The Control Logic of MotoTron Controller

1. Introduction to MotoTron control system for configurable hybrid electric learning modules (CHELM)

The MotoTron control system of the CHELM consists of Sensor Module, Control Module, and Actuator Module. The input/output signals and their relationship are illustrated in Figure 1.

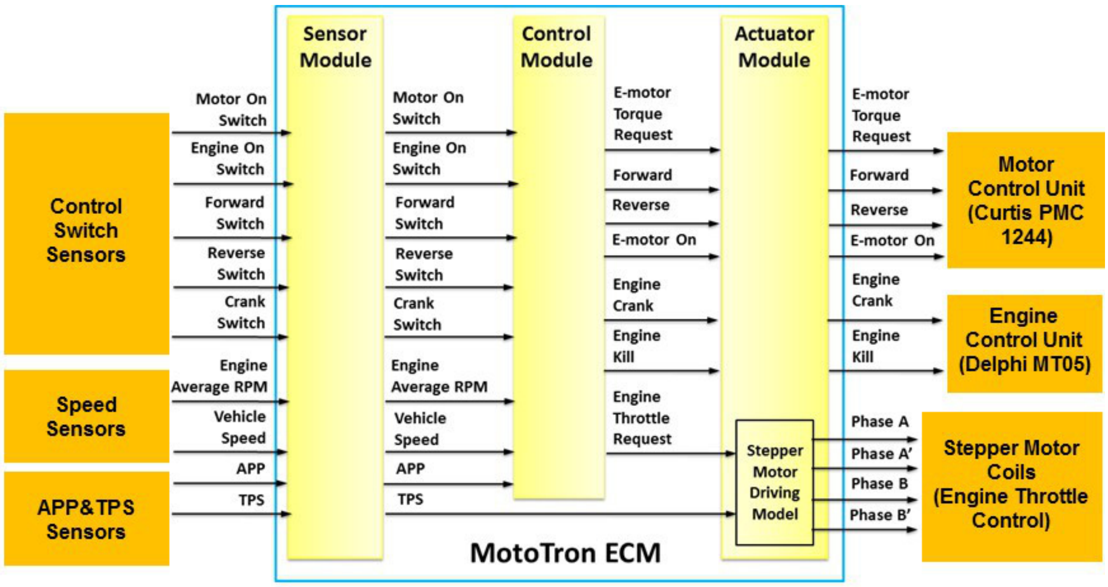


Figure 1. Overview of the MotoTron control system for the CHELM (APP = PPS1 and PPS2).

The major tasks of the course project are to design and validate MotoTron control system model, including at least six sub-models in the control module and a stepper motor driving model in the actuator module. This document provides control logic and input/output signals of each sub-model. Figure 2 shows the signal flow among these sub-models. To clearly illustrate different types of signals, the input signals to the control module are labeled as green, the output signals of the control module are labeled as red, and the intermediate signals among sub-models within the control module are labeled as blue.

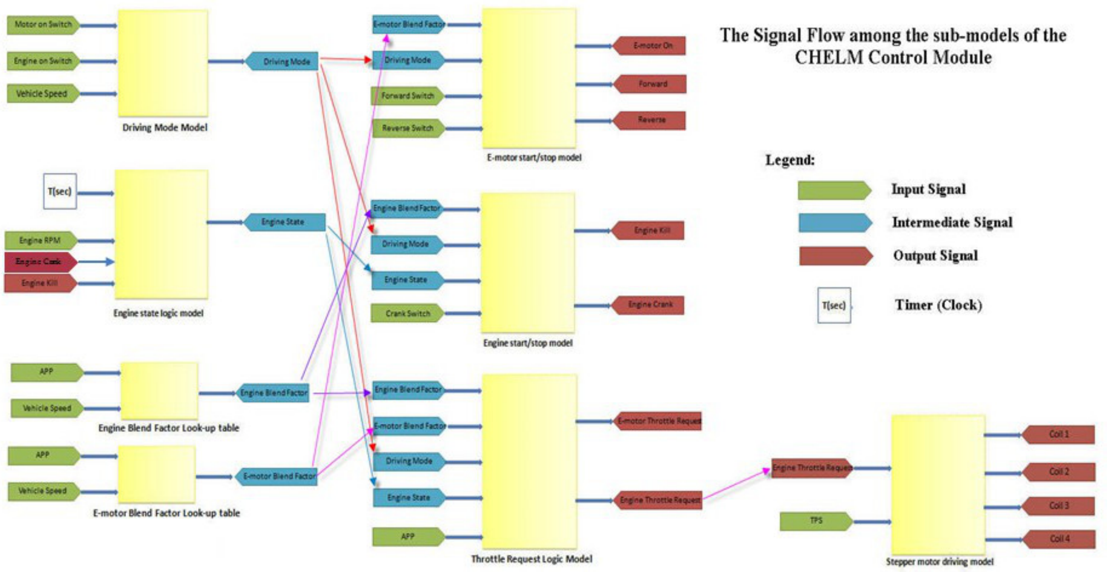


Figure 2. Signal flow among sub-models.

2. Control logic of the models in the control module

2.1 Driving mode model

The CHELM has three driving modes: Electric Solo Mode, Blending Mode, and Engine Solo Mode. In the electric solo mode, the E-motor is the only source providing driving force for the vehicle. In the blending mode, both engine and motor provide driving force for the vehicle. In the engine solo mode, the Engine is the only source providing driving force for the vehicle. The driving mode of the CHELM is determined by two input switches: *Motor On Switch and Engine On Switch*. The CHELM can switch from one driving mode to another only when the vehicle speed is less than 1 mph.

The input and output signals of the driving mode model are shown in Figure 3. The value of the output signal, *Driving Mode*, is equal to 1 in *Electric Solo Mode*, 2 in *Blending Mode*, and 3 in *Engine Solo Mode*, respectively.

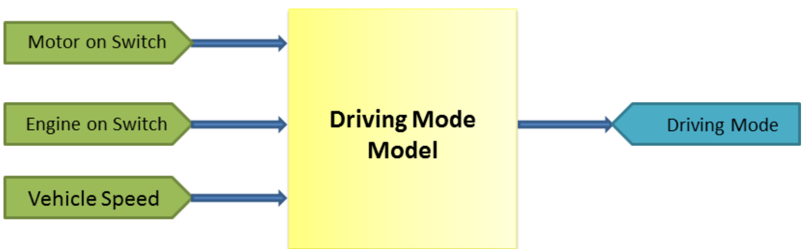


Figure 3. Driving mode model.

The logic between the output signal and input signals is listed in Table 1.

Table 1. Determine driving mode based on switch signals.

Input			Driving Mode Output		
Engine on Switch	Motor on Switch	Vehicle Speed	Electric solo mode (1)	Blending mode (2)	Engine solo mode (3)
True	False	v<1 mph	False	False	True
False	True		True	False	False
False	False		False	True	False
True	True		Driving Mode will stay unchanged		
		v>1 mph	Driving Mode will stay unchanged		

Driving Mode is an important intermediate signal, which will be used in Engine star/stop logic model, E-motor start/stop logic model, and torque/throttle request logic model.

2.2 Blend factor look-up tables (only useful for the blending mode)

In electric solo mode, the Motor torque request=APP and the Engine throttle request=0. In engine solo mode, the Engine throttle request=APP and the Motor torque request=0.

In blending mode, the *Engine Blend Factor* and *E-motor Blend Factor* determine how much output power is requested from engine and motor. The values of the *Engine Blend Factor* and *E-motor Blend Factor* depend on the speed of the vehicle and the APP value as shown in Figure 4.

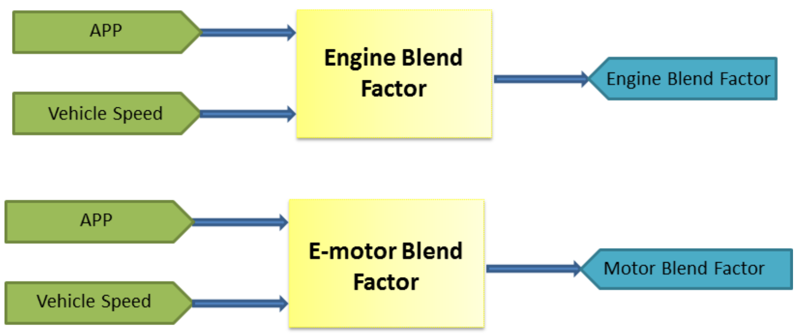


Figure 4. Blend factor look-up tables in blending mode.

Two sample maps of *Engine Blend Factor* and *E-motor Blend Factor* are provided.

You are required to design better power split strategies between the engine and motor to improve the overall performance of the vehicle. Just static maps may be not enough for some cases, such as engine start fails.

2.3 Engine state logic model

The input and output signals of the engine state logic model are shown in Figure 5. This model determines the state of the engine based on engine RPM, a system clock, the engine crank signal and the engine kill signal.

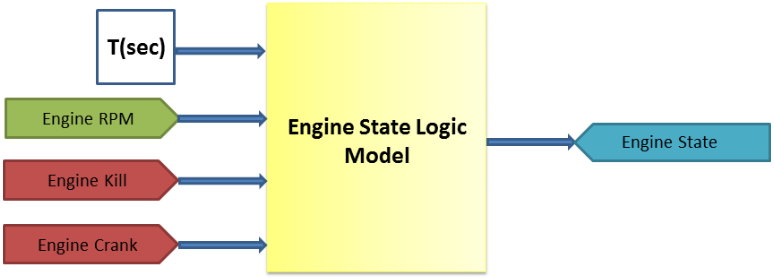


Figure 5. Engine state logic model.

There are five engine states: Engine Off State (1), Engine Crank State (2), Engine Warm-up State (3), Engine On State (4), and Engine Start Fail State (5). The values of the Engine State output signal corresponding to these five states are 1, 2, 3, 4, and 5, respectively. The conditions of the state transitions are listed in Table 2. Engine Crank Time and Engine Warm-up Time are the time duration of the Engine Crank State and the Engine Warm-up State. A "T (sec)" block can be used to count the time duration of these two states. The output of Engine State is an intermediate signal, which will be used in engine start/stop logic model and throttle request logic model.

Table 2. The conditions of engine state transitions.

Current state	Condition	Next state
Engine Off State (1) (default state)	Engine Crank=True, Engine Kill=False, Delay 1 sec.	Engine Crank State (2)
Engine Crank State (2)	Engine RPM>800 and Engine Crank Time>1.6 sec.	Engine Warm-up State (3)
	Engine Crank time>2 sec. and Engine RPM≤800	Engine Start Fail State (5)
Engine Warm-up State (3)	Engine Warm-up time>3 sec. and Engine RPM≥500	Engine On State (4)
	Engine Warm-up time>3 sec. and Engine RPM<500	Engine Start Fail State (5)
Engine On State (4)	Engine RPM<50 or Engine Kill= True	Engine Off State (1)
Engine Start Fail State (5)	Delay 1 sec.	Engine Off State (1)

2.4 Engine start/stop model

Engine start/stop model determines when to start and stop the engine. Figure 6 shows the input and output signals of this model.

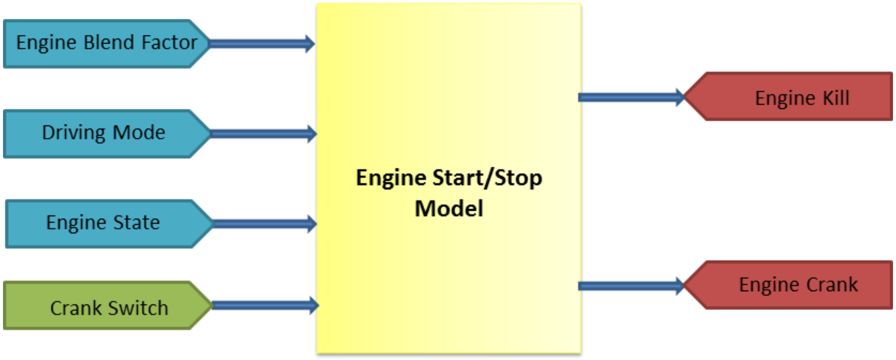


Figure 6. Engine start/stop model.

Engine Kill output signal is determined by the driving mode and engine blend factor as shown in Figure 7. If the engine blend factor is very small in blending mode, it means that the output power requirement from the engine is small. At this time, the engine needs to be shut off due to the efficiency reason. Table 3 shows the determination of the Engine Kill signal under various conditions.

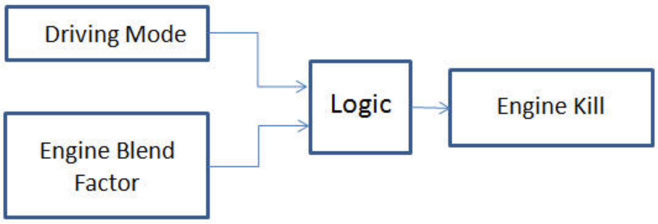


Figure 7. Engine Kill logic.

Table 3. The impact of driving mode and engine blend factor on engine kill signal.

Conditions	Driving Mode	Electric solo mode (1)	Blending mode (2)		Engine solo mode (3)
	Engine Blend Factor	No impact	>0.01	<0.01	No impact
Engine Kill		True	False	True	False

Figure 8 shows that engine can be started either manually or automatically. The Engine Crank signal is the logic OR of the Manual Crank and Automatic Crank signals. In your model, include probes for the Manual Crank and Automatic Crank signals. The Manual Crank is determined by the Crank Switch as shown in Table 4. The Crank Switch is the vehicle key. When a driver turns on the vehicle key, it will stay on until the vehicle stops. The Manual Crank to start the engine only works in the engine solo mode (driving mode = 3). The Automatic Crank works in the blending mode (driving mode = 2). In the blending mode, the engine will be automatically started when the Engine Blend Factor is greater than a certain value and the engine is at the Engine Off State as shown in Table 5.

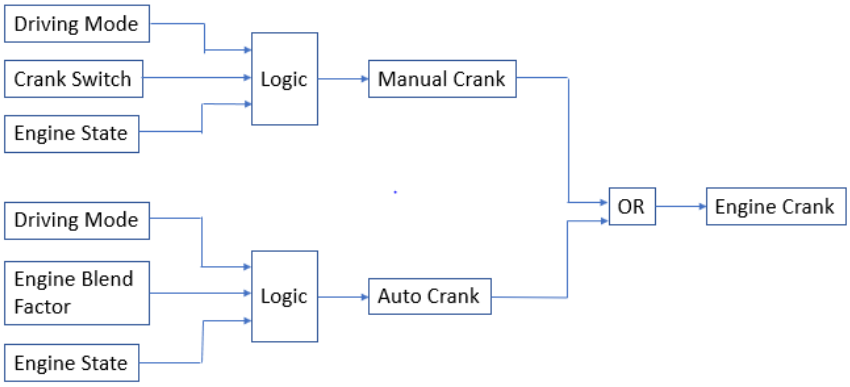


Figure 8. Engine start logic.

Table 4. The logic of Manual Crank signal.

Driving Mode	Electric solo mode (1)	Blending mode (2)	Engine solo mode (3)
Manual Crank	False	False	True when the Crank Switch is True and the engine state is 1

Table 5. The logic of Automatic Crank signal.

Conditions	Driving Mode	Electric solo mode (1)	Blending mode (2)			Engine solo mode (3)
	Engine Blend Factor	Irrelevant	>0.01		<0.01	Irrelevant
	Engine State	Irrelevant	==1	==4	Irrelevant	Irrelevant
Automatic Crank		False	True	False	False	False

2.5 Motor torque request and engine throttle request model

Torque/throttle request model determines the percentage of the output power is requested from motor or engine based on APP, driving mode, blend factors, and engine state as shown in Figure 9.

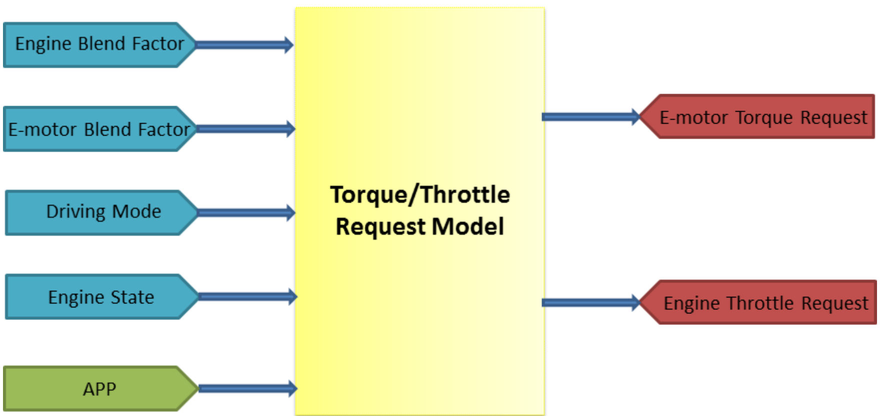


Figure 9. Torque/throttle request model.

Figure 10 shows the factors that affect the value of engine torque request. When a vehicle is in electric solo mode (driving mode = 1), the engine throttle request is equal to zero. When the vehicle is in engine solo mode (driving mode = 3), the engine throttle request is equal to APP. When the vehicle is in blending mode (driving mode = 2), the engine throttle request is determined by engine blend factor and APP (Engine Throttle Request = APP * Engine Blend Factor). When the engine is being started, the engine throttle request is a pre-defined value as shown in Table 6.

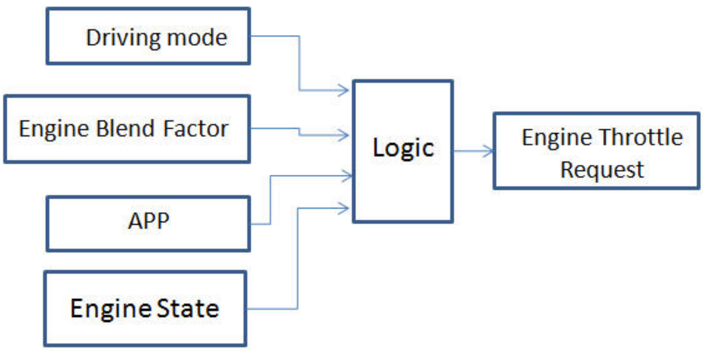


Figure 10. Engine throttle request.

The impact of engine state on engine throttle request is listed in Table 6. The engine throttle request will be used in stepper motor driving model.

Table 6. The impact of engine state on engine throttle request.

Conditions	Driving Mode	Electric solo mode (1)	Blending mode (2)			Engine solo mode (3)
	Engine State	No impact	==2or==3	==1or==5	Engine On State	No impact
Engine throttle request		0	7.5	0	APP*(Engine Blend Factor)	APP

The control logic for motor torque request is similar to engine throttle request. Figure 11 and Table 7 show the input signals and formulas that determine the value of the motor torque request.

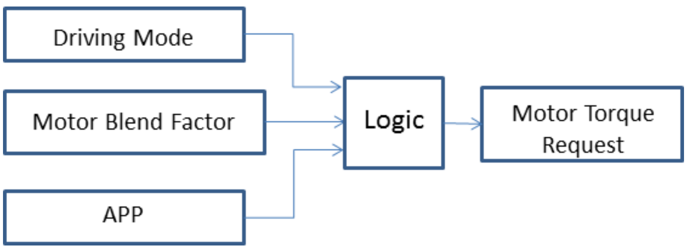


Figure 11. Motor torque request.

Table 7. The impact of driving mode on motor torque request.

Driving Mode	Electric solo mode (1)	Blending mode (2)	Engine solo mode (3)
Motor torque request	APP	APP*(Motor Blend Factor)	0

2.6 E-motor start/stop model

Figure 12 shows the input and output signals of the E-motor start/stop model. The E-motor On signal is determined by the Driving Mode and Motor Blend Factor as shown in Figure 13. Table 8 illustrates the logic of Motor On signal relating to the Driving Mode and Motor Blend Factor.

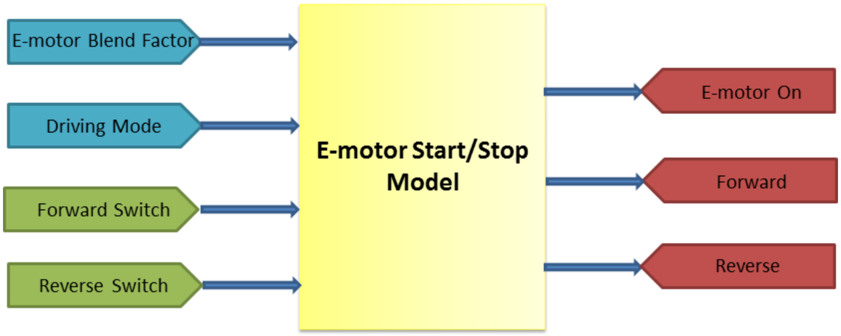


Figure 12. E-motor start/stop model.

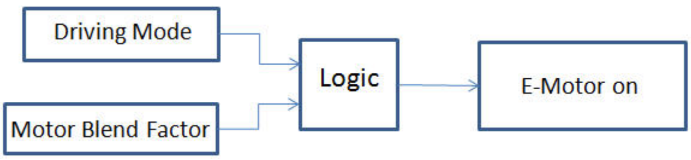


Figure 13. E-motor start logic.

Table 8. The logic of Motor On signal.

Conditions	Driving Mode	Electric solo mode (1)	Blending mode (2)		Engine solo mode (3)
	Motor Blend Factor	Irrelevant	>0.01	<0.01	Irrelevant
E-motor On		True	True	False	False

The spinning direction of the motor is determined by the Driving Mode, Forward Switch, and Reverse Switch as shown in Figure 14, Table 9, and Table 10.

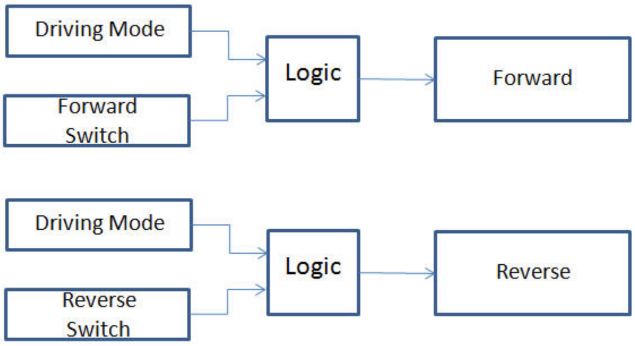


Figure 14. E-motor forward and reverse logic.

Table 9. The Forward logic.

Driving Mode	Electric solo mode (1)	Blending mode (2)	Engine solo mode (3)
Forward signal	Forward Switch status	True	False

Table 10. The Reverse logic.

Driving Mode	Electric solo mode (1)	Blending mode (2)	Engine solo mode (3)
Reverse signal	Reverse Switch status	False	False

Note that the Forward Switch and the Reverse Switch only be used to determine the Forward and Reverse signals in the Electric solo mode. The Forward and Reverse Switches can only be changed when vehicle speed is less than 1mph and cannot be True/False at the same time.

2.7 Stepper motor driving model

A stepper motor is used to control the throttle opening of the engine. The stepper motor driving model generates driving signals for stepper motor coils. The stepper motor has 4 coils. The driving signals of these coils are determined by the Engine Throttle Request (ETR) and Throttle Position Sensor (TPS) as shown in Figure 15.

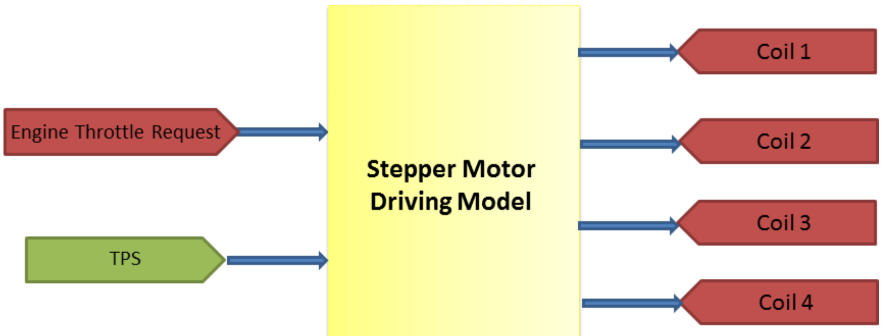


Figure 15. Stepper motor driving model.

Assume that 4 coils are bifilar wound. Figure 16 shows how to determine if there is a need to drive the stepper motor and the direction of rotation. Figure 17 show the driving circuit and a sequence of driving signals for half-step driving. Please use half-step driving in your model.

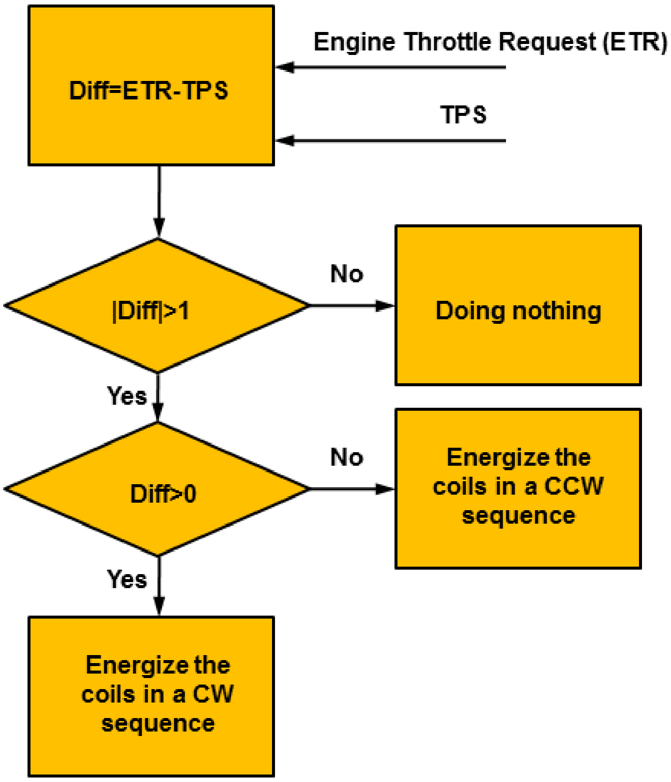
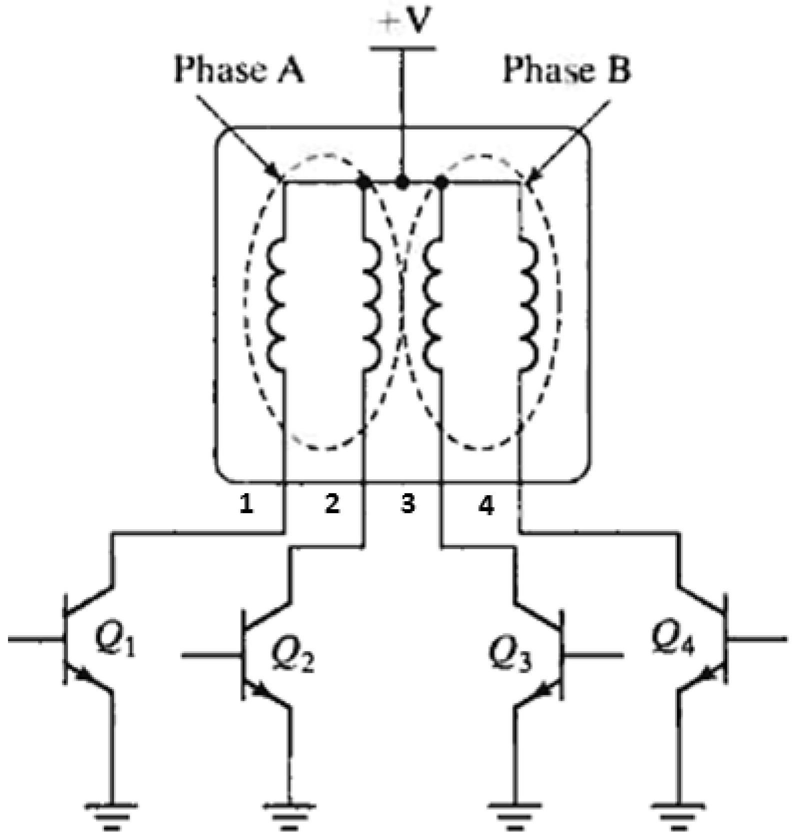


Figure 16. The flowchart for the determination of coil driving signals of the stepper motor.



Unipolar Drive

CW ↓ / ↑ CCW

Step	Q_1	Q_2	Q_3	Q_4
1	On	Off	On	Off
2	On	Off	Off	Off
3	On	Off	Off	On
4	Off	Off	Off	On
5	Off	On	Off	On
6	Off	On	Off	Off
7	Off	On	On	Off
8	Off	Off	On	Off
1	On	Off	On	Off

Figure 17. The driving circuit and driving signals for half-step driving.