Efficient Bunch Parameter Reconstruction from an Electron Synchrotron with a GPU

M. Krausewitz*, M.-D. Noll, J. L. Steinmann, E. Bründermann, M. Caselle and A.-S. Müller

Motivation

- KAPTURE-2 can sample a signal using eight ADCs with an track-and-hold technique.
- In this specific use case KAPTURE-2 is intended to process real time signals from Beam Position Monitors (BPMs) in the booster synchrotron of KARA.
- The BPMs sum signal can be approximated by a Gaussian pulse.
- The parameters computed by the reconstruction, can be used to monitor the beam properties inside the booster, like width, arrival time and amplitude.

Efficiently Solving a Gaussian Fit

$$f(x, \sigma, \mu, A) = A e^{-\frac{(x-\mu)^2}{2\sigma^2}}.$$

$$\Rightarrow \ln(f) = \underbrace{-\frac{1}{2\sigma^2}}_{a} x^2 + \underbrace{\frac{\mu}{\sigma^2}}_{b} x + \underbrace{\ln A - \frac{\mu^2}{2\sigma^2}}_{c}$$

$$\Rightarrow \vec{y} = X\vec{\beta}$$

with

$$X = \begin{pmatrix} x_1^2 & x_1 & 1 \\ x_2^2 & x_2 & 1 \\ \vdots & \vdots & \vdots \\ x_n^2 & x_n & 1 \end{pmatrix}, \qquad \vec{\beta} = \begin{pmatrix} a \\ b \\ c \end{pmatrix}.$$

This system of linear equations can be solved by gradient-based least-squares minimization[1]:

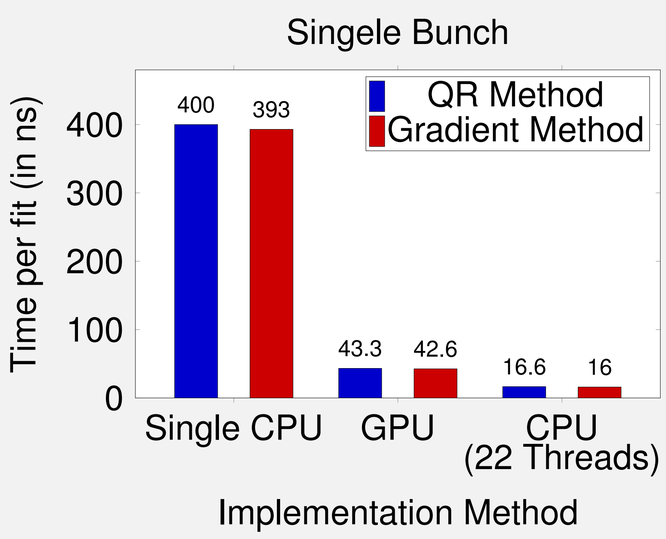
$$\Rightarrow \quad \vec{\beta} = (X^T X)^{-1} X^T \vec{y}$$

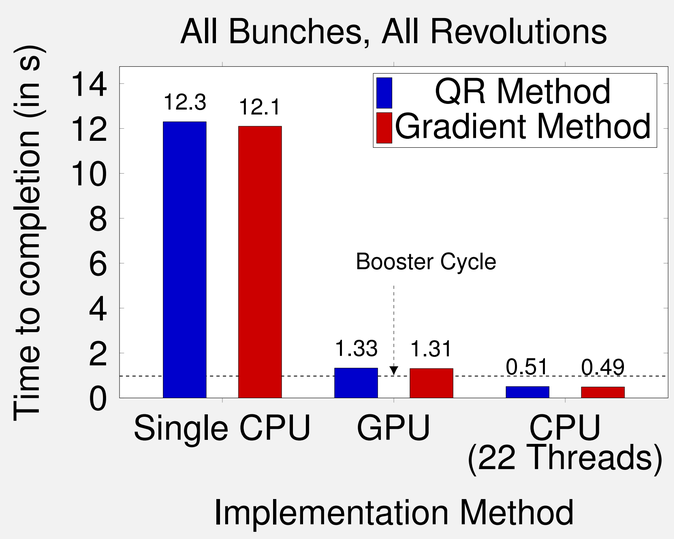
or using a QR decomposition:

$$\Rightarrow R\vec{\beta} = Q^T \vec{y}$$

with $X = QR$, $Q^\top Q = I$, R upper triangular.

Gauss Fit Performance CPU vs. GPU



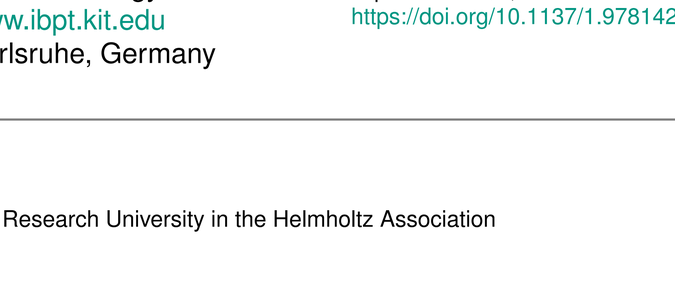


Parameter Reconstruction

The parameters can now be reconstructed using the following formulas:

Width	$\sigma = \sqrt{-\frac{1}{2a}}$
Arrival time	$\mu = -\frac{b}{2a}$
Amplitude	$A = e^{c - \frac{b^2}{4a}}$

Bunch-width in the Booster



Conclusion

- While the gradient-based reconstruction is faster, the QR approach is more stable[2,3].
- The GPU calculation time for the QR methods consists of an actual kernel runtime of approximately 66 ms, memory transfers (in both directions) totaling about 154 ms and CPU overhead of around 1115 ms.
- To calculate the Gauss fit fast, the signal acquired by KAPTURE-2 needs to be logarithmized, which must be done carefully to avoid data loss.

Summary and Outlook

- The multi-threaded implementation is already fast enough to calculate Gaussian fits for an entire booster cycle in about half a second.
- The GPU-implementation is currently too slow for real-time or near real-time analysis due to a large CPU overhead.
- Apart from the CPU overhead, the GPU requires only 7.14 ns for a fit (including memory transfers for the QR method).
- With further optimization, the GPU could be faster than the multi-core CPU implementation.

*martin.krausewitz@student.kit.edu

Contact
*Martin Krausewitz – martin.krausewitz@student.kit.edu
Institute for Beam Physics and Technology
www.ibpt.kit.edu
Karlsruhe, Germany

References
[1] M. Martin, "Rekonstruktion der Form von THz-Pulsen aus kurzen Elektronenpaketen mit hohen Wiederholraten an KARA", April 2019
[2] N. J. Higham, "QR Factorization, Accuracy and Stability of Numerical Algorithms", pp. 353–380, https://doi.org/10.1137/1.9780898718027.ch19
[3] G. H. Golub and C. F. Van Loan, "Matrix Computations", 4th edition, 2013, Johns Hopkins University Press, chapter 5.3.7 Normal Equation vs QR, https://doi.org/10.1137/1.9781421407944

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