# State estimation of delays in telepresence robot navigation using Bayesian approaches

Barnali Das, Gordon Dobie and Stephen Gareth Pierce

Dept. of Electronic & Electrical Engineering, University of Strathclyde, Glasgow, UK
{barnali.das, gordon.dobie, s.g.pierce}@strath.ac.uk

## 1 Introduction

Telepresence systems allow a human operator to control and navigate a mobile robot around the remote environment and interact with their audiences through video conferencing. Telepresence robots suffer significant challenges during navigation due to communication time delays. If the time delays are not compensated to estimate the robot pose correctly in the remote site, the robot may crash due to inaccurate pose estimation by the operator. In this work, we propose a Bayesian approach to model such delays using state estimation techniques that are useful for robust navigation.

Robot state estimation in dynamical systems is essential in real world applications, as the actual state is undetermined and sensors provide only a sequence of noisy measurements. Extended Kalman filter (EKF) generally acquires an estimate of the true state from noisy sensor measurements. However, when a filtering processor is attached to a network, there is a communication time lag. Additional time is required if there is a need to post process the raw sensor data for updating the state of the dynamical system. As a result a delay is introduced between the acquisition of measurement and its availability to the filter.

This paper proposes state estimation techniques of delayed navigation of telepresence robots. Considering a small delay in the system, an augmented state Kalman filter (ASKF) [2] is proposed. As any delayed measurement carries information about a past state, the current state cannot directly be corrected only using the measurement. The past state corresponding to a delayed measurement should be determined before using the delayed measurement in the state estimation. The current state is then corrected after correcting the appropriate past state. We also assume that the delay is not precise and hence the uncertain delay is modelled using a probability density function (PDF) [2]. To our best knowledge, the proposed approach is first of its kind in compensating delay in telepresence robot navigation.

## 2 Proposed methodology

Two most significant systematic errors, generated by unequal wheel diameters and the uncertainty in the effective wheelbase were measured and modelled using a well-known UMBmark [1] method. This is followed by a number of state estimation steps governed by the equations below.

In this research, the robot navigation is dependent on raw sensor data which, we assume, is corrupted with significant random delay (*e.g.,* communication, processing *etc.*). The sensor data arrivals to the filter is not consistent and arrives at a different time steps. Considering $\tau$ is the number of delayed time steps, we have defined the measurement equation as,

$$z_k = h(x_{k-\tau}, v_{k-\tau}), \tag{1}$$

By augmenting several states, the current measurement, containing information of the past state, can be used to directly correct the augmented state vectors using ASKF. This means, when the delay is given, we can determine the corresponding past state in the augmented vector. The past state is updated using the delayed measurement and the current state is simultaneously corrected in the augmented vector. The augmented state vector can be estimated recursively via the EKF algorithm. Equations for multi step delays representing the process model and the measurement model are given in Eq. (2) and Eq. (3) respectively, where, $x_k$ is the augmented state vector defined by $\left[x_k^T \; x_{k-1}^T \cdots x_{k-n}^T\right]^T$ and $n$ is the maximum number of delayed time steps.

$$x_{k+1} = \left[\begin{bmatrix} & f(x_k, u_k) & & \\ I & 0 & 0 & 0 \\ & \ddots & 0 & \vdots \\ 0 & & & \\ 0 & 0 & I & 0 \end{bmatrix} x_k\right] + \begin{bmatrix} w_k \\ 0 \\ \vdots \\ 0 \end{bmatrix} \tag{2}$$

$$z_k = h\left(\begin{bmatrix} 0 \\ \vdots \\ I \\ \vdots \\ 0 \end{bmatrix}^T \begin{bmatrix} x_k \\ \vdots \\ x_{k-\tau_k} \\ \vdots \\ x_{k-n} \end{bmatrix}\right) + \begin{bmatrix} 0 \\ \vdots \\ v_{k-\tau_k} \\ \vdots \\ 0 \end{bmatrix} \tag{3}$$

We believe this time delay cannot be measure properly due to the uncertainty and assume the delayed steps as a random variable with a corresponding PDF.

## 3 Results and Conclusions

To demonstrate and evaluate our proposed hypothesis, we have built an experimental framework on a commercially available telepresence robot, Beam+, due to its telepresence capability controlled via WiFi. We customised an open-source ROS driver *rosbeam*[1] and installed within BEAM+, replacing its original control software to perform experiments in a controlled environment. We have captured the robot's navigation data using a VICON motion capture system. In initial experiments, we measured systematic errors of the robot using the UMBmark method which is then used to simulate the robot's erroneous navigation. With the estimation of noisy VICON measurement we shall apply EKF to compensate navigation error. As the next step we intend to apply ASKF and PDF to further improve the navigation. Our initial experiments have shown good noise estimation of robot navigation which is the first step of this work-in-progress research.

## References

1. Borenstein, J., Feng, L.: UMBmark: A benchmark test for measuring odometry errors in mobile robots. In: SPIE Mobile Robots X. vol. 2591, pp. 113–125 (1995)
2. Choi, M., Choi, J., Chung, W.: State estimation with delayed measurements incorporating time-delay uncertainty. IET Control Theory and Applications 6, 2351–2361(10) (Oct 2012)

[1] https://github.com/xlz/rosbeam