

AQUILA-BASED MODEL PREDICTIVE CONTROL OF AN ADAPTED FRIDGE DISPLAY CASE MODEL FOR VACCINE PRESERVATION

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Introduction

Temperature excursions and vaccine freezing are results of poor temperature control systems used in vaccine cold chain. The use of medium temperature fridges due to inadequate vaccine refrigerators has had great negative impacts on the coverage of national immunization programs in developing countries, as many vaccines are often wasted due to loss of vaccine potency, thereby leading to wastage of investment.

To surmount these challenges, an adapted fridge display case model using Aquila-based model predictive control strategy for preserving vaccines at the correct temperature range of 2°C and 8°C is proposed.

Methodology

The linearized system of the fridge display case model is given as:

$$\begin{bmatrix} \dot{T}_{goods} \\ \dot{T}_{air} \\ \dot{T}_{wall} \\ \dot{M}_{refrig} \end{bmatrix} = A \begin{bmatrix} T_{goods} \\ T_{air} \\ T_{wall} \\ M_{refrig} \end{bmatrix} + B \begin{bmatrix} V_p \\ P_{suc} \end{bmatrix} + E[Q_{airload}]$$

$$\begin{bmatrix} T_{goods} \\ T_{air} \end{bmatrix} = C \begin{bmatrix} T_{goods} \\ T_{air} \\ T_{wall} \\ M_{refrig} \end{bmatrix} + D \begin{bmatrix} V_p \\ P_{suc} \end{bmatrix}$$

Model Predictive Control (MPC) can be mathematically represented below

$$\min \{ \sum_{k=0}^{N-1} (\| y_{t+k} - r(t) \|^2 + \rho \| u_{t+k} - u_r(t) \|^2) \}$$

$$s. t. : x_{t+k+1} = f(x_{t+k}, u_{t+k})$$

$$y_{t+k} = g(x_{t+k}, u_{t+k})$$

$$u_{min} \leq u_{t+k} \leq u_{max}$$

$$y_{min} \leq y_{t+k} \leq y_{max}$$

$$x_t = x(t), k = 0, \dots, N - 1$$

Methodology

The objective function is:

$$f(x) = \min \sum_{i=1}^N (T_{air} - T_{air_{reference}})^2$$

The constraints are:

$$T_{air_{min}} \leq T_{air} \leq T_{air_{max}}$$

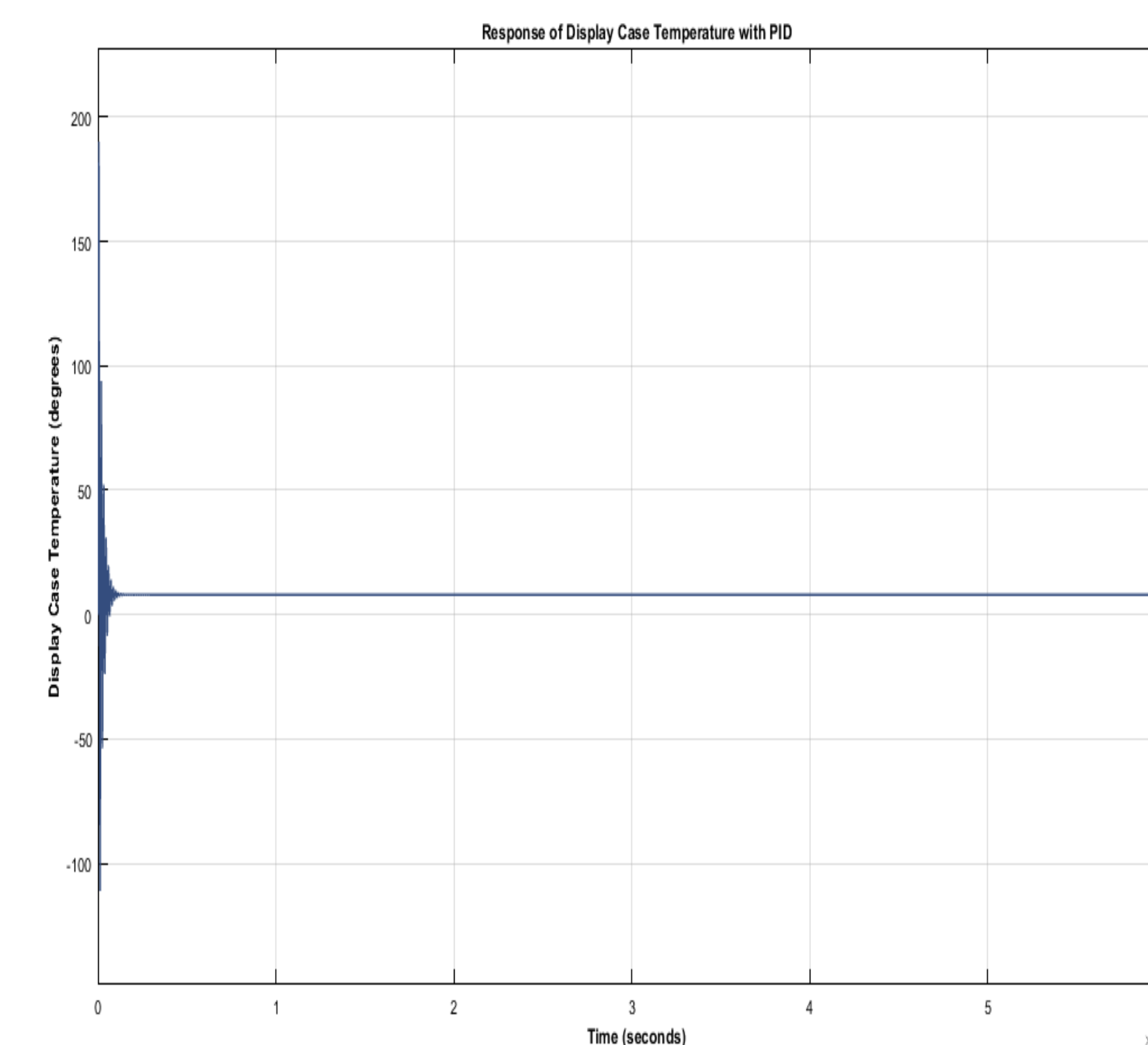
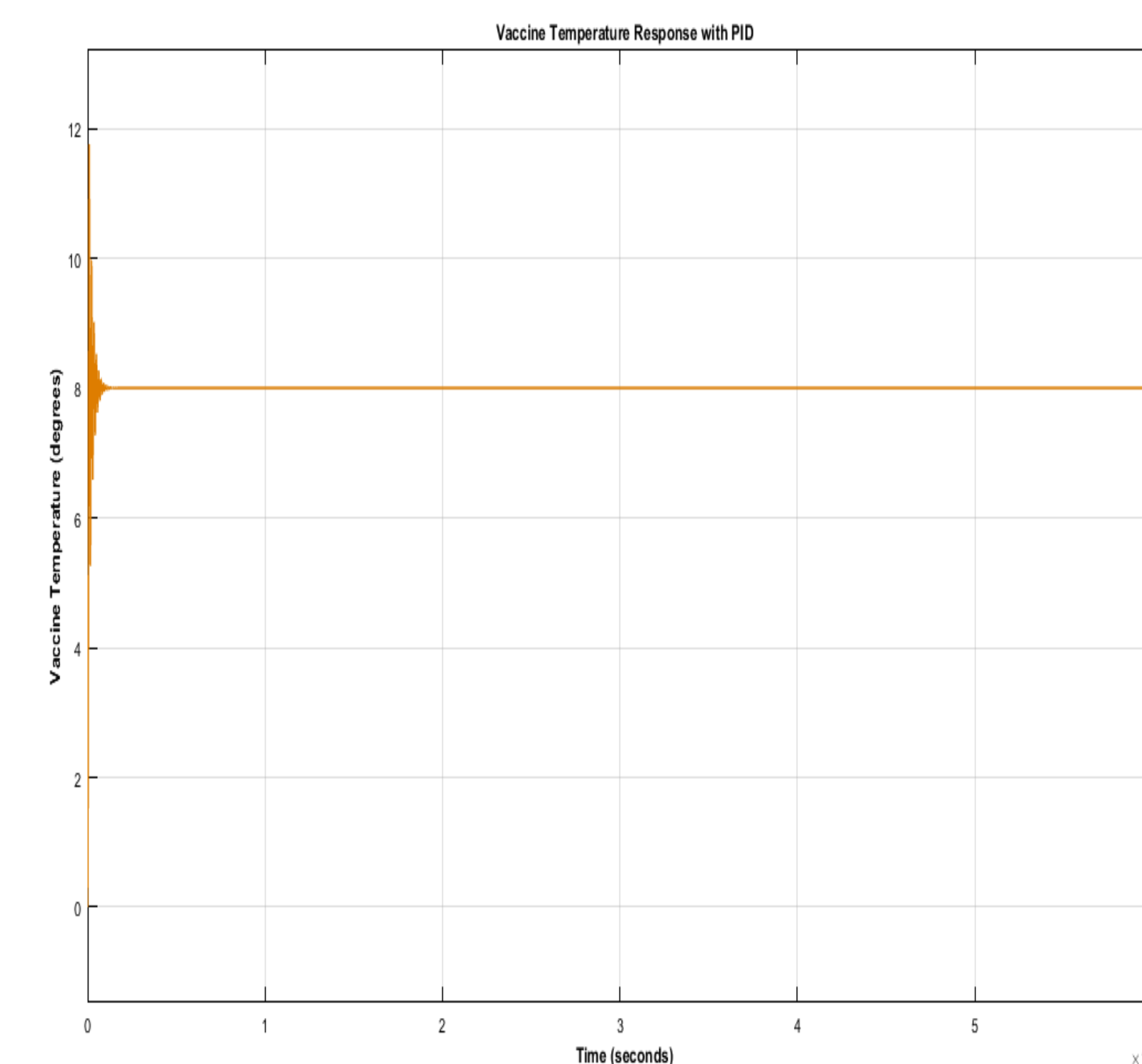
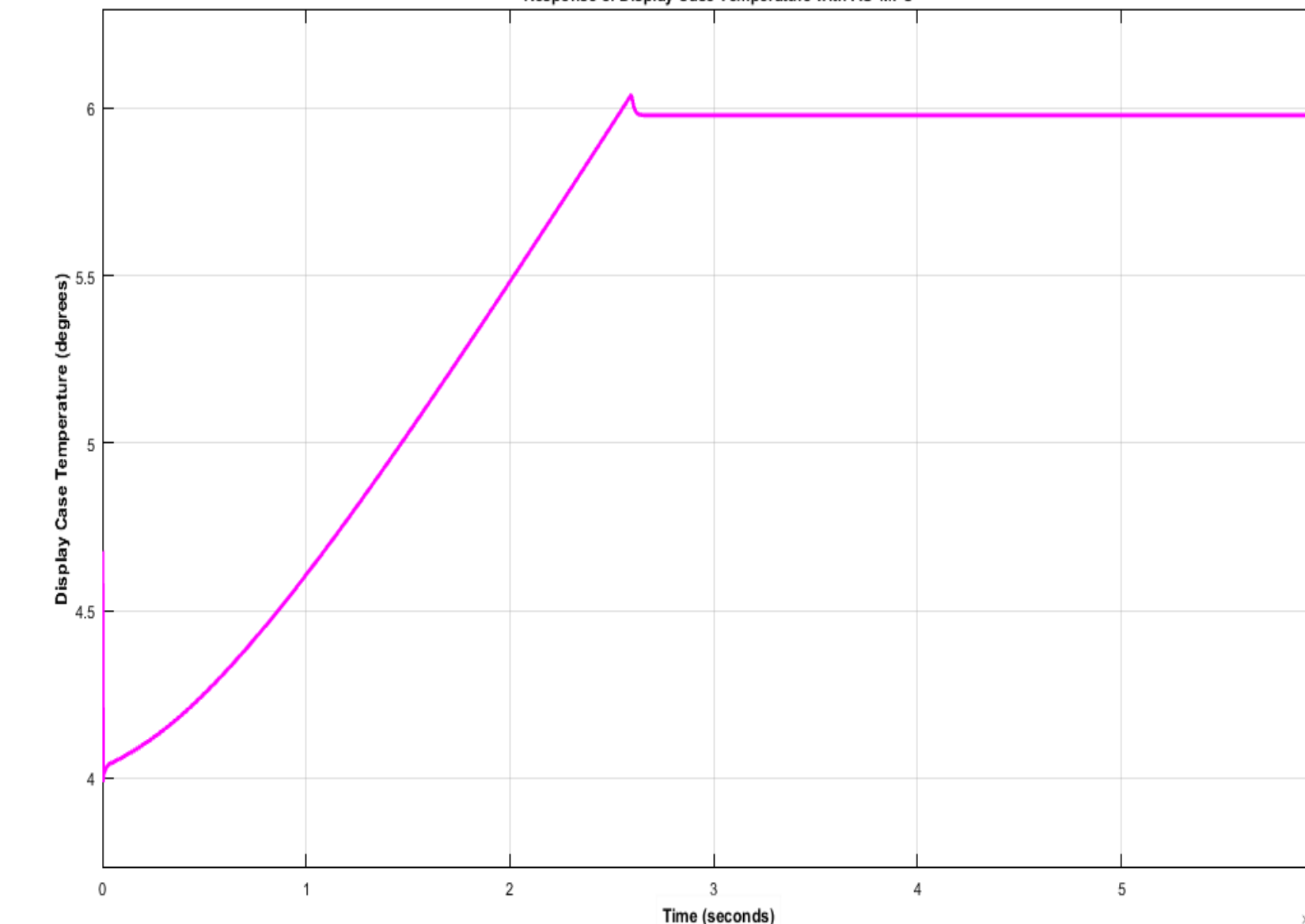
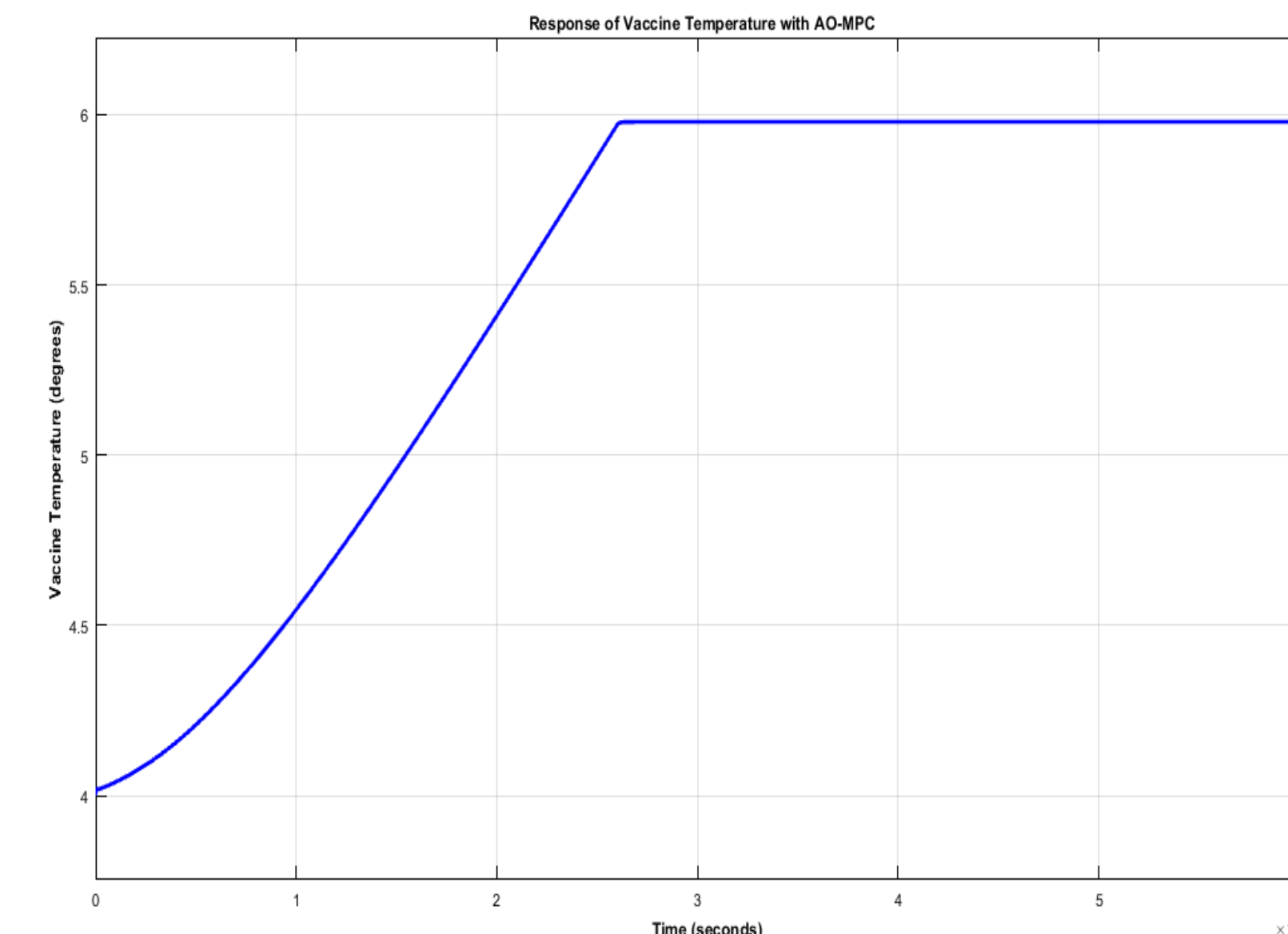
$$T_{goods_{min}} \leq T_{goods} \leq T_{goods_{max}}$$

$$V_{p_{min}} \leq V_p \leq V_{p_{max}}$$

$$P_{suc_{min}} \leq P_{suc} \leq P_{suc_{max}}$$

$$\dot{Q}_{amb-air_{min}} \leq \dot{Q}_{amb-air} \leq \dot{Q}_{amb-air_{max}}$$

Results



Conclusions

A metaheuristic-based model predictive control strategy using Aquila optimizer for adapting a medium temperature fridge display case for vaccines preservation in primary health care centers of developing countries, where professional vaccine refrigerators are inadequate, is presented. The Aquila optimizer (AO) was able to stochastically determine the prediction and control horizon of the linear MPC by tuning. The use of AO-MPC was able to maintain the vaccine temperature within the recommended temperature range of 2°C and 8°C, as recommended by the drug authority, while the use of PID had initial oscillations above the recommended temperature range for about 4.5 hours before finally settling at 8°C. This shows that AO-MPC outperformed PID controller in the presence of additive disturbances, such as opening of the fridge display case, which could lead to infiltration of heat load from the environment. The AO-MPC was found to be robust because can accommodate external disturbances while maintaining the temperature constraints needed for vaccine safety and quality. This adaptation strategy will help to bridge the technical gaps in immunization programs in developing countries.

References

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