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EXPANDING AN EXISTING DC MOTOR DRIVER WITH A CURRENT CONTROL LOOP

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Abstract: *In this paper an improvement of a previously designed small DC motor driver is presented. The drawback of the original design is the lack of the current control loop. Only the current limit has been implemented. The previous design has two nested digital control loops. The inner one for the speed and the outer one for the position control. The output of the digital controller, either for speed or position, produces the PWM signal which in turn directly controls the full bridge that feeds power to the DC motor. Changing the existing hardware as little as possible, an improved version has been developed. This new version includes hardware current control loop and also the possibility to implement a digitally controlled current loop.*
Key Words: ***DC motor, driver, control loop***

1. INTRODUCTION

Small, low inductance DC motors have a significant role in robotics and mechatronics. Very small and accurate motions can be achieved using these motors, if high quality drivers and control algorithms are used. In this manner, a small DC motor driver has been developed [1, 2]. Its main advantages are that it is fully digital, controlled by a contemporary 8-bit microcontroller (AVR series), it can be controlled by different digital systems via serial or I2C interfaces. One of its greatest advantages is that it incorporates a fully programmable PID controller. Its parameters can be set using either one of the digital interfaces. Motion commands can also be sent the same way.

Since the DC motors for which the driver has been developed have low inductance, the rotor current can have considerable current ripple. In this situation a cycle-by-cycle current limit effectively protects the motor from over-currents, but the average motor current can be very low, as well as the produced torque. As a result, the motion control gets seriously compromised. This makes the driver practically unusable for applications where high torques and finer motion control are needed. The driver had to be upgraded to include current control loop.

2. THE FIRST VERSION OF THE DRIVER

The main reason for developing the small DC motor driver was to provide the students participating on the European small autonomous robot competition – Eurobot [1]. Simplicity and low cost were of paramount importance because of the high number of participants from our university who the drivers were developed for. Another important point was that the same driver should easily be adapted to different robotic applications ranging from wheeled locomotion to powering small mechanism inside the autonomous robot. This adaptation is achieved by altering the parameters of the digital PID controller implemented in the firmware of the microcontroller – the heart of this system. The controller can be fine-tuned by user friendly software.

The effectiveness of this driver turned out to be extraordinary, at least for most of the applications in these student projects. But soon emerged the need to use the driver in other scientific projects in the field of robotics, where high demands are put on the driver. Therefore, the idea to expand the driver with current control appeared – not to change the existing driver at all, but expand it with an add-on printed circuit board (PCB).

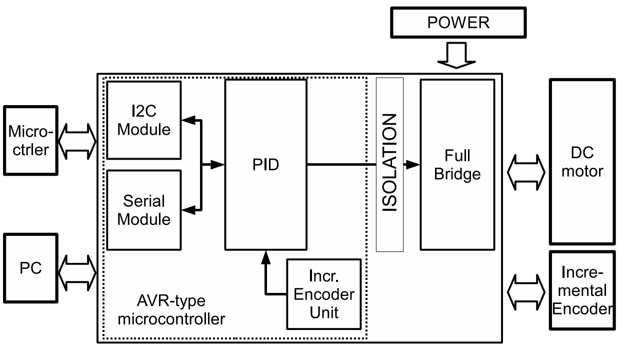

Fig. 1 *Structure of the first version of the DC motor driver. The inside area of the dotted rectangle represents the part implemented in AVR microcontroller hardware and software*

In Fig. 1, the structure of the first version driver can be seen. It is easy to notice that almost all the functionality is contained within the microcontroller: its hardware capabilities are utilized to communicate with a PC computer via serial asynchronous interface, with another microcontroller via I^2C bus. One of the timers helps obtaining positional and speed data from the DC motor's incremental encoder. A mosfet-implemented full-bridge delivers power to the DC motor itself. The bridge is isolated from the controller part in order to avoid noise propagation and ground level shifting because of the high currents the motor can draw in certain situations.

The most important thing to notice is that the PID affects the pulse width (PWM) delivered to the motor, effectively controlling the voltage between the motor's terminals. No current control is involved in any form, except for the current limitation implemented in the full bridge. This current limitation simply shuts down the bridge for the rest of the PWM cycle, when a preset current level is exceeded, thus preventing the damaging of the bridge components, the PCB connections or the motor itself.

The described driver implements positional and speed control of the motor. The current limitation mentioned above makes practically impossible all applications where the positional controller is required to hold its position under load or low speeds are demanded from the speed controller. Such situations are common in robotic applications, what led us into thinking about a current control upgrade.

3. THE UPGRADED DRIVER

Since the inductance of the DC motors for which the driver was meant to power is very low (in the range of hundreds of µH), current changes rapidly in the rotor windings. To implement current control in pure software in these conditions requires a microcontroller with a very high speed core. Although chips of the required capabilities are available today, we decided not to use them. We decided to keep the existing AVR microcontroller and to implement current control using analog circuits. This way, the already proven existing software needs practically no changing and additional high processing power processor is not needed. This way, the simplicity and low cost of the device remain unchanged.

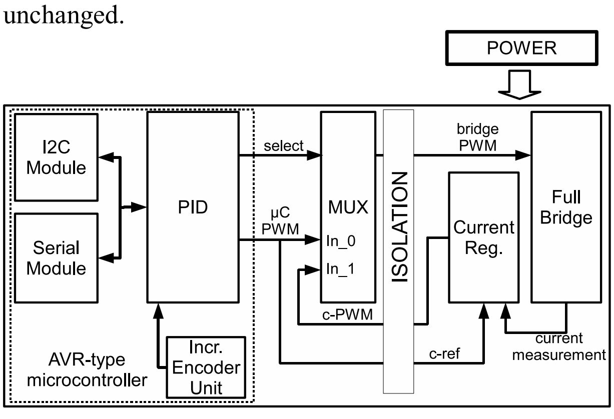

Fig. 2 *Structure of the upgraded motor driver. A choice between direct bridge PWM control and current control is provided*

In Fig. 2 the structure of the upgraded motor driver is shown. Isolation is preserved, although it complicates the electronic circuit of the system.

An additional multiplexer unit (MUX) is added that enables the microcontroller software to disable or enable the current control. If the first case (select=0) the microcontroller-generated PWM signal (µC PWM) is directly routed to the bridge and the current control is effectively disabled. The driver can use its previous control algorithm.

However, if the select=1, the PWM signal generated by the current controller (c-PWM) is routed to the bridge. The microcontroller-generated PWM signal (µC PWM) is low-pass filtered (Fig. 4) and it is used by the current controller as a reference signal. Based on the motor current measured at the bridge, the current controller produces its PWM signal (c-PWM).

The current measurement is achieved by using a contemporary integrated circuit (IR2175) which allows the measuring of a floating voltage over a 0.1Ω resistor (R_m) connected in series with the DC motor (Fig. 3). The measured current is converted to a PWM signal (50% duty-cycle for zero current). By low-pass filtering this signal (Fig. 4) the current measurement signal is obtained.

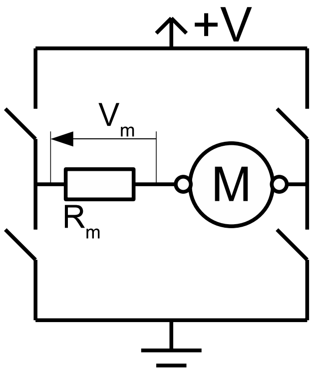

Fig. 3 *The motor current is measured using a resistor connected in series with the motor*

Current control is implemented by the SG3525 integrated circuit. The circuit is primarily designed as a switching power supply controller, but here it has been used in a non-specific way. The PWM generator works at a fixed frequency while the error amplifier output determines the duty-cycle. Instead of the usual voltage reference, output from the microcontroller is used (low-pass filtered PWM). The abovementioned current measuring circuit provides the feedback. As output, the IC provides another PWM signal that can be routed to the bridge when current control mode is selected by the microcontroller.

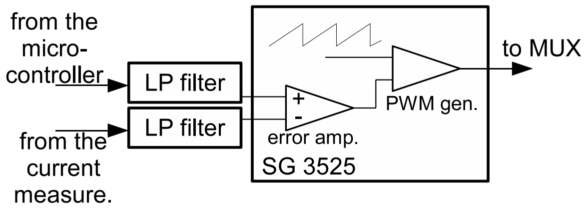

Fig. 4 *Details of the current control*

4. TEST RESULTS

To investigate the behavior of the designed additional current feedback loop some tests were conducted. The tests considered the closed loop speed control behavior of the system with and without current feedback loop. During the experiment the PID parameters were the same in both cases. The response of the motor shaft speed with current loop is shown on Fig. 5, while the response with current feedback loop omitted from the speed control loop is shown on Fig. 6.

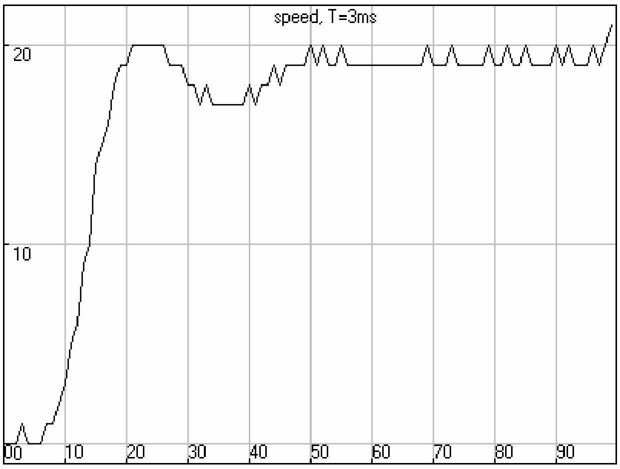

Fig. 5 *Motor shaft speed response with current loop*

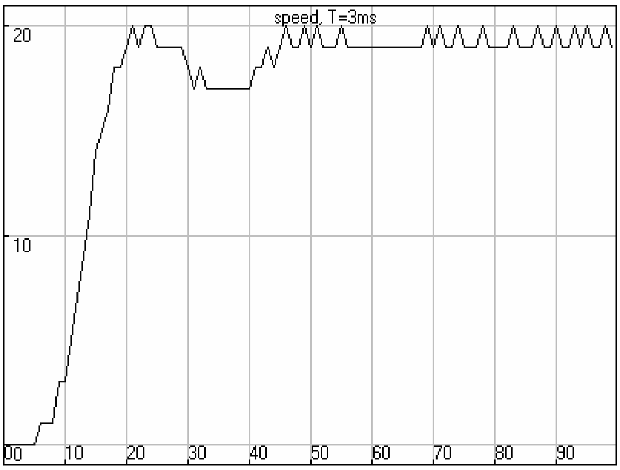

Fig. 6 *Motor shaft speed response without current loop*

We can see two almost identical responses. In other word additional current loop fits well in the control chain. The benefits of the current loop are not seen from this response but there are at least two. The first one is that now the motor current and therefore motor torque is directly controlled and the current limit circuit acts only for very excessive currents. Additional benefit is an easy implementation of the software current limit by simply limiting the voltage controller output that serves as the input to the current controller.

Additional tests included current sense circuitry. The contemporary current sense integrated circuit IR2175 is used to measure the motor current. The output of this circuit is PWM signal whose duty factor defines measured current. The frequency of the signal is 120 kHz. This signal is filtered and fed to the error amplifier of the analog current controller. To have a nice filtration we must put the filter corner frequency to about 1/10 of the PWM frequency. Therefore the electrical time constant of the motor must also produce the corner frequency lower then defined by the filter. In other case the control will be either unsatisfied or impossible. The lower signal on Fig. 7 and Fig. 8 is the voltage on the shunt resistor on which the H-bridge current is measured by the current limiting circuit. An additional fine two-port resistor that measures motor current is placed at H-bridge terminals in series to the motor. The voltage across the resistor is measured by the IR2175 and the output is the upper signal on the figures. The Fig. 7 presents the situation when no load is applied and the current is small. In contrast to that situation, the signals with the applied load are shown on Fig. 8.

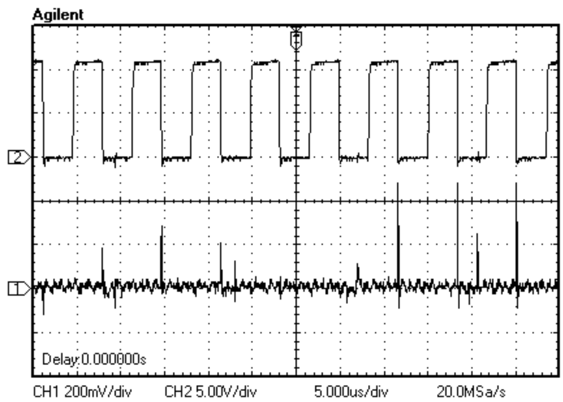

Fig. 7 *Voltage of the current sensor and on the current sense resistor with no load*

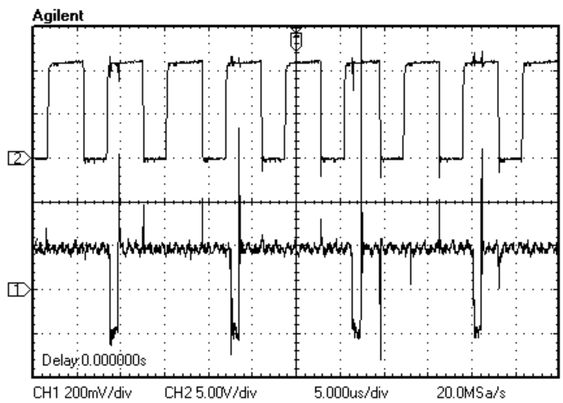

Fig. 8 *Voltage of the current sensor and on the current sense resistor with a load*

The current sense circuit output signal is than filtered and the results are shown on Fig. 9 and Fig. 10. The upper signal is the sensor output signal and the lower one is filtered signal. Two situations are shown, the first with the positive current and the second with the negative current. Here, as said, there is a trademark between degree of filtration and the transient response to the sudden current change. If the filtration is poor the control will suffer. If the filtration is good the filter may not be appropriately fast to follow the motor current rate of change. This also badly influences the control. This restrictions presents the lower limit to the motor electrical time constant so that the L/R<10/(2π120·10^3). The motor used in this experiment satisfied the restriction and the control was good.

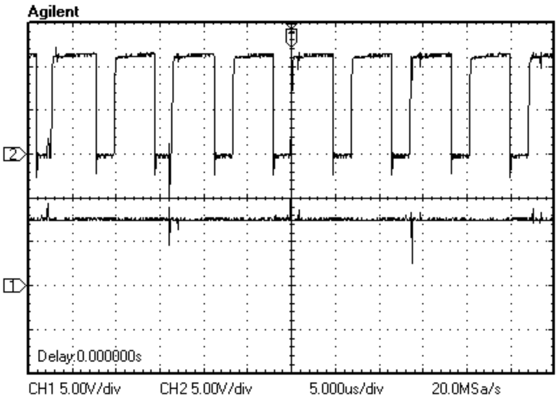

Fig. 9 *Voltage of the current sensor before and after filtration with a load and a positive rotation direction*

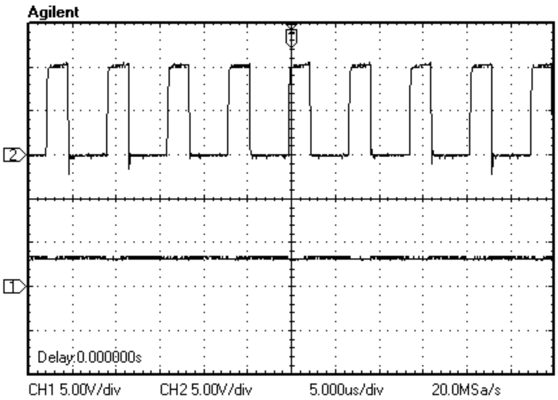

Fig. 10 *Voltage of the current sensor before and after filtration with a load and a negative rotation direction*

5. CONCLUSION

An updated version of the small DC motor driver is constructed and tested. It proved effective in the whole working range of the motor, especially when high torques and low speeds are required.

ACKNOWLEDGEMENT

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6. REFERENCES

[1] Damir Krklješ, Kalman Babković, László Nagy, Branislav Borovac and Milan Nikolić, *DC Motor Drive for Small Autonomous Robots with Educational and Research Purpose*, Eurobot 2009 Conference, La Ferté Bernard, France, May 21-23

[2] Damir Krklješ, Laslo Nađ, Kalman Babković, *Parametric DC Motor Drive*, International Symposium on Power Electronics - Ee 2007, Novi Sad, 7th - 9th November, 2007, pp. 1 - 5, ISBN 86-7892-065-3.