University of Peradeniya

Intelligent Obstacle Avoidance: Learning Model Predictive Control for Autonomous Robots

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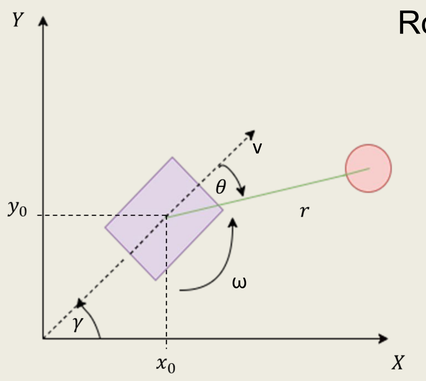
Abstract- This project enhances autonomous robot navigation using Q-learning integrated with Model Predictive Control (MPC). Utilizing LiDAR for obstacle detection, the optimized MPC, accelerated by FPGA and implemented with ML on a Jetson board, significantly improves path planning and obstacle avoidance.

Introduction

Autonomous robots face challenges in dynamic environments due to unpredictable obstacles. This project combines Q-learning with Model Predictive Control (MPC) and LiDAR detection to enhance navigation, optimizing path planning and obstacle avoidance for improved robot performance in real-time scenarios with FPGA implementation.

Mathematical model of the Robot



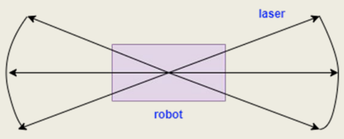
Robot pose in a 2D X-Y plane

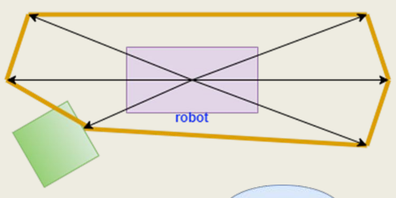
x , y	-	position
γ	-	yaw angle in earth frame
ω	-	Angular velocity
V	-	Forward velocity
dt	-	sampling time

$$\begin{bmatrix} x_t \\ y_t \\ \gamma_t \end{bmatrix} = \begin{bmatrix} x_{t-1} + v_{t-1}\cos\gamma_{t-1} * dt \\ y_{t-1} + v_{t-1}\sin\gamma_{t-1} * dt \\ v_{t-1} + \omega_{t-1} * dt \end{bmatrix} = \begin{bmatrix} f_1 \\ f_2 \\ f_3 \end{bmatrix}$$

Lidar-based Object Avoidance Method

LIDAR (Light Detection and Ranging) with π/3 radians field of view is used for obstacle detection.

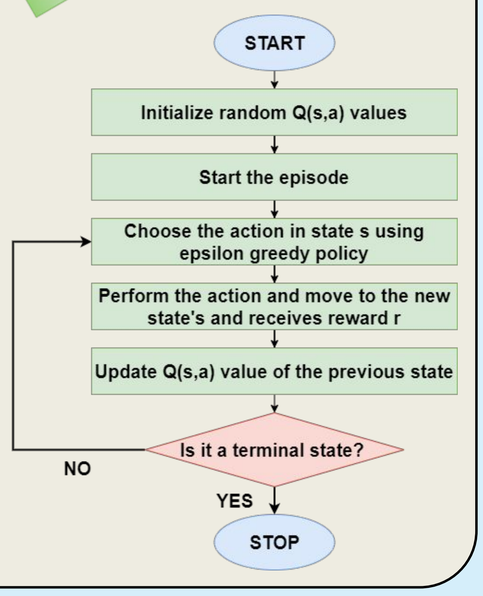




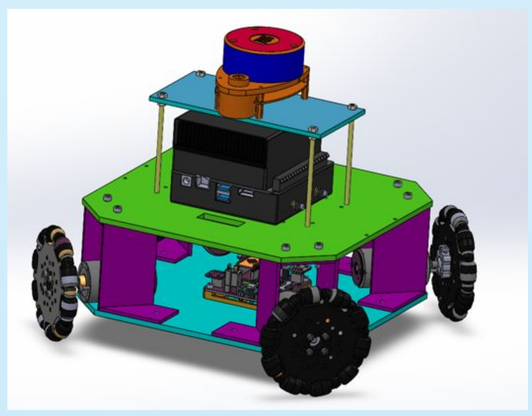
Q-Learning

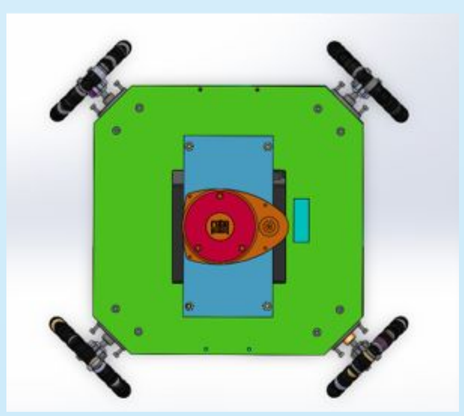
Q-learning was Integrated with the MPC model to enhance performance in obstacle avoidance.

The flowchart of the Q-Learning algorithm is shown here.

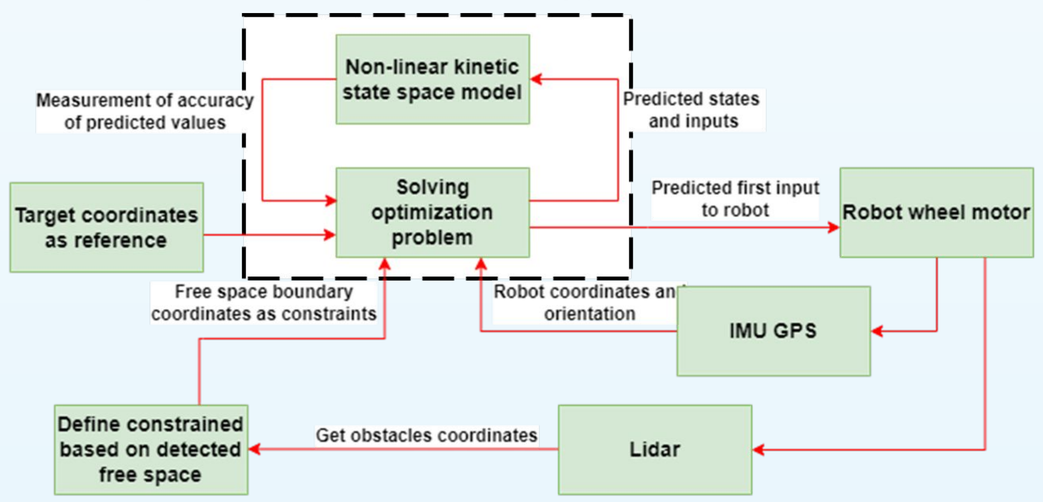


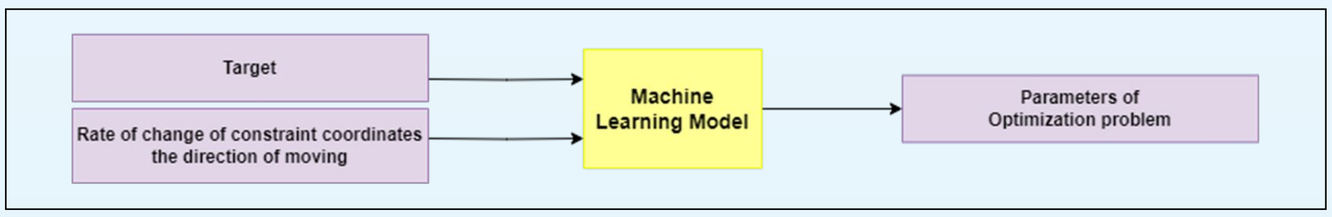
Hardware design





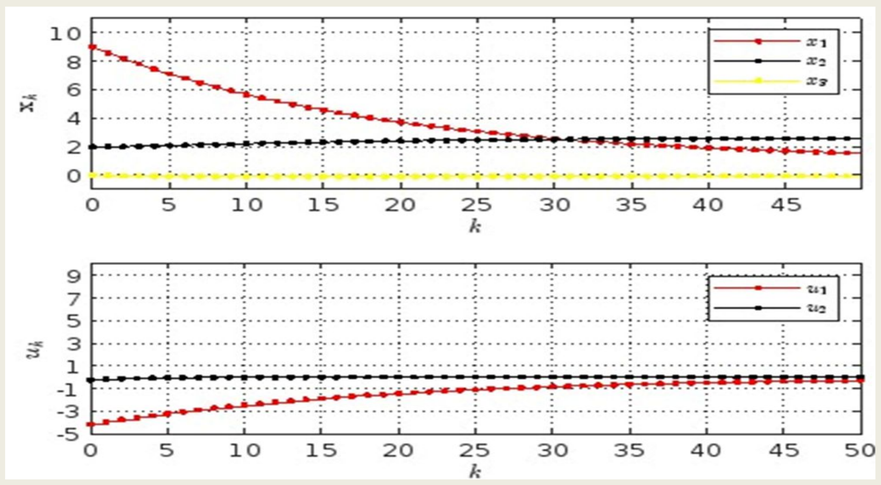
Block Diagram of Methodology





Results

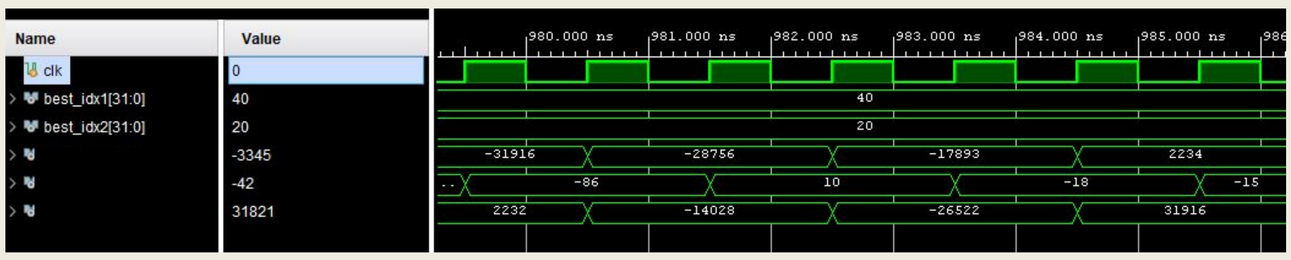
Matlab simulated scenario without obstacles

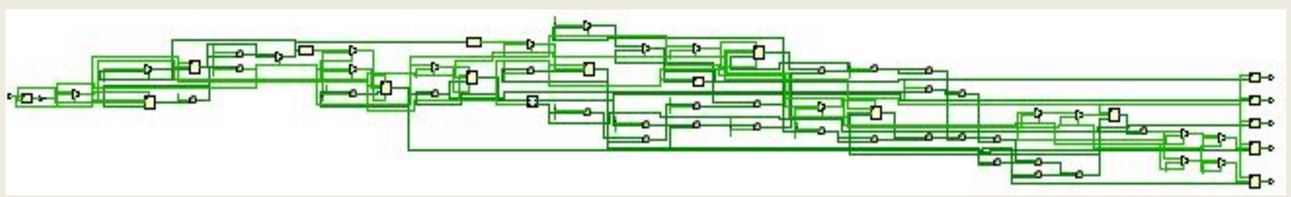


States
X1 , X2 , X3

Control inputs
U1 , U2

Vivado simulation output waveforms and schematic of MPC algorithm without obstacles





Conclusion

The integration of Q-learning with MPC and hardware acceleration by implementing MPC on FPGA, demonstrates significant advancements in autonomous robot navigation, enhancing obstacle avoidance capabilities for improved performance in dynamic environments.

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