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ADDING AN ARDUINO PID TO A 4QD PORTER-100 DC MOTOR CONTROLLER

Contents

Introduction

This doco briefly covers how to wrap a closed-loop manager around an open-loop DC motor controller so that the user's throttle will select a (maximum allowed) *current* rather than a given *PWM duty cycle*.

Such a controller is of benefit in power-limited systems - for example a Hacky Racer in which the maximum allowed instantaneous power is dictated by an inline battery fuse.

Software and hardware are covered.

Warning

Don't use this in any safety-critical application. See the license terms!

Overview

Core

The core controller - in this case a 4QD Porter-100 - is an open-loop device which converts an input signal into a high-current PWM output for (say) a large DC motor.

In the default open-loop set-up of a Porter-100, the user's input (0-100%) simply* instructs the controller to provide a matching output (0-100% PWM).

**In fact, the Porter-100 is not quite that simple and it does not directly copy the input to the output - internal logic manages the maximum rate-of-change of the output, as well as limiting the peak current to protect the controller output stages against overload. So there is some lag and some peak-cropping between the user's input and the actual output.*

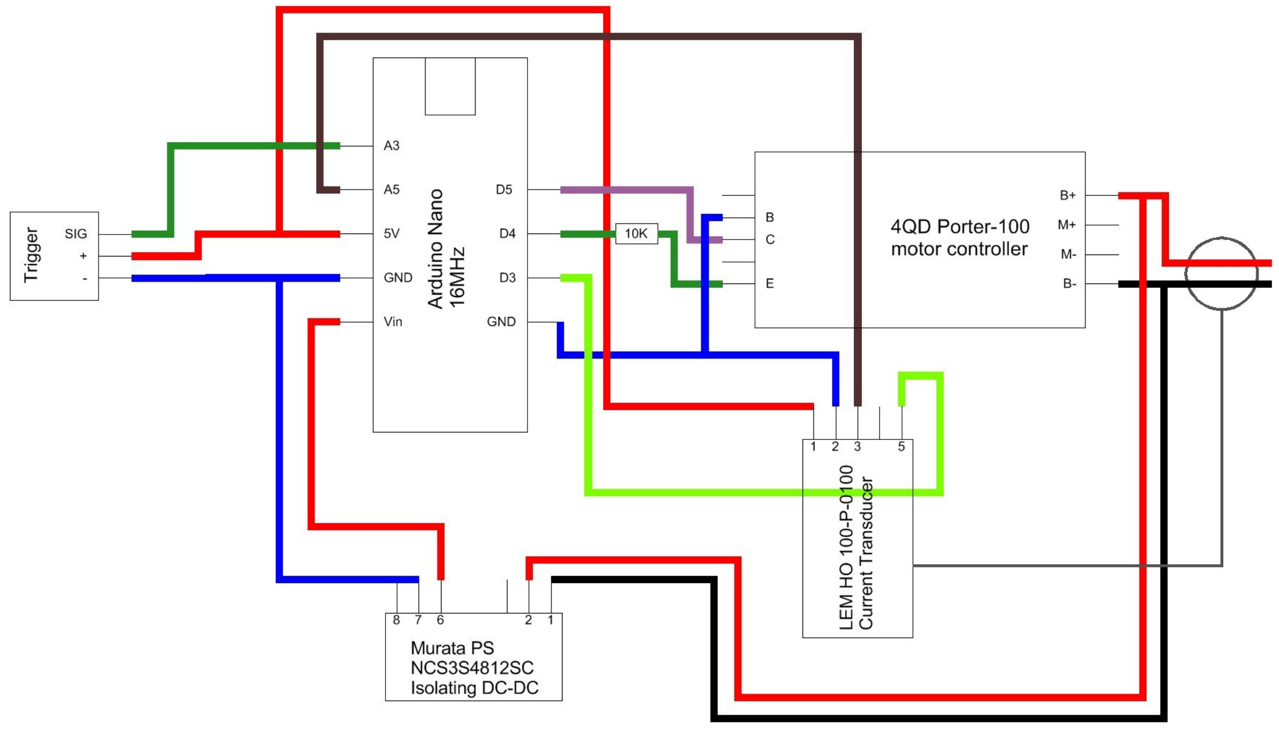
In a system which is *not* power-limited (i.e. there is effectively no upper limit on the permitted current other than the controller's own limitations) then a Porter-100 is a sufficient controller without needing the closed-loop additions documented here.

PID Wrapper

The additional closed-loop wrapper consists of two parts: a current sensor in the battery wires; and an Arduino which monitors the current. The user's input to the system is now via the Arduino, which converts that input to a demanded *current* in a fixed range (typically 0 to 30A) rather than a demanded *duty cycle*. The processor implements a PID feedback loop to match the actual battery current to the demanded current. Sort of :-)

Circuit

Here's a basic circuit diagram.



IMPORTANT: note that all the Porter-100's control inputs (A/B/C/D/E) must be isolated from the main power supply and from the motor. Therefore there must be **no common ground** between the main battery (B+/B-) and the Arduino's power (Vin/5v/GND). It is essential, therefore, to use an **isolating** DC-DC converter to supply the Arduino and it is essential to leave the Arduino GND floating.

Observe that the Arduino GND is connected to the Porter-100's 'B' ground terminal - not to the 'A' terminal as documented by 4QD. We find this to be more reliable.

The 'Trigger' should be a Hall-sensor throttle (output 0.8V to 4.2V typically) or a 5K/10K potentiometer (giving 0V to 5V). Adjust software to match.

The Arduino's 5V PSU has - to date - proven adequate to supply both the current sensor and the trigger as shown. If prefered, a separate common-ground regulator could be installed on the isolated 12V output to supply these.

Beware that swapping the 12V supply for an isolating 5V supply (wired direct to the Arduino 5V input) is inadequate and results in frequent brown-out reboots of the Arduino irrespective of any capacitative smoothing employed.

Other Core Controllers

The same circuit can be employed on cheap 'Chinese' motor drivers. These are typically 1-quadrant devices, cost about £10-£20, and often come with a potentimeter to select the speed and a physical switch to select on/off. Some even have a reverse implemented by two large relays (ick). Typically the on-off switch is non-logic i.e. it controls the full battery voltage (e.g. 48V) supply into whatever regulator supplies the logic circuitry.

So in general the wiring will need to be changed in the following ways:

- All grounds can - and should - be commoned. But check the circuit to be sure, before doing this. Quite possibly the expensive DC-DC isolating converter could then also be replaced by a simpler 3-wire regulator - although 48V-capable regulators are not commonplace.
- The on/off switch should either be operated by a relay/transistor/FET (via the Arduino's D4 output) or - our preference - should simply be soldered closed.
- The potentiometer should be removed and the Arduino's D5 output connected to the pin on the controller which was previously connected to the pot's wiper. A 10Kohn resistor should be fitted to pull this pin to ground, otherwise the motor will run at random (but dangerously non-trivial) power during boot-up.

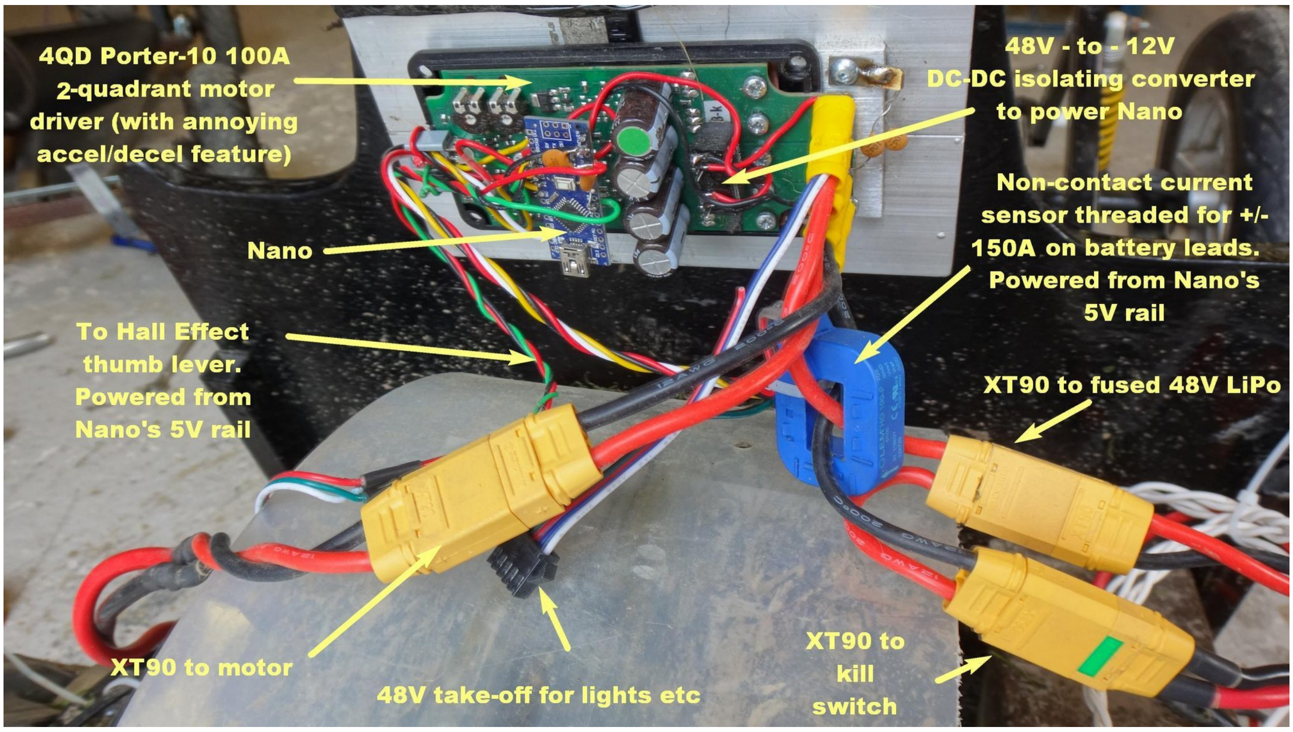
In addition software changes may be required:

- Reversing the logic of the D4 output.
- Setting the D5 output to range from 0% to 100% to emulate the full range of a pot.

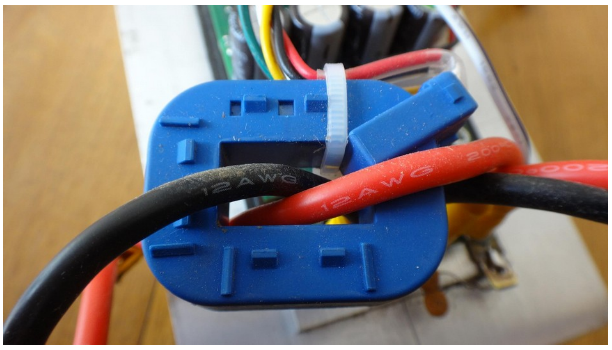
Further software enhancement - in the case of a reversing controller with relays - would be to enable the reverse changeover only when the throttle and the current draw are at zero. Perhaps with a time delay to prevent driving the motor (say) in reverse whilst carrying forwards momentum - which would cause a very large current surge probably destroying the controller. Further reverse protection could be applied by limiting the maximum reverse PWM to - say - 20%.

Assembly

The Arduino and the power supply can be fitted inside the Porter-100's case.



Note carefully how the current-sensor is threaded: exactly two passes of the main battery wires should thread through the centre of the transducer. Here, we've threaded the positive battery wire one way, and the negative battery sire the opposite way. Direction of threading does matter.



The pictured threading method has significant disadvantages due to physical movement and stray currents induced from nearby wiring. Future builds will instead thread the sensor using rigid copper wire wrapped twice through the centre and locked securely in place with adhesive, with nearby power cables also locked into position relative to the sensor. This should ensure more consistent readings. (Bearing in mind that *consistency* is more important that absolute *accuracy*.)

Threading Notes

The current sensor is threaded for +/-125A. This might seem an excessive range, given that we're trying to control only 0A to 30A.

However, the core controller is a PWM on/off device, a typical LiPo power supply has effectively zero internal resistance, and the load motor (at standstill) has an extremely low impedance. So at motor start-up - even when using very low duty-cycles - the *peak* current of the PWM cycle can be many times the demanded *average* current. We cannot afford to allow the sensor to crop the signal (because we would underestimate the actual current) so we need to thread it for very large currents.

Core Controller Notes

We're sensing *battery* current, not motor current, because we want to protect the battery fuse. Motor average current can be much higher than battery average current, something to keep in mind when choosing the core controller's maximum current capability (which is rated on motor current.)

Software

The software is written for Arduino using the standard Arduino IDE v1.8.3 on Linux. (We have seen issues with some older Arduino IDE versions - especially on Windows - which may require forward declarations to be added to some code. We haven't tested this.)

Note that our code has multiple issues in design, implementation, coding misconceptions, and indeed some complete c*ck-ups not worthy of a coding professional <embarrassed emoji>. We've annotated some of these and we do know about the others, so please don't tell us about them. Our lives are busy and short and this code does work as-is to achieve its main goal. Which is to drive the motor reasonably hard but without blowing fuses. Fixing the errors - without enhancing the code in other ways - changes the software behaviour in undesirable ways. I.e. it blows fuses and/or reduces the motor power. So, for your peace of mind, please do set the IDE's warning-level to “none”, buid it, flash it, and forget it :-)

One improvement, that you may like to add, is to wrap the grabbing of <setpoint> and <input> values in the main loop as an ATOMIC operation. We have done so in the devel version (not uploaded). Otherwise there is risk that these values will be occasionally corrupted.

Find the stable code at:
https://github.com/MechanicalCat/HackyRacerPID

The code uses our own internal DEBUG library. So either strip out our debugging from the code, or get the library from:
https://github.com/MechanicalCat/Debug
This library is not 'properly' packaged. But it's so small you'll easily figure it out. Just copy the files Debug.h and Debug.cpp into a directory at .../libraries/Debug

You'll also need the third-party PID AutoTune library. See:
https://playground.arduino.cc/Code/PIDAutotuneLibrary

We're working on a new bug-fixed version with a more elegant method of managing fuse heating. We're hoping this will work on cheaper (£10) dumb controllers, rather than only on the more expensive intelligent Porter-100. So feel free to contact us via www.MechanicalCat.org if you'd like to ask if there's an updated version of our code available.

Software Notes

Instance <sensor> of class <SenseI> maintains a rolling-average of the sensed battery current from 1000+ samples spaced over several milliseconds. Clearly this is slightly laggy and slightly imprecise - but it has to be because it is necessarily averaged over a/some duty cycle(s). For the purposes of this software this rolling-averaged current is deemed to be the *instantaneous* current.

Instance <fuse> of class <Fuse> maintains a rolling average of the instantaneous current over the past 3 seconds and the past 90 seconds. It also maintains a copy of the immediate instantaneous current.

Class <Fuse> allows comparison of the various average/instantaneous currents against the fuse's documented/guessed performance, and can suggest a maximum safe current that the fuse is capable of bearing, based on the recent history of current-flow (and therefore heating) that the fuse has endured. It does this by enforcing cool-down periods after certain current limits are exceeded.

Instance <motor> of class <Motor> is the interface to the core open-loop motor controller (the Porter-100). The method <drive> sets the controller's PWD duty cycle.

Instance <thumb> of class <ThumbLever> reads the user's input as a user-demanded current.

In the main loop, instance <pid> of class <PID> constantly modifies the Porter-100's output (via <motor>) in order to maintain <input> (read from <sensor>) at the same value as <setpoint> (read from <thumb>). Meanwhile <fuse> constantly adjusts the maximum permitted value of <setpoint> to prevent the physical circuit fuse being blown. In high-load usage, <input> should more-or-less track <setpoint>. But, when the physical motor is running at high speed and low load, the value of <input> may be lower than <setpoint>, even though the duty cycle is pushed all the way to 100%.

Also in the main loop, a separate check is kept on <thumb>: if the user's demand is ever zero (i.e. they let go the thumb lever) then all the above logic is short-circuited and the motor is immediately set to zero power. There are three reasons for this kludge:

- The 'off' response is as immediate as possible, although there may still be lag in the Porter-100 itself.
- The Porter's full regen/braking capability is engaged.
- The need to precisely calibrate* IZERO is obviated.

**Of all the reasons, this is - surprisingly - the most significant.*