Anomaly Detection Using Machine Learning Techniques for Beam Injections from the SPS to the LHC at CERN

Marc Ferriggi

Supervised by Dr. Gianluca Valentino

Department of Computer Science

Faculty of ICT

University of Malta

May, 2019

A FYP submitted in partial fulfilment of the requirements for the degree of B.Sc. (Hons.) Computing Science AND Statistics and Operations Research.

Statement of Originality

I, the undersigned, declare that this is my own work unless where otherwise acknowledged and referenced.

Candidate Marc Ferriggi

Signed ____________________

Date March 11, 2019

Acknowledgements

Abstract

Contents

List of Figures

List of Tables

List of Abbreviations

CERN European Organization for Nuclear Research
IQC Injection Quality Check 2
LHC Large Hadron Collider 2
LS Logging Service 2
MJ Mega Joule
PCA Principal Component Analysis
SPS Super Proton Synchrotron

1

Introduction

2

Background and Literature Review

2.1 Understanding the Problem Domain

The aim of the Large Hadron Collider (LHC) at CERN is to accelerate and collide two proton beams [1]. In order to fill the LHC with a beam of the required intensity, twelve injections consisting of a number of electron bunches of around 1 MJ of stored energy each are required [2]. This is a challenging task given the high energy of the beam, the very small apertures and the delivery precision's tight tolerances. Thus, multiple sensors are installed around the CERN particle accelerator complex [4] which gather readings and data that can be used to check the quality of the injected beam.

For this particular study, data generated from the sensors around the injection from the SPS to the LHC will be of particular interest. This data is stored using CERN's Logging Service (LS) [5]. While many studies have been made using this logged data and lots of statistical tests have been done with regards to injection quality checks for the LHC (such as [2] and [3]), no literature was uncovered where researchers used unsupervised machine learning methods to analyse this data. Figure 2.1 highlights the particular area of interest of this study.

The Injection Quality Check (IQC) software currently installed has a set of hard-coded rules for detecting anomalies in the SPS-LHC injection [2], however there are documented cases in the past where situations occurred which were outside the originally foreseen rules and were therefore not caught as anomalies.

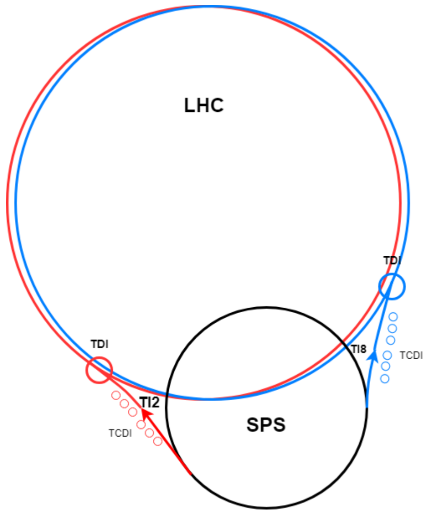

Figure 2.1: Diagram of the particular area of interest of the CERN Particle Accelerator Complex for this study

2.2 Feature Selection and Reduction Techniques

PCA uses statistical and mathematical techniques to reduce the dimension of large data sets, thus allowing a large data set to be interpreted in less variables called principal components [6]. This non-parametric method can be used as a means of revealing the simplified structures underlying complex datasets with minimal effort. The fact that this technique is non-parametric gives it the advantage that each result is unique and only dependent on the provided data set since no parameter tweaking is required [7] however, this is also a weakness of this technique as there is no way of exploiting prior expert knowledge on the data set.

2.3 Unsupervised Anomaly Detection Techniques

References

[1] G. Valentino, R. Brruce, S. Redaelli, R. Rossi, P. Theodoropoulos, and S. Jaster-Merz, “Anomaly Detection for Beam Loss Maps in the Large Hadron Collider,” presented at the 8th Int. Particle Accelerator Conference, 2017.

[2] L. N. Drosdal, B. Goddard, D. Jacquet, R. Gorbonosov, S. Jackson, V. Kain, D. Khasbulatov, M. Misiowiec, J. Wenninger, and C. Zamantzas, “Automatic Injection Quality Checks for the LHC,” in *Proc. ICALEPCS*, 2011, pp. 1077–1080.

[3] V. Kain, V. Baggiolini, W. Bartmann, C. Bracco, L. Norderhaug Drosdal, B. Goddard, E. Holzer, D. Khasbulatov, N. Magnin, M. Meddahi, A. Nordt, M. Sapinski, and M. Vogt, “Injection Beam Loss and Beam Quality Checks for the LHC,” in *Proc. of IPAC*, 2010, pp. 1671–1673.

[4] C. Lefevre, “The CERN Accelerator Complex,” 2008, Technical Report.

[5] C. Roderick, L. Burdzanowski, and G. Kruk, “The CERN Accelerator Logging Service - 10 Years in Operation: A Look at the Past, Present and Future,” presented at the 14th Int. Conf. Accelerator & Large Experimental Physics Control Systems, 2013.

[6] M. Richardson, “Principal Component Analysis,” May 2009, Class Lecture.

[7] J. Shlens, “A Tutorial on Principal Component Analysis,” April 2014.