# QoC-aware Remote Control of a Hexapod Platform

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## ABSTRACT

In this demonstration we show the effect a wireless network link in a use case that definitely needs low latency control loops. We also propose a QoC-aware (Quality of Control) wireless resource allocation mechanism based on the categorization of the hexapod leg movement phases into high and low QoC movements. We demonstrate the benefits of our proposed method in a simulation environment. The evaluation shows that approximately 60% of the radio time can be saved without affecting the movement accuracy of the hexapod robot. The video demonstration is available on [5].

## 1 INTRODUCTION

In the past few years, there has been an increasing demand from customers towards the manufacturing industry to provide more and more customized products [1]. Personalized production is one of the key motivations for manufacturers to start leveraging new technologies that enable to increase, for instance, the flexibility of production lines. High flexibility in general is needed to realize cost effective and customized production by supporting fast reconfiguration of production lines, as well as, easy application development. In typical industry applications, data packets are time-sensitive and require high reliability end-to-end. In the paradigm of Industry 4.0, the introduction of wireless technologies that ensure high reliability and low latency can help to address the flexibility needs. Ultra-reliable and low-latency communications (URLLC) is a new service category that will be supported in the 5G New Radio (NR). Application of such a wireless technology in manufacturing enables, for instance, to reduce cabling in a factory. In case the industrial applications are connected over wireless, there is a need to analyze the effect of network delay which is not an issue with cable-based connectivity. One of the most challenging applications in which the importance and capabilities of URLLC can be demonstrated is the low-level remote control of servos.

When introducing higher collaboration and adaptation capabilities into industrial applications such as robot arms and robot cell control, collaboration of a massive amount of servos may be required, making the use case even more challenging. In our demonstration a wide spectrum of the challenges that arise in a Industry 4.0 robot cell e.g., servo control, collaboration, etc. are demonstrated in a visually engaging way.

A hexapod can be considered as six 3 degree of freedom (DOF) robotic arms connected via a base link. In our demo, all servos at the 18 joints are controlled separately from a computer residing a wireless network hop away from the hexapod. This way the hexapod proves to be a good choice for visualizing the effect of synchronized collaboration that results in stable center position, while any glitch in the system results in jiggling of the platform.

We also evaluate an evolved system, where the network and the robotic platform share state information in order to reduce the cost of radio communication, i.e. achieve increased spectral efficiency [2], while achieving the same performance of the hexapod robot as in the baseline case. Figure 1 shows the concept of the proposed system.

## 2 DEMONSTRATED FEATURES

### 2.1 Introducing network effects into hexapod control

The Robot Operating System (ROS) package of a hexapod robot [3] provided a regular position controller for the 18 joints (6 legs, 3 joints per leg). The control of the actuators are deployed locally on the robot i.e., there is no sensor or actuator delay at all. To introduce the possibility of analyzing the effect of networking into the system, our first task is to lift the deployment into a cyber-physical system (CPS). To overcome the current limitation of Gazebo that provides only local control loops we developed a plugin [4] that can introduce the network effects into a non-CPS system.

To properly control our robot we need to exchange information, such as velocity commands and encoder state information, between the controller and the arm in high frequency. The baseline system is completely steady after initialization of the simulation. Unless very small, the introduced network delay in both sensing and actuating processes results in jiggling of the whole robotic platform even at stationary status. The jiggling results in small jumps of the robot resulting in deterring from the original orientation. When the hexapod starts to walk, the jiggling occurs during the movement as well and the robot ends up at different position compared to the baseline.

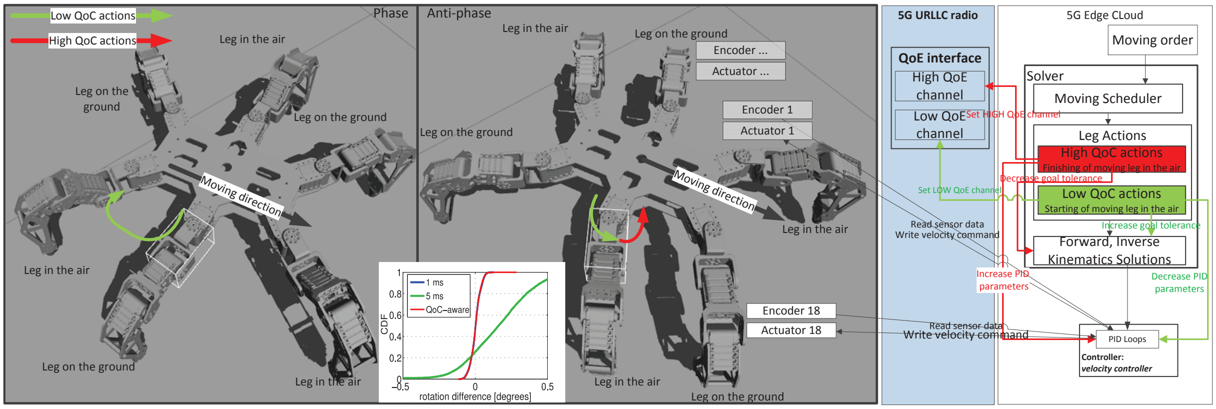


**Figure 1: Visualization of the concept of the QoC-aware wireless resource allocation strategy**

## 2.2 Proposed QoC-aware wireless resource allocation strategy

In case of a hexapod three legs are the minimum for a static and stable movement. The robot in our simulation uses exactly 3 legs in one moving phase and the other 3 in the other moving phase. The 3 joints per legs are coupled in the control software and the horizontal orientation of the joint connecting the leg to the base influences the rest of the joints in the knee and knuckle.

We argue that the movement can be decoupled into two phases: one is a high QoC phase which influences the accuracy of the movement of the robot the most and a low QoC phase that has less impact on this. We found that the most important part of movement is the one right before putting the legs currently in the air back to the ground. This part of the movement influences the orientation of the robot the most and causes cumulated error of the orientation if this part fells to be accurate.

Our QoC extension is a new ROS-topic that publishes the priority of the action during the joint controlling commands. The priority of the action is translated into a queue length of the delay plug-in. Low QoC movements are translated into longer buffering of simulation ticks, high QoC movements are translated into shorter buffering of simulation ticks.

# 3 DEMONSTRATED GAINS

The benefit of a low latency control loop provided by URLLC is clearly demonstrated even with visual inspection at the steady state of the robot. The robot jiggles in case of any higher than 1 ms control loop latency. In case of moving the clear indication of the benefit of low latency control loop can be seen on the trajectory of the robot e.g., during a simple forward movement command. In case of low latency control loops, the trajectory is straight, while introducing latency in the control loop causes drifting away from the straight line. We quantified this drift by extracting the robot base link position and orientation around $z$ axis from the simulation in every 0.1 sec. We calculated the differences of the orientation timeseries and applied a 1 sec moving average smoothing on the timeseries as the hexapod has a natural periodic waving in the base link. Bottom of Figure 1 shows the CDFs of the above time series for the 3 scenarios. We can see that in case of low latency control loop, the robot has a normal distribution with a mean around 0. In the 5 ms case, the distribution is shifted into the positive direction causing an drift of the robot. The QoC-aware method results in a higher standard deviation normal distribution than the 1 ms base line but the expected value around 0 results in a non-drifting straight movement.

The switching between the low and high QoC phases is currently a parameter set to the last 20% of the leg movement phase (and anti-phase as well) resulting in the robot spends 40% time in high QoC and 60% time in low QoC phase during movement. The spectrum efficiency of the high QoC phase (1 ms) is about third of the low QoC phase (5 ms) according to [2].

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