McPhail Trap Main Board v1.0

Collect, analyze, and report back the environmental data.

This is an attempt to reproduce the work of identifying fruit flies from the following papers:

- 2017: Automated Surveillance of Fruit Flies
- 2015: Insect Biometrics: Optoacoustic Signal Processing and its Applications to Remote Monitoring
- 2014: The Electronic McPhail Trap
- 1979: Optical Tachometer for Measurement of Wingbeat Frequency of Free-Flying Insects

Parallels the European ENTOMATIC project.

Hardware Version Notes

- v1.x, proof of concept, collect data on SD card and over USB Fona breakout board supports texting
- v2.x, switch to ARM MSP430 or other ADC-specific chip, collect data on SD card
- v3.x, integrate mesh net or other networking, possibly more sophisticated offboard analysis

Design Notes

Physical Housing

Putting the electronics in acrylic separate from the insects so the ultrasonic isn't bothering them. An acrylic housing placed on top of the trap provides protection from the elements as well as protects the insects from any electronics noise.

If all circuitry is on the board at the top, the IR emitters and photodiode detectors can be the only items in the trap with the insects and be connected by a minimum of cabling.

The boards will all be 0.063" (1.6mm) thick FR-4 with purple solder mask over bare copper and an ENIG (gold) finish.

Board dimensions

Board	Dimensions
Emitter Board	2.71x0.51 inches (68.76x12.88mm)
Detector Board	2.71x0.51 inches (68.76x12.88mm)
Main Board	3.18x2.24 inches (80.82x56.79mm)

Security and Connectivity Platforms for reference

- Particle
- Electric Imp

v1 FONA808 GSM+GPS MODULE

- PS is power status. Check this after toggling KEY. Pin is low when module is off, and high when module is on.
- NS is network status. It pulses to signal current module status
- RST is hard reset to be used only when module is really stuck.
- RX/TX are pins capable of Software Serial. They are auto-baud so whatever baud you send "AT" after reset or boot is the baud rate the module will use.
- RTS is hardware flow control. Optional. Turn it on in module if you want to use it.
- RI is the ring indicator output. Use it as an interrupt. Default high. Pin will pulse low for 120ms when a call or SMS is received.

The GPS is accessible on the Rx/Tx lines so you can query using AT commands and get the values back. No additional pins are necessary.

Microcontroller

The reference papers call for a 14-bit ADC.

The Atmel AVR chips we initially considered (Atmega32u4, Atmega2560) had 10-bit ADC, which isn't enough. We chose the ATSAMD21G Cortex M0 with 12-bit ADC since it still can be programmed with a cheap programmer, doesn't require dedicated hardware, has built-in USB for programming and monitoring.

It is compatible with adalink and avrdude, which we already use for programming other boards.

We added a $6 16-bit ADS1115 which receives on two differential or four single channels (we could use the four) and outputs the result over I2C.

Another possible solution would have been the $6 MSP432 or a similar chip, could pick up a $14 dev board as well. This is a TI chip that requires CodeComposer Studio, newest version is CCSv6. It's Linux-compatible and I have a Windows machine just in case it's not.

The downside of the MSP432 is the $45 additional programmer we need to buy, getting set up with a new dev environment, etc.

ADC and Noise Notes

The 2-layer board is routed using a split ground plane to separate the analog and digital signals. Care was taken to provide clear analog return paths but the A0, A1, and A2 signals right at the microcontroller are next to the I2C signals and this may end up as a source of noise.

If noise is still an issue, we may need need a 4-layer board (which doubles board cost). It's unclear if ENTOMATIC are actually getting and using all 14 bits.

Does 5V in the ENTOMATIC system vs 3.3V in our system make a difference? How?

We need to review the ENTOMATIC calculations – seems like my back-of-envelope has 32ms, not 16ms as from their paper.

For power and noise control, we should turn off everything but the ADC when sampling.

Discussion of cheap 16-bit ADC

Software Approach

We collect the value from the ADC in a variable and poll it at the desired rate.

Architecture could be a finite state machine.

Next step is to go through and set up all the registers first to initialize serial comms, ADC, RTC, low power mode, the interrupts, and so on. Then, make sure we have libraries for accessing the SD, etc. This will not be an Arduino project, but an AVR GCC project. Need to get the environment set up and document it so someone else can reproduce the work in the same way we did.

RTC

The DS1307 real time clock is out of date and hard to find.

We used the MCP7940N with an external 32.768kHz external crystal, following the suggested PCB layout on page 14 of the datasheet.

There is a discussion of digital trimming on page 29 to mitigate temperature and intrinsic clock issues. We can figure out the values in this digital trimming register by testing the physical board and calculating the the trim value with the equations on paeg 30.

Temperature

Kyle put a thermometer in the trap and measured the temperature inside over two days in direct sunlight. Both times the internal temp was 10 F degrees higher than the ambient air temp. (110/100F first day @ 5pm, 108/98F second day @ noon).

Prior to measuring, he left the thermometer in the trap for an hour, so that should be a reflection of what we'd see in the field. The combination of size and materials is keeping the temperature from getting much higher.

Capacitors

Mostly ceramic capacitors were chosen for cost and size, with C0G/NP0 and X7R temperature coefficients. Aluminum electrolytic capacitors were chosen where ceramics were cost-prohibitive or where specifically indicated in datasheets.

The temperature coefficients:

X7R means a capacitor is a temperature-stable (EIA Class 2) cap which only varies up to ±15% from -55°C to +125°C. ref

C0G/NP0 means a capacitor is temperature-compensating (EIA Class 1) which varies less than ±0.3% C from -55°C to +125°C. Capacitance drift or hysteresis is less than ±0.05%. ref

Detector/Receiver Board

Interestingly, the receiver part number TEMD5080X01 does not have the same package as in the photos of the McPhail trap. These are $1.31 each at 25 and the design calls for ten of them.

They are good from -40C to 100C and are 5mm x 4.24mm.

The board is 2.71x0.51 inches (68.76x12.88mm) and costs $7 from OSH Park for a set of three ($2.33 each).

The stencil costs $5 from OSH Stencils.

Emitter Board

The 940nm emitters are in the $2 range and the board will probably be the same size as the detector board.

The difference in frequency range is due to the ENTOMATIC folks optimizing for response time over exact frequency match, to save on power. They also drove the LEDs at the edge of the board at higher current to make sure the infrared intensity was uniform no matter where the bug flew through the IR field.

The diffuser needs more investigation.

The board is 2.71x0.51 inches (68.76x12.88mm) and costs $7 from OSH Park ($2.33 each).

The stencil costs $5 from OSH Stencils.

Complete Assembly and Cost Information

The following layout is only to get a rough idea of how much area the parts would require if they were all on one side of one board. The area is 3 inches x 3 inches, or 9 square inches, and a set of three bare boards would cost $48.20 for three with a manufacturing turnaround of about ten days.

Rough cost of parts for a single board is about $50.

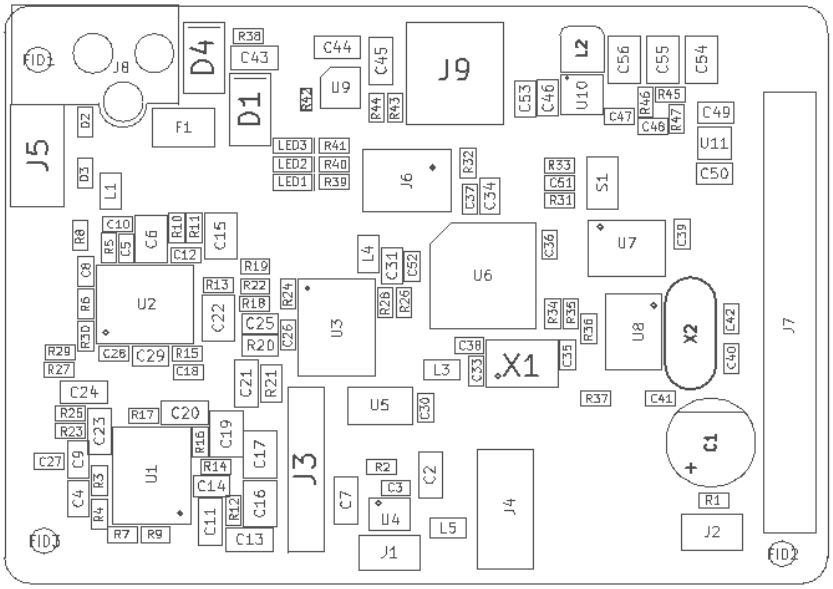
The stencil from OSH Stencils costs $16.90. A tube of solder paste in the same package costs $14.

Stencils are 3mil-thick polyamide (orange) film which is reusable.

Total cost for one complete stack of three boards: $129

Assembling a further one complete stack of three boards: $93

Item	Cost
Emitter Board PCB	$3
Emitter Parts	$13
Emitter Stencil	$5
Detector Board PCB	$3
Detector Parts	$13
Detector Stencil	$5
Main Board PCB	$16
Main Board Parts	$45
Main Board Stencil	$17
Leaded Solder	$14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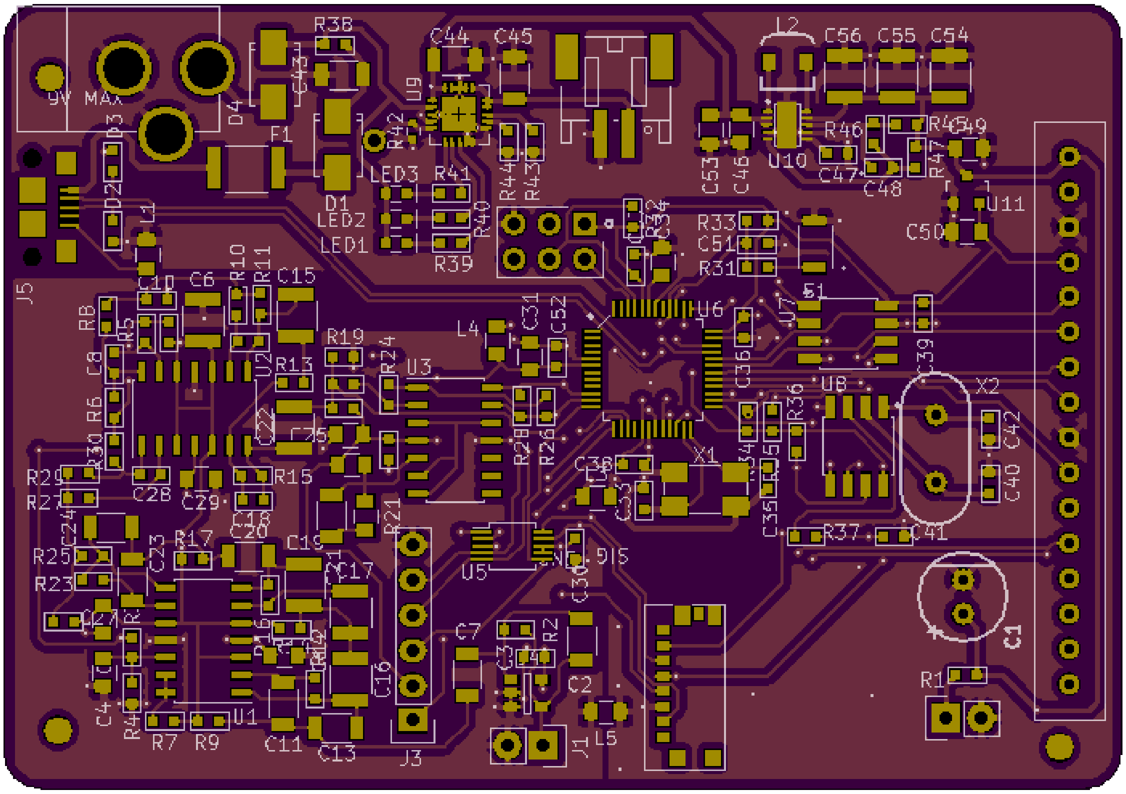
J8
D4
R38
C43
C44
C45
J9
L2
C56
C55
C54
J5
D2
F1
D1
U9
R42
R44
R43
C53
C46
U10
R46
R45
C47
C48
R47
C49
U11
C50
LED3
R41
LED2
R40
LED1
R39
J6
R32
R33
C51
R31
S1
D3
L1
C37
C34
R8
C10
C6
R10
R11
C15
R5
C5
C12
U7
C39
C36
L4
C31
C52
U6
C8
R19
U2
R13
R22
R24
R18
C22
R6
C25
R28
R26
R34
R35
U8
X2
C42
J7
U3
R36
R30
C26
R20
C38
R29
C28
C29
R15
X1
C35
C40
R27
C18
L3
C33
C21
R21
C24
U5
C30
R37
C41
C1
R25
C20
R17
C23
C19
R23
R16
C17
J3
C27
C9
U1
R14
R2
C2
J4
R3
C14
C3
C4
C7
C16
R1
R12
U4
C11
R4
L5
J2
FID3
R7
R9
C13
J1
FID2


BAT1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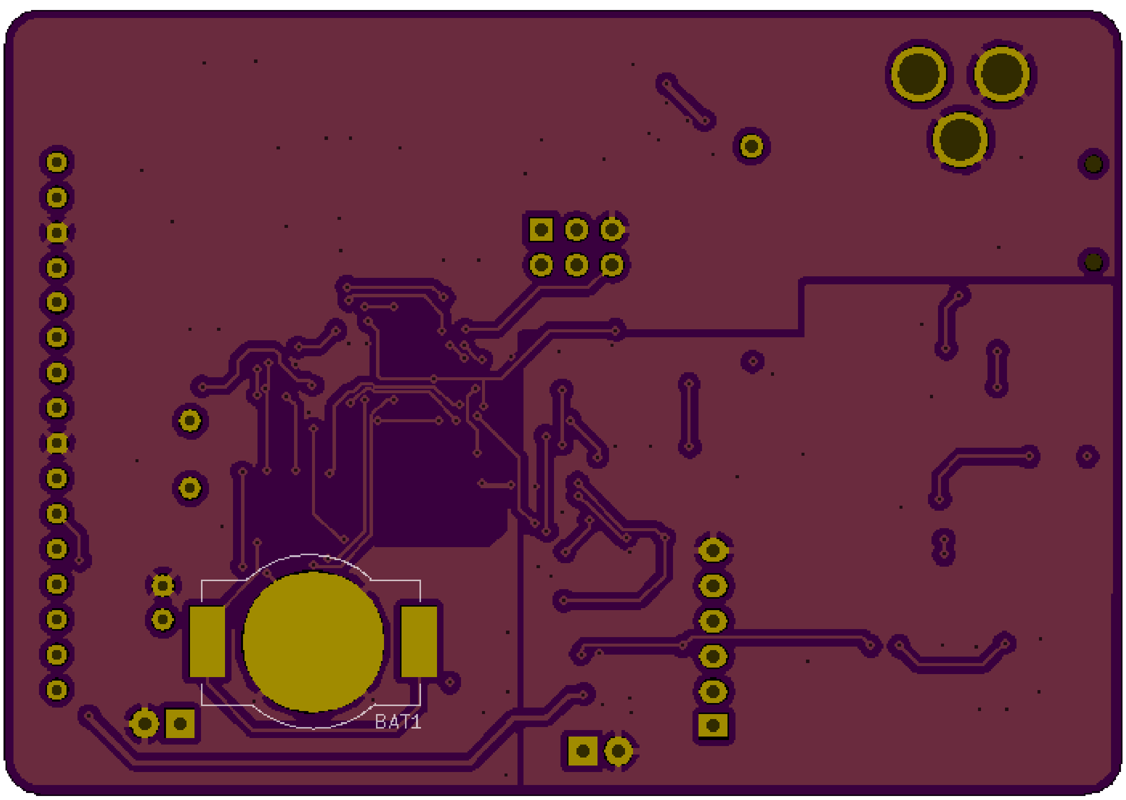
J5
F1
D1
D4
LED1
LED2
LED3
U1
U2
U3
U5
U6
U7
U8
U9
U10
U11
X1
X2
J1
J3
L2
L4
L5
C1
R1
R38
C44
C45
C54
C55
C56


BAT1

Bill of Materials

Ref	Qty	Description	Digikey PN
BAT1	1	CR1220 BATTERY HOLDER SMT FLATPIN	BK-916-CT-ND
C1	1	CAP ALUM 330UF 20% 16V RADIAL	732-8798-1-ND
C10	1	CAP CER 0.27UF 16V X7R 0603	490-6427-1-ND
C11 C13 C2 C7	4	CAP CER 1.5UF 25V X7R 1206	1276-6873-1-ND
C12 C28 C8	3	CAP CER 0.01UF 50V X7R 0603	490-1512-1-ND
C14 C29 C34 C4 C49 C50 C9	7	CAP CER 1UF 25V X7R 0805	1276-1066-1-ND
C15 C54 C55 C56 C6	5	CAP CER 22UF 25V X7R 1210	1276-3392-1-ND
C16 C17 C19 C22	4	CAP CER 2.2UF 25V X7R 0805	1276-2953-1-ND
C18	1	CAP CER 33PF 16V X7R 0603	478-6211-1-ND
C20 C21 C23 C24 C43 C44 C45	7	CAP CER 4.7UF 50V X7R 1206	1276-2789-1-ND
C25 C31 C46 C53	4	CAP CER 10UF 16V X7R 0805	1276-2872-1-ND

Ref	Qty	Description	Digikey PN
C26 C30 C36 C37 C38 C39 C47 C51 C52	9	CAP CER 0.1UF 100V X7R 0603	490-3285-1-ND
C27	1	CAP CER 0.022UF 50V X7R 0603	1276-2004-1-ND
C3	1	CAP CER 0.22UF 25V X7R 0603	1276-1111-1-ND
C33 C35	2	CAP CER 22pF 50V NP0 0603	399-9031-1-ND
C40 C42	2	CAP CER 2PF 50V C0G/NP0 0603	490-10713-1-ND
C41	1	CAP CER 100PF 50V C0G/NP0 0603	490-1427-1-ND
C48	1	CAP CER 10PF 50V NP0 0603	1276-2154-1-ND
C5	1	CAP CER 0.039UF 50V X7R 0603	1276-2056-1-ND
D1 D4	2	DIODE SCHOTTKY 20V 1A SMA	SS12-E3/61TGICT-ND
D2 D3	2	VARISTOR ESD PROTECT USB	CG0603MLC-05ECT-ND
F1	1	RESETTABLE FUSE 500mA 15V MF-MSMF	MF-MSMF050-2CT-ND
J1 J2	2	HEADER MALE 2POS TH 1x02 0.1IN	952-2262-ND
J3	1	HEADER MALE 6POS KK100 0.1IN SHROUD TH	WM4204-ND
J4	1	CONN MICRO SD CARD PUSH-PULL	WM9731CT-ND

Ref	Qty	Description	Digikey PN
J5	1	USB MICRO-B RECEPTACLE 5PIN SMT R/A STUDS	609-4616-1-ND
J6	1	HEADER FEMALE 6POS 2x3 0.1IN	A30729CT-ND
J8	1	CONN PWR JACK 2.5X5.5MM HIGH CUR	PJ-202BH
J9	1	CONN HEADER PH SIDE 2POS 2MM	455-1719-ND
L1 L3 L4 L5	4	FERRITE BEAD 30 OHM 0805 1LN	MH2029-300YCT-ND
L2	1	FIXED IND 1UH 3.3A 1226AS-H-1R0N	490-14149-1-ND
LED1 LED2 LED3	3	LED AMBER DIFFUSED 0603 SMD	475-2712-1-ND
R1	1	RES SMD 220 OHM 5% 1/10W 0603	311-220GRCT-ND
R10	1	RES SMD 732 OHM 1% 1/10W 0603	P732HCT-ND
R11 R8	2	RES SMD 1.43K OHM 1% 1/10W 0603	P1.43KHCT-ND
R12 R16 R23	3	RES SMD 2.26K OHM 1% 1/10W 0603	311-2.26KHRCT-ND
R13 R33 R36	3	RES SMD 10K OHM 1% 1/8W 0603	RNCP0603FTD10K0CT-ND
R14 R39 R40 R41	4	RES SMD 470 OHM 5% 1/4W 0603	RHM470DCT-ND
R15	1	RES SMD 97.6K OHM 1% 1/10W 0603	P97.6KHCT-ND
R17	1	RES SMD 68 OHM 1% 1/10W 0603	P68.0HCT-ND

Ref	Qty	Description	Digikey PN
R18 R19	2	RES SMD 91K OHM 1% 1/10W 0603	P91.0KHCT-ND
R2	1	RES SMD 64.9K OHM 1% 1/10W 0603	P64.9KHCT-ND
R20 R21	2	RES SMD 220K OHM 5% 1/8W 0805	P220KACT-ND
R22 R26	2	RES SMD 2.2K OHM 5% 1/10W 0603	P2.2KGCT-ND
R24 R28	2	RES SMD 22K OHM 5% 1/10W 0603	P22KGCT-ND
R25 R29	2	RES SMD 4.32K OHM 1% 1/10W 0603	P4.32KHCT-ND
R27	1	RES SMD 2.94K OHM 1% 1/10W 0603	P2.94KHCT-ND
R3 R4 R44	3	RES SMD 100K OHM 1% 1/10W 0603	RMCF0603FG100KCT-ND
R30 R6	2	RES SMD 3.83K OHM 1% 1/10W 0603	P3.83KHCT-ND
R31	1	RES SMD 330 OHM 5% 1/10W 0603	311-330GRCT-ND
R32 R37	2	RES SMD 1K OHM 1% 1/10W 0603	1276-3484-1-ND
R34 R35 R43	3	RES SMD 2K OHM 1% 1/8W 0603	RNCP0603FTD2K00CT-ND
R38	1	RES SMD 0.0 OHM JUMPER 1/8W 0603	MCT0603-0.0-ZZCT-ND
R42	1	NTC THERMISTOR 10K OHM 1% 0402	445-2550-1-ND
R45 R47	2	RES SMD 1M OHM 5% 1/10W 0603	P1.0MGCT-ND
R46	1	RES SMD 111K OHM 5% 1/10W 0603	P110GCT-ND

Ref	Qty	Description	Digikey PN
R5	1	RES SMD 1.87K OHM 1% 1/10W 0603	P1.87KHCT-ND
R7	1	RES SMD 10 OHM 1% 1/10W 0603	P10.0HCT-ND
R9	1	RES SMD 470 OHM 5% 1/4W 0603	311-1.02KHRCT-ND
S1	1	SWITCH TACTILE SPST-NO 0.05A 12V	SW1020CT-ND
U1 U2	2	IC OPAMP QUAD GP RRO 1MHZ SOIC14	MCP6004T-I/SLCT-ND
U10	1	IC REG BUCK BOOST ADJ 2A 10WSON	296-30204-1-ND
U11	1	IC REG LDO 3.3V 0.25A MCP1703 SOT23A-3	MCP1703T-3302E/CBCT-ND
U3	1	IC OPAMP GP 3MHZ RRO 14SOIC	296-39258-1-ND
U4	1	IC OPAMP GP 1MHZ RRO MCP6001 SOT23-5	MCP6001T-I/OTCT-ND
U5	1	IC ADC 16BIT SPI 860SPS ADS1118 10MSOP	296-38850-1-ND
U6	1	IC MCU 32BIT 256KB FLASH ATSAMD21G 48TQFP	ATSAMD21G18A-AUTCT-ND
U7	1	IC EEPROM 1MBIT 400KHZ 24AA1025 SOIC8	24AA1025-I/SN-ND
U8	1	IC RTC CLK/CALENDAR I2C MCP7940N SOIC8	MCP7940N-E/SN-ND
U9	1	IC USB/AC BATT CHRGR MCP73871 20QFN	MCP73871T-2CCI/MLCT-ND

Ref	Qty	Description	Digikey PN
X1	1	CRYSTAL 16MHZ 30PPM 18pF 4SMD	CTX1206CT-ND
X2	1	CRYSTAL 32.768kHz 7pF CFS-20632768DZYB	300-8842-ND

Ref	Qty	Description	Adafruit PN
B1	1	Lithium Ion Polymer Battery - 3.7v 500mAh	1578
J7	1	ADAFRUIT FONA 808 + GPS	2542