Eddy Current Detection with Linux

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- Linux for low cost eddy current detection
- Finding nails in your walls & cracks in your aircraft using a full duplex sound card and some wire
Outline – Frequently Asked Questions

• What is CanDetect anyway?
• What is Eddy Current (EC) Testing?
• Why use a computer sound card?
• What sensitivity does this achieve?
• How do two coils look inside walls?
• How does a circuit board inspect an aircraft?
• Which wire designs are worth building?
• Where is the code to make measurements?
• What are the future plans?
What is CANDETECT?

• Corroding
  • Aluminium slowly corrodes in salty and humid air

• Aircraft
  • 5000 repair stations, 163000 small aircraft in the USA

• Non Destructive
  • Minimal damage, to permit frequent inspections

• Evaluation Tools
  • 340000 (a third of a million) aviation technicians in the USA

• Eddy Current Tester
  • Induce electrical currents in the metal to find cracks
Approach to being low cost

- The CanDetect project uses ordinary sound cards
- It monitors the environment by magnetic induction
- The sensor can be as simple as some wire loops
- The software sends and receives magnetic signals
- The application can build as a bootable Linux floppy
What is Eddy Current Testing?

• Apply a changing magnetic field to a piece of metal
  • This causes electricity to invisibly flow in a loop inside
  • This so-called eddy current has to stay inside the metal
  • It cannot get across cracks or through corrosion, etc

• So we have a current loop, how do we know where it is?
  • Any electrical current generates a magnetic field
  • The shape of the field depends on the path of the current
  • Simply measure magnetic field of the eddy current
    where it conveniently extends outside the metal
Creating and detecting magnetic fields

• The magnetic field is generated by electrical current
  • There is field going in a circle around each short bit of current
  • Add up all the bits of field from all the bits of current

• The magnetic field is detected by electrical voltage
  • A change in the field across the wire generates a voltage
  • If the field doesn't change, there will be no voltage
  • Add up all the voltages along the wire to get the total

• Have to make sure that the field is always changing
  • Swap the direction of the electrical current regularly
Interesting pieces of metal

• The screws and power cables in your walls
  • Don't want to hang a picture by putting its nail through a cable

• The small tab on the door or window
  • The coil on the door frame is used to trigger an alarm

• The metal structure of an aircraft
  • It should stay intact from takeoff to landing

• The moving core of a LVDT (position sensor)
  • The manufacturing tool wants to know where it cuts/welds
Why does Linux help

· All those applications are for products
  • They have embedded computers for decision making
  • The algorithms are often changed and improved

· Linux is a popular embedded kernel
  • Ideal for low cost products, because no royalties
  • No hard real time support, but that's fine for this

· It's nice to have the same kernel on the desktop
  • Makes writing code and porting it to the target easier
  • Much larger pool of developers and consultants

· The code is small, easily fits on a floppy or flash chip
  • Linux kernel can be recompiled to optimize its feature set
Small and cheap Linux computers

· Required features of a small computer
  * Hardware multiply for processing the signals
  * Heavy math or display updates must not block audio
  * Must have full duplex sound at 16 bits
  * Other than that, almost any processor

· The ARM port of Linux looks good, being used in PDAs
  * Many PDA chipsets only simplex, or 8 bit duplex
  * Or documentation ambiguous/inadequate
  * Battery charge must not change electrical performance
  * That is actually a challenge, depending on electronics design
Why use a computer sound card?

• They can generate programmable analog waveforms
  • On one, two, four or even six electrical outputs
  • Most offer 1 V drive from less than 100 ohms

• They can also retrieve analog waveforms
  • On one or two electrical inputs
  • Most accept 0.1 V at much higher impedance

• Some of them can do both at the same time

• Why does every computer have something like that?
  • Maybe you can't sell a computer if it can't play games ...
  • People expect games to make lots of interesting sounds
Full Duplex – not always available

• More complexity to play and record simultaneously
  • Hardware could have bugs, driver might not be written right
  • Not needed to play all games, though often can be helpful
  • Problems may not impair sales a lot and might not get fixed

• Full duplex is popular for Internet phone calls
  • Similar situations too, such as multi-user gaming
  • But people accept noisy low quality for voice calling
  • So full duplex might work but be too poor for CanDetect

• Linux lets us fix the driver when there's problems
  • We can't fix hardware, but we can only choose it ...
Test and choose the best sound card

• Linux has drivers for many different sound chips
  • Two products may have the same chip, but different boards - one boards may have less noise than the other one
  • Those differences will be invisible to the Linux driver
  • The only way to find out is to actually do the testing

• Tests should measure the actual analog performance
  • Make sure the sound card really does run in full duplex
  • Collect data for a minute or so and compute statistics
  • Some chips warm up when being used in full duplex
  • Such a temperature change can cause a lot of drift

• Repeat until a good card is found ...
Running the sound card tester

• The test may be automated, just a program to run
  • Could boot from floppy, but not all laptops have floppy drives
  • Could use a CDROM, but it is hard to change the program
  • Also, there is nowhere to store the results from the test
  • Easier to use NFS to run the program and store results

• Most people prefer to have a GUI when testing
  • Modify Knoppix or equivalent to add the test program
  • This means mastering and burning CDROMs until it works

• Network boot avoids all those disadvantages
  • Many can boot at once (no need to make lots of CDs)
LTSP – run the test program everywhere

· Linux Terminal Server Project – has the infrastructure
  • It converts each computer you netboot into an X terminal
  • Leave all test programs and result storage on one server

· One change to client's /etc/rc.local on the LTSP server
  • Runs the test program from NFS and writes the results to file
  • Choose the filename from, for example, the client IP address
  • When test is completed, immediately reboots the computer

· To test, simply network boot all available computers
  • Some can use PXE, others need a floppy with EtherBoot
  • After triggering the network boot, no reason to wait around
  • All results will be ready for comparison within minutes
Linux offers hardware independence

- CanDetect still uses the Open Sound System (OSS)
  - All models of sound card basically look the same
  - Work in progress to transition CanDetect source to ALSA

- Linux treats sound interfaces on the USB bus the same
  - Use several sensors without needing additional PCI slots
  - The external bus separates the computer and sensor further because the sensor plugs into the sound card, not the computer, and the computer can be a strong source of magnetic noise!

- Potential to add support for expensive DAS boards
  - At my day job we use a 12 output and 12 input port board
Sound card experiences

• Careful choice, but not price
  • No audible hiss from microphone at full volume
  • Full duplex capable (recording during playback)
  • 16 bit operation (because 8 bits is way too few)
  • Most PCI cards are ok, but ISA are not

• Maestro 2E sound chip, in a notebook, works well

• CMI8738 from C-Media is acceptable, no issues
  • Used in the obsolete NIC, that booted from CDROM

• TI PCM2900, a USB audio chip, has low noise
  • But, under Linux, randomly swaps the input channels around

• Via82cxxx, has not yet correctly operated a probe
Problems with Linux drivers

• USB audio
  - This is a generic class driver, supporting many vendors
  - Texas Instruments PCM2900 – Random record channel swaps
  - Software workaround to determine whether they're swapped

• Via82cxxx chipset
  - OSS 2.4.25 and 2.6.7 – Full duplex never actually plays sound
  - ALSA 2.6.7 – Fragments are two sizes, data not synchronous
  - Software workaround is to keep measuring synchronization
What sensitivity does this achieve?

• Sound cards use sigma-delta conversion
  • They take millions of readings per second on each channel
  • These are digitally combined together and averaged
  • After averaging, a 16 bit integer is reported to the computer
  • Usually 32000 times per second, about every 31 microseconds

• Computer software can do more averaging if it wants
  • Combining four readings into one – is like an extra bit
  • Doing the combination four times gives us four extra extra bits
  • So the data can also be 20 bit integers, 30 times per second

• 20 bit integers can count up to a million
  • Data have resolution of one part per million (ppm)
Maestro chip, 150 Hz silence

- Carrier 150 Hz for 30 sec
  - Noise 0.87 ppm/rtHz, Drift 0.15 ppm/s, Offset 21.6 ppm
  - See? 1ppm – works.
Comparison with other measurements

- < 2 digits  Analog moving needle voltmeter
- 2 digits  8-bit A/D, such as in an old ISA sound card
- 3.5 digits  Most modern handheld digital voltmeters
  - 12-bit A/D installed in cheaper computer cards
- 4.5 digits  Std lab bench voltmeters, usually with lockin
  - 16-bit A/D in a high quality data acq cards
- 6 digits  What we're achieving with a Linux computer
  - can see incredibly subtle signals and changes
How do two coils look inside walls?

• Coils driven in series
  • Current provided differentially using two output channels
  • Both are pushing that magnetic field into the wall
  • Same current in identical coils; midpoint stays near zero

• Both coils detect response of course
  • The midpoint is the average
  • One input channel monitors it

• One closer to the metal
  • That coil's voltage is larger
  • Software measures that
Homemade probe – overview

• Two coils, glued to a piece of wood
  • An audio patch cable, cut in half, for speaker and mic
Homemade probe – detail views

• The neat windings are visible
  • Covered with tape for protection
  • The four wire ends from the coils pass through a hole in the wood

• Patch cables connect to coils
  • Simply soldered together
  • Heat shrink tube for insulation
  • Transparent cover for protection
  • Avoids damage during transport

• Two tie-wraps for strain relief
Frequency sweeps are easily scripted

- Dry wall nail – magnetic response at many frequencies
  - Suitably big anywhere between 100 Hz and 1kHz
Signal from sliding probe along wall

· This is the dry wall nail
  • Signal strength changes rapidly
  • The nail is inside the loop, or not
  • Negative for one coil
  • Positive for the other

· This is for a power cable
  • Signal strength changes gradually
  • Depends on how much wire visible
  • Changes as wire goes across coil

· Easy to find midpoint ...
How does a circuit board inspect aircraft?

- Cracks tend to grow out of one rivet towards the next
  - The eddy current has to try to flow between the rivets
  - If it doesn't, the current path would not changed by a crack
  - The magnetic field has to be pointing along the rivet line

- A flat magnetic field can be made by two spiral patterns
  - One clockwise and one anticlockwise, next to each other
  - These are not used to receive – we're only look in one place
  - A separate small coil measures the field out of the surface

- Coils are not very good at the low frequencies
  - Prototype uses a special MR sensor instead of the small coil
Probe design for rivet rows

- Optimized for cracks on rivets at low frequencies
  - This prototype was designed/built by Dr W.F. Avrin

- Cheap circuit board
  - A: the MR sensor
  - B: one of the spirals

- Green/yellow wires
  - Spiral current drive

- Pairs of red wires
  - Sensor power/signal
Cessna 172 measurement setting
Underside of C172 right wing

- Track is right to left
  - @25: starts right of the right hand access panel
  - @34: passes the right row of rivets
  - @46: left row of rivets

- Manual motion was 1 sec/rivet
Aircraft scan – High spatial freqs

3: High freq at 0 deg, shows the rivets
4: High freq at -45 deg, absence of crack
Simulate – is the design worth building?

• It is easier to simulate a new design idea than to build it
  • The design can then be adapted/improved before being built

• Python's numeric and scientific libraries can do magnetics
  • Compute the coupling between all coils and pieces of metal
  • Coupling data can be analyzed by “gnucap” if necessary

• Such coupling calculations need lots of CPU power
  • Each position and shape of the metal is a separate calculation
  • This is an ideal case to solve with a Linux-based cluster
  • MPI and similar is not needed, an OpenMosix kernel suffices
Probe designs – proving that they work

• Test data and qualification trials are necessary
  • Proving that a given probe is reliably detecting a given flaw
  • Before it is safe for anyone to use or rely on the results from it
  • Mistakes cost lives on any aircraft or infrastructure inspection

• It is usually necessary to have multiple probe designs
  • To ensure that all the different flaws are reliably detected

• Much more effort goes into qualification than into design
  • So it is really important to get the design right first
Where is the Code?

- A script connects four programs
  - Greatly simplifies customization
- Main program reports all measurements
  - First two columns are intended to be useful in real time
- Tee program ensures a record is kept
  - Post-processing, such as using Octave and/or GnuPlot
- XOscope program provides scrolling display
  - Allows user to optimise measurement activities
Low level library – AudNet

• Operates the sound card
  • Precomputes a backlog of outgoing audio data
  • Keeps track of the list of pending sound fragments
  • Retrieves and processes recorded incoming data
  • Matches incoming data to associated outgoing data

• Manages multiple requests
  • Each has defined repetition and set of output waveforms
  • Application adds references to requests into a queue
  • Permits multiple parameters to be measured on a rota

• Adaptive operation is easy
  • As results become available, change future queue content
Diagnostic application – xoscope

- xoscope was originally an oscilloscope
  - Monitors signal source for a trigger condition
  - Then grabs a waveform fragment to be displayed
  - But it discards the input signal when display busy

- Probe capable of continuous movement
  - The discarding causes occasional data gaps
  - Modification necessary to the standard source code
  - Thus, CANDETECT uses a patched version of xoscope
  - Patch doesn't work against recent CVS releases though

- XOSCOPE only plots 10 ppm of the full scale
  - No loss of resolution in recorded data files
Real time display, in use

- Dynamic range of 10000 available i.e. 80 dB
- Graphs scroll to the left, variable speed
Why is Linux needed?

• Multiplatform
  • Desktop and lab workstations for development
  • Handheld, laptop and embedded computers for production
  • All have exactly the same kernel/API, not just similar

• Multidevice
  • Many sound card drivers, all sharing a simple code API
  • Standard support for up to eight installed sound cards
  • One computer making many simultaneous measurements

• Easy development
  • Network boot, LTSP, CD boot, NFS, UML, etc
  • Remote service infrastructure and network audio
  • Use of low latency patches permits adaptive algorithms
What are the future plans?

• Address issues with drivers for popular sound chips
  • Need software to work with almost any modern laptop

• Update library to use API for ALSA instead of OSS
  • OSS is now legacy and support will degrade over time

• Package software for inclusion in distributions
  • Enables it to be built into subsequent live CD images

• Extend algorithms for tracking the sensor's position
  • Makes it easier for the user to know where data was taken
Conclusions

• Linux enables stable sub-ppm performance
  • Because its latencies never enough to pause audio stream

• Direct connection of probe feasible with sound card
  • Eliminating the cost and complexity of additional electronics

• Computer can also be used for other tasks
  • Instead of buying a dedicated NDE system, reboot an existing Windows-based workshop data retrieval station