DRONE SITL BRINGUP WITH THE IIO FRAMEWORK

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Open Source Summit, Europe, 2018

WHAT'S THIS ABOUT ?

- My experiments with bringing up sensors on a x86 board
- Understanding the IIO framework
  - Interfacing the framework with SITL code to verify sensors are working

WHAT ISN'T THIS ABOUT ?

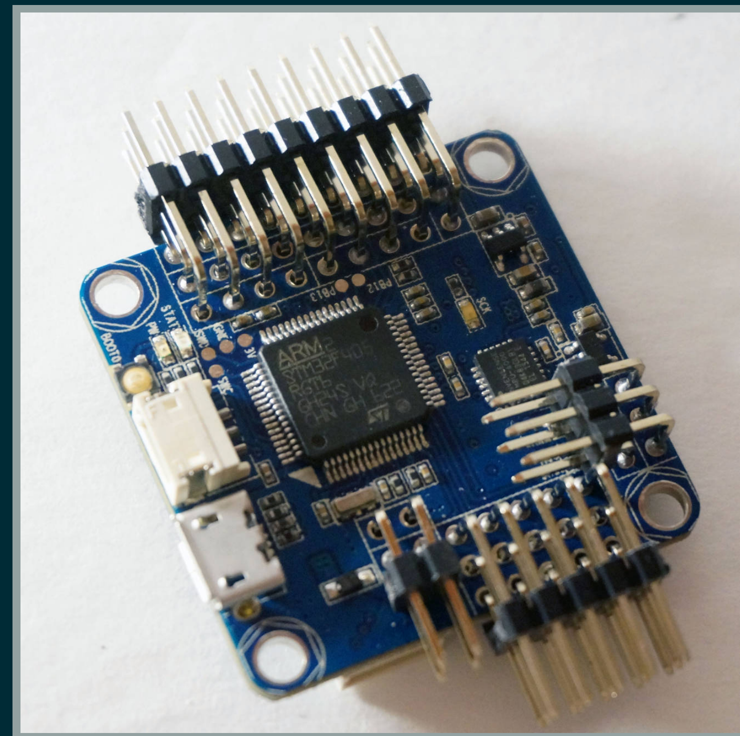
- Flying
- Drones, I am a newbie!

ACKNOWLEDGEMENTS

- Real Time systems group at BU
- https://www.cs.bu.edu/~richwest/index2.html
- Microkernels, Cache scheduling algorithms, Virtualization, Predictable time

STATE OF THE ART

HARDWARE



- Most drone boards belong to the STM32 family
- Becoming faster/powerful everyday!
- Low power requirements

SOFTWARE

- Ardupilot, Betaflight, iNav, Cleanflight

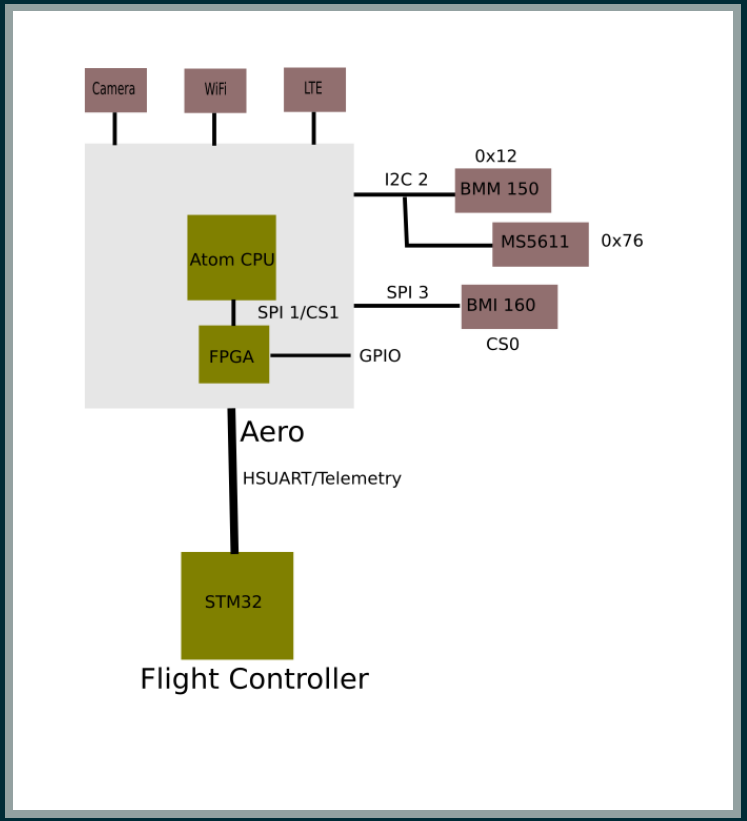
WHY X86 ?

- Increasingly complex tasks and onboard peripherals
- Processing power
- The case for reactive drones
- Low power x86 boards are a reality although not common

WHY LINUX ?

- Robust operating system
- Drivers for a wide variety of sensors/peripherals
- Choice of schedulers

A LOOK AT THE INTEL AERO COMPUTE BOARD



Aero as a Companion Computer

HOWEVER...

- The Aero is a powerful computer
- Onboard sensors to run standalone as a flight controller
- Access to GPIO pins/motor outputs through onboard FPGA

MOVING FC OPERATIONS TO A X86 BOARD

- Reinventing the wheel
  - Customized Linux that jumps to a flight controller loop with specific tasks
- Leverage on existing solutions
  - Run an existing flight controller software as a process

INTERFACING WITH THE ONBOARD SENSORS

- spidev/i2cdev - userspace drivers
- Linux already has drivers for most sensors
  - exposed by the Industrial IO interface (IIO)
- Advantages
  - Minimizes latency
- Disadvantages
  - Crashes can be deadly

AN INTRODUCTION TO THE IIO INTERFACE

- Industrial Input/Output
  - Examples include Humidity Sensors, Temperature sensors, Magenetometer etc
  - v4.18: ~20 classes, each containing numerous device drivers
  - Most devices connected via I2C or SPI
- IIO provides a hardware abstraction layer over these devices
  - Sharing of infrastructure
  - Developer focus on device function rather than knowledge of plumbing internals
  - Consistent application development framework
  - Data buffer for continuous data and single shot access via sysfs

GETTING STARTED WITH IIO

- Device drivers
  - BMI 160 Inertial Measurement Unit

    ```
    ls drivers/iio/imu/bmi160/
    bmi160_core.c bmi160_i2c.c bmi160_spi.c
    ```

  - BMM 150 3 axis Geomagnetic Sensor

    ```
    ls drivers/iio/magnetometer/
    bmc150_magn.c bmc150_magn_i2c.c bmc150_magn_spi.c
    ```

  - MS5611 Pressure Sensor

    ```
    ls drivers/iio/pressure/
    ms5611_core.c ms5611_spi.c ms5611_i2c.c
    ```

GETTING STARTED WITH IIO

- Key components
  - Device drivers
  - Channels
  - Buffers
  - Triggers

GETTING STARTED WITH IIO

- Channels - One of the many functions provided by the device
  - BMI160

    ```
    cat /sys/bus/iio/devices/iio\:device0/name
    bmi160
    ls /sys/bus/iio/devices/iio\:device0/
    in_accel_x_raw in_accel_y_raw in_accel_z_raw
    ```

  - BMM150

    ```
    cat /sys/bus/iio/devices/iio\:device1/name
    bmc150_magn
    ls /sys/bus/iio/devices/iio\:device1
    in_magn_x_raw in_magn_y_raw in_magn_z_raw
    ```

GETTING STARTED WITH IIO

- Buffers
  - Raw continuous data read from the device
  - Specific channels can be enabled
  - Data format specified by channels
    - Example:

```
cat /sys/bus/iio/devices/iio\:device1/scan_elements/in_magn_x_type
le:s32/32>>0
```

  - Kfifo backed
  - Read using standard fileops by accessing /dev/iio:deviceX
  - mmap based interface supported by a DMA backend (high speed devices)

GETTING STARTED WITH IIO

- Triggers
  - Capture data only when needed
    - Based on a hardware event
    - User initiated (eg: via sysfs)
    - Software trigger (eg: hrtimer based)
    - Enabling trigger enables data capture

GETTING STARTED WITH IIO

- Initializing SPI/I2C devices
  - Not enumerated at the hardware level
  - SPI (BMI160)
    - Device tree
    - ACPI
    - Board initialization file
    - Example:

```
static struct spi_board_info imu_board_info __initdata ={
.modalias= "bmi160",
.bus_num= SPIDEV_SPI_BUS,
.chip_select= SPIDEV_SPI_CS,
.max_speed_hz= SPIDEV_SPI_HZ,
};
...
master = spi_busnum_to_master(SPIDEV_SPI_BUS);
...
dev = spi_new_device(master, &imu_board_info);
...
```

GETTING STARTED WITH IIO

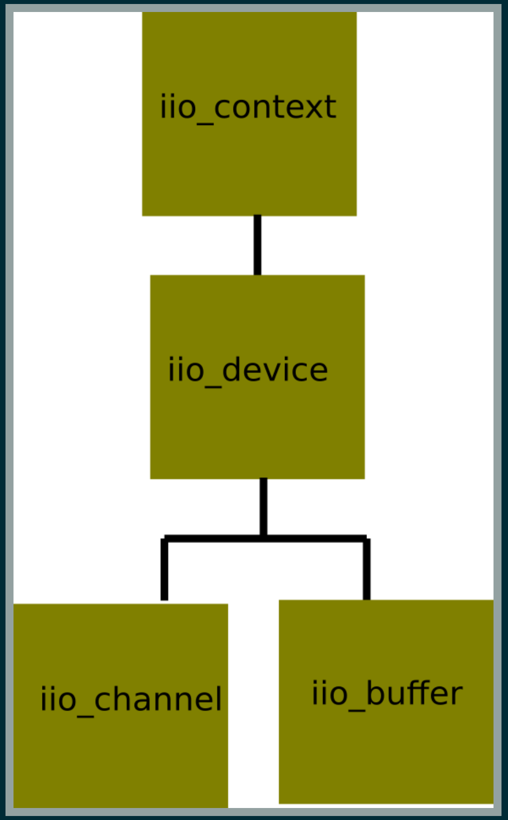
- Initializing SPI/I2C devices
  - I2C (BMM150)
    - Device tree
    - Board initialization file
    - sysfs interface
    - Example:

```
echo bmc150_magn 0x12 > /sys/bus/i2c/devices/i2c-2/new_device
```

CREATING A TRIGGER

```
mkdir /sys/kernel/config/iio/triggers/hrtimer/trigger0
echo 5000 > /sys/bus/iio/devices/trigger0/sampling_frequency
cd /sys/bus/iio/devices/iio:device0 #Associate trigger with BMI160
echo trigger0 > trigger/current_trigger
echo 1 > scan_elements/in_accel_x_raw
echo 1 > buffer/enable
```

SHIM LAYER: LIBIIO



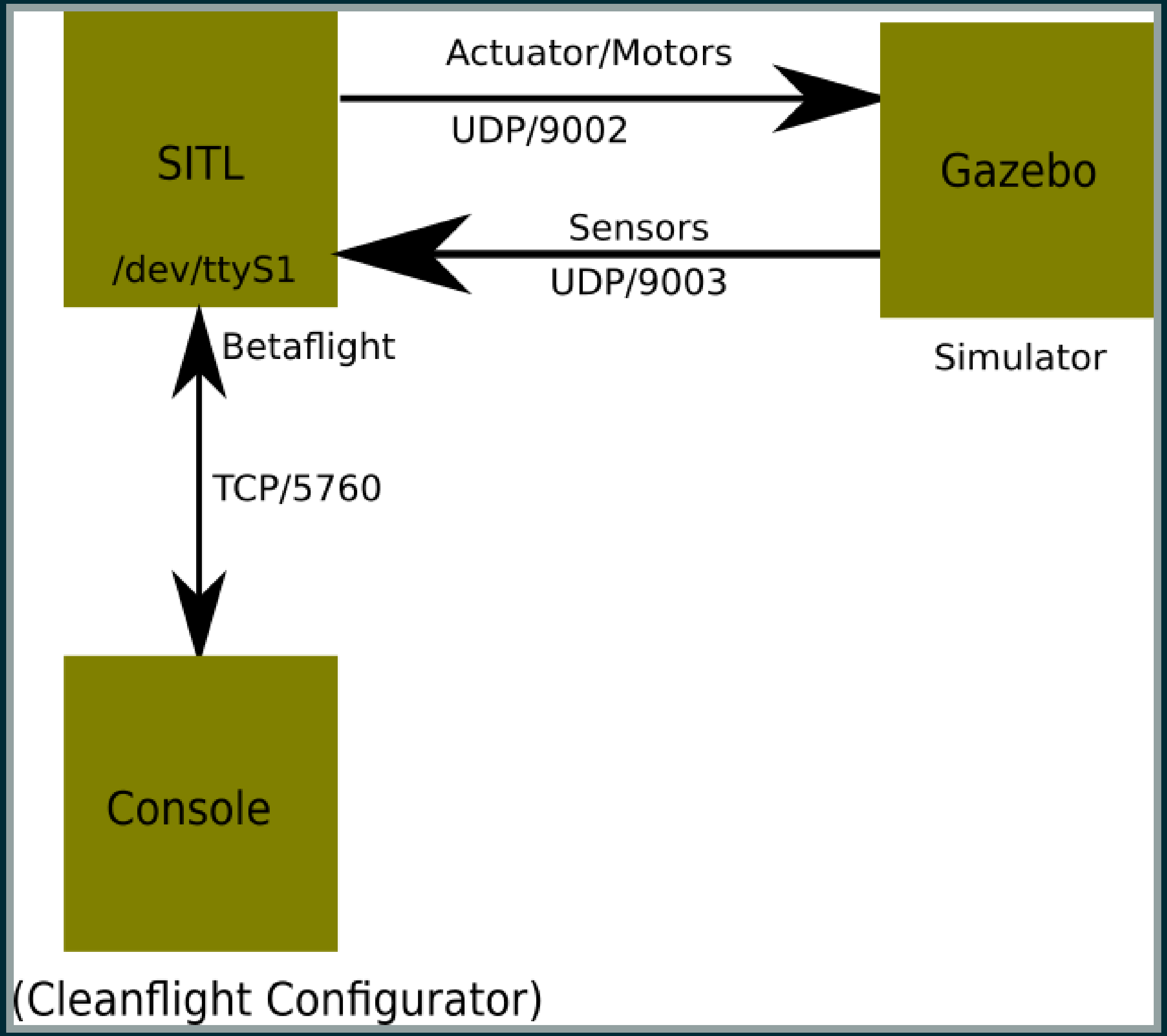
libiio: Building blocks

- Library that interfaces with the IIO API
- Ease of developer interacting with the IIO framework

SIMULATION FRAMEWORKS (SITL/HITL)

- SITL
  - Modified flight controller software running in a simulator environment
  - Control signals come from software or a controller
  - Simulator feeds sensor data back to firmware feedback loop
  - Actuator outputs fed to simulator
- HITL
  - Flight controller software runs on the actual board
  - Sensor data and outputs fed to a simulator
  - Enables testing in closer to real-world conditions

SITL SETUP IN BETAFLIGHT

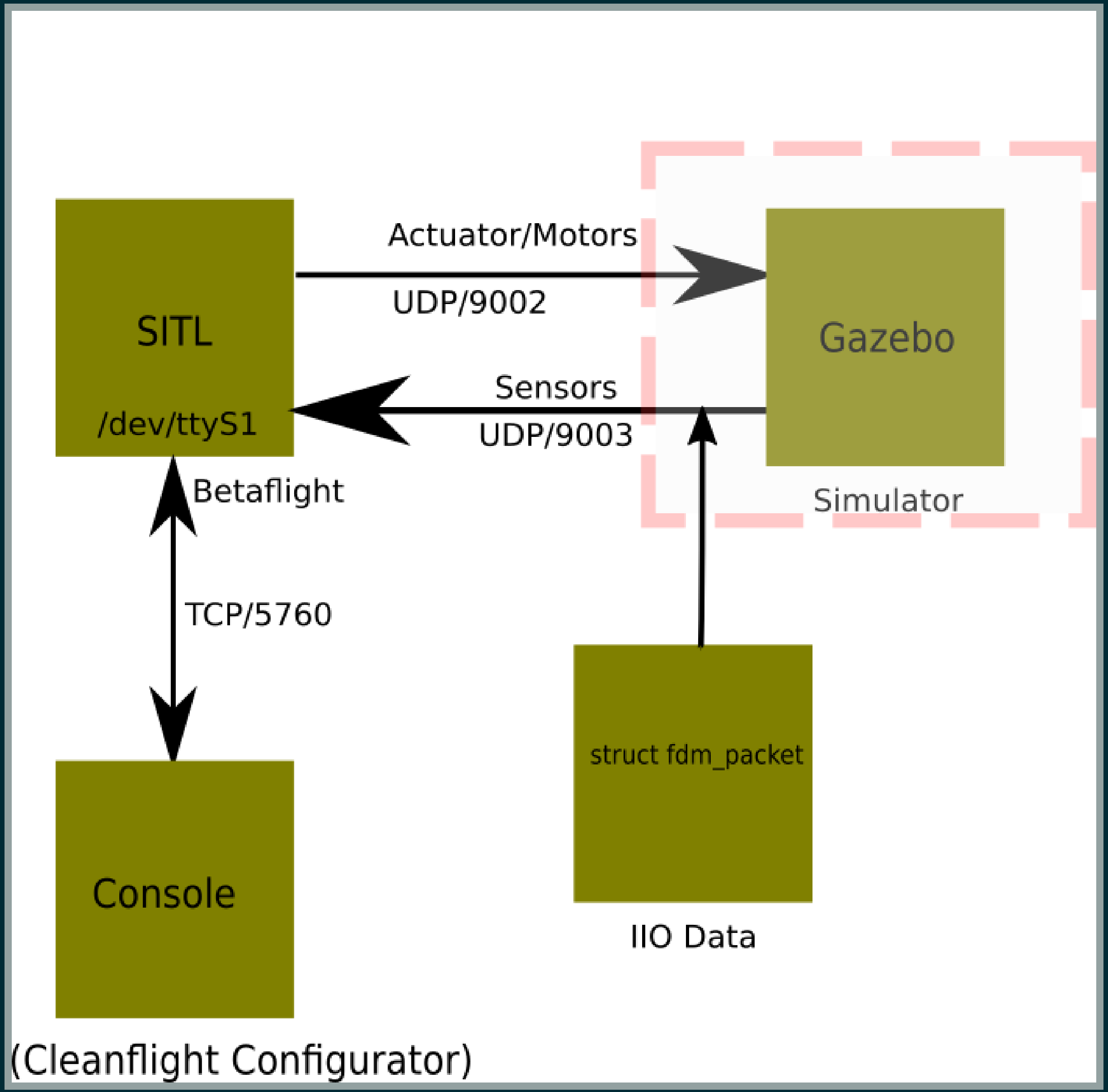


Basic SITL setup in Betaflight/Cleanflight

SENSOR DATA FORMAT

```
 typedef struct {
        double timestamp;
        double imu_angular_velocity_rpy[3];
        double imu_linear_acceleration_xyz[3];
        double imu_orientation_quat[4];
        double velocity_xyz[3];
        double position_xyz[3];
} fdm_packet;
```

PLUGGING IN IIO DATA IN THE SITL LOOP



PLUGGING IN IIO DATA IN THE SITL LOOP

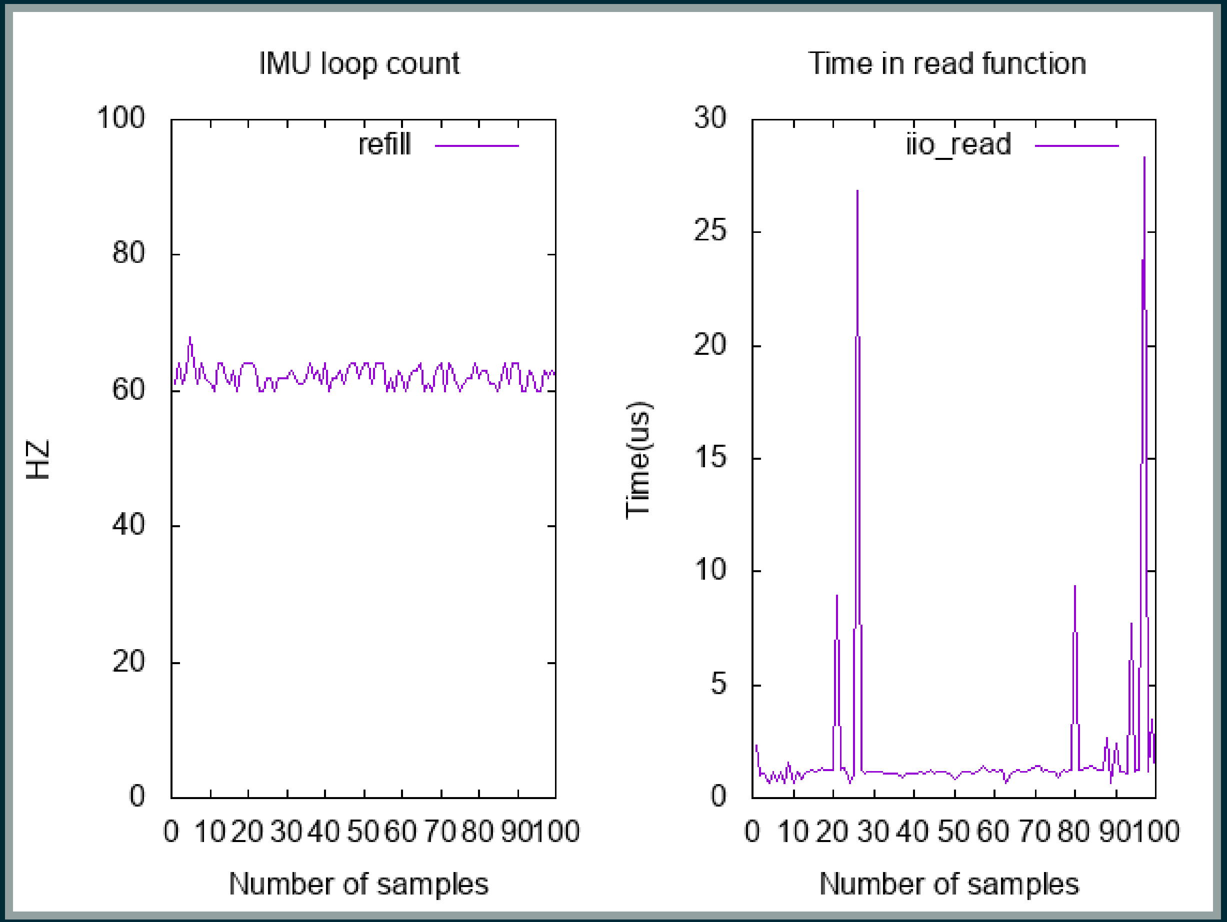
- Visual indication of correct functioning of sensors
- Sensors output in a more readable format or graph (eg. Cleanflight Configurator)

BETAFLIGHT TASKS

```
/* TASK_COUNT = ~30 */
cfTask_t cfTasks[TASK_COUNT] = {
...
   [TASK_GYROPID] = {
       .taskName = "PID",
       .subTaskName = "GYRO",
       .taskFunc = taskMainPidLoop,
       .desiredPeriod = TASK_GYROPID_DESIRED_PERIOD,
       .staticPriority = TASK_PRIORITY_REALTIME,
   },
   [TASK_ACCEL] = {
       .taskName = "ACC",
       .taskFunc = taskUpdateAccelerometer,
       .desiredPeriod = TASK_PERIOD_HZ(1000),      // 1000Hz, every 1ms
       .staticPriority = TASK_PRIORITY_MEDIUM,
   },
   [TASK_ATTITUDE] = {
       .taskName = "ATTITUDE",
       .taskFunc = imuUpdateAttitude,
       .desiredPeriod = TASK_PERIOD_HZ(100),
       .staticPriority = TASK_PRIORITY_MEDIUM,
   },
   ...
   #ifdef USE_MAG
   [TASK_COMPASS] = {
       .taskName = "COMPASS",
       .taskFunc = compassUpdate,
       .desiredPeriod = TASK_PERIOD_HZ(10),        // Compass is updated at 10 Hz
       .staticPriority = TASK_PRIORITY_LOW,
   },
   #endif
   ...
```

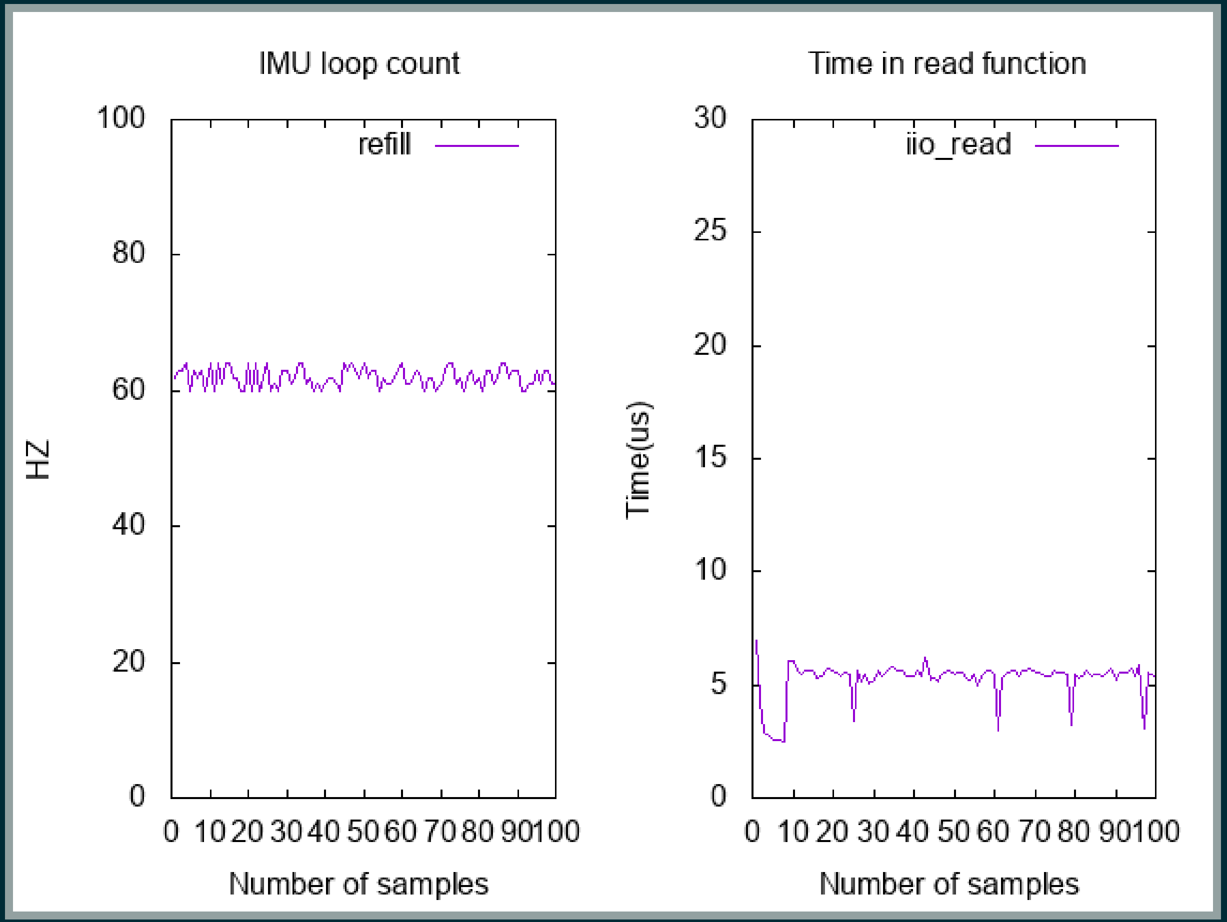
```
};
```

IMU LOOP COUNT



- Standard upstream kernel
- No specialized config

IMU LOOP COUNT



- Standard upstream kernel
- isolcpus=2-3
- irq thread on CPU 2 and read process on CPU 3

REFERENCES

- https://bitbucket.org/bdas/iio_sensors (Code snippets for the SITL/IIO interface)
- https://lwn.net/Articles/370423/ (Secrets of the Ftrace function tracer)
- https://github.com/betaflight/betaflight (Betaflight source)
- https://archive.fosdem.org/2012/schedule/event/693/127_iio-a-new-subsystem.pdf (IIO, a new kernel subsystem)
- https://github.com/analogdevicesinc/libiio (Library for interfacing with IIO devices)
- https://www.youtube.com/watch?v=ealH3qP_pBE (APM on Linux: Porting Ardupilot to Linux1)
- https://archive.fosdem.org/2015/schedule/event/iiosdr/ (Using the Linux IIO framework for SDR)
- https://www.cs.bu.edu/~richwest/index2.html (Rich West's Home page)
- https://github.com/intel-aero/meta-intel-aero/wiki (Intel Aero Wiki)

WRAP UP NOTES

- Running a flight controller software as a process
- Interfacing with IIO appears to be straightforward
- Further investigation on latency and performance
- Running a PREEMPT_RT kernel
- More experiments with affinities