A Software Defined Radio Based Airplane Communication Navigation Simulation System

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Abstract. Radio communication and navigation system plays important role in ensuring the safety of civil airplane in flight. Function and performance should be tested before these systems are installed on-board. Conventionally, a set of transmitter and receiver are needed for each system, thus all the equipment occupy a lot of space and are high cost. In this paper, software defined radio technology is applied to design a common hardware communication and navigation ground simulation system, which can host multiple airplane systems with different operating frequency, such as HF, VHF, VOR, ILS, ADF, etc. We use a broadband analog frontend hardware platform, universal software radio peripheral (USRP), to transmit/receive signal of different frequency band. Software is compiled by LabVIEW on computer, which interfaces with USRP through Ethernet, and is responsible for communication and navigation signal processing and system control. An integrated testing system is established to perform functional test and performance verification of the simulation signal, which demonstrate the feasibility of our design. The system is a low-cost and common hardware platform for multiple airplane systems, which provide helpful reference for integrated avionics design.

1. Introduction

Radio communication and navigation system plays an important role in ensuring the safety of civil aircrafts in flight. The function and performance of airplane systems need to be tested before they are installed on the airplane. Conventionally, a set of transmitter and receiver should be designed on ground to communicate with the systems on-board [1-4]. Normally a set of hardware was designed for each system, which took a lot of space and time consuming.

Software defined radio (SDR) is a new technology in the field of radio engineering, which uses as much as software to replace the work of hardware [5]. Normally a common hardware platform is used for multiple systems and different signal processing software is developed for different system. Also software can be divided into common module and specialized one and the common module can be called by different systems. SDR make it possible to integrate many systems and at the same time reduce the weight and size.

Many researches have been performed in the field of signal simulation. FPGA or DSP techniques are used for avionics, radar and GPS system [6-8]. In this paper, a set of communication/navigation simulation system is designed based on SDR to give a way of avionics testing and verification.
2. Basic principles of airplanes communication and navigation system
This section describes the basic principles of communication and navigation systems of civil airplane [2, 8].

2.1. Communication system
Airplane communication includes HF and VHF system. VHF is used between flight crew and ground crew during take-off/landing or flying over control airspace. HF is a long range communication system used for contact with ground stations and the other airplane. The modulation method used by HF is AM or SSB, the working frequency is 2M to 29.999 MHz with 1kHz gap. VHF uses AM or FM modulation, where AM frequency band is 117.975M to 137MHz with 8.33kHz gap, FM frequency band are 108M to 173.975MHz and 225M to 399.975MHz.

2.2. Automatic direction finder
The automatic direction finder (ADF) determines the relative bearing to conventional broadcast stations or beacons through calculating the direction of the receiving radio. ADF works in 190k~1750kHz to communicate with civil radio station and NDB station with different identification signal, which is composed of two English character Morse code transmitted 20~30 characters per minute. The signal transmitted through horizontal, longitudinal and vertical antenna are

\[
\begin{align*}
V_x &= A \cos \theta \cos \omega t \\
V_y &= A \sin \theta \cos \omega t \\
V_z &= B \sin \omega t
\end{align*}
\]

Where \( A \) and \( B \) is the amplitude, \( \theta \) is the relative bearing, \( \omega \) is the angular frequency of the carrier. After a series of processing, including balance modulation, mixing with local oscillator, frequency detection and LPF, we can obtain the bearing angle

\[
\theta' = \arctan\left(\frac{\sin \theta}{\cos \theta}\right)
\]

3. Airplane communication navigation simulation system design

3.1. System architecture based on SDR
Normally the architecture of SDR includes two parts: front end and back end. The front end comprises analog front end, A/D, D/A, and digital front end. The back end is baseband signal processing. According to airplane communication and navigation system, we give the architecture of the simulation system, shown in Figure 1.

A wideband antenna receives all the signal of different systems. The avionics software is composed of multiple functions for the communication and navigation systems. Through interactive menu and control to the hardware interface, the current status, working frequency, data wave and configuration parameter are displayed to the user.

Figure 1. Airplane communication system architecture based on SDR.
3.2. Hardware configuration
The hardware we used for our system is shown in Figure 2. Voice is collected by the sound card of the computer and is input to the computer to be modulated and processed by the avionics software. Then it is fed to USRP N210 through Ethernet. After D/A transform and frequency conversion it is transmitted. The receiving process is reverse.

The USRP transceiver is a kind of universal software defined radio peripheral developed by NI company and popular used by radio system simulation and design. The principle is shown in Figure 3.

USRP N210 mainly includes FPGA motherboard, radio board and analog digital transform. FPGA is used for baseband digital signal processing. The FPGA motherboard is connected to a computer through Giga Ethernet. All the digital wave signal processing, e.g., modulation and demodulation, are performed on the CPU of the computer. All the universal high speed processing, e.g., frequency up/down conversion, interpolating and sampling, are executed in FPGA. The radio board can be selected for different radio systems.

3.3. Software architecture
Signal processing software design is the key point of our simulation system. For each communication and navigation system, there is a transmitting/receiving and signal calculating method.

Through detail analysis of the principle of each system, we can extract some modules that used by several system as common module. These common modules are: carrier generation, mixer, amplifier, LPF, BPF, CIC, pulse identification, random pulse generation, etc. And the special software modules of different systems are shown in Table 1.

| System | Software Module |
|--------|-----------------|
| HF     | SSB mod/demod, Hilbert transform, |
| VHF    | FM mod/demod, |
| VOR    | Signal generation, AM/FM mod/demod, Morse code generation, Bearing angle calculation |
| ADF    | Signal generation, IQ signal selection, AM mod/demod, Bearing angle calculation |
| ILS    | Signal generation, DC estimation, Morse code generation, AM mod/demod, DDM calculation, Warning module |

3.4. Software design
There is several application software that USRP N210 can support, i.e., GNU Radio, Visual C++, Matlab/Simulink, LabVIEW and etc. By comparing them we selected LabVIEW because it can be used on our Windows operation system, is easy to developed and has friendly man-machine interface. Especially, it includes many toolkits for radio signal processing, which make it suitable for our systems. The combination of USRP hardware and the software give a popular used prototype platform.

The parameter of some function module should be configured for designated signal before transmitting and receiving. The main parameters are IP address, IQ sampling rate, antenna and gain, etc. A voice collection and playback program is design based on the sound card of the computer to verify it proper functioning. And a test programs are needed for the navigation systems to verify that the signals we generate are correct.
For airplane communication system, the software includes AM, SSB and FM transmitting and receiving program. For navigation system, based on the principles mentioned in part two, there needs to design specific program for each system.

As an example, we give a flow chart of ADF receiving program, shown in Figure 4. Figure 5 gives an example of a receiving program compiled in LabVIEW.

![Signal receiving flow chart of ADF system](image)

**Figure 4.** Signal receiving flow chart of ADF system.

![An example of the compiled LabVIEW program](image)

**Figure 5.** An example of the compiled LabVIEW program.

4. Simulation test

The test platform composes two computers, two USRP N210 and antennas.

Two computers work as transmitter and receiver. The transmitter collects voice signal or generate specified signal for the communication and navigation system. After modulation and digital processing, they are fed to USRP through Ethernet. USRP transform the signal to radio band and transmit them through the antenna. The receiving process is vice versa.

As mentioned above, before the communication and navigation system simulation tests, first we perform voice collection/playback and navigation signal test, as shown in Figure 6.

![Signal test and analysis](image)

**Figure 6.** Signal test and analysis.

Figure 7 is an example of a receiving program. The left part of the panel is the parameter configuration area and the right is the received wave form, frequency spectrum.
Measure should be taken to verify the correctness of the design. For communication systems, we can listen to the received voice and compare the quality with the collected one. For the navigation systems, the received angle or deviation can be compared with the pre-defined parameter of the transmitted signal. An example is given in Figure 8 to show the error of ADF bearing signal. It shows that the error is between \( \pm 0.01^\circ \), which satisfies the design requirement.

5. Conclusion

This paper illustrates a communication/navigation simulation system designed on the bases of SDR hardware USRP and LabVIEW. It can generate signal of various airborne avionics and gives a way to test them. This simulation system is low-cost, light and easy to design. And more systems can be added to it according to one’s needs of the system design.

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