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ABS and Anti-skid on a LEGO car
–A project in Embedded Systems –

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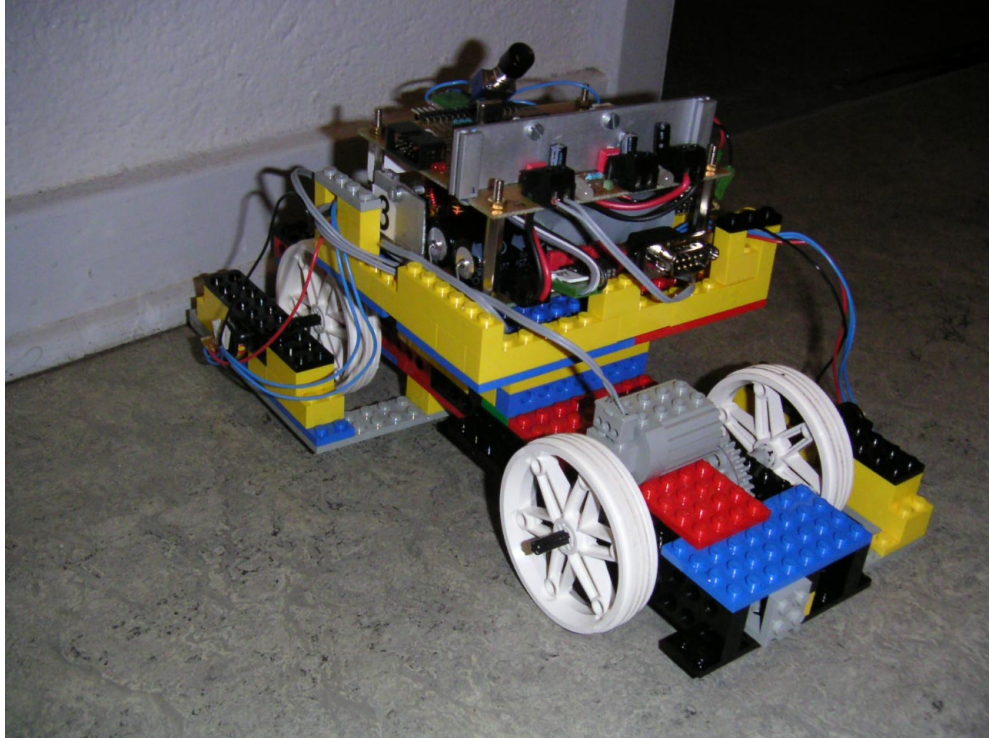


Figure 1 The constructed car used in the project. It has a DC motor drive on one of the axles and the controller board together with the battery pack on the top. The position sensors for the wheels are mounted on each of the axle.

1. Introduction

This work is the result of a course project in Embedded Systems. The goal was to implement a wheel-slip control system on a LEGO car using a microcontroller. The car allows front-wheel or back wheel driven configuration. Experimental results are presented for dry and wet surfaces.

2. The mechanical components

The car is built from LEGO parts (see Figure 1). The wheel axes are fixed, that is there is no steering mechanism on the car. One of the axes is fitted with a 5V DC motor (in the experiments we managed to use the motor even for higher voltages). The same motor is used for both acceleration and braking of the vehicle. This means that it is possible to drive the car both with the driven axle in the front or in the back (i.e. front-wheel driven/ back-wheel driven). This will enable us to effectively demonstrate the usefulness of the anti-skid system.

There are two position sensors used on the vehicle that measure the angular position of the two axles. These are mechanical sensors that can be found in mechanical PC-mouse units. The conferred accuracy is approximately 300 ticks per revolution. In turns, the sensors give the angular velocity of the wheels. This way the sensor on the uncontrolled axle (i.e. the one without the motor) gives the velocity of the vehicle.

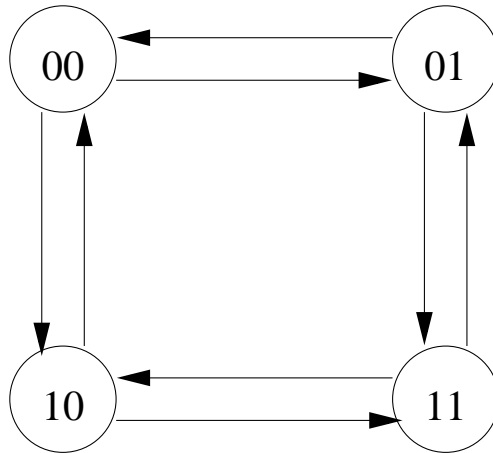


Figure 2 State machine for wheel-position counter.

The wheels have a diameter of 6 cm. Notice that the rubber has been initially removed from the wheels in order to obtain better sliding characteristics.

3. The microcontroller

The microcontroller used in the course is a ATmega8(L). It is a 8-bit microcontroller based on the AVR RISC architecture with 8 Kbytes programmable flash memory. It runs on a base frequency of 147 MHz. It has, among other, 2 analog inputs, 3 digital inputs/outputs, 3 PWM channels, possibility for RS232 serial communication [1]. The latter can be conveniently used for debug purposes. It also contains two 8-bit timer/counters and one 16-bit timer/counter.

For the application in question the following features have been used:

- 1 PWM channel
- 4 digital inputs:
- the 16 bit counter
- RS232 serial port

The serial port is used for debug, data logging and parameter tuning.

Each of the position sensors give two digital signals that are “out of phase”, this enables to decode the rotational direction. The position counter is implemented by the state-machine in Figure 2.

The coding of the entire control system was done using C.

4. The control problem

Due to the control action on the driven axle, the corresponding wheel will present more or less sliding on the surface. At extremes (i.e. wheel lock) this can lead to total loss of directional control for the vehicle (i.e. in case of braking the car starts spinning). This is due to the fact that the friction force between the wheels and the surface is dependent on the relative velocity between the

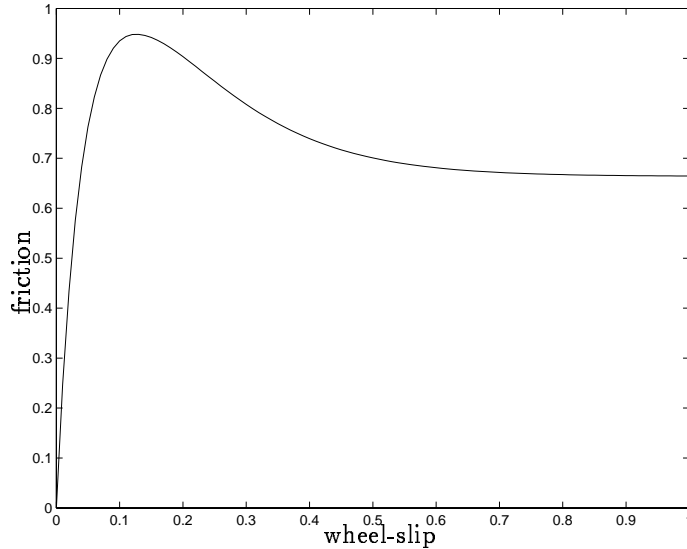


Figure 3 The friction force between the wheel and the surface depends nonlinearly on the wheel-slip.

wheel and the surface. It is customary in the automotive community to define the wheel-slip variable as:

$$\lambda = \frac{v - \omega r}{v} \quad (1)$$

where v is the vehicle velocity, ω is the wheel-angular velocity and r is the wheel radius. Thus, wheel-lock is described by $\lambda = 1$ and free rolling is characterized by $\lambda = 0$. A typical dependence of the friction between the wheel and the surface w.r.t. the wheel-slip is shown in Figure 3.

In modern ABS systems, one is not only preventing wheel lock, but it is required to control the wheel-slip (λ) at a given set-point. This is the control objective that is used also in this work. By controlling the wheel-slip, one has a controlled braking and also a control acceleration (i.e. the same principle is used for traction control).

The controller used here has been introduced in [2], and has the form:

$$u(t) = k(\lambda_r - \lambda)v + \int k_i(\lambda_r - \lambda)v dt$$

where λ_r is a reference wheel-slip, k and k_i are tuning parameters. The reference slip is a constant that is set at the beginning of each braking or acceleration.

5. Implementation issues

As mentioned previously, the system has two position sensors. The one on the non-driven axle gives the vehicle velocity (denote this angular velocity as ω_{nd}). Then, in order to minimize the number of multiplications, the control law can be written as:

$$u(t) = k(\omega_{nd}(\lambda_r - 1) + \omega) + \int k_i(\omega_{nd}(\lambda_r - 1) + \omega) dt$$

The controller is implemented in C using fixed-point computation. By using fixed point arithmetics one can use fixed scale to get decimals. The result from multiplication the requires rescaling, but addition is just like normal. This makes that the reference slip can be modified as integer parts of 1/8.

The discrete controller has the form:

$$u(k) = k e(k - h) + k_i (e(k) - e(k - h)) / h$$

where $e(k) = \omega_{nd}(k)(\lambda_r - 1) + \omega(k)$. The sampling rate of the controller is $h = 26$ ms. The sampling rate of the encoders is $h = 1$ ms.

The wheel slip can be changed through the RS232 connection, where the following user interface has been implemented:

b – Back wheel drive

f – Front wheel drive

s[slipvalue] – Set the slip value to [slipvalue]

t – Transmit data from last experiment

All commands have to be confirmed by pressing enter key.

6. Experimental results

The experiments consists of the following sequence:

1. The test-runs start with a *controlled acceleration*. Here the controller is used to achieve a desired velocity by setting the $\lambda_r > 1$. It is important to control the acceleration in order to maintain the car on a straight track.
2. After achieving a desired velocity (which is set to ... ticks/second), a *controlled braking* is commenced. Here the values of $\lambda_r > 0$ are smaller or equal to 1. Since we have no mechanical means to block the wheel on the vehicle, even this has to be controlled by setting $\lambda_r = 1$.

There two different type of experiments carried out. One is when the controlled axle is the front axle and the other when the controlled axle is in the back.

Figure 4 shows a braking with controlled front axle. After an acceleration, braking is commenced by inverting the voltage on the DC motor and producing a braking torque. The surface on which the braking is carried out is dry plastic-linoleum floor.

The first plot shows the slip which is controlled at the reference values 1/8. The second plot shows the vehicle velocity (uncontrolled axle) and the controlled axles velocity. The deference between the latter two is given by the wheel slip. The third plot shows the control signal to the DC motor while braking. Figure 5 shows braking with a locked wheel. Since on the vehicle, there is no mechanical way to lock the wheel, also this braking is controlled by the controller, with the setpoint $\lambda_r = 1$.

The same experiments have been done on wet surface. The previously used floor is wet with a solution of soap and water. The result is shown in Figure 8.

Experiments were carried out also when the car was back-wheel driven. Figure 6 shows the case when the reference slip was $\lambda_r = 1/8$ and the surface is wet. Figure 7 shows result when the car was back-wheel driven and the slip was $\lambda_r = 1$, that is locking the wheels. Notice that in this case the car is

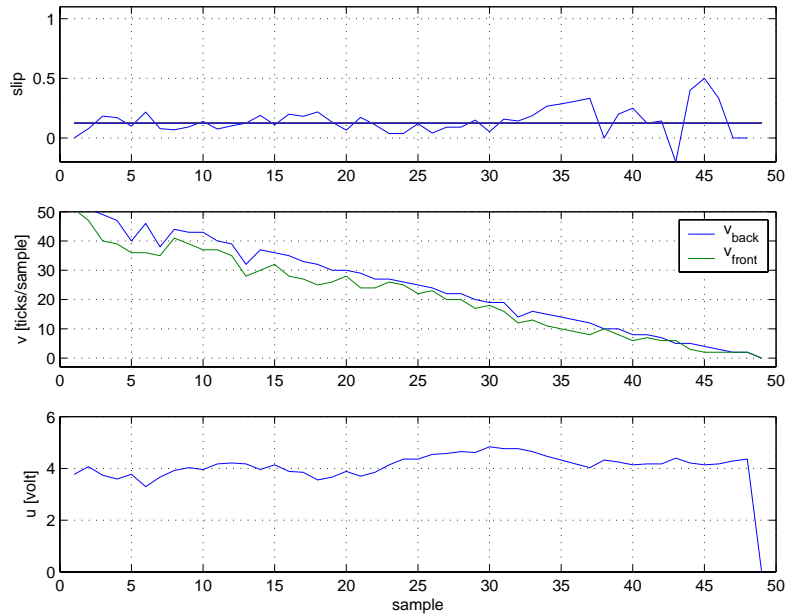


Figure 4 Controlled braking with forward controlled axle and $\lambda_r = 1/8$. Observe that the closer the vehicle is to standstill, the harder it becomes to control the slip.

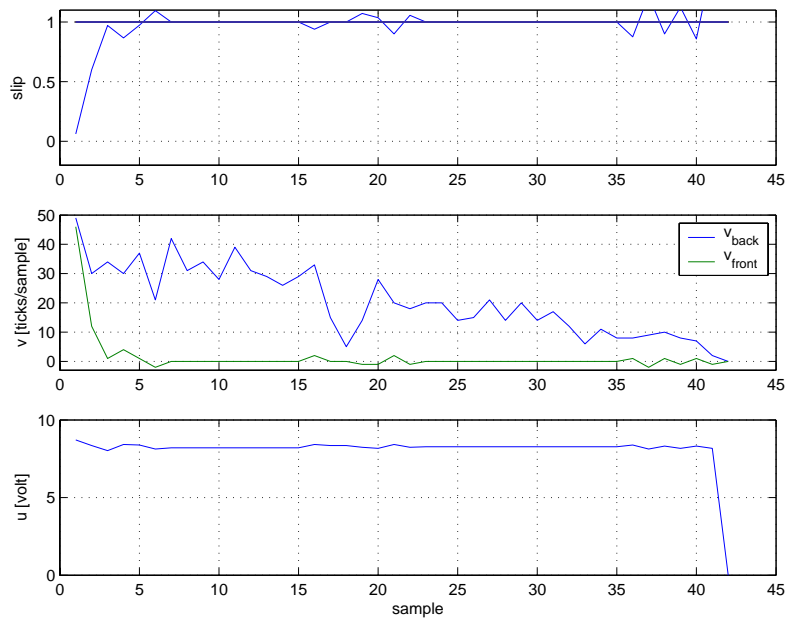


Figure 5 Braking by locking the wheel.

not stable and will rotate almost 180 degrees. This is due to the fact that the friction side-forces on the front rotating wheels are higher than on the locked back wheels. This can give rise to a torque that will spin the car. This happens after approximately 26 samples and results in a slip value larger than one.

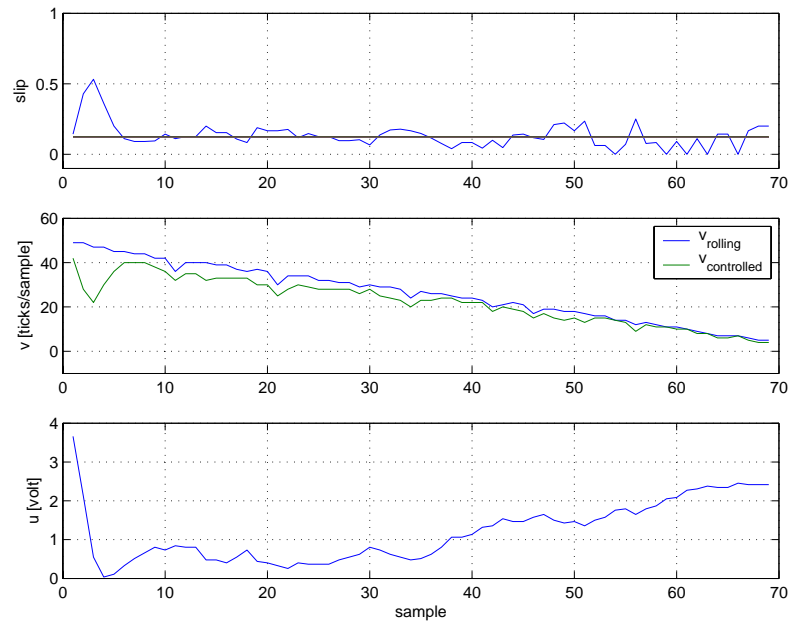


Figure 6 Controlled braking with backward controlled axle and $\lambda_r = 1/8$.

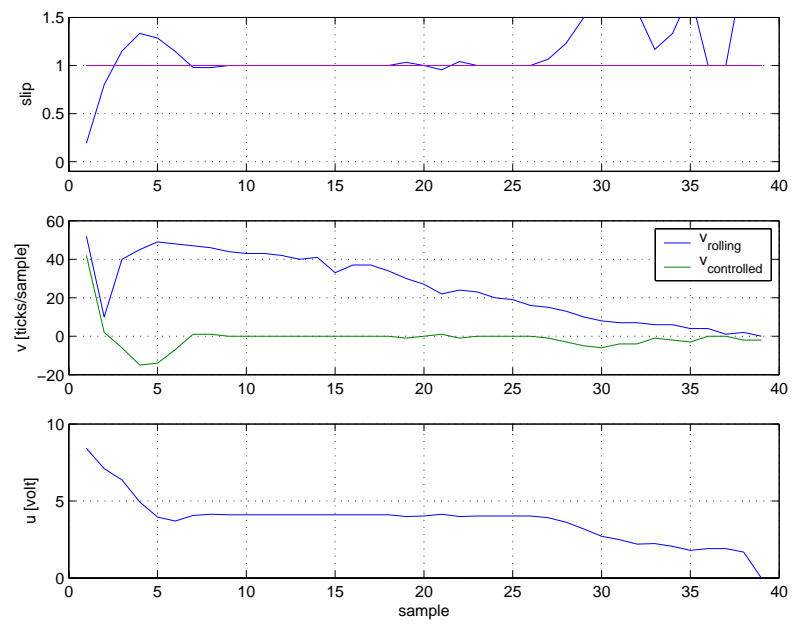


Figure 7 Controlled braking with backward controlled axle and $\lambda_r = 1$ (wheel-lock).

7. Appendix A. – Experimental Results

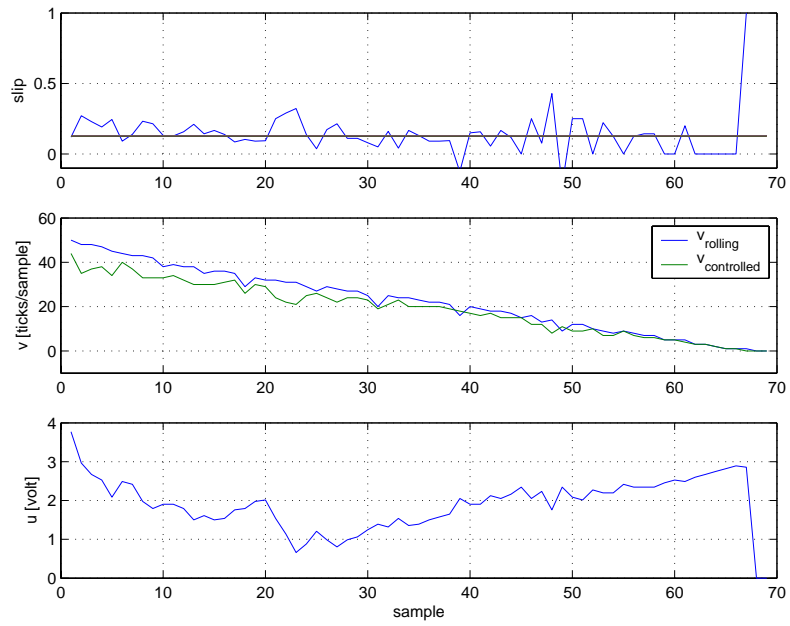


Figure 8 Controlled braking with forward controlled axle and $\lambda_r = 1/8$ on a wet surface with a solution of soap and water.

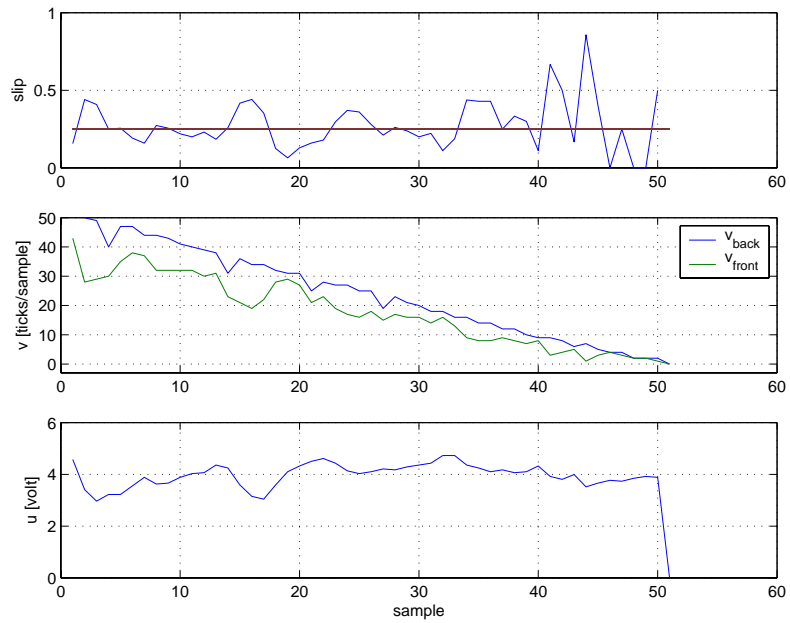


Figure 9 Controlled braking with forward controlled axle and $\lambda_r = 2/8$. Observe that the closer the vehicle is to standstill, the harder it becomes to control the slip.

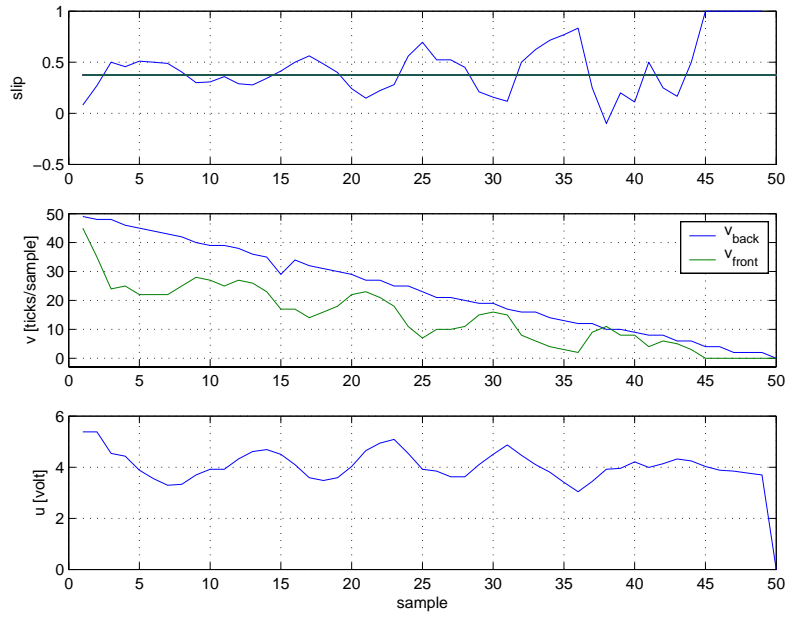


Figure 10 Controlled braking with forward controlled axle and $\lambda_r = 3/8$. Observe that the closer the vehicle is to standstill, the harder it becomes to control the slip.

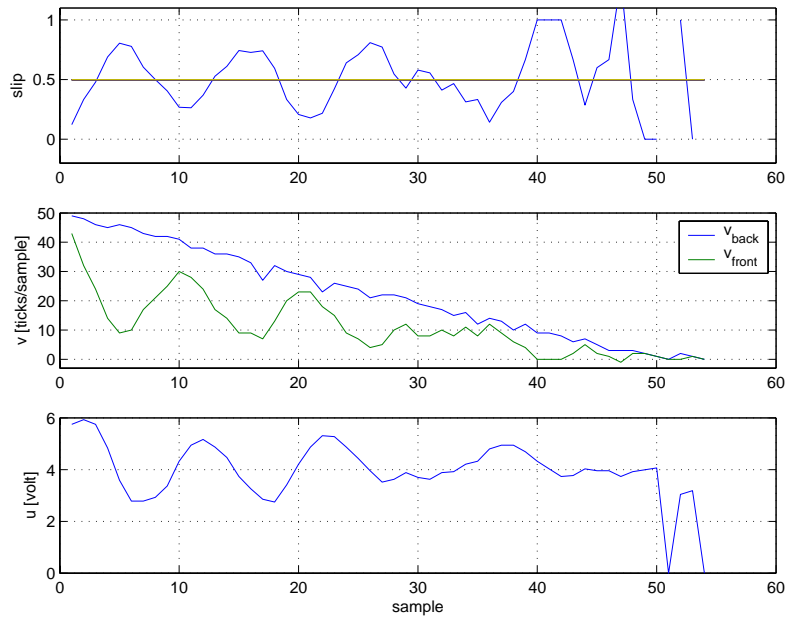


Figure 11 Controlled braking with forward controlled axle and $\lambda_r = 4/8$. Observe that the closer the vehicle is to standstill, the harder it becomes to control the slip.

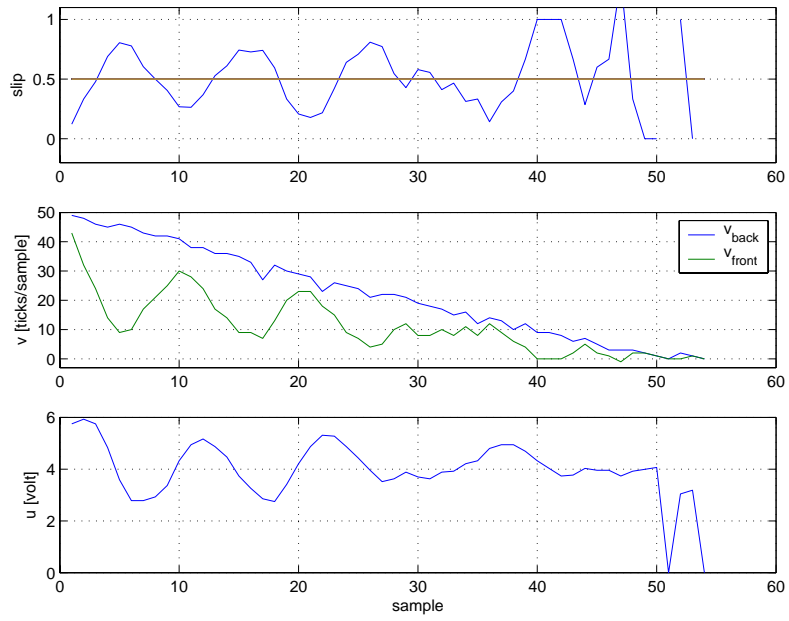


Figure 12 Controlled braking with forward controlled axle and $\lambda_r = 5/8$. Observe that the closer the vehicle is to standstill, the harder it becomes to control the slip.

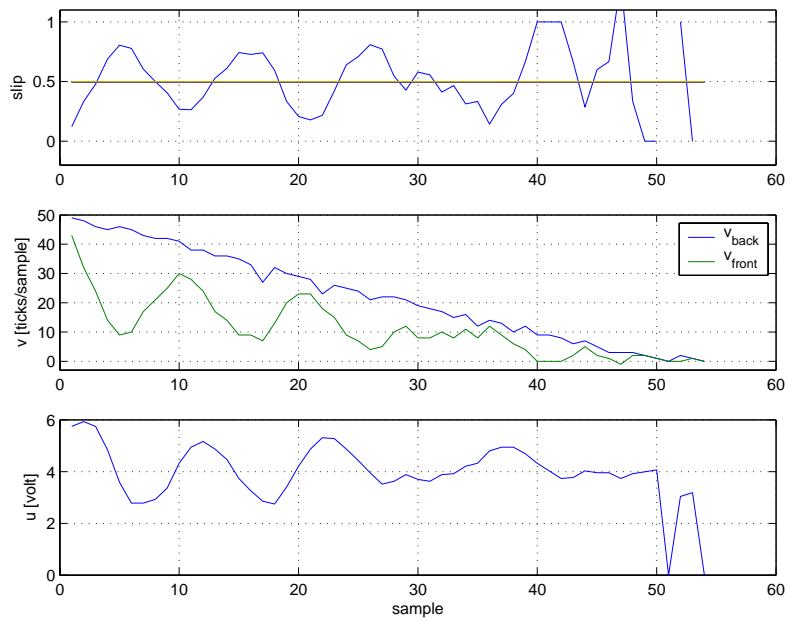


Figure 13 Controlled braking with forward controlled axle and $\lambda_r = 6/8$. Observe that the closer the vehicle is to standstill, the harder it becomes to control the slip.

8. References

- [1] Atmel, ATmega8(L) – users manual.
- [2] Stefan Solyom. Synthesis of a model-based tire slip controller. Technical Report Licentiate thesis LUTFD2/ TFRT--3228--SE, Department of Automatic Control, Lund Institute of Technology, Sweden, June 2002.