AVR480: Anti-Pinch System for Electrical Window

AVR® Microcontrollers

Application Note

Automotive motorized window or door apparatus which closes automatically involve risks for trapping, squeezing or injury to people. They must reverse their movement in case the force applied by the motor gets higher than one normalized limit. The feature implies the constant monitoring of the speed, current, position of the glass. For cost and simplicity reasons, the system described in this application note uses universal brush motor equipped with hall effect sensors. The detection algorithm is based on speed derivate and torque and has been verified for robustness and fault tolerance. It is applicable to all ATMEL AVR® with A to D converter and Interrupt-on-Change I/O.

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Powered Equipments in Modern Cars

Today, electronic components and systems account for over 20% of the cost of a high end passenger car. The ability of dense electronics to better control sensors and actuators is utilized to enhance comfort and safety in cars and it is very predictable that most of the middle and upper class vehicles will be systematically equipped with motorized window or door systems.

The majority of these equipments come with full automation, means that they must be accompanied by safety systems to prevent people injury or mechanical degradations.

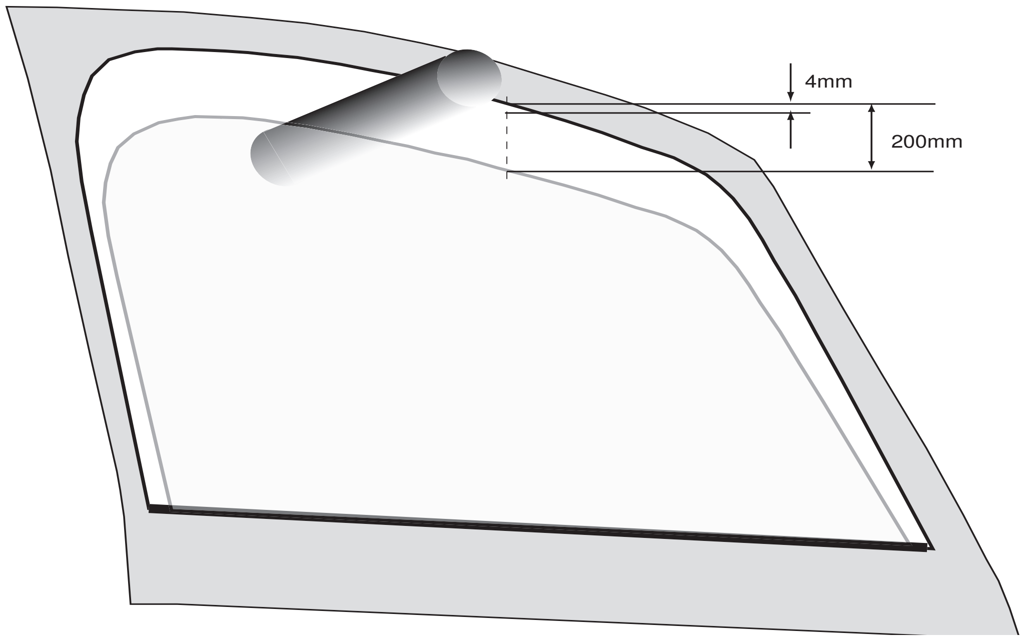
The legislation offers set of rules to which powered systems must comply. This is particularly true for window lifts or sliding doors. This application note describes how to implement an anti-pinch algorithm which was initially developed for a powered window but which can be easily adapted to any other moving part.

The Standards

The automotive power-operated windows are governed by international standards, like MVSS118 in USA or 74/60/EEC in Europe. For those relatives to the elimination of danger to children, the requirements expressed in these documents can be summarized as follows (see Figure 1):

- Detection area: 4 mm to 200 mm,
- Maximum pinch force = 100N,
- Reverse direction on a pinch.
- Tests with determined deflection ratio objects: 5N/mm to 20N/mm

Figure 1. Anti-Pinch window lift rules as per MVSS118



Hardware Consideration

Different detection strategies are possible to determine whether an obstacle is entering the critical pinching area:

- Without mechanical contact. It reacts before the pinch effort is exerted on the object. This is the optimal protection since no force is applied to the obstacle. It is also independent to vibration, aerodynamic variations, deformations. But, it requires integrated sensors (infrared, ultrasonic, ...) with their electronic modules and wires leading to additional costs.
- With mechanical contact. The pressure measurement will tell the system an object is being pinched. Also there, designers have two fundamental technologies available:
  - Direct measurements: Force sensors or contactors are integrated on the door seal. These solutions are inherently high cost and reduce the styling for window/door designs
  - Indirect measurements via physical monitoring. This is a globally cost optimized solution.

Anti-Pinch Algorithm Specification

The pinch detection algorithm shall, at first, respect the standards (FMVSS118 & 74/60/EEC) requirements:

- Detection area from 4 to 200mm
- Maximum exerted force of 100N
- Reverse direction on Pinch detection
- Normalized tests for validation

It has to be adaptive since:

- The mechanical elements involved in the lift system will vary with time (ageing, local deformation, wear, ...)
- The electrical characteristics could evolve significantly
- The environment will affect the friction forces (temperature, moisture, freeze, etc.)

The system should not react to disturbances neither detect inopportune pinches. It must be robust against air friction, road vibration, power-cuts, etc...

Solution Using Motor's Physical Parameters

The force applied to the glass can be extrapolated from the current through the motor. The position of the moving elements permanently provides information on speed. Both parameters can then be used to determine whether an obstacle has been encountered and whether:

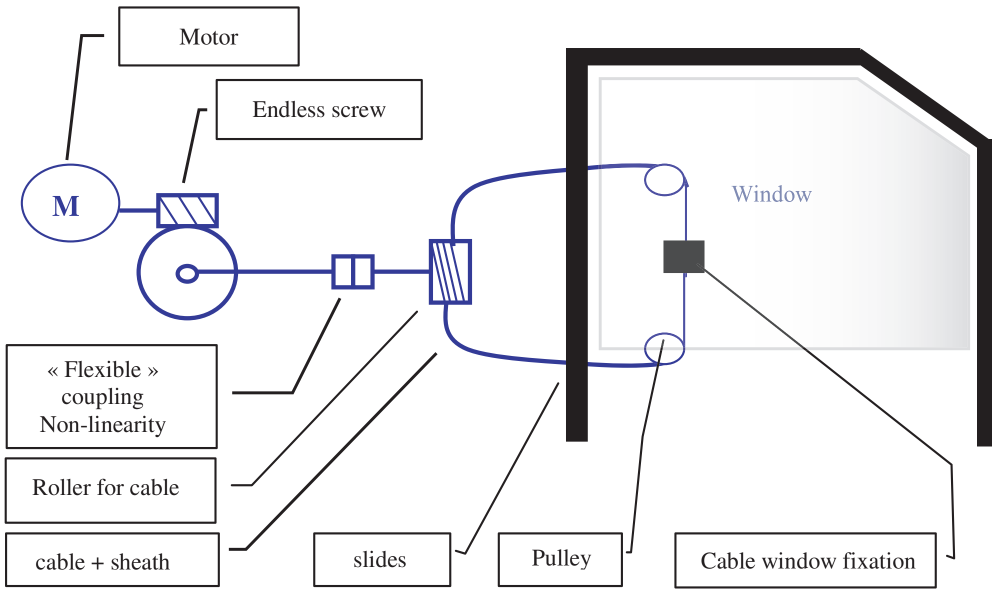
- It is in the detection area
- The force applied gets higher than the limit

This document describes one anti-pinch algorithm developed to work with motor current measurements and hall-effect speed indications. With very little changes, it can adapat to other systems like sliddding doors or roof panels.

Modeling, Simulation

To better design the pinch-detection algorithm, the physical parameters involved in the lift system have been extracted. Starting from a generic description of an opening/closing aparatus, one more precise model has been developed for the powered window. It is broken down into several main components as illustrated in Figure 2.

Figure 2. Powered Window Mechanical Components



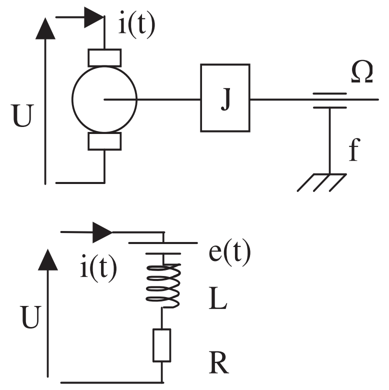
The identification of the mechanical components leads to consider:

- Motor Effects
  - Mechanical Parameters
  - Electrical Parameters
- Window-Lift:
  - Frictions (limited to slides)
  - Machanical non-linearity (coupling mostly)
  - Inertia (glass weight)

Motor Model

The DC universal motor used can be modeled using a very classical scheme as illustrated in Figure 3.

Figure 3. DC Motor Equivalent Model



U=Supply Voltage
i(t)=Motor Current
Ω=Rotation Speed
J= Inertia
f= Frictions
(Inductor is not represented here: The DC motor has permanent magnet)

e(t)= Back (induced) Electromotive Force
L= Self-Inductance of the Armature
R= Equivalent Resistor of the Armature

Differential (t) and Laplace domain (p) equations are extracted for Electrical and Mechanical elements:

$$U(t) = e(t) + Ri(t) + L\frac{di}{dt} \qquad U(p) = E(p) + RI(p) + LpI(p)$$

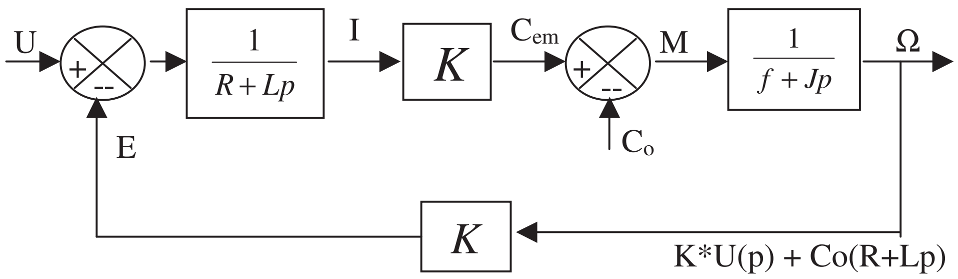
$$e(t) = k\ \Omega(t) \qquad E(p) = k\ \Omega(p)$$

$$m(t) = k\ i(t)\ \text{, motor torque} \qquad M(p) = k\ I(p)$$

$$J\frac{d\Omega}{dt} = m(t) - f\Omega(t) \qquad Jp\Omega(p) = M(p) - f\Omega(p)$$

The model chosen is a second order process. This allows the simulation of the motor, with its power supply (Voltage), including speed and current measurements. It also authorizes to inject disturbances or connect load (Co). It is detailed in Figure 4.

Figure 4. Second Order Motor Model

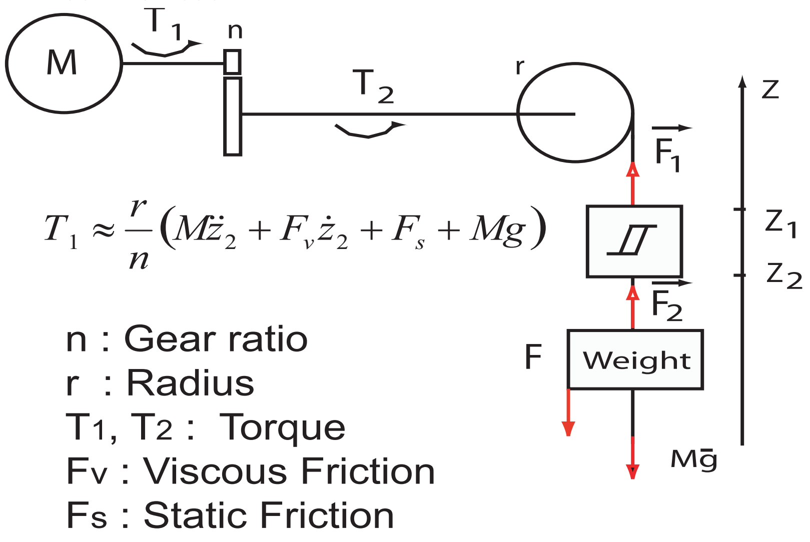


$$\Omega(p) = \frac{K^*U(p) + Co(R+Lp)}{(f+Jp)(R+Lp)+K^2}$$

Window-lift Model

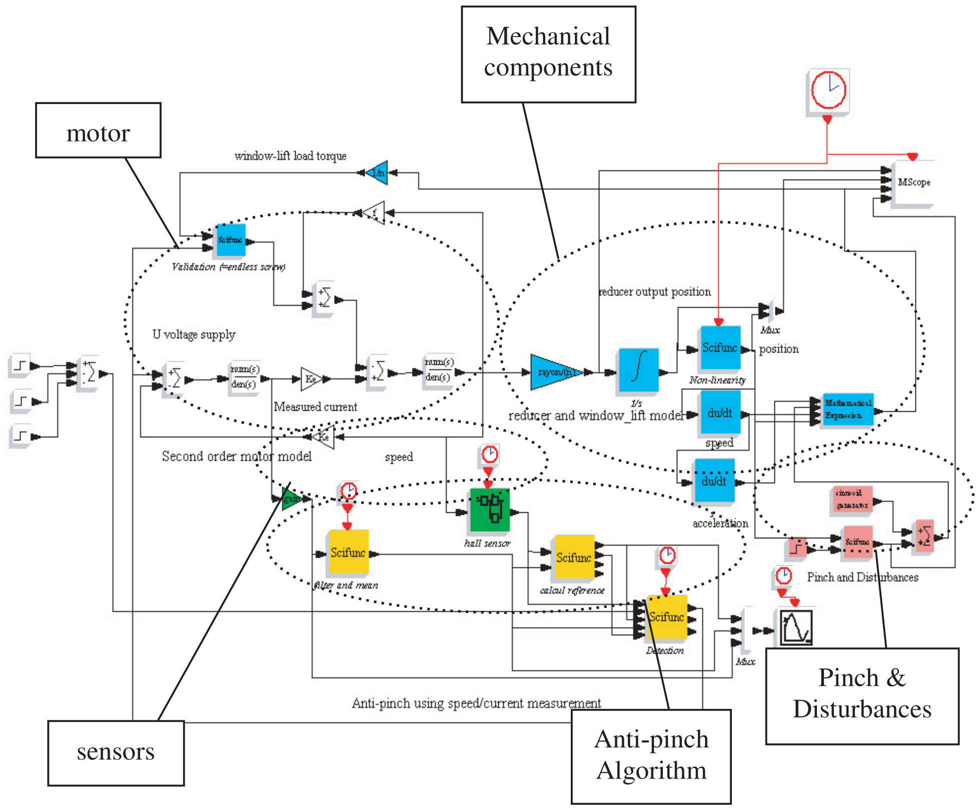
In addition to the DC motor model, the components from the window-lift system must be inserted. They are introduced to estimate the torque provided by the motor, and to access to position, speed and acceleration. The mechanical elements are described in Figure 5.

Figure 5. Window-lift Model



This model is executed to obtain system behavior and to verify the pinch-detection algorithm. Described parameters and others (static and viscous frictions, weight,...) are tuned and introduced in the model to verify their influence.

Figure 6. Full Window-lift and Pinch-detection Algorithm Model



Pinch Detection Algorithm

Usual pinch-detection algorithm operation is using indirect measurements out of the window-lift system:

- Current (torque)
- Position (speed)

The algorithm detailed in this document agregates two techniques based on

- Calibrated torque stored in non-volatile memory: Preliminary learning sequence is executed and torque values are stored in memory. This is quite memory consuming and requires regular calibration sequences
- Speed derivate calculation: Interesting method since it requires less memory but needs more computing power

and takes benefit from the two methodologies.

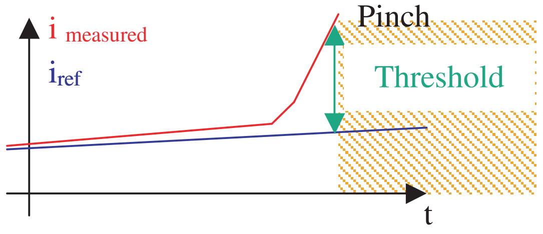
Pinching Condition

A pinch is detected by comparing the current measurement with a reference (see Figure 7).

$$M(t) \,)\, k\varphi \times i(t) = K \times i(t)$$

The threshold can be determined out of the Motor Torque constant (K) combined with the response time of the system (Motor and the load).

Figure 7. Condition for Pinch

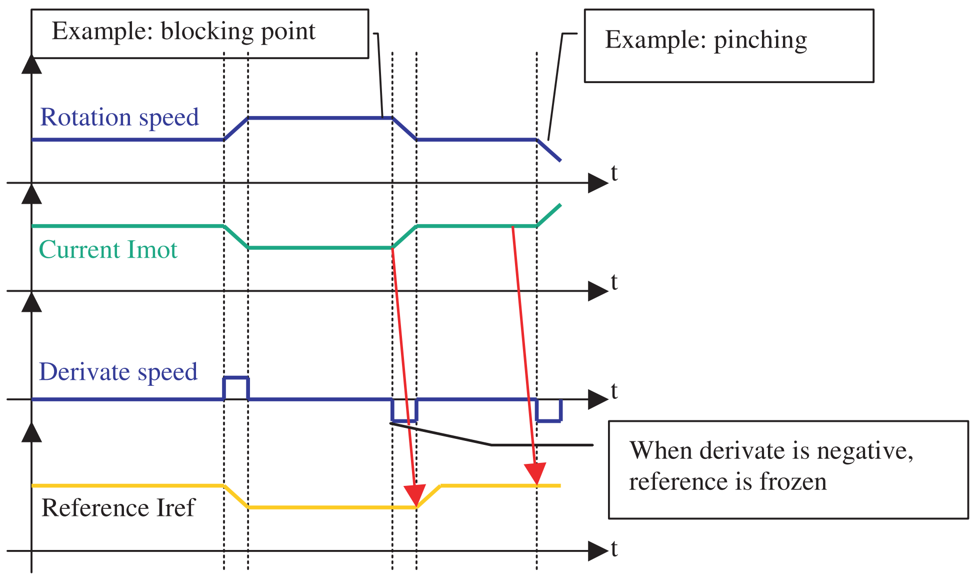


Current Reference Synthesis

One solution to elimnate need for calibration is to calculate **expected** current all along the movement. One pinch condition makes the speed decreasing and the current growing upassociated with increasing torque. Those two conditions are used to determinate the occurence of a pinch. In this document, speed derivate is preferred for its higher robustness to noise or fast disturbances.

An example is given in Figure 8. The Current Reference (Iref) is permanently calculated until the speed increases or remains unchanged. As soon as the speed decreases rapidly (Derivate becomes negative), Iref is frozen. Current through the motor (Imot) continues to be measured and compared with Current Reference + Margin. In case Imot gets higher than the limit, then a Pinch is declared and several actions are taken by the application (First is to stop the motor and reverse its rotation to release the obstacle).

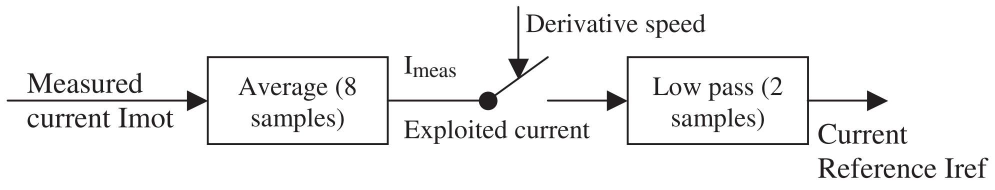
Figure 8. Example of a Pinch detection



Algorithm Robustness Current Filtering

The permanent calculation of the Iref allows for highly adaptative algorithm. To even increase the robustness of the alogrithm, the Current Reference is averaged over 8 consecutive measurements (see Figure 9).

Figure 9. Global Current Reference Synthesis Principle



Algorithm Robustness Blocking points

As Iref permanent calculation allows a highly adaptative algorithm, local great frictions variations called blocking points could involve bad pinch detection. Indeed, a local friction increase, eventually in addition to other disturbances (bumpy road, wind...) could result in a pinch condition, as Iref would be frozen.

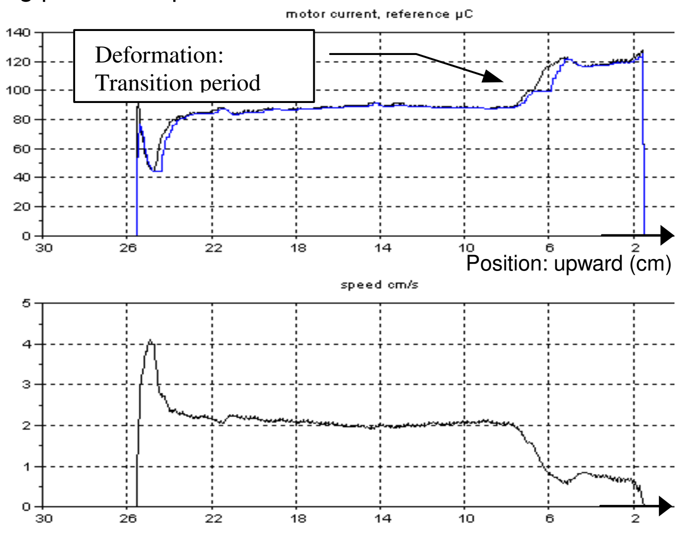
Those blocking points are detected the same way as pinches. The difference between current and reference is monitored. When it is greater than a threshold, it is detected and blocking point charateristics are stored into EEPROM.

A blocking point is described only by a position interval and an event counter (number of detections) to minimize memory requirements. It could be more precise by storing magnitude in the interval or by using several threshold. But it would use more memory.

A table containing all hard point informations is stored in non volatile memory

When a blocking point is known (stored in table) and its event counter allows to consider it as a blocking point, the threshold is added to pinch margin, in the correspondig interval, to increase robustness.

Figure 10. Blocking point example



State Machine

The main finite state machine (FSM) manages motor commands and pinch detection (Figure 11 presents states for upward movements. Downward operation is presented in Figure 12).

Figure 11. Finite State Machine for Moving Upward Operation

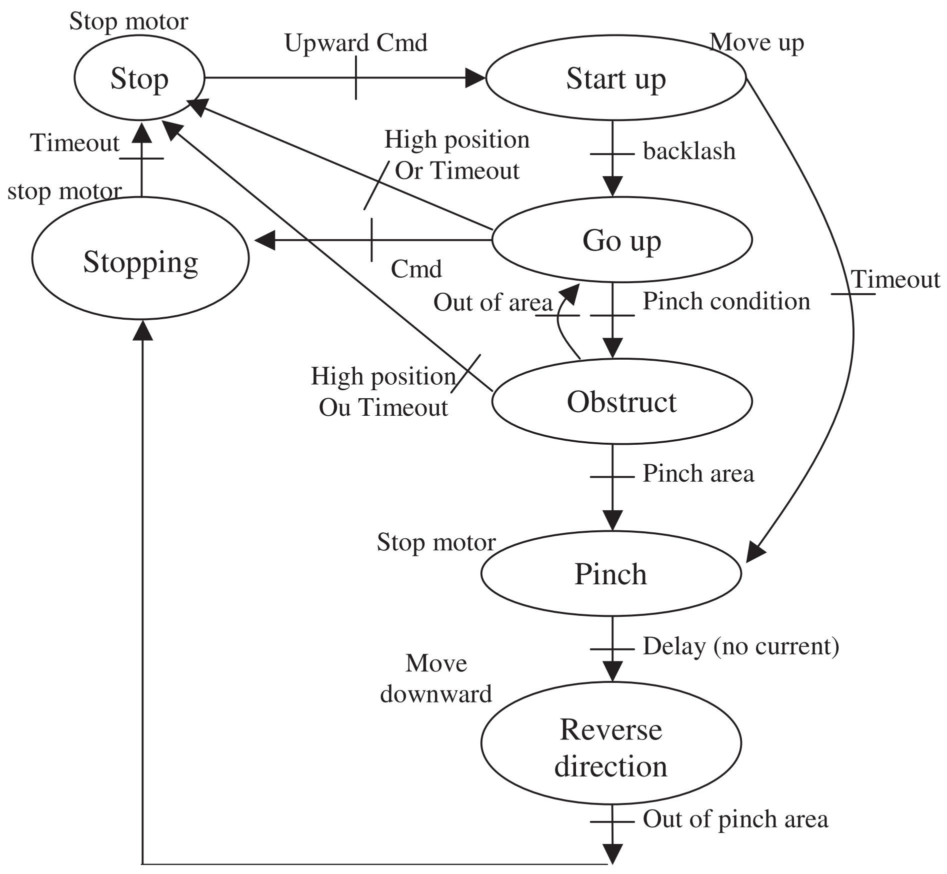
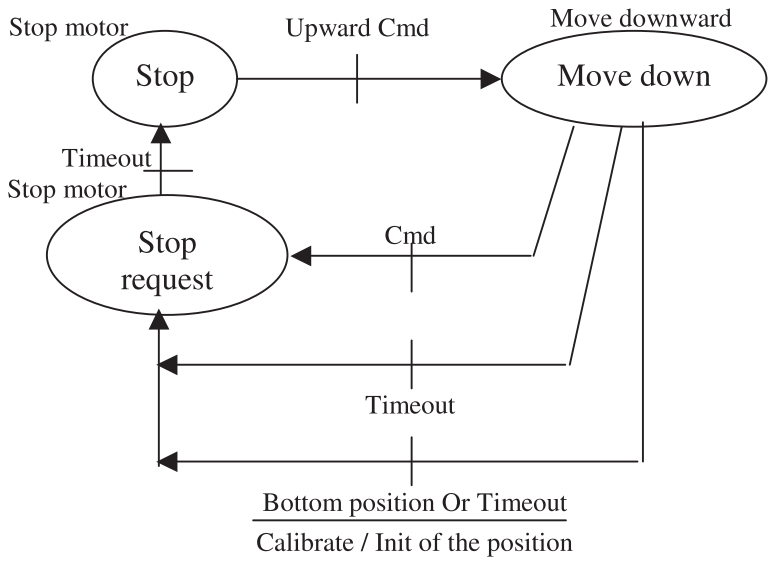


Figure 12. Downwward Movement Finite State Machine



Adaptation function, portability

FSM requires parameters (backlash, top and bottom ends, hall sensors resolution...) to work properly. Those parameters could be constant parameters or measured at initialisation. Some of them could change from one window lift to another. Thereby, optional adaptation function acquire those parameters at first initialisation by operating the window lift. It also monitors blocking points to initialize the memorization table.

This optionnal adaptation routine disables anti-pinch while running. It then operates window lift downward and upward to detect bottom and top positions. Simultaneously, it monitors the blocking points. To acquire backlash, It operates downward and upward into the pinch detection area (by comparing current reference to acquired current).

Other Interesting Functions

Not described here are secondary functions necessary for Window-lift operation:

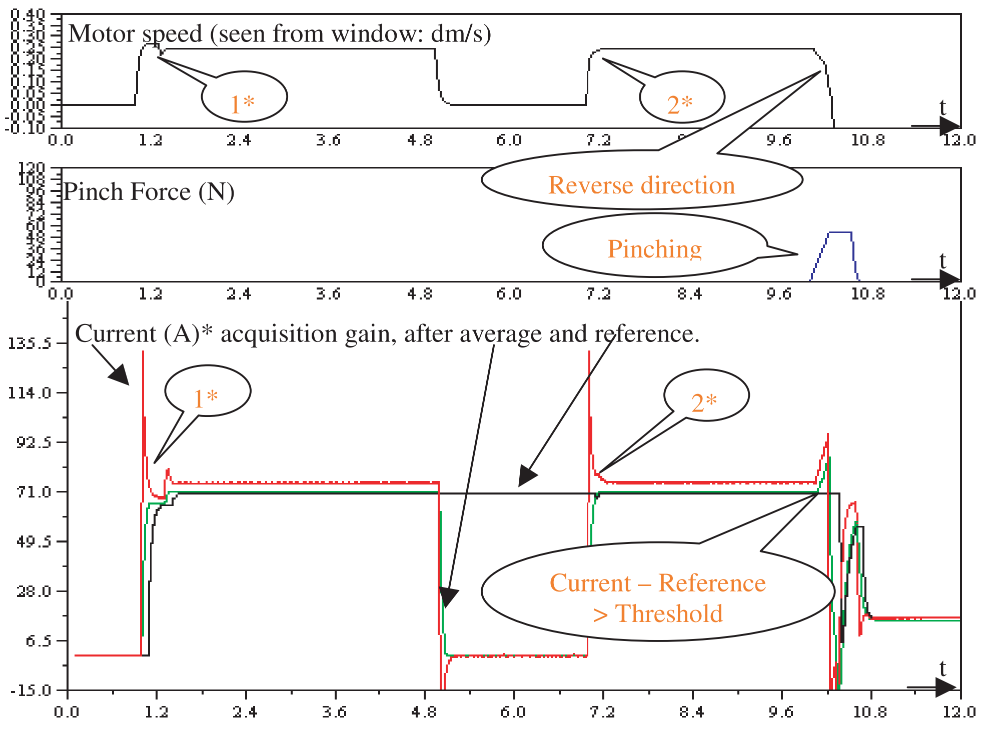
- Measuring current, filtering
- Hall-Effect interrupt generation, counting, speed calculation, direction
- Push-button management
- Memorization of critical parameters (position, last operation direction, ...) in case of power-fail

Simulation Results

Numerous simulations have be ran to assess and tune the different parameters for the detection threshold loop. Figure 13 visualizes how the speed and motor torque behave at the first and second 'go-upward' commands. Also, a pinch condition is injected at t=10s with a compression spring of 10N/mm.

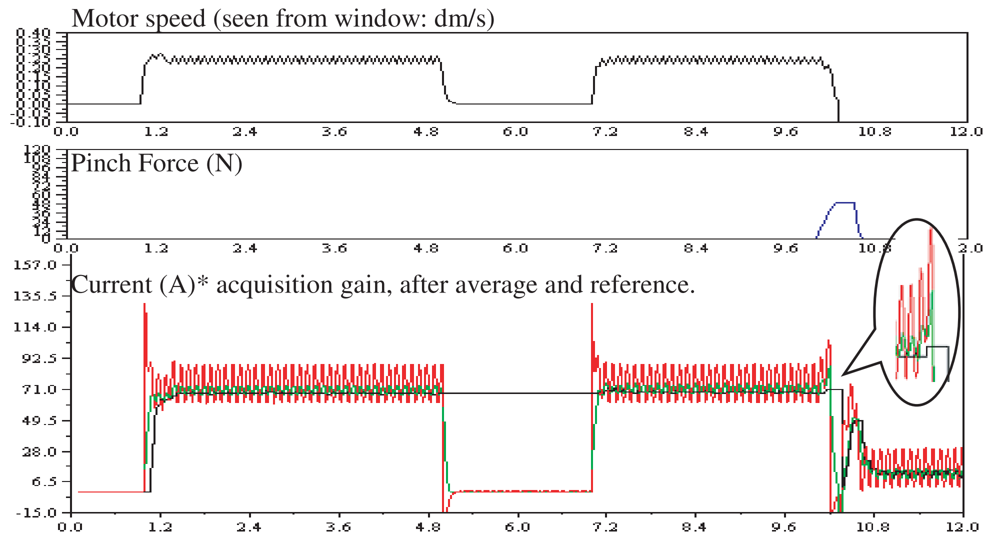
Figure 14 shows the same curves but disturbances in motor torque are injected (frequency of 10Hz, 50N), after a second 'go-upward' command.

Figure 13. Simulation of the Algorithm with two Consecutive 'Go-Upward' Commands



1. The non-linearity of the transmission causes a speed overvalue at motor start. The torque looks like un-coupled for a few moment.
2. There, the elasticity of the transmission system is no more involved and the torque and speed images are different.

Figure 14. Algorithm Simulation Injecting 10Hz, 50N Disturbance



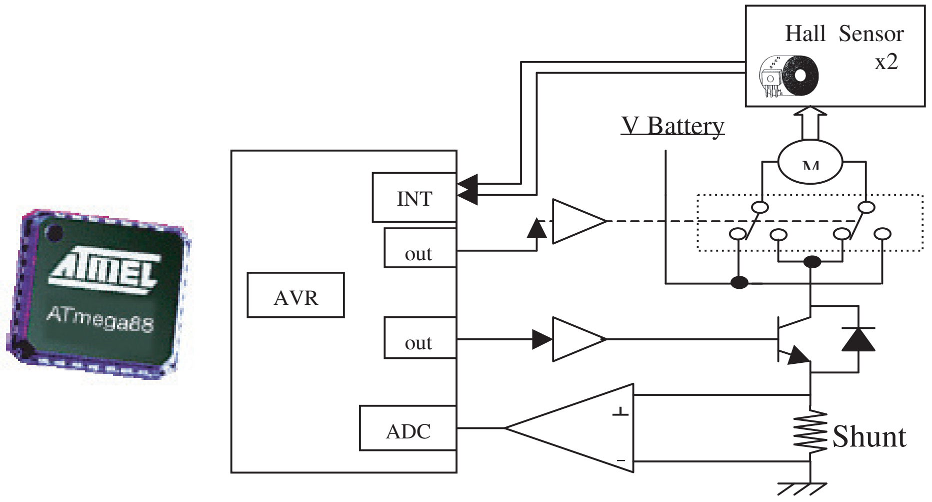
AVR Implementation

The algorithm detailed in the previous paragraphs has been implemented and tested using an AVR ATMEGA88 based board.

Hardware Specification

The hardware used for the implementation of the algorithm is described in Figure 15. It implements one standard ATmega88 as well as analog chain to measure motor current. It has two hall effects sensors. The motor direction is controlled via one two-poles relay while the ON-OFF of the motor is activated by a Mosfet.

Figure 15. ATmega88 Controlling the Window-lift with Anti-pinch Feature



The software involves several microcontroller resources as defined in Table 1.

Table 1. Hardware / Software Partitioning

Feature	A to D Converter	Timer0 (8-bit)	Timer1 (16-bit)	PCINT9	EEPROM	IDLE (Soft)
Current Acquisition	X	X				
Position, Speed, direction			X	x		
Determine Current Reference			X	X		
Timeout			X			
Save Parameters			X		X	
Filter						X
Anti-Pinching						X
Operate Window-Lift						X

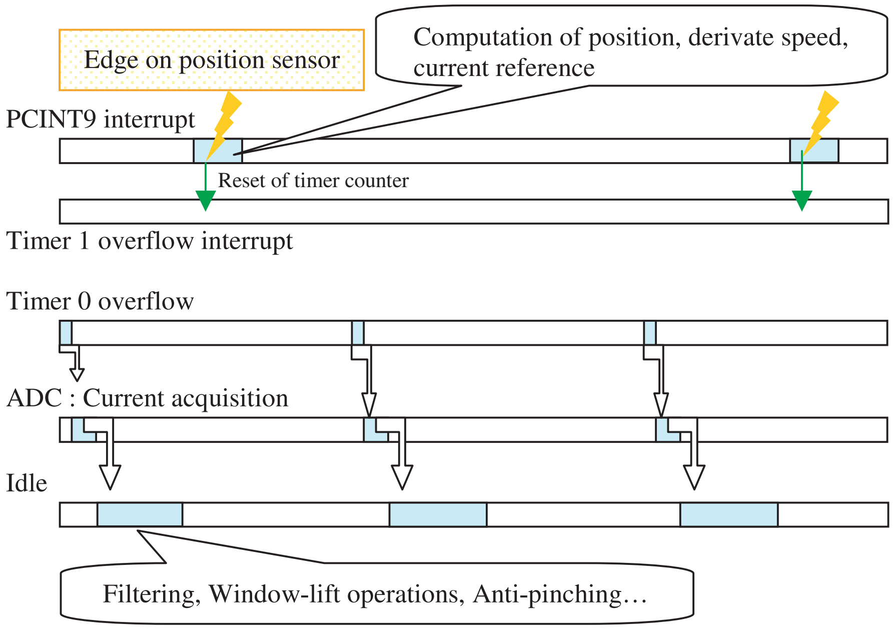
Task Scheduling

By considering, the algorithm described previously, as well as the allocation of hardware and software resources, we obtain the following scheduling of the program

Normal Operations

This schedule is valid when the algorithm is running in standard operating condition, i.e. when the motor is operating (rotating) or is stopped. Indeed, position, speed and reference calculations are refreshed when events occurs from the position sensors (hall effect sensors) or don't have to be done (when the motor is stopped in a stable and normal state).

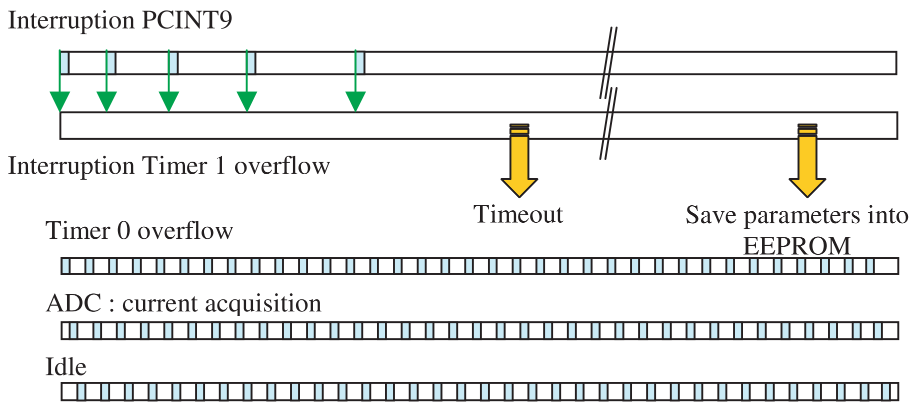
Figure 16. Task Scheduling When Normal Operation


Edge on position sensor
Computation of position, derivate speed, current reference
PCINT9 interrupt
Reset of timer counter
Timer 1 overflow interrupt
Timer 0 overflow
ADC : Current acquisition
Idle
Filtering, Window-lift operations, Anti-pinching…

Other Operations

When the motor is brutally stopped, rotates abnormally slow or doesn't start for several reasons (motor blocked, hall sensor disconnected…), timer1 is used to generate a timeout and to shut down the power (or to reverse direction).

Figure 17. Task Sceduling When Timeout or Parameter Save Request has been Set


Interruption PCINT9
Interruption Timer 1 overflow
Timeout
Save parameters into EEPROM
Timer 0 overflow
ADC : current acquisition
Idle

Algorithm porting

Such an algorithm should be portable from one opening aparatus to another. So, it uses like a database stored into eeprom, which contains algorithm parameter set (extracted from model). This allows algorithm to be portable. Refer to algorithm adaptation procedure (AVR191) for more details.

Software Description

All code is implemented in C language using IAR EWAVR 4.20. Implementation of basic functions (position management, initializations, current measurements, window operations and anti-pinch monitoring) requires **2Kb** of flash memory. Adding extended functions like eeprom storage, calibration, adaptation, blocking points detection increases code size up to **5.7Kb**.

```
void init_window_peripherals (void)
```

Initialize pin change interrupt to be used with a Hall effect position sensor (sensitive to rising and falling edges). It also initializes timers and the ADC used to measure speed and motor current.

```
void init_window_parameters (signed char *go_down)
```

This function load window lift parameters from EEPROM or from default values, to initialize the window-lift. Those values are window dimensions, sensor values, pinch threshold, pinch area, last known position… If a default is found on position, it is able to ask for a go down command to initialize the window-lift at bottom-end limit.

```
void init_window_size_position()
```

Allows to automatically operate window down, then up to detect top and bottom positions, identify blocking points and backlash : It's an adaptation routine.

```
void save_window_parameters(void)
```

This function saves window lift parameters to EEPROM.

```
U8 window_ctrl (signed char *up_cmde, signed char *down_cmde ,U8
no_anti_pinch)
```

This contains the window-lift state machine. It controls window operations, with given events parameters. It monitors the position, up and down end limits, and the anti-pinching condition. It returns the state of the window-lift (same value as the get_window_state function).

```
__interrupt void hall_sensor_ISR (void)
```

This interrupt sub-routine is executed on hall sensor edges. It computes rotation direction, position, derivative speed and motor current reference.

It's also able to detect a default on a hall effect sensor (which is not connected to an interrupt pin) by counting successive direction changes. It is used to force the window to stop after a defined step.

```
__interrupt void TIMER0_OVF_ISR (void)
```

This interrupt sub-routine is executed on timer 0 overflow to shedule ADC conversion starting.

```
signed char get_window_state (void)
```

It returns the state of the window-lift state machine (value used in the window_ctrl function).

```
signed char force_window_state (signed char temp)
```

Set-up window-lift state: useful to force operations (stop request…).

```
unsigned char mean (unsigned char)
```

Compute a mean on the 8 last samples. Used for filtering motor current.

```
void push_button (signed char *push)
```

This function monitors a push button and generates operation command events to be transmitted to the window_ctrl function.

```
U8 blocking_point(signed char window_state)
```

This function monitors blocking points by comparing current value with reference. It shall be synchronized with window control state machine. So, it requires window_ctrl to be called before and its returned state shall be provided in parameter.

```
U8 update_point (void)
```

This function shall be called by `blocking_point` routine to sort, create or refresh blocking points data table when a blocking point has just been completly detected. When this blocking point was existing, it updates its event counter and its position interval. If it wasn't existing, routine insert it in the blocking points table.

```
void clean_point(void)
```

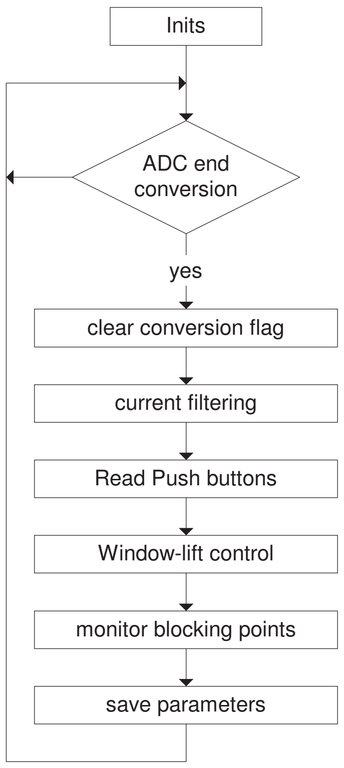
This routine shall be called by `blocking_point` routine and the end of each upward operation. It's in charge of decreasing blocking point event counter in the parsed area. It cleans blocking points which event counter has decreased to zero (means they no more exists or it was a disturbance or a pinch and have no more been detected)

```
U8 get_block_point(U16 position)
```

This function returns the corresponding threshold value to add to pinch margin value if a blocking point has been confirmed at the provided position in parameter. Otherwise, when there are no blocking point at this postion, it returns zero.

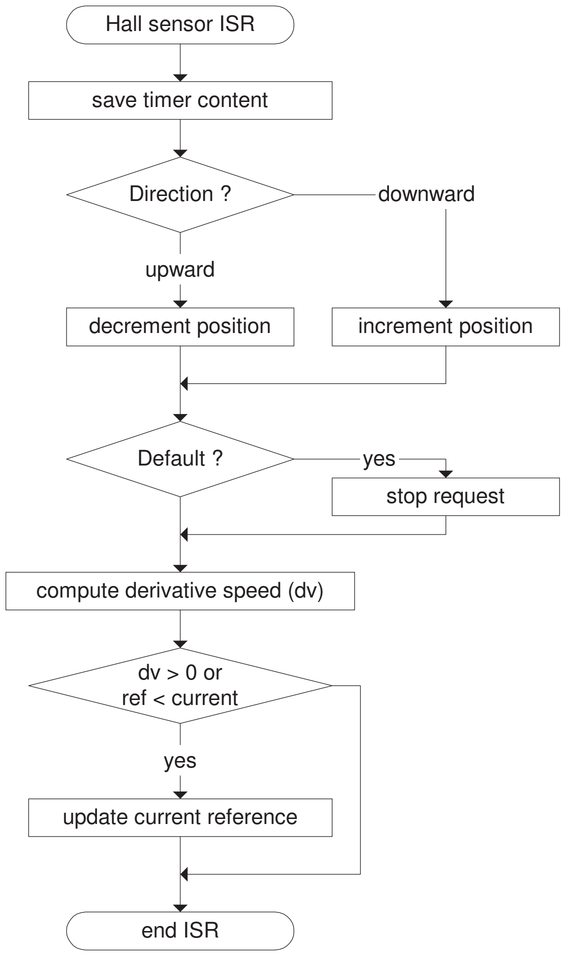
Main Control Loop

Figure 18. Main Control Loop



Hall effect Position Sensor Interrupt Sub-routine

Figure 19. *Hall effect Position Sensor Interrupt Sub-routine*



Window Control State Machine Implementation

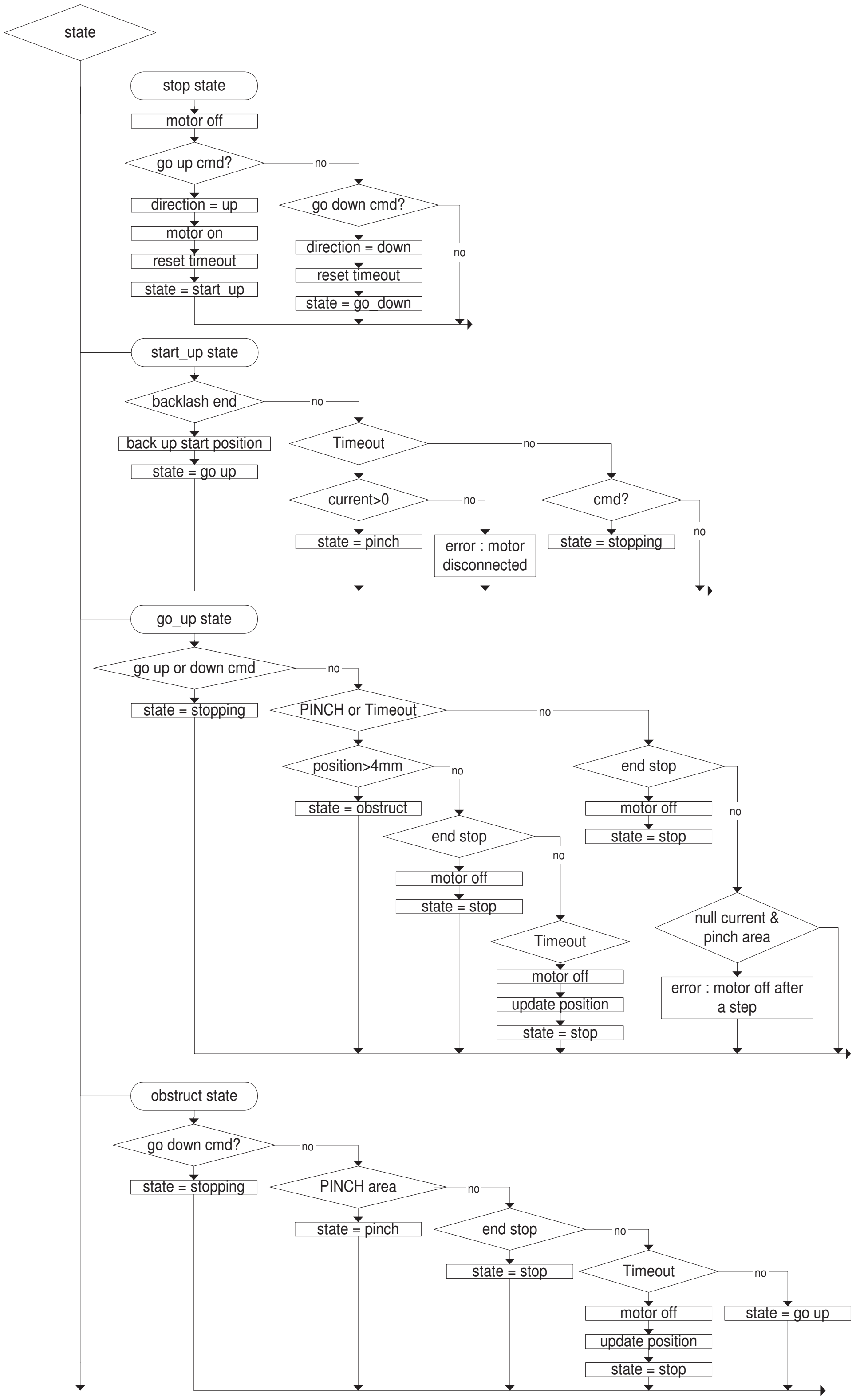


Figure 20. Window Control State Machine Implementation (part 1)

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