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Effect of Packet Loss on the Quality of Control of a Networked Mobile Robot

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Abstract: This paper describes a wireless network based control of a Khepera mobile robot moving in a WLAN distributed infrastructure. Due to the dependence of quality of control (QoC) over network quality of service (QoS), a simulation is performed for packet losses and compared to actual results in the lab environment. The network effects are examined and critical limit is determined for which control quality is acceptable. A Bayesian network approach is proposed for the decision of switching between the embedded and off-board controller as well as the horizontal handoff in multi-station scenario.

Keywords: Autonomous mobile robots, Networked control systems, Wireless network, Bayesian networks, Horizontal handoff, TrueTime simulation.

1. INTRODUCTION

In mobile robotics, the control information is usually exchanged between the infrastructure and the mobile robot through a wireless network. This approach offers some advantages over embedded controller where computational power, weight and battery are limited. However, introducing a wireless network in the control loops presents some disadvantages such as band limited channels, sampling delays and packet dropouts (Hespanha et al., 2007). On the other hand, for communication with the infrastructure or base station, a good quality of service (QoS) is mandatory for an acceptable control quality (QoC). Thus there are tradeoffs in choosing embedded or off-board controller for mobile robot application as well as horizontal handoff in multi station scenario. The decision to choose either of the controller or the WLAN Access Point (AP) needs to be evaluated intelligently by taking into account the communication and control bounds. Our work presents a criterion for making decision based on Bayesian network to change the AP in multi station environment and switching between controllers. Based on this approach it is realistic to model the quality of service of the wireless network by taking into account some key parameters such as received signal strength indication (RSSI), Packet losses and delay as well as the quality of control (QoC) of the mobile robot in the criteria for controller switching. However, unlike in (Toibero et al., 2007), stability analysis at switching times is not performed. Our focus is to establish a criterion to estimate wireless network quality that is able to support our application. If the condition is satisfied with sufficient network quality, the current AP and off-board control are preferred which offers less energy consumption and more processing power with lower communication cost. However, in case of degradation in networked communication, changing the AP would be the strategy if there is another AP with a sufficient QoS. Otherwise the full autonomous mode utilizing on-board control is preferred.

In the literature, many researchers have proposed a horizontal hand off (HHO) strategy (Wang et al., 2007). They proposed

making a decision by taking into account the Received Signal Strength (RSS), the power consumption and the cost of communication (Chen et al., 2004). We propose to add into these parameters, the influence of the QoS on the QoC of the robot (Mechraoui et al., 2009). The dependence between these parameters is formulated by using the graph approach. Whereas, the stochastic nature of the wireless network is exhibited by making use of the probability theory. The combination result between the probability theory and the graph one is Bayesian network which is one of the powerful tools of artificial intelligence. Bayesian networks (Pearl, 1988) can be considered as a convenient tool which permits to handle two big problems commonly encountered in artificial intelligence, in applied mathematics and in engineering; i.e., the uncertainty and complexity (Mechraoui et al., 2009). They are used especially for diagnosis (Mechraoui et al., 2008) and prognosis (Muller et al., 2004) of the complex hybrid systems and also to make intelligent decision (Weber et al., 2008) as in our case.

In this paper, only one part of the Bayesian network based approach is studied to define all modes and their probability values. The effect of the packet loss on the QoC of the mobile robot is crucial to define, as observed for the case of our mobile robot and its control system. The 'a priori' conditional probability of each node is used to quantify the QoC of the robot as a function of the QoS of the wireless network.

The paper is organized as follows. The second section presents a brief description of the model of the Khepera robot (Lambercy and Caprari, 2007), notably the kinematic model and the dynamic part. In the third section, the controller design is described and the simulations of the trajectory tracking are presented. Section 4 presents the control over WLAN network and the influence of the integration of this network on the control performance depending on the rate of packet losses. The comparison between TrueTime simulations and the actual results of the lab environment is shown in this section. After that, the Bayesian network which models the behaviour of the wireless network is presented and the quantification of QoC

depending on QoS and packet losses is studied. Finally, the conclusion and perspectives are highlighted.

2. MODEL OF THE ROBOT

This section presents the mathematical modeling of a unicycle Khepera III robot Lambercy and Caprari (2007). Khepera III is a unicycle mobile robot intended for research and education and conceived by the Swiss society K-TEAM. The robot measures diameter 130mm for a height of 70mm. It is provided with 5 ultrasonic sensors and 11 infrared sensors. The robot works under Linux and includes a serial connection, USB connection, Bluetooth and Wifi. The wheels of this robot are moved by two DC motors. Each motor has its own embedded incremental encoder, placed on the motor axis, gives 16 pulses per revolution of the motor. Each DC motor is driven by its own motor controller implemented in a PIC18F4431.

Consider a unicycle robot (Khepera) as shown in Fig. 1. Let x , y and θ be the state variables where $x \in \mathbb{R}$ and $y \in \mathbb{R}$ are the Cartesian coordinates, $\theta \in [0, 2\pi[$ is the robot's orientation with respect to the X-axis. We consider ' v ' and ' ω ' respectively as the linear and the angular velocities of the robot. The kinematic of the robot can be modeled as

$$\dot{x} = v \cos \theta, \quad \dot{y} = v \sin \theta, \quad \dot{\theta} = \omega \quad (1)$$

The kinematics model of the mobile robot has two control inputs ω_{left} and ω_{right} i.e. the left and right wheels velocities. These are related to the linear velocity v and the angular velocity ω of the robot according to the following equations

$$V_{right} = v + R\omega, \quad V_{left} = v - R\omega \quad (2)$$

where R is half the distance between the two robot's wheels. The dynamic model of the robot wheels is characterized by the equations of the DC motors driving the wheels. They are represented by a first order model

$$\frac{\omega_{(left, right)}^*}{U} = \frac{K}{\tau s + 1} \quad (3)$$

where U is the voltage applied to the motor and $\omega_{(left, right)}^*$ are angular velocities generated by each motor. τ is the time constant ($\tau = 0.63s$) and K is the gain ($K = 5.3$).

3. CONTROLLER DESIGN

The objective of this section is to present how to control the robot to track any trajectory. Two levels of controllers are re-

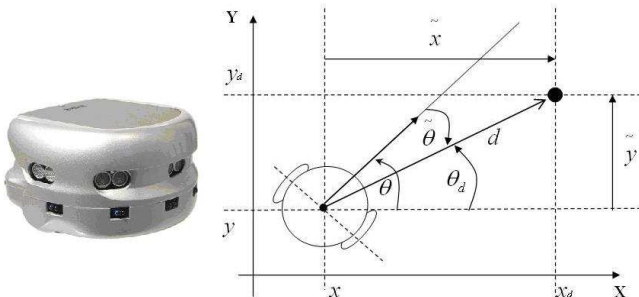


Fig. 1. Robot Model

quired. The first one is needed to control the angular velocities of the motors. PI controllers are implemented. The second one controls the linear and angular velocities of the robot. Let us consider the controller presented in Toibero et al. (2007), where the robot can reach a desired target point $[x_d \ y_d \ \theta_d]$. Errors are defined as

$$\tilde{x} = x_d - x, \quad \tilde{y} = y_d - y \quad (4)$$

and the tracking error (Eq. 5a) and the orientation error (Eq. 5b) are calculated as

$$d = \sqrt{\tilde{x}^2 + \tilde{y}^2} \quad (5a)$$

$$\tilde{\theta} = \theta_d - \theta = \tan^{-1}(\tilde{y}/\tilde{x}) - \theta \quad (5b)$$

According to Toibero et al. (2007), the following control actions are defined

$$v = \frac{v_{max}}{1 + |d|} d \cos(\tilde{\theta}) \quad (6a)$$

$$\omega = \frac{v_{max}}{1 + |d|} \cos(\tilde{\theta}) \sin(\tilde{\theta}) + K_{\tilde{\theta}} \tanh(k_{\tilde{\theta}} \tilde{\theta}) \quad (6b)$$

where v_{max} is the maximum linear velocity that the robot can reach ($v_{max} = 0.3m/s$) and $K_{\tilde{\theta}}, k_{\tilde{\theta}}$ are constants. Those controllers are stable according to Toibero et al. (2007) using the Lyapunov candidate function V_t .

$$V_t = \tilde{\theta}^2/2 + d^2/2 \quad (7)$$

4. CONTROL OVER NETWORK

The controller discussed in section 3 is digitized and the WLAN wireless network is integrated with the control system (see Fig. ??). The effects of network on control system are analyzed.

4.1 WLAN 802.11b/g

The WLAN 802.11 a/b/g is a part of 802.11 specifications (ISO/IEC 8802-11) which describe the characteristics of a wireless local area network (WLAN). The 802.11b/g standards are the most widely used variants of WLAN. The version 'b' offers a maximum throughput of 11 Mbps (however, 6 Mbps in practice) and a range of up to 300 metres in an open environment by using the 2.4 GHz ISM frequency range, with

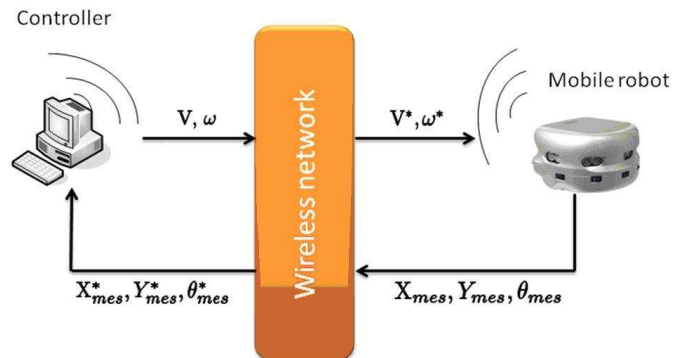


Fig. 2. Control over WiFi wireless network

3 radio channels available. The 802.11g standard offers higher bandwidth than 802.11b (54 Mbps maximum throughput, 30 Mbps in practice) on the same 2.4 GHz ISM frequency range. The 802.11g standard is also backward compatible with the 802.11b standard, thus supporting the 802.11g with 802.11b simultaneously.

4.2 Control over Wifi

Control feedback loops are closed through a real-time network. To perform this study, the following conditions are considered:

- WLAN throughput of 1 Mbps in the physical layer.
- Transmit power of 20dBm.
- Receiver signal threshold of -48dBm.
- Retry limit of 0.

TrueTime simulator is used to simulate WLAN Network. Two tasks are programmed, the first is the controller task that generates the controller flow and the second one is a periodic sensor task that generates sensors flow. The controller task is event-triggered, which means that the controller calculates and sends the control signals v and ω after successfully receiving the measurements of x , y and θ .

Fig. 3 shows the simulated trajectory with initial conditions $(x_0, y_0, \theta_0) = (0, 0, \pi/2)$ and the trajectory of the real robot using those controllers. x , y and θ are measured with sampling interval of ($T_s = 100ms$) using odometry method. The results of the simulation are obtained with TrueTime which is a Matlab/Simulink toolbox for real time control and network simulation. In this figure, We show that there is a negligible difference between the trajectory of the real robot and the simulation results, and the little difference is caused by errors of odometry method to estimate the position of the real robot. Fig. 4 shows linear and angular velocities of the real robot and also simulation. The orientation of the robot is also shown in this figure.

5. SIMULATION SCENARIO

The objective of this paper is to study the influence of packet loss on the QoC of the robot. This we are targeting to quantify all modes of QoS and QoC according to the rate of packet

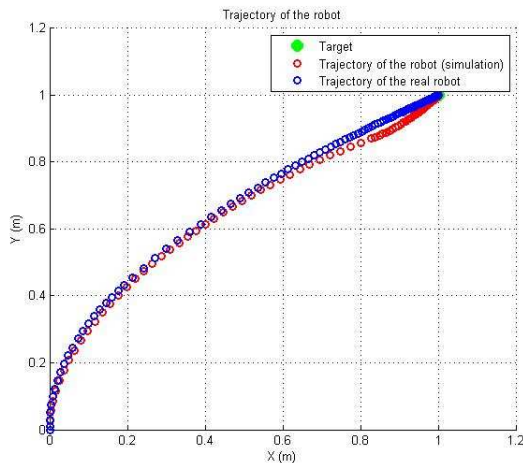


Fig. 3. The trajectory of the robot to join a fixed target

losses. The final objective is to define all probabilities *à priori* for a Bayesian network (Fig. 5) that models the behavior of the wireless network. Based on the network conditions, Handoff decisions will be made. The diagnosis to detect the reason of the possible degradation of the QoS and the QoC and prognosis to predict a possible degradation comes afterwards. Fig. 5 presents a proposed Bayesian network (BN); the qualitative aspect of this BN is modeled according to the dependence between all variables. The quantitative model based on the probabilities can be defined by conducting statistical study between each two linked nodes. In this paper, we are concentrating on three principal nodes within the BN, Packet losses, QoS and QoC. Packet loss node is a continue variable ranged between 0% and 100%. QoS and QoC are discrete nodes with three modes each: good, degraded or bad. By changing the rate of packet loss, we observe its influence on the QoC of the robot both in simulation and with lab testing. To simulate the packet loss, an algorithm is implemented when the message is received (control flow or sensor flow) according to table 1. Packets will be rejected or accepted according to the rate of loss packet. If the message is rejected, the last control value is kept.

Table 1. Simulation setup for mobile robot over WLAN

Packet loss rate	Period	Number of losses packet
0%	100ms	0
75%	400ms	3
90%	1000ms	9
95%	2000ms	19
96%	3000ms	29
98%	5000ms	49
99%	10000ms	99

5.1 Simulation

For the simulation of the Khepera mobile robot in an infrastructure of WLAN, a TrueTime simulation is performed with gradual packet losses. These results are then compared to the actual tests conducted in a lab environment.

The results are shown in Fig.6 and Fig.7. These plots reflect a similarity between the TrueTime simulation and the actual scenario. However, at certain places, especially at 95% of packet losses, control response with packet losses differs from the

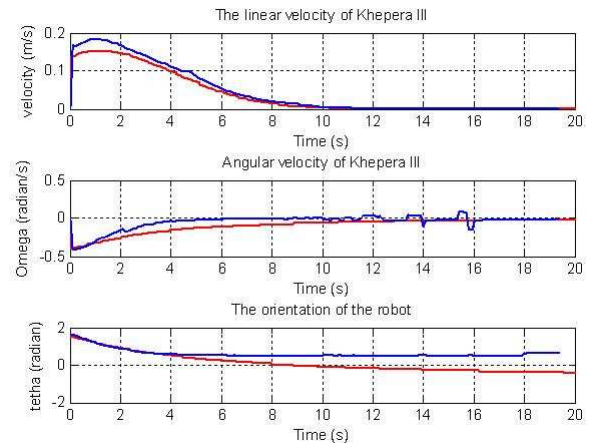


Fig. 4. Evolution of the linear and angular velocities of the robot and its orientation

TrueTime. The reason of these differences seems to be due to additional packet loss which we cannot detect at the moment in the real scenario.

We note that from 95% packet loss, the QoC is degraded and from 98% packet loss the QoC is bad and the robot cannot reach the target. To well determine the interval of good, degraded or bad QoC, an evaluation criterion is considered. The error between the actual position of the robot and the position of the robot with 0% packet loss is compared in each sampling period. Fig.8 shows the result of this criterion based on the error according to packet loss rate. The criterion is chosen according to this equation

$$QoC_{criterion} = \sum_{i=0}^k |\epsilon| \quad (8)$$

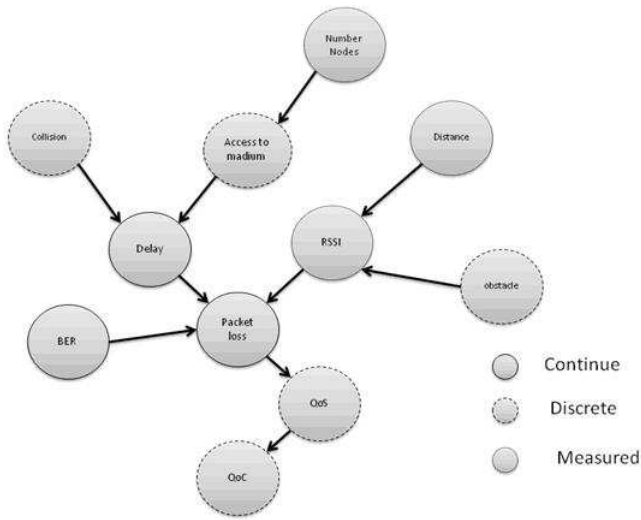


Fig. 5. Proposed bayesian network to modelling the behaviour of the wireless network

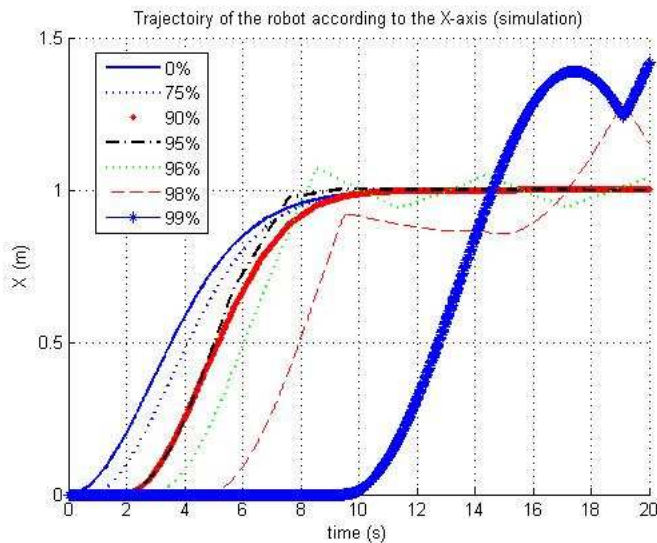


Fig. 6. The different trajectories according to X-axis of the robot contingent upon rate of packet loss using TrueTime simulator

6. CONCLUSION

This paper presents the effect of degradation of network QoS on control performance. A bayesian network based approach is used as a decision criterion to switch between off board and on board controller. In the next step, complete proposition of the parameters affecting network QoS and thus QoC of the system will be presented.

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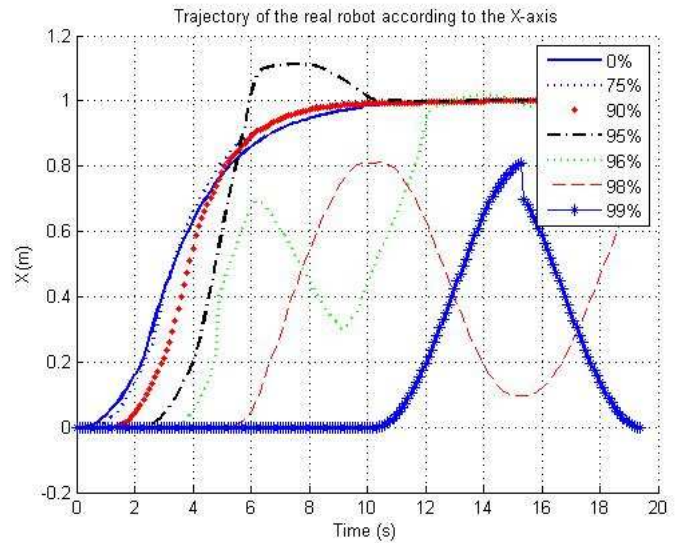


Fig. 7. The different trajectories according to X-axis of the real robot contingent upon rate of packet loss

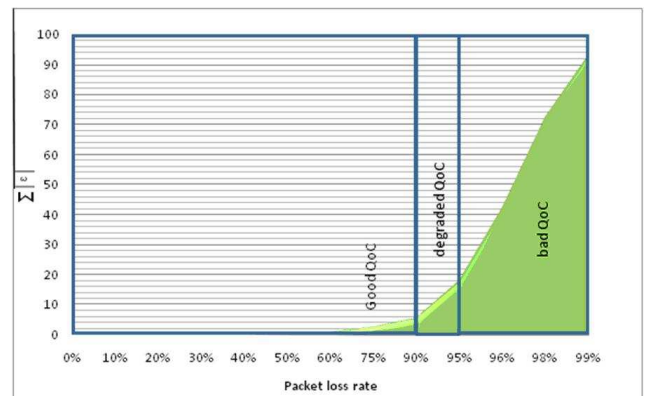


Fig. 8. The grading of QoC w.r.t packet loss rate

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