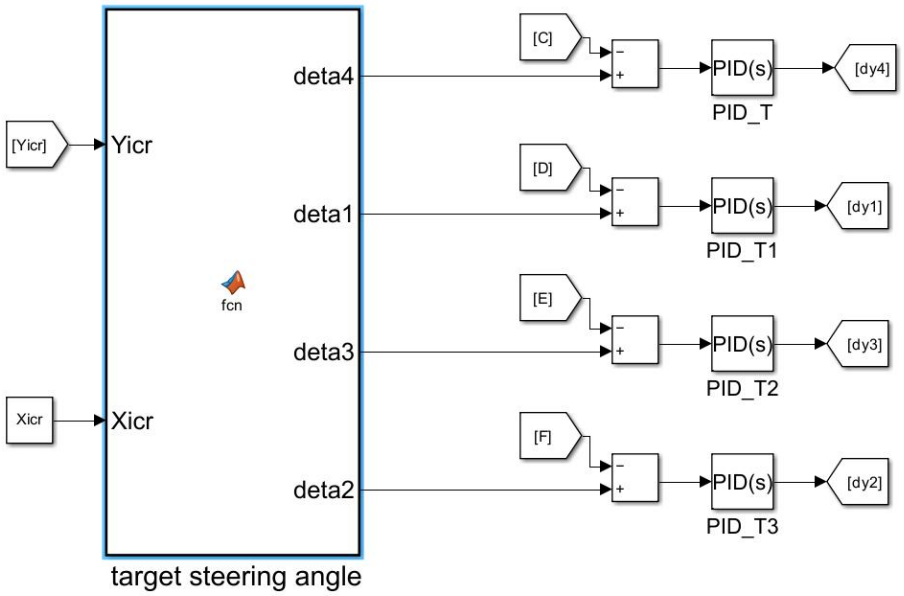

Fig. 1. Target control loop.

Fig. 1 illustrates the role of the target steering angle in the control process. First, the target steering angles of each wheel are calculated based on the desired instantaneous center of rotation (Xicr, Yicr). These angles are then subtracted from the outputs of the four Goto modules (C, D, E, and F, which represent the actual steering angles of the four wheels) to obtain the target steering angle error signals. The error signals are then fed into the PID_T controller, which outputs the steering control signal dy, ensuring that the wheel steering angles eventually return to their target values.

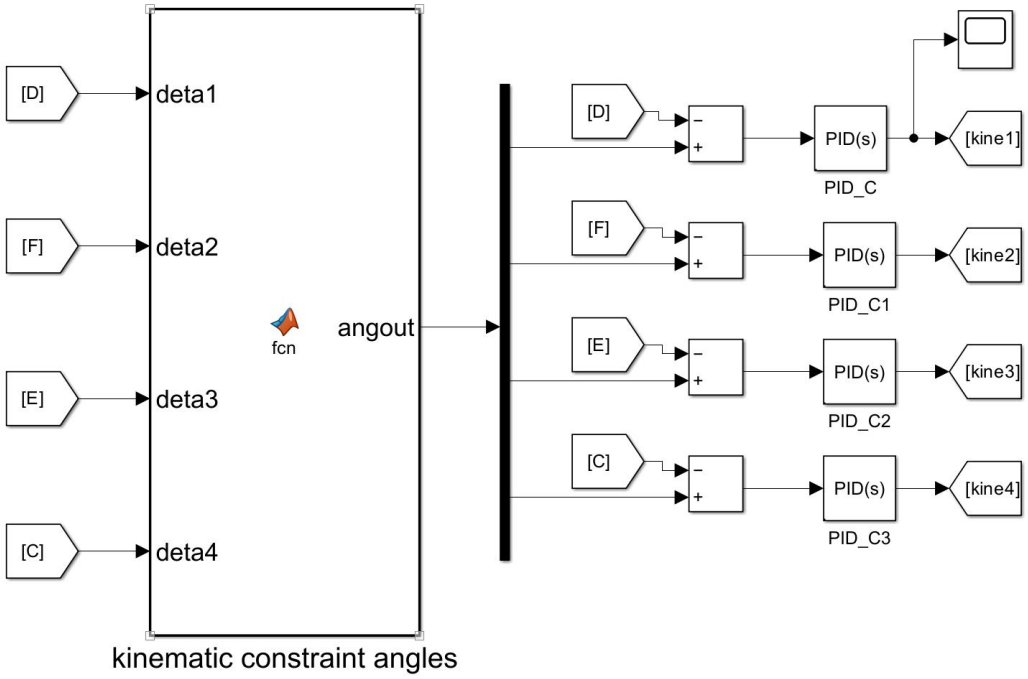

Fig. 2. Kinematic constraint control loop.

Fig. 2 illustrates the role of the kinematic constraint steering angle in the control process. First, the kinematic constraint steering angles of each wheel are calculated based on the actual steering angles obtained from the four Goto modules (C, D, E, and F). These calculated angles are then subtracted from the corresponding actual steering angles represented by the Goto modules to obtain the kinematic constraint steering angle error signals. The error signals are then fed into the PID_C controller, which outputs the steering control signal kine, thereby reducing wheel slip.

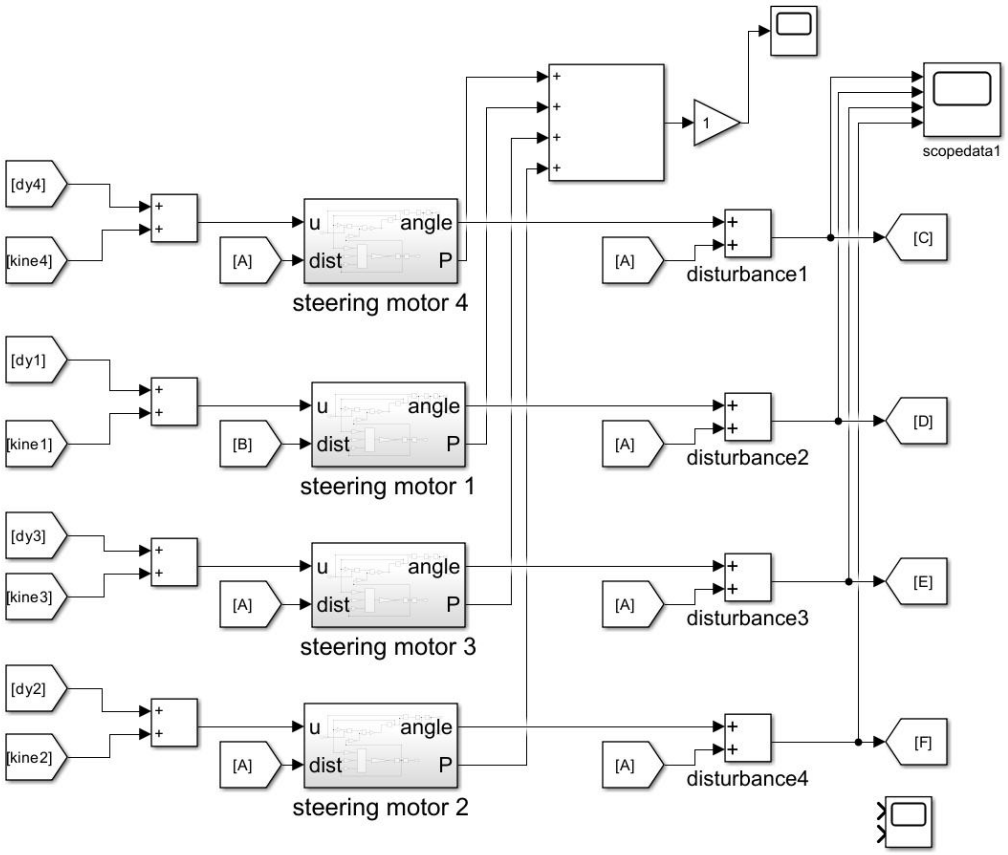

Fig. 3. Actual steering angle output

Fig. 3 illustrates the process of generating the final actual steering angle output of the wheels. First, the outputs of the previous PID_C and PID_T controllers, kine and dy, are added together, and the sum is used as the steering motor input u. Meanwhile, the steering motor includes a disturbance input port dist to simulate the effect of external disturbances on the steering angle. The motor has two outputs: one is the motor's power consumption P, and the other is the final wheel steering angle output. The subsequent disturbance block simulates the influence of external disturbances on the wheel steering angle.

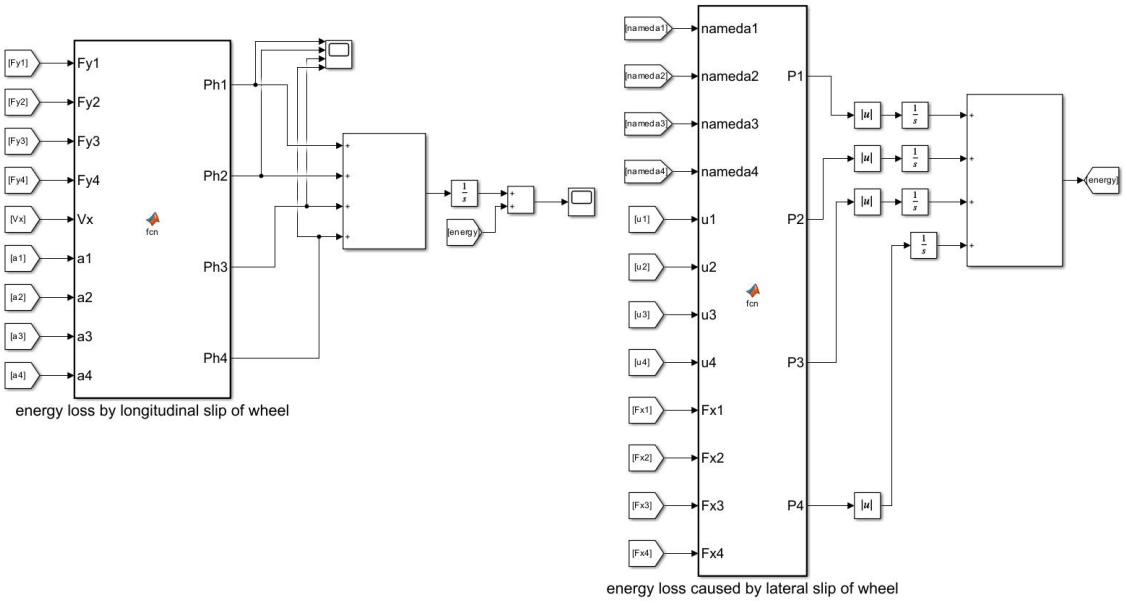

Fig. 4. Wheel slip loss

In Figure 4, the longitudinal and lateral slips of the tires are calculated separately, and their sum is used to obtain the total slip loss of the tires.

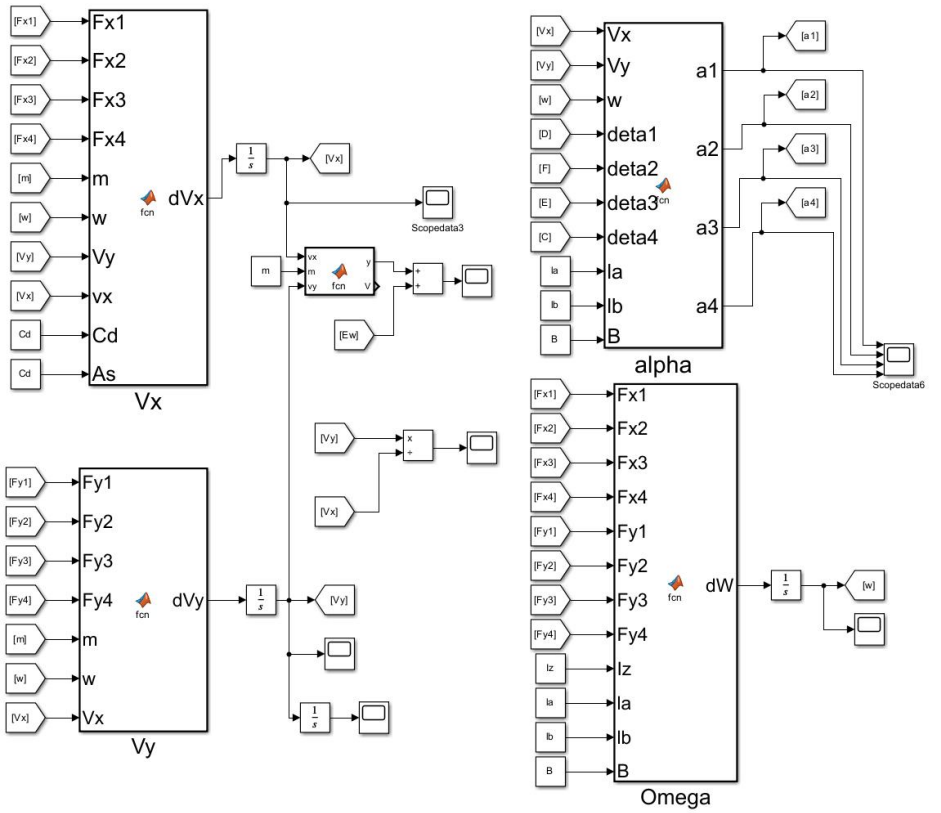

Fig. 5. Vehicle model.

Fig 5 shows the vehicle dynamics model, which includes the lateral, longitudinal, and yaw dynamics. The module in the upper right corner represents the tire sideslip angle calculation.

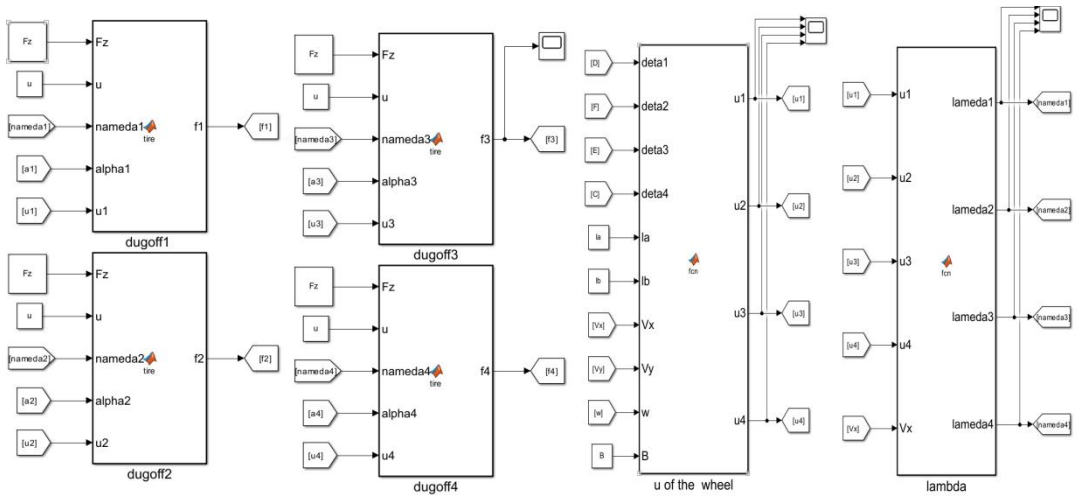

Fig. 6. Tire model, the center speed of wheel and the slip ratio of wheel.