Nonlinear Model-Based Adaptive Robust Controller Design for Hydraulic Winch in Oil and Gas Wireline Operation:
Model based design with docker container

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Outline

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- ❑ Project background
- ❑ Model based design and docker
- ❑ Winch control hardware setup
- ❑ Winch system model development
- ❑ Winch controller design
- ❑ Controller software architecture, implementation and testing
- ❑ Conclusion

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Autonomous wireline operation

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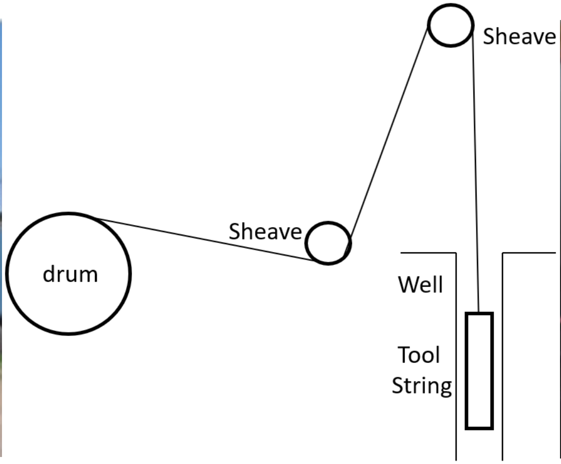

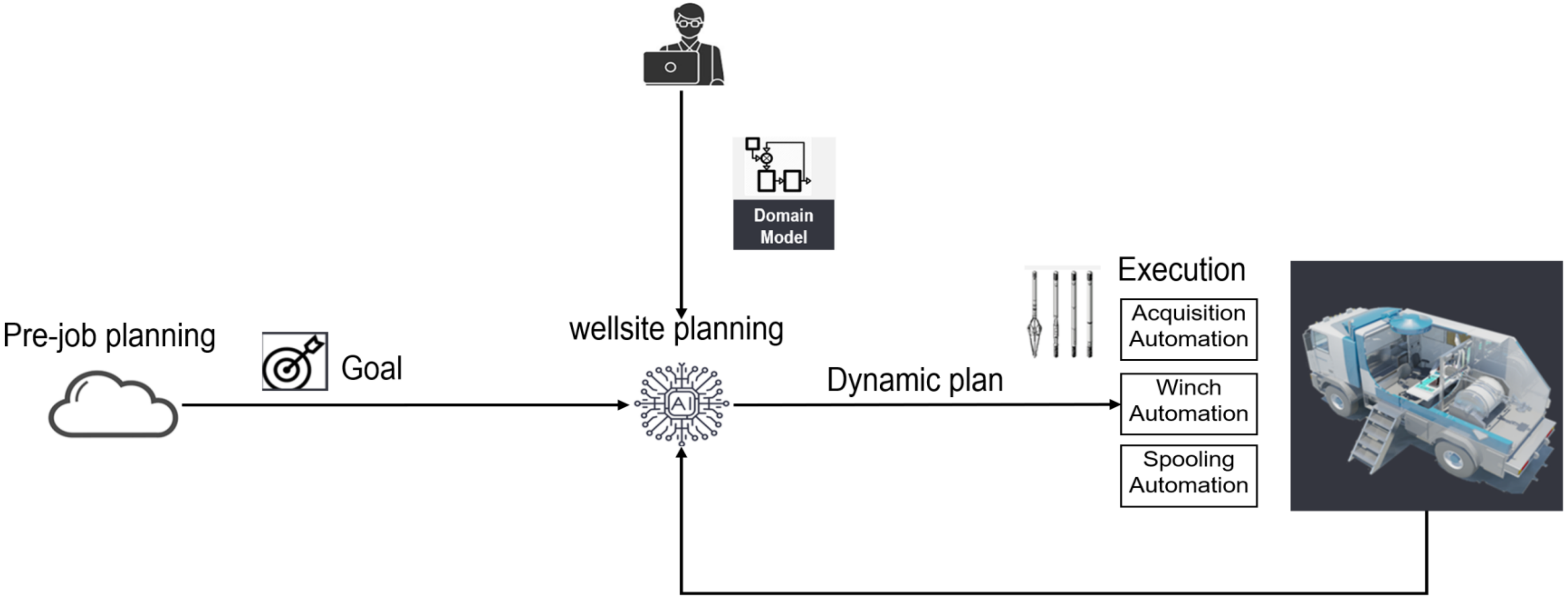

Model based design and docker container

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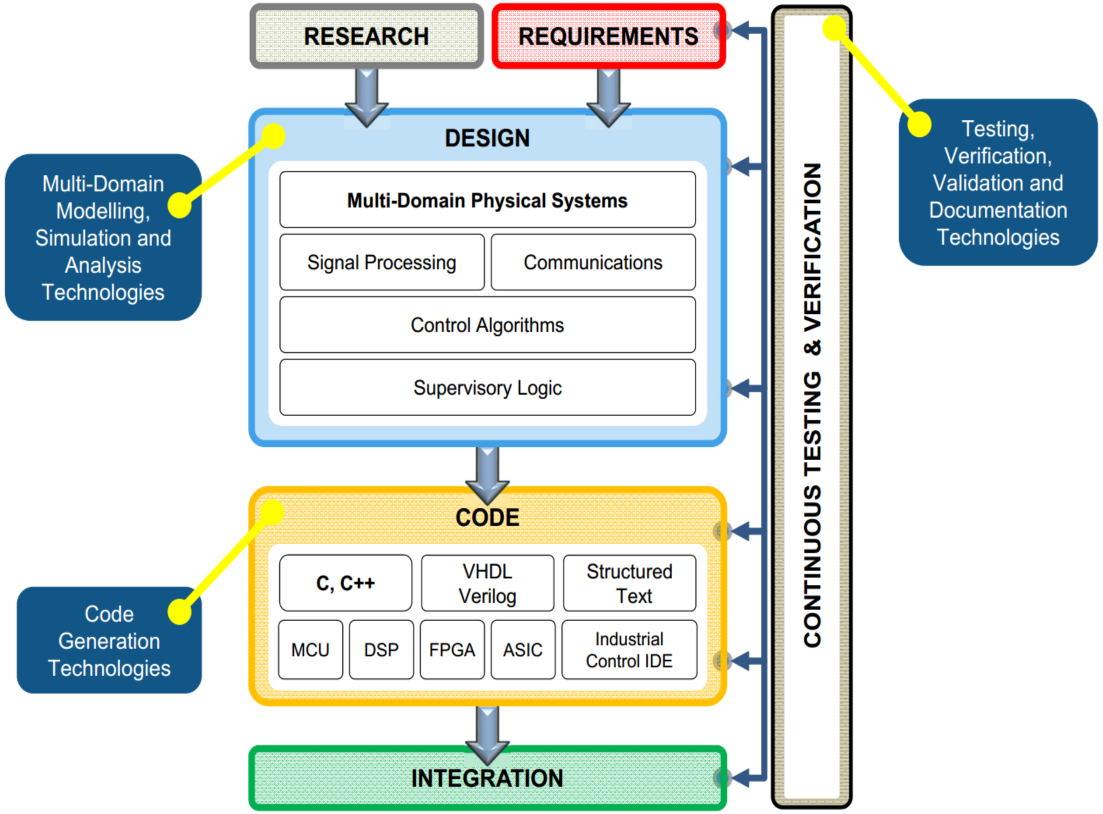

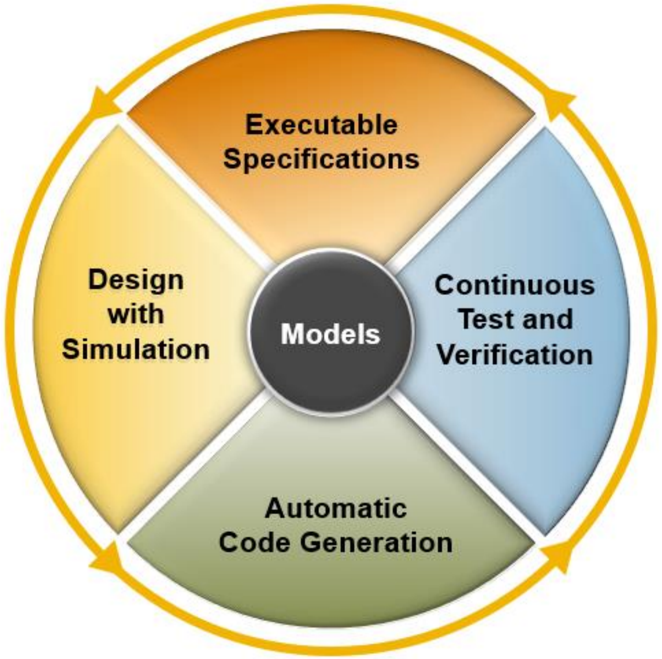

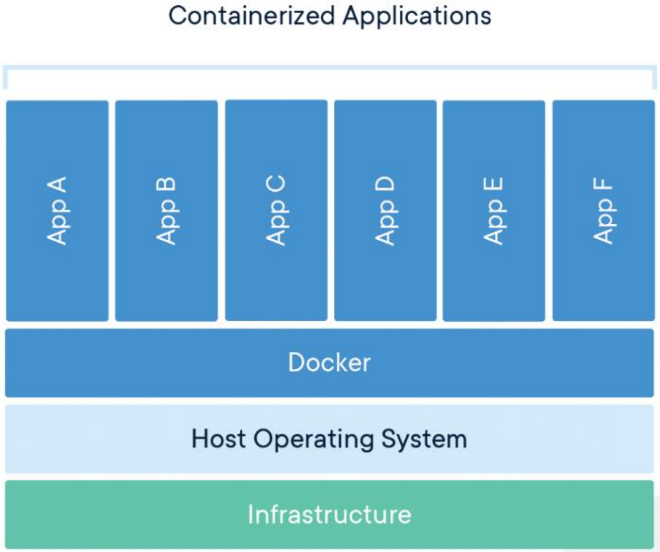

Slides from Mathworks presentation

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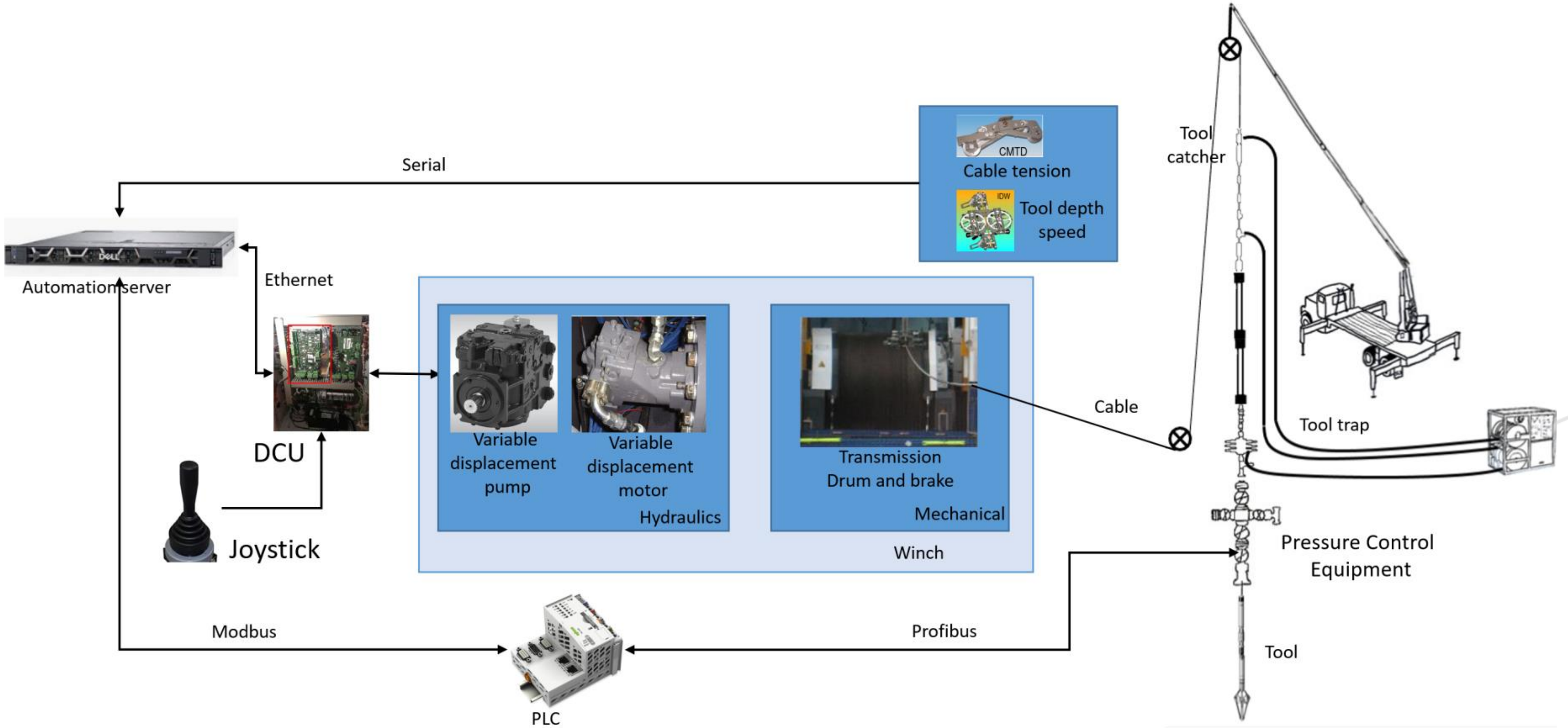
Current hardware setup for winch control



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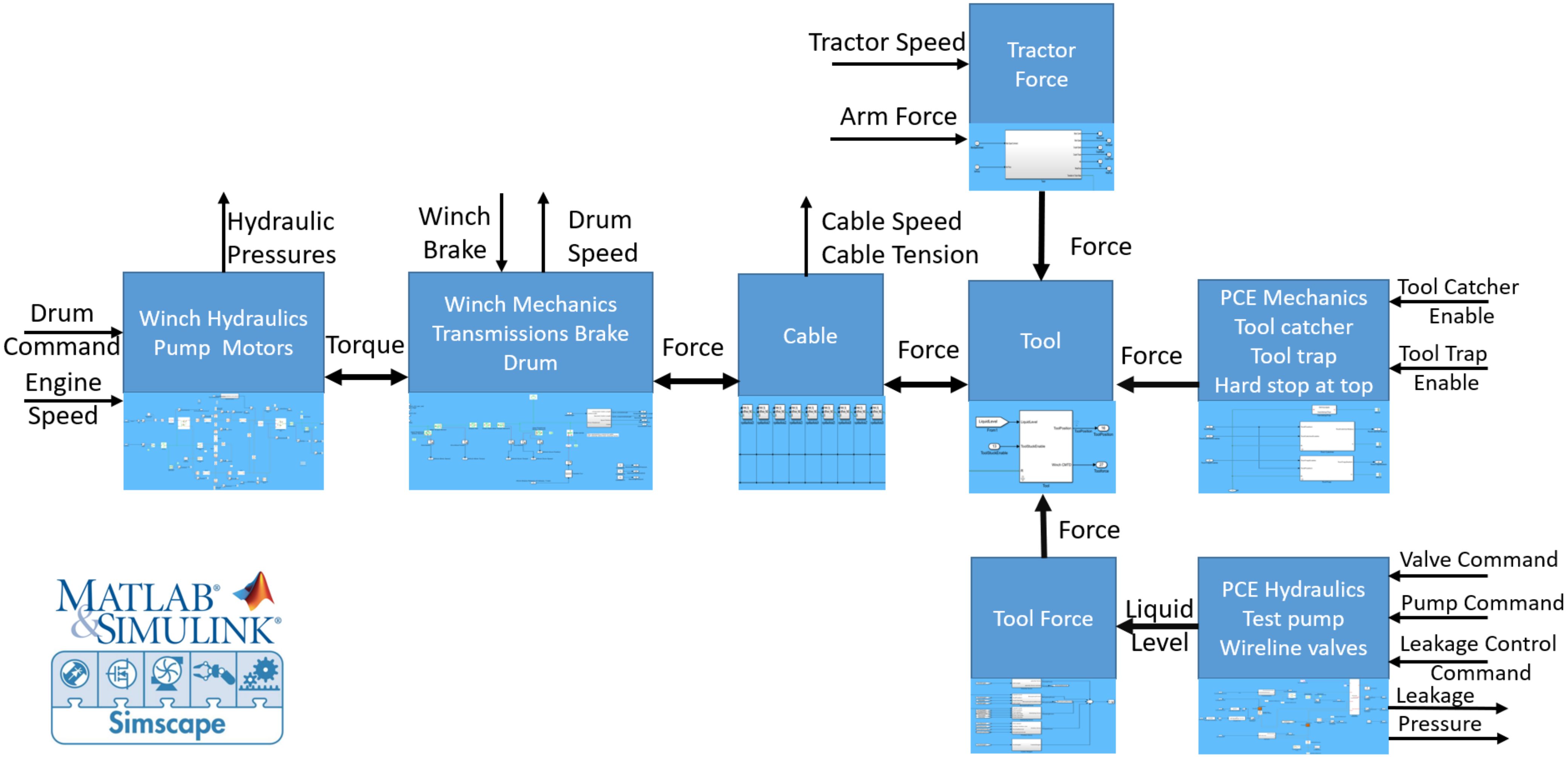
Equipment model and simulator: overview



Equipment model and simulator

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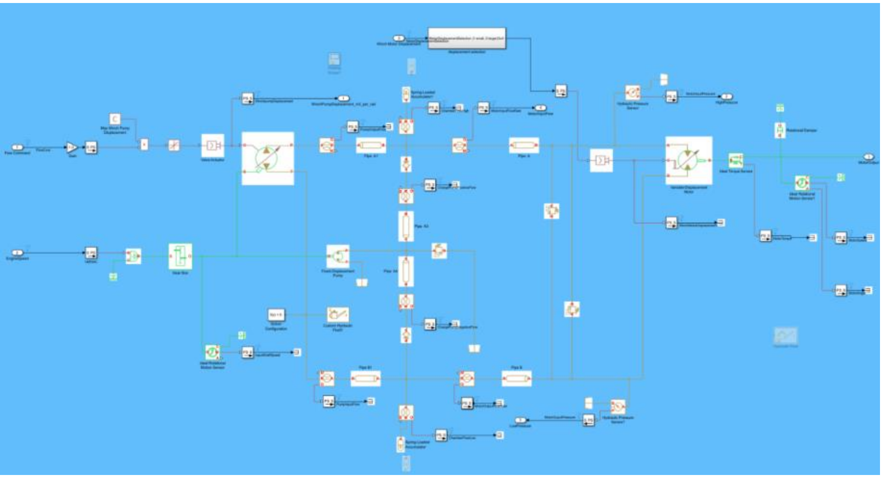
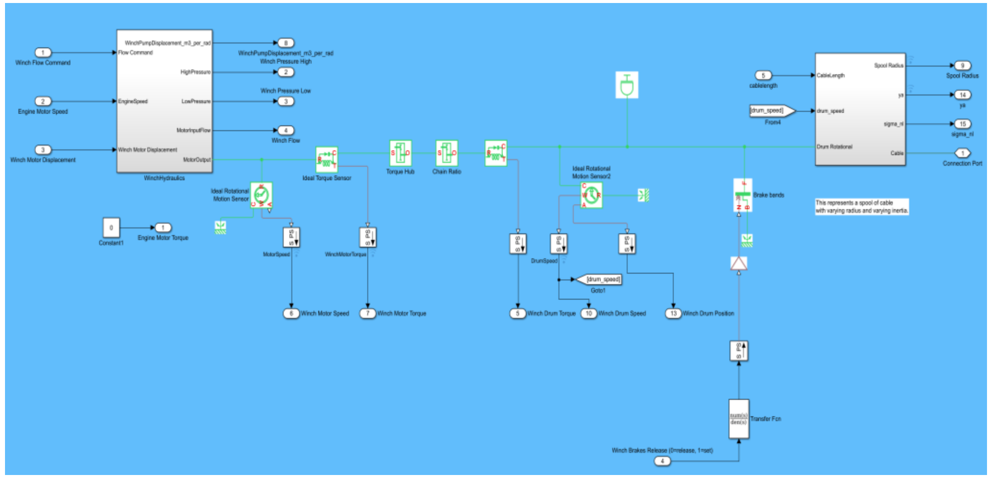
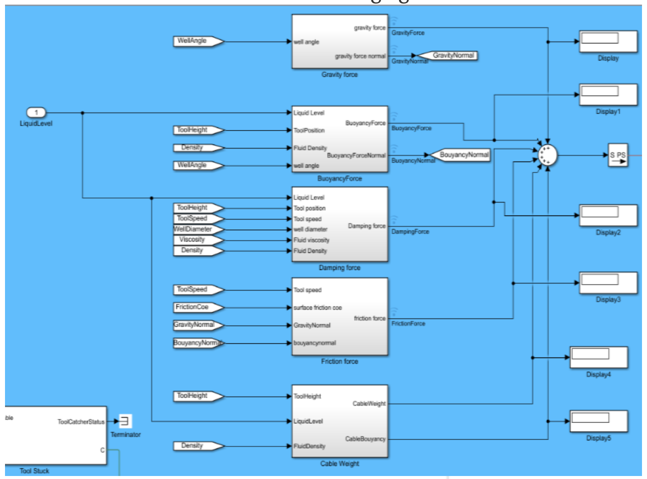


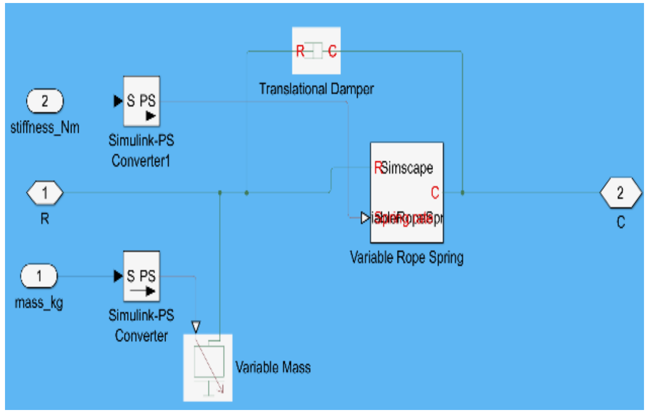
Hydraulics



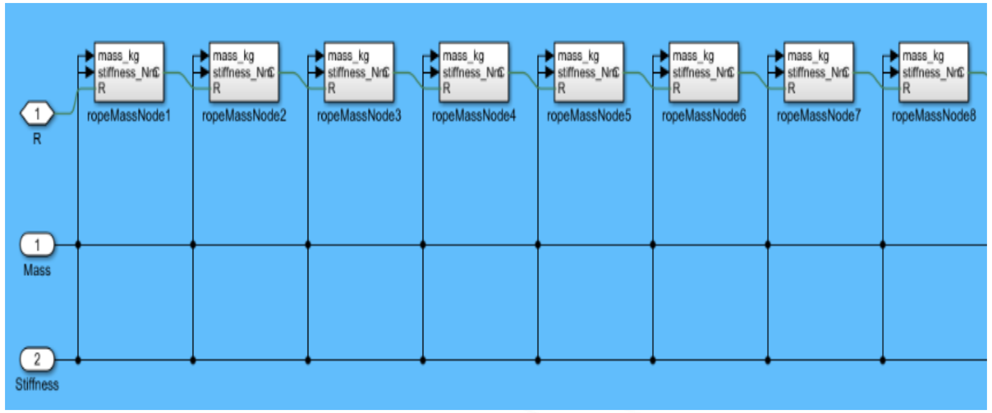
Transmission and drum



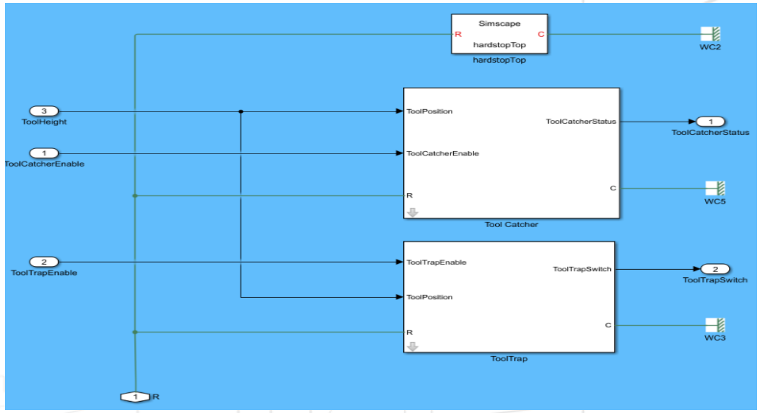
Tool force



Cable node



Cable



Tool Trap and Catcher

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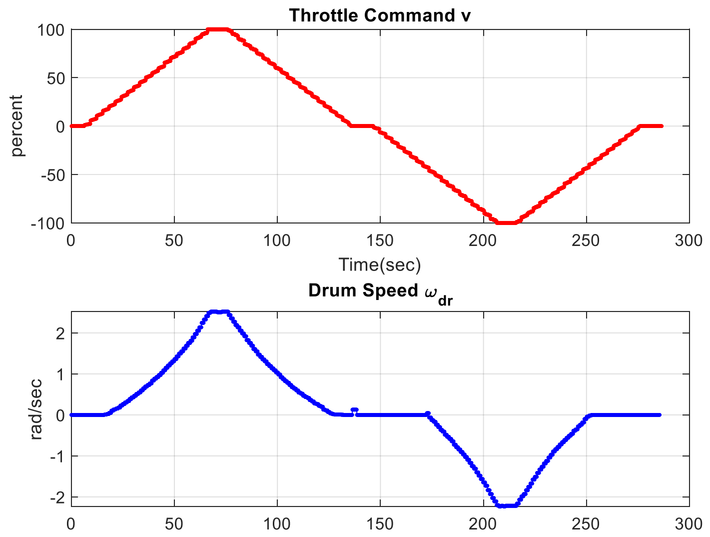
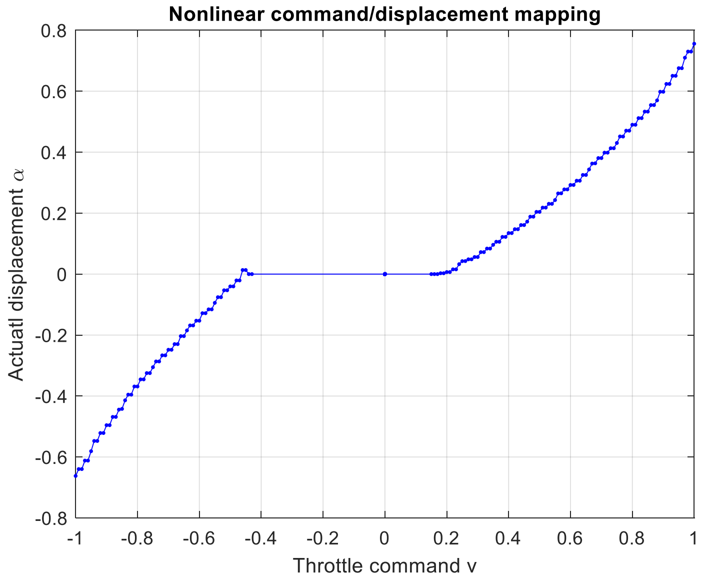
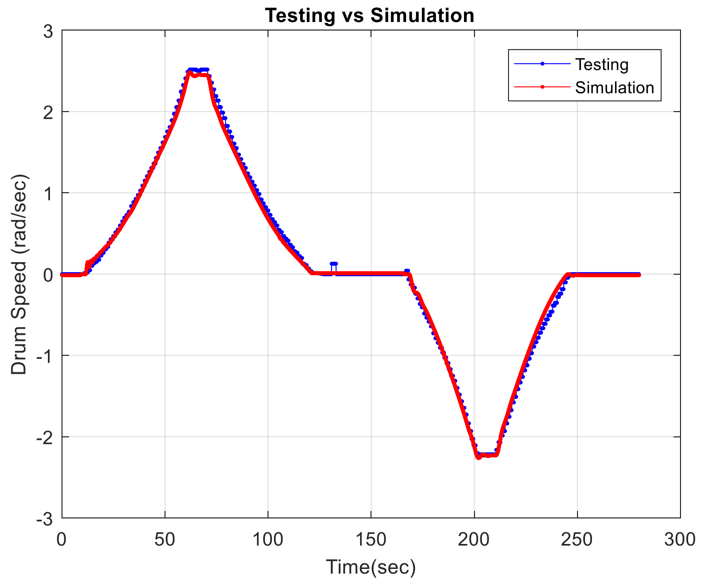
Model calibrations







Winch controller design: design system model

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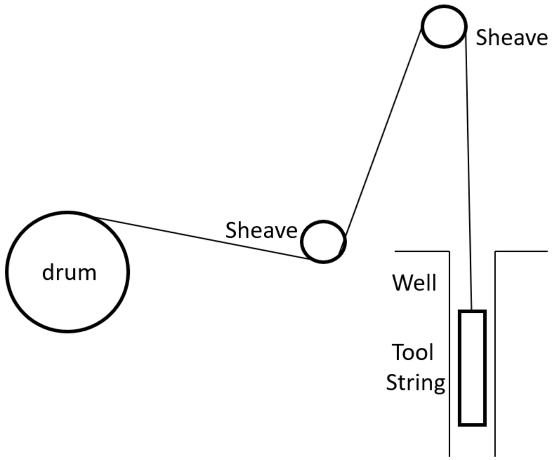

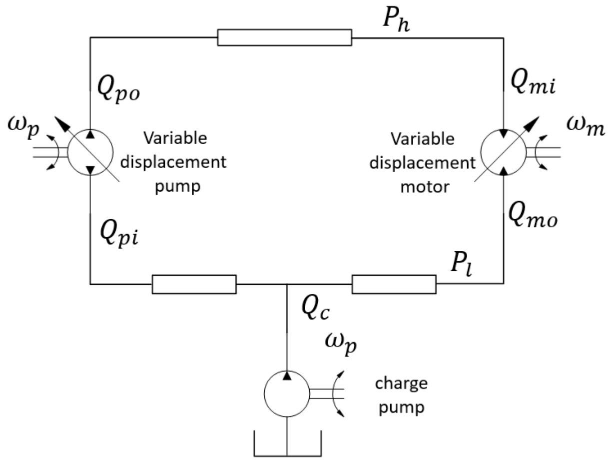

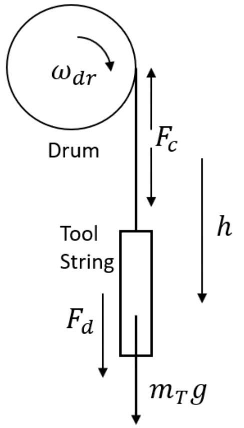

Hydraulic Flow

Variable displacement pump

$$Q_{pi} = D_p \omega_p \quad D_p = G_p \alpha \quad \alpha = f(v)$$

$$v \in [-1,1] \quad \alpha \in [-1,1]$$

$$Q_{po} = \eta_{vp} Q_{pi}$$

Variable displacement motor

$$Q_{mo} = D_m \omega_m$$

$$Q_{mi} = Q_{mo}/\eta_{vm}$$

$$T_m = D_m (P_h - P_l)\eta_{tm}$$

Charge pump

$$Q_c = D_c \omega_p$$

Pressure dynamics

$$\frac{V_h}{\beta_e}\dot{P}_h = Q_{po} - Q_{mi} - Q_{lh}$$

$$\frac{V_l}{\beta_e}\dot{P}_l = Q_{mo} + Q_c - Q_{pi} - Q_{ll}$$

Motor torque

$$T_m = D_m (P_h - P_l)\eta_{tm}$$

Winch Mechanics

Drum

$$\omega_r = \omega_m / n$$

$$T_r = n T_m$$

$$(J_r + J_c)\dot{\omega}_r = T_r - T_L + T_d$$

$$T_L = F_c R$$

Tool

$$(\rho h + m_T)\ddot{h} = (\rho h + m_T) g - F_c + F_d$$

Design model in state space

load pressure $P_L = P_h - P_l$

$x = [x_1, x_2, x_3]^T = [h, \dot{h}, P_L]^T$,

$$\dot{x}_1 = x_2$$

$$\dot{x}_2 = \frac{A_m}{m_s} x_3 + \frac{(\rho x_1 + m_T)}{m_s} g + \theta_1 + \tilde{F}_d$$

$$\dot{x}_3 = \frac{\beta_e}{V_T}(C_p \omega_p \alpha - C_m x_2 - D_c \omega_p) + \theta_2 + \tilde{Q}_L$$

$$\alpha = f(v)$$

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Winch controller design: ARC controller design using backstepping

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Step 1: A desired load pressure α_2 is designed for the system load pressure x_3 such that the tool motion x_1 will follow the desired motion trajectory x_{1d}.

$$\alpha_2 = \alpha_{2a} + \alpha_{2s} \quad \alpha_{2s} = \alpha_{2s1} + \alpha_{2s2}$$

$$\alpha_{2a} = \frac{m_s}{A_m}\left(-\frac{\rho x_1 + m_T}{m_s} g - \hat{\theta}_1 + \dot{x}_{2eq}\right)$$

$$\alpha_{2s1} = -\frac{m_s}{A_m} k_2 z_2$$

Step 2: Synthesize a control law α_3 for the actual pump displacement α such that the load pressure x_3 will track the virtual control function α_2 designed in the first step.

$$\alpha_3 = \alpha_{3a} + \alpha_{3s} \quad \alpha_{3s} = \alpha_{3s1} + \alpha_{3s2}$$

$$\alpha_{3a} = \frac{1}{C_p \omega_p}\left[C_m x_2 + D_c \omega_p + \frac{V_T}{\beta_3}\left(-\hat{\theta}_2 + \dot{\alpha}_{2c} - \frac{\omega_2}{\omega_3}\frac{A_m}{m_s} z_2\right)\right]$$

$$\alpha_{3s1} = -\frac{1}{C_p \omega_p}\frac{V_T}{\beta_3} k_3 z_3$$

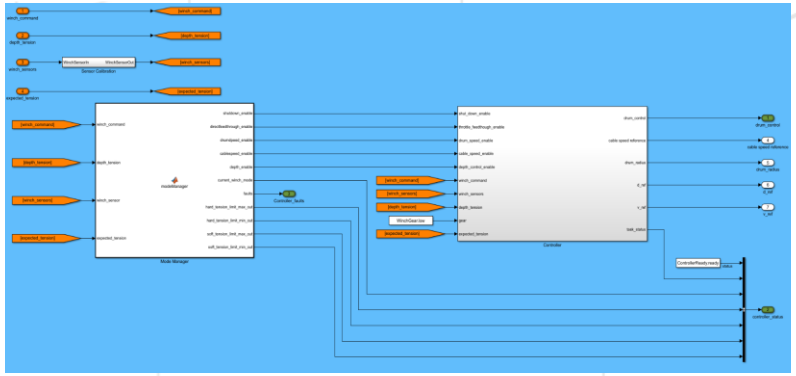
Step 3: The actual control command v can be calculated from inversed nonlinear mapping $v = f^{-1}(\alpha_3)$

$$\dot{x}_1 = x_2$$

$$\dot{x}_2 = \frac{A_m}{m_s} x_3 + \frac{(\rho x_1 + m_T)}{m_s} g + \theta_1 + \tilde{F}_d$$

$$\dot{x}_3 = \frac{\beta_e}{V_T}(C_p \omega_p \alpha - C_m x_2 - D_c \omega_p) + \theta_2 + \tilde{Q}_L$$

$$\alpha = f(v)$$



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Winch controller implementation

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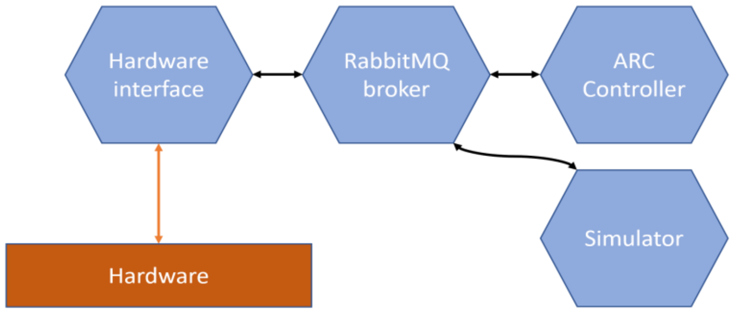
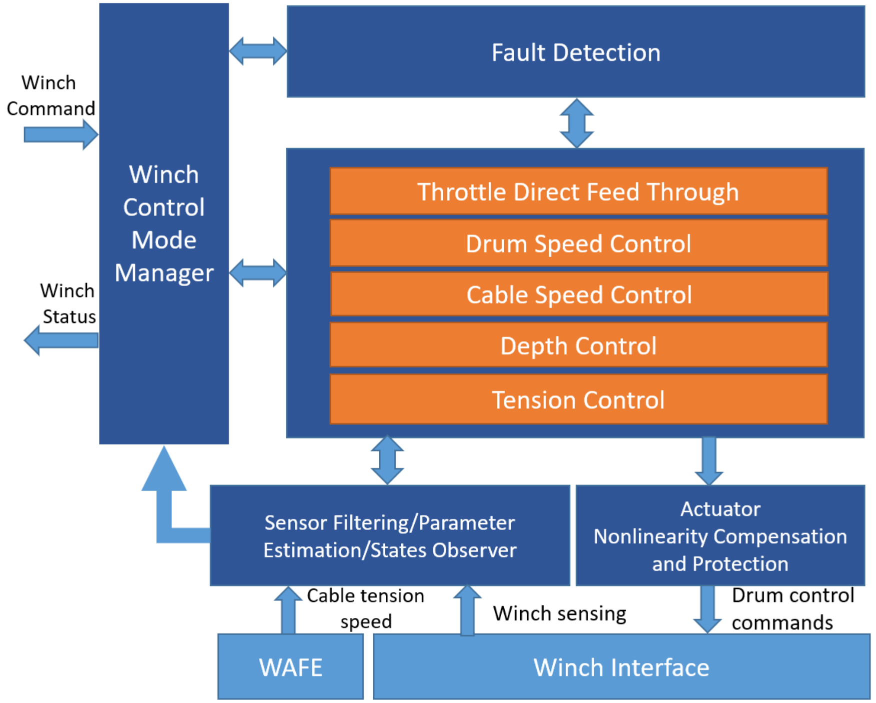
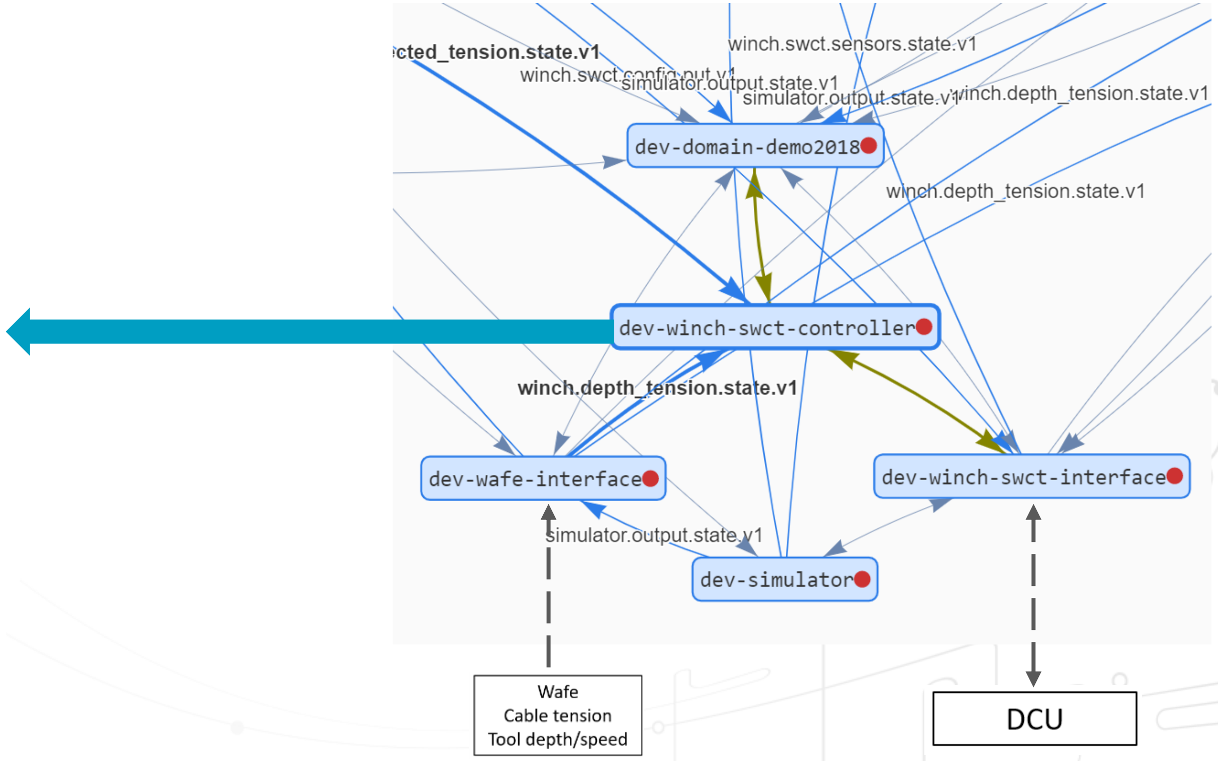




RabbitMQ

docker



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Build container services from Simulink/SimScape

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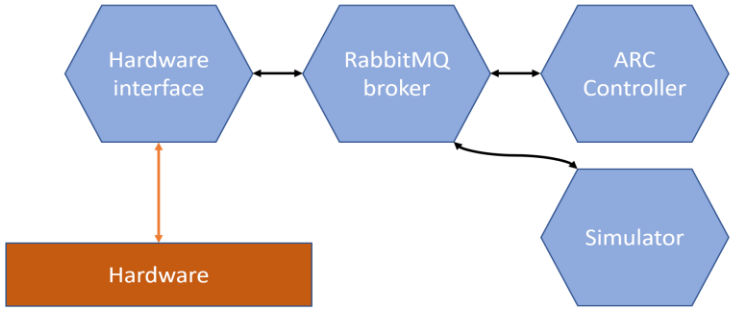

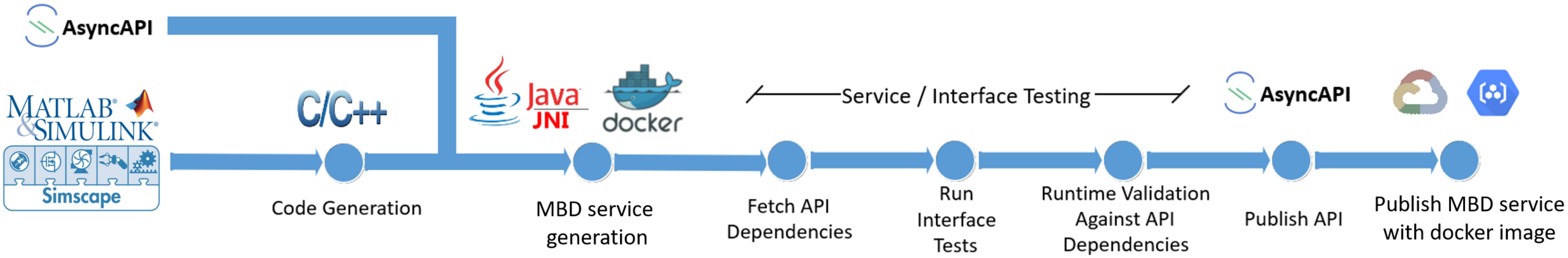

Figure courtesy of Ken Ditlefsen's poster

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Model-in-loop testing

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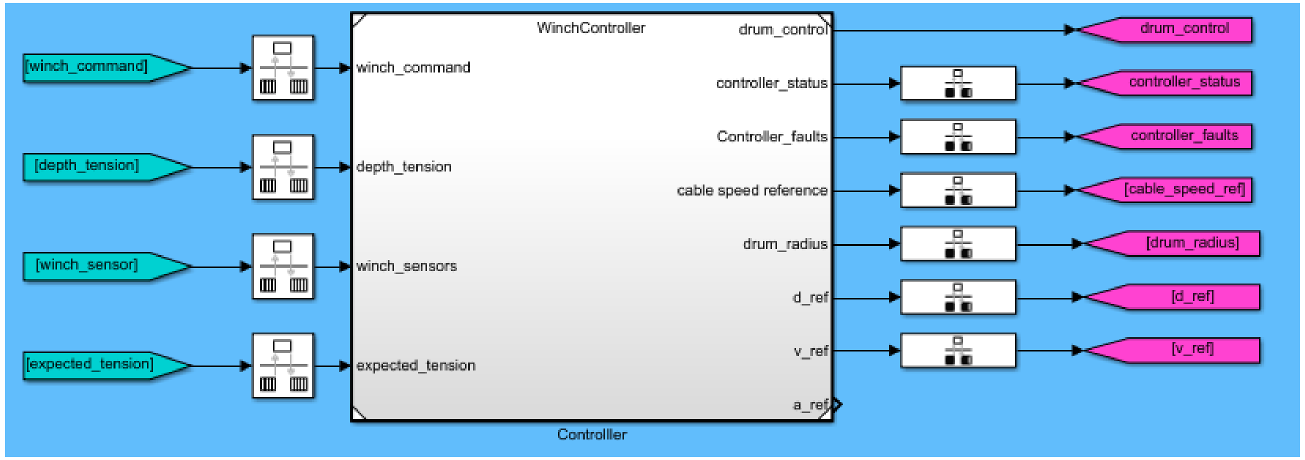

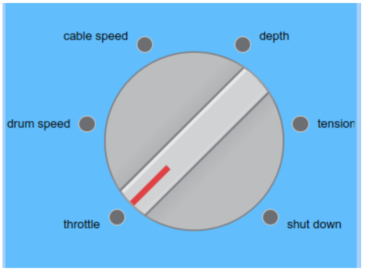

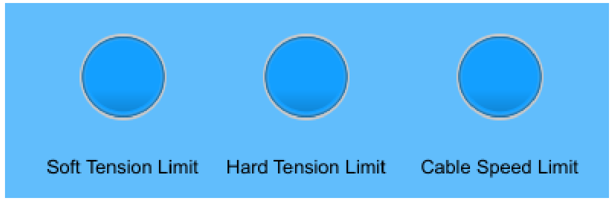

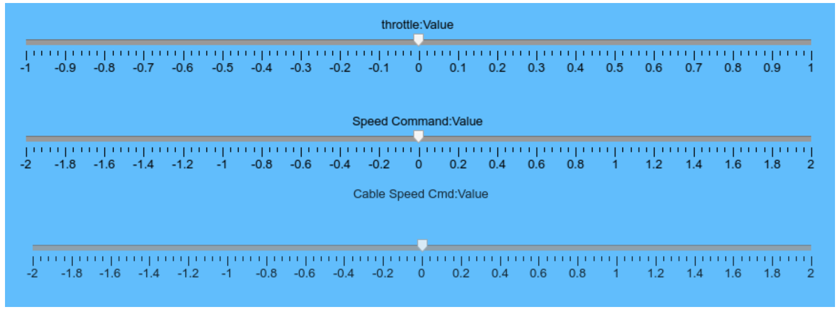

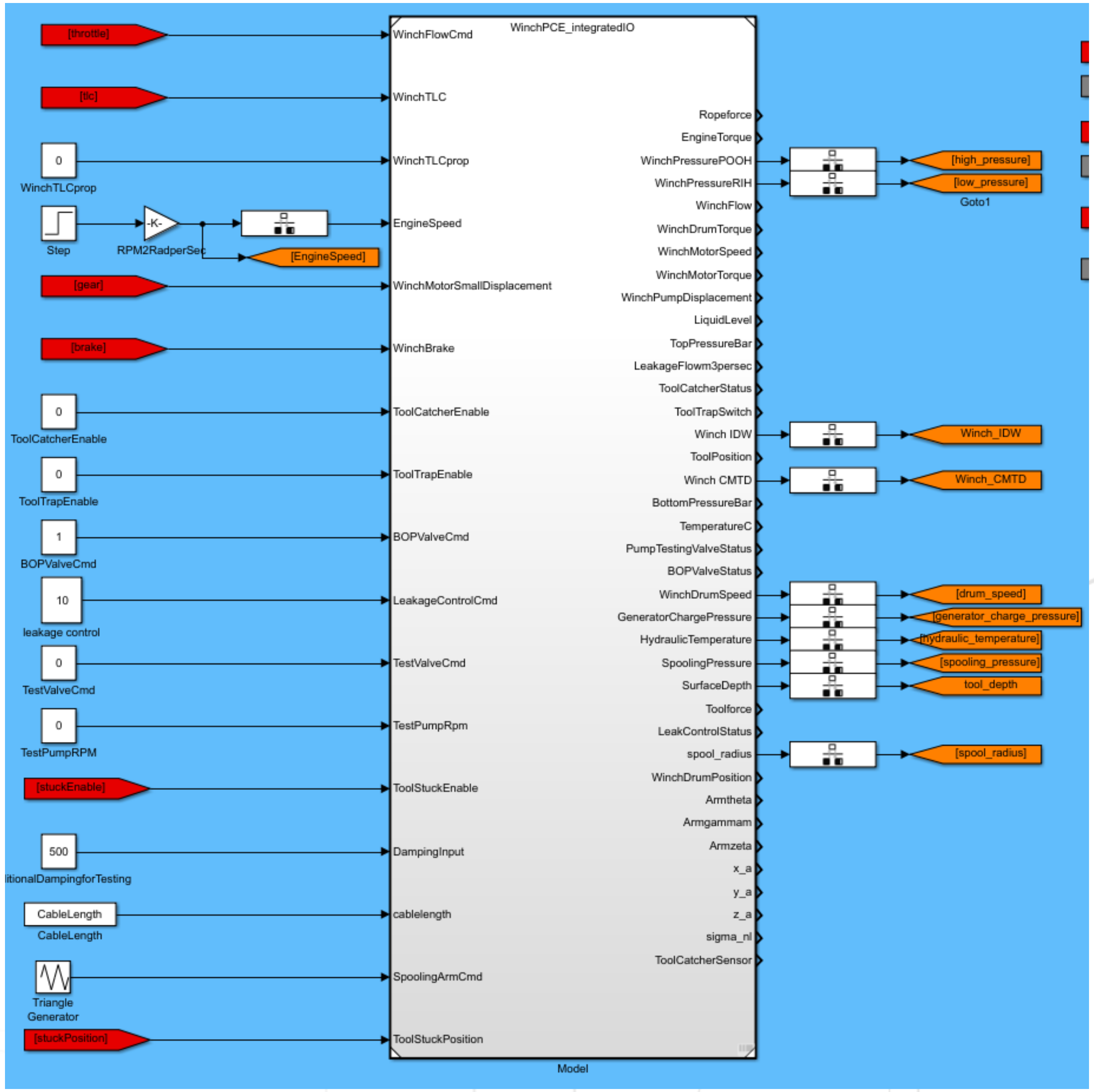

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Software-in-loop testing

Back to Dashboard
Status
Changes
Build Now
Full Stage View
Open Blue Ocean
Embeddable Build Status

Build History trend

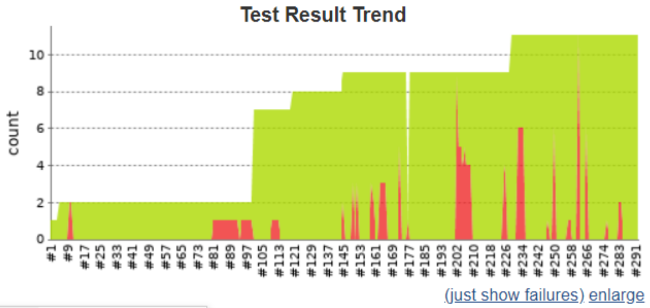
find

#292	May 2, 2019 6:50 PM
#291	Apr 29, 2019 5:11 PM
#290	Apr 26, 2019 9:28 PM
#289	Apr 26, 2019 8:15 PM
#288	Apr 24, 2019 5:49 PM

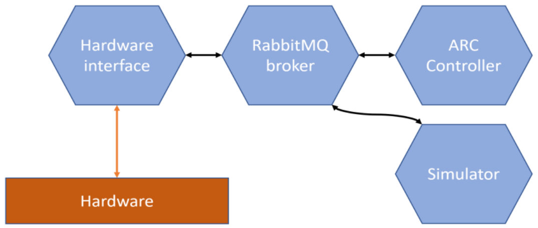
Pipeline dev-integration-tests_wafe-swct

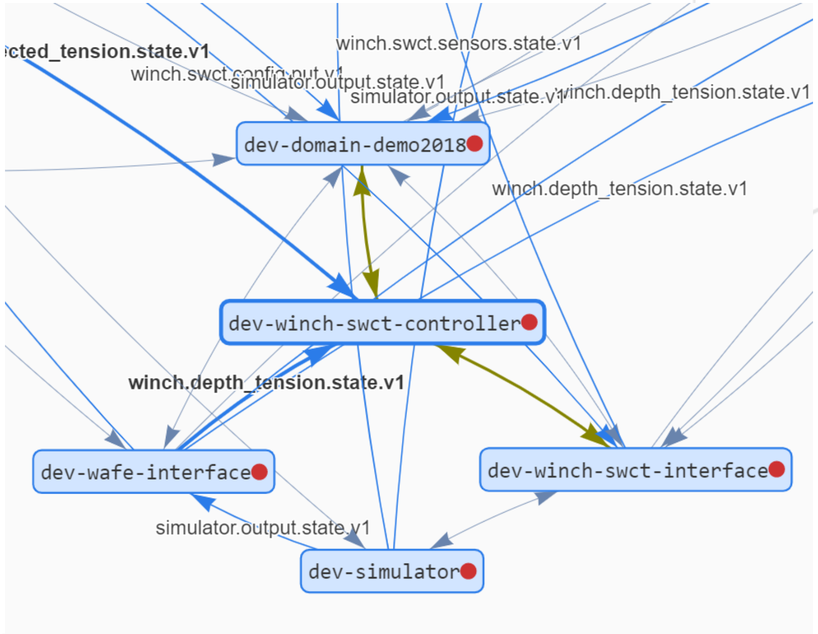
Recent Changes

Stage View



	Declarative: Checkout SCM	Prepare	Fetch Image Dependencies	Integration Test
Average stage times: (Average full run time: ~11min 47s)	678ms	1s	13s	10min 42s
#292 May 02 13:50 2 commits	1s	1s	13s	11min 40s






```python
@pytest.mark.timeout(600)
def test_ctrl_depth(evertest, depth_cmd, winch_mode_cmd, tension_offset_cmd, simulator_input_cmd):
    """
    Try to run in hole and pull out of hole by sending depth commands to dev-winch-swct-controller.
    Verify command response by reading dev-wafe-interface output.
    """
    start_depth = evertest.get_value(WAFE_INTF_DEPTH_TENSION_STATE_TOPIC, 'depth', timeout=1)
    assert start_depth is not None
    depth_cmd['depth_min'] = start_depth - 1 # m
    depth_cmd['depth_max'] = start_depth + 1 # m
    depth_cmd['cable_speed_limit_min'] = 0 # m/s
    depth_cmd['cable_speed_limit_max'] = 1 # m/s
    assert evertest.publish_msg(WINCH_CTRL_DEPTH_CMD_TOPIC, depth_cmd)
```

Truck Testing

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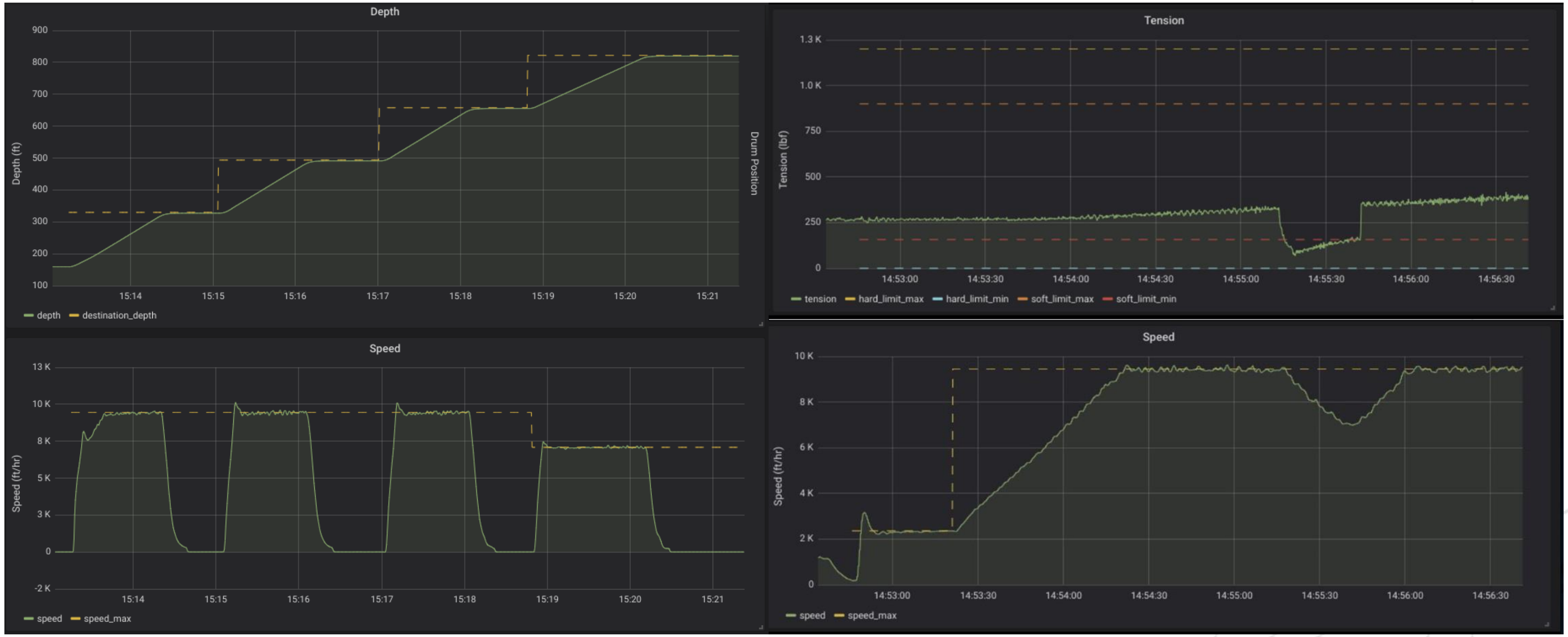

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Conclusion

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- ❑ Multi-domain physical system modeling using SimScape/Simulink
  - ❑ Using existing libraries
  - ❑ Customized component modeling using SimScape language
- ❑ Control algorithm design using Simulink/Stateflow
  - ❑ Together with other tools (Control system Toolbox, Simulink Design Optimization) offered by Mathworks to speed up controller design
- ❑ MIL simulation and testing
  - ❑ Quick what-if analysis and automation using Simulink Test
- ❑ Code generation for both controller and system model(Simulator)
  - ❑ Eliminate manual coding and speed up implementation
- ❑ Containerized controller and simulator
  - ❑ Facilitate CI/CD
  - ❑ Democratize model simulation
- ❑ Build and test automation (SIL) using Jekins/Azure devops
  - ❑ Automatic build and regression test

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