Machine learning-based dynamic method of rock characterisation for rotary-percussive drilling

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Abstract. This study presents an unconventional method of rock characterisation at the drill-bit head using drill-bit acceleration signals and machine learning. The signals were processed for features that could be indicative of the stiffness of impacted rock. An impact oscillator mimicking bit-rock impact actions and multilayer perceptron network were used to validate the proposed method numerically and experimentally.. Limited experimental data were augmented into RANDEXP and MIXDEXP dataset via random sampling with replacement and mixing with simulation data, respectively. Evaluation of the simulation models showed coefficient of determination (R^2) between 0.982 to 0.999 with normalised mean absolute error (NMAE) values of 0.079 and 0.015, respectively. The best performing experimental model, R^2=0.86 and NMAE=0.08 was achieved with RANDEXP data. MIXDEXP models were however more consistent in performance as eight out of the nine models showed R^2 greater than 0.75 compared to RANDEXP data models which were only two.

Introduction

Conventional logging-while-drilling sensors are often housed at a distance ($> 100ft$) from the drill-bit [1], thus yielding lagged information about the drilled rock. Drilling technologies like the vibro-impact drilling [2] requires quantitative rock information at the drill-bit head to function properly. This study presents an unconventional method of rock characterisation at the drill-bit head using drill-bit vibrations and machine learning [4]. Drill-bit acceleration signals were collected and processed for features that could be indicative of the stiffness of impacted rock. An impact oscillator mimicking bit-rock impact actions was employed to theoretically and experimentally validate the proposed method (Fig. 1). Due to its simplicity, low memory usage and ability to model complex nonlinear problems; a supervised multilayer perceptron network [3] was adopted to quantitatively map extracted features to rock stiffness. During experimental validation, the scarce experimental data were augmented into new dataset indexed RANDEXP and MIXDEXP by random sampling with replacement and by mixing with simulation data, respectively.

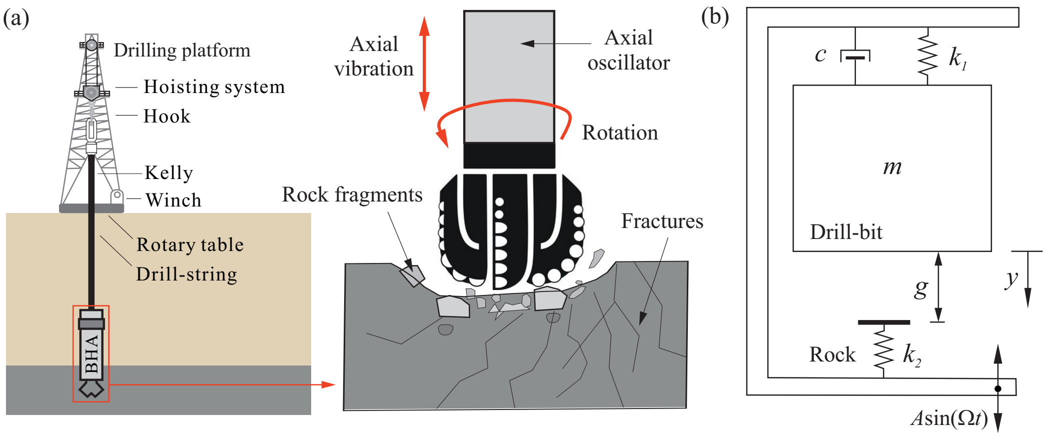

Figure 1: (a) Rock fragmentation in rotary-percussive drilling, and (b) physical model of the impact oscillator.

Results and discussion

Either of the extracted features including average impact duration, statistics of impact durations and statistics of raw signal data were used alongside system parameters as network inputs. Evaluation of simulation data models showed R^2 between 0.982 and 0.999 with NMAE value of 0.079 and 0.015, respectively. The best performing model on experimental data with R^2=0.86 and NMAE=0.08 was achieved using the average impact duration of the RANDEXP dataset. MIXDEXP data models however showed better consistency as eight out of the nine models showed R^2 greater than 0.75 unlike the RANDEXP data models which were only two.

Acknowledgement: This work was supported by the Petroleum Technology Development Fund, Nigeria.

References

[1] Pei J., Dahl T.G., Macpherson J.D., Jogi P.N., Reckmann H. (2019) Synthetic formation evaluation logs based on drilling vibrations. *US Patent* **10,352,158**

[2] Pavlovskaia E., Hendry D.C., Wiercigroch M. (2015) Modelling of high frequency vibro-impact drilling. *Int. J. Mech. Sci* **91**:110-119.

[3] Gallinari P., Thiria S., Badran F., Fogelman-Soulie F. (1991) On the relations between discriminant analysis and multilayer perceptrons. *Neural networks* **4(3)**:349-360.

[4] Afebu, K.O., Liu, Y., Papatheou, E.(2022) Machine learning-based rock characterisation models for rotary-percussive drilling. *Nonlinear Dynamics* **Doi:**10.1007/s11071-022-07565-6, pp.1-21.