reducing the changes that the pilot will accidentally believe that the system is in GPS mode.

Appendix A contains the user's manual, which also includes instructions for setting up the program. The large displays and pull down menus also sever to ease the complexity of operating the project.

The only design goal left incomplete was final verification of the system's operation in an aircraft. The test was scheduled for April 30, 1999. Bad weather forced rescheduling of the test, which resulted in the test not being completed by the project deadline. It is hoped hat this goal will be met after the project has been submitted.

Advantages Analysis

The project offers many advantages over aviation instrumentation projects conducted at San Jose State University. One of the main advantages is the successful integration of Great Circle formulas. A higher level of accuracy was possible using Great Circle formulas instead of traditional spherical formulas.

Interfacing the laptop to the GPS unit with the aid of the NMEA-0183 protocol was another major feat achieved. Previous instrumentation projects failed to overcome this challenge. With encouragement from the project advisor, Professor Strasilla, the Labview files and documentation for retrieving data from the GPS unit were provided to other teams faced with the problem.

Disadvantages Analysis

The one-second delay for updating the instruments in GPS mode is a slight disadvantage. Though the delay does not significantly affect the project's outcome, the delay could be magnified in time-critical applications.

Conclusion

Project Summary

One of the main lessons learned throughout this project is that a hardware oriented design language can still be used to solve a software challenge while preserving the hardware nature of the language. Previous attempts of Labview based projects in San Jose State University's Engineering program often disregarded Labview's extensive hardware oriented capabilities, choosing to implement projects with an engineering methodology and design which only emphasized Labview's "software" abilities such as sequential statements and case statements.

For this project, the Internet provided a wealth of information and knowledge form sources worldwide. Further, productivity was increased by using proven formulas and standards found using the Internet's search engines.

Future Applications

This project can be used as the foundation for more extensive flight instrument duplicating efforts. Current projects being developed by San Jose State University students can be interfaced with this system to provide more complete navigation capabilities. Possible enhancements include instruments for Instrument Landing System (ILS), Horizontal Situational Indicator (HIS), and Terrain Avoidance Systems. The addition of these three instruments would complete the navigation panel found in many commercial aircraft.

Additional features that could be added to the project include a low altitude warning indicator to provide audio or visual alarms when the aircraft flies below a specified altitude.

A vertical ascent/descent rate indicator could be helpful to indicate the rate at which the aircraft is changing altitude. This information is crucial for a safe landing and to avoid stalling the aircraft. A bank rate indicator could provide information about the aircraft's bank.

Another feature could include local area or high altitude map libraries for the Track Record. Also, the position data saved by the Track Record could be saved in a format that is recognized by commercial map software.

Users may find it helpful to have a utility to ease making modifications to the VOR or ADF data files. The utility would eliminate the user's need to understand formatting required in these files.

Another utility could download previously saved data from a GPS unit and convert the data to the required format for File Mode.

“Hot keys’ could be implemented to allow the user to quickly select a menu.

An instrument zoom function would allow the user to zoom to an instrument.

Support in Simulation Mode for other computer peripherals including a control column and rudder pedals could be implemented.

Interfacing the system with Flight Planning/Management software could provide automatic setting changes for the instruments. This implementation would be equivalent to an automated navigator which advises the pilot on changing instrument settings as well as course status and deviations.

Finally, a function to locate the nearest VOR station, ADF station, or airport and display its data could be beneficial in an emergency.

The list of features and enhancements is extensive, providing the possibility of extending the life expectancy of this instrumentation system.

Credits

The project’s team, Lee-John Fernandes and Haile Asore, would like to thank Professor Strasilla, San Jose State University, and Lockheed Martin for the interest and motivation to pursue this joint project between San Jose State University’s Electrical Engineering and Computer Engineering Departments.

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