Clock and Power-Based Bias Correction for UWB Ranging Measurement.

Justin Cano[1,2], Gaël Pagès[2], Éric Chaumette[2] and Jérôme Le Ny [1]

[1] EE Department, Polytechnique Montréal/GERAD, Canada
[2] DEOS/NAVIR[2]ES, ISAE-Supaéro, Toulouse, France

UWB Ranging and the Bias Issue

Ultra-Wide Band (UWB) is a class of radio-frequency signals defined by a broad bandwidth of at least 0.5 GHz. Allows estimating the signals' Time of Flight (ToF) between two transceivers and then deduce their distance with decimeter-level accuracy.

Fig. 1: UWB transceiver.

Advantages for robot navigation system : low power consumption, inexpensive and low computational requirements. Can replace GPS indoors.

However, even in perfect Line-of-Sight (LoS), ToF measurements are subject to errors due to clock drift, antenna delay and signal distortion. Uncorrected ToF measurements yields *systematic errors, i.e.,* biases, of up to 30 centimetres.

Bias Modelling

Our goal : compensate the bias with only intrinsic information provided by UWB modules. We identified two major sources of bias :

1. clock drift $\Delta_c^{B/A}(t_{R,T})$ between emitter A and receiver B at the reception time $t_{R,T}$;
2. bias term $\delta_p^B(\mathcal{P}_R^B)$ that depends on the received power $\mathcal{P}_R^B$.

We *postulate* the following measurement model for the ToF

$$\tilde{\tau}_{AB} = t_R^B - t_T^A = \tau_{AB} + \Delta_c^{B/A}(t_{R,T}) + \delta_p^B(\mathcal{P}_R^B)/c + \nu, \qquad (1)$$

where ν are unmodeled effects, considered as noise.
Two preliminary steps are required to estimate the biases :

1. Estimate the clock-induced bias $\Delta_c^{B/A}(t_{R,T})$;
2. Acquire empirically a reception power-induced bias map $\hat{\delta}_p^B(\mathcal{P}_R^B)$ at several received power levels after compensation for $\Delta_c^{B/A}(t_{R,T})$.

Acquisition of the Calibration Maps

- We acquire UWB measurements between a fixed anchor and a robot at several poses and hence at several received power levels.
- The ground truth is given by a motion capture system (MoCap);
- Errors are computed after synchronization while First Path Received Powers (FPRxP) $\tilde{\mathcal{P}}_f$ are collected by the robot.
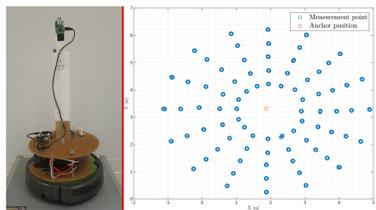

Fig. 2: UGV and poses used to build the calibration dataset

- For convenience, we express the bias as a function of $\tilde{\mathcal{P}}_R = 10^{\tilde{\mathcal{P}}_f - \alpha_{dB}}$;
- A simple fitting yields calibration curves as displayed in Fig. 3.
- Several calibration maps for different module pairs are plotted in Fig. 4.
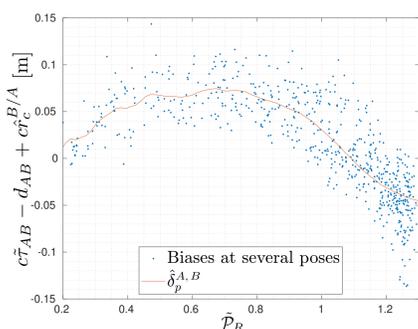

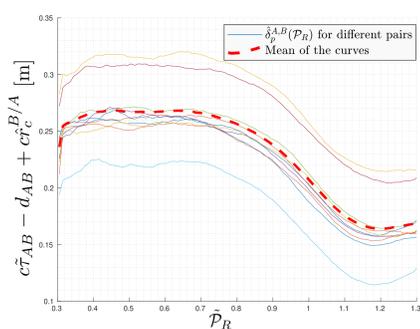Fig. 3: Calibration map built from RxFP data.

Fig. 4: Calibration maps for tag/anchor pairs and average.

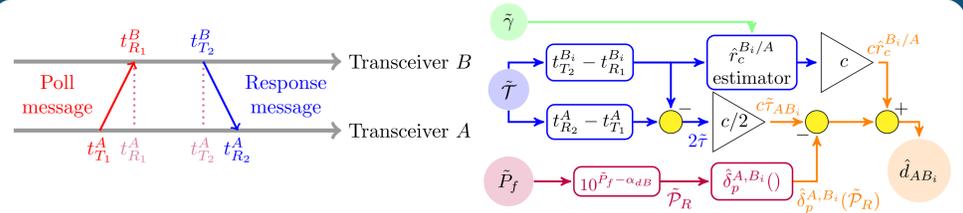## The Case of the SSTWR Protocol

Fig. 5: SSTWR protocol

Fig. 6: Compensation scheme used for SSTWR protocol

If the SSTWR protocol is used, then the ToF is computed as follows

$$\tilde{\tau}_{AB} := \frac{t_{R_2}^A - t_{T_1}^A - (t_{T_2}^B - t_{R_1}^B)}{2} = \tau_{AB} - r_c^{B/A} + \delta_p^{AB}(\mathcal{P}_R)/c + \nu.$$

To remove the bias, we must evaluate two terms :

1. The clock bias $r_c^{B/A} = \int_{t_{R_1}^B}^{t_{T_2}^B} \gamma(t)dt$, given the clock skew $\gamma(t) := \dot{\Delta}^{B/A}(t)$. This term is dynamically tracked by a Kalman Filter thanks to the clock skew $\tilde{\gamma}$ and the timestamp $\tilde{\mathcal{T}}$ measurements provided by the UWB sensor;

2. The power $\tilde{\mathcal{P}}_f = \frac{\mathcal{P}_f^A(t_{R_2}^A) + \mathcal{P}_f^B(t_{R_1}^B)}{2}$ is evaluated through FPRxP measurements gathered by the UWB modules and is used as an input of FPRxP calibration maps.

Experimental Results

We validate our methodology to dynamically compensate ranging measurement biases while a transceiver is moving. A robot, shown in Fig. 2, is carrying an UWB tag and follows the trajectory plotted in Fig. 7 while two fixed UWB anchors are present. This yields : raw distance measurements $\tilde{d}_1$ and $\tilde{d}_2$ between tag and anchors; compensated estimates $\hat{d}_1$ and $\hat{d}_2$ using the scheme of Fig. 6. Ranging errors (based on MoCap reference) and estimated biases are shown in Fig. 8.
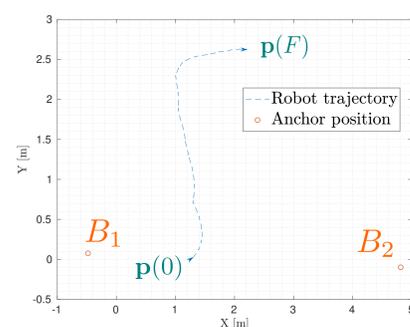

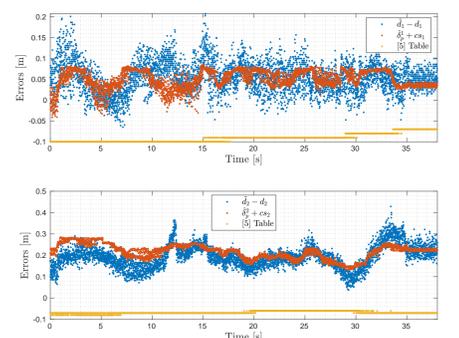Fig. 7: UGV trajectory used for the test.

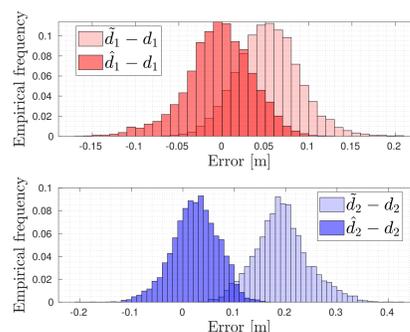Fig. 8: Time series of the ranging errors and bias estimates.

Fig. 9: Error histograms before and after compensation.

Conclusions :

- The bias is significantly reduced by our algorithm. The residual bias is about 3 centimeters *vs* up to several decimeters at the input (Fig. 9).
- The correction is straightforward and can be applied in real-time;
- Experiments carried out in two different places with the same calibration dataset have shown effective bias removal.

Acknowledgments