Diagnosing Drilling Problems Using Visual Analytics of Sensors Measurements

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***Abstract*— One of the major challenges in the drilling industry is the quick detection of problems that can occur during drilling a deep well due to high cost implications. These problems can occur for various reasons and can exhibit varying symptoms, which make them difficult to identify or prevent automatically. Visual Analytics has emerged as an alternative approach for data analysis. It combines both the computational power of computers and the experience of domain experts to analyze and gain insights into large data. This paper describes a procedure for analyzing and identifying drilling problem using Visual Analytics techniques. It provides results of an elaborated analysis of sensor measurement datasets that contain "Stuck Pipes" situations - one of the most common drilling problems. Statistical features are calculated from the dataset using the sliding window method. We show how visual analysis by means of linked scatter plots enable relating the problem patterns to the computed features and can hence help in identifying "Stuck Pipes" problems.**

Keywords: Drilling Problem Diagnosis, Sensors Data, Visual Analytics.

I. INTRODUCTION

Monitoring industrial processes is an important need in nowadays standards. Normally the monitoring process is performed based on different measurements collected from the process using industrial sensors. The drilling industry uses a set of sensors mounted on each drilling rig to acquire different measurements from the drilling process [1]. All these measurements are transferred in real-time and are used both for monitoring and for further and deeper analysis.

Detecting the states of drill-rig operations is an important step for monitoring and analyzing the drilling process. Many classification systems are used to detect the rig states by recognizing the patterns of sensors data [2, 3, 4]. Drilling problems are the states in which the drill rigs run unexpectedly. Automated classification of drilling problems from sensors measurements is a big challenge caused by a number of reasons. On the one hand, the same drilling problem can have different unexpected patterns in sensor measurements. On the other hand, obtaining training data with enough drilling problem cases is not an easy task. Furthermore, the nature of sensors mounted to drilling rigs poses physical limits on the data quality [5].

Visual Analytics has been defined as "the science of analytical reasoning facilitated by interactive visual interfaces" [6]. Compared with classical data analysis methods, it offers new possibilities for analyzing and understanding large amount of data, and enables domain experts to use their knowledge and perform analytical reasoning to understand the past and present situation of the drilling problems from the sensors' measurements.

In this paper we present Visual Analytics techniques to identify drilling problems from sensor data (explained in Section II). These techniques combine computational methods at which computers are efficient (Section III) with interactive visual methods (Section IV) to enable domain experts to determine the key features and trends in the data that can reliably identify drilling problems.

II. RILLING PROBLEMS

Analyzing drilling problems is a complex task. This is caused by the large number of factors that need to be studied and monitored to find out the reasons of the problem. Moreover, each drilling problem exhibits different symptoms and can occurs in certain circumstances. This makes it difficult to develop automatic methods use pre-defined rules to detect these problems.

One interesting class of drilling problems is "Stuck Pipes". Such problems occur when the drill string becomes unmovable and thus the control over the well is significantly restricted. There are many reasons that can cause stuck pipe, one of them is borehole collapse. Another reason is differential pipe sticking where differential pressure between borehole and formation will enforce drill collars to suck into the filter cake of the borehole wall [7]. Fig. 1 shows sensors' measurements before, during, and after a "Stuck Pipes" problem. This problem happened after starting the drilling process and lasted around one complete day. The case study presented in this paper aims at visually analyzing this problem, and concludes finding that help in identifying similar problems.

III. STATISTICAL FEATURES

Table 1 shows the eight sensor measurements and their explanations. From these measurements statistical features are calculated for each time step using a sliding window. The following statistical features are computed for each sensor: standard deviation, variance, mean, median, minimum, maximum, mode, second moment, percentiles, kurtosis, skewness and entropy.

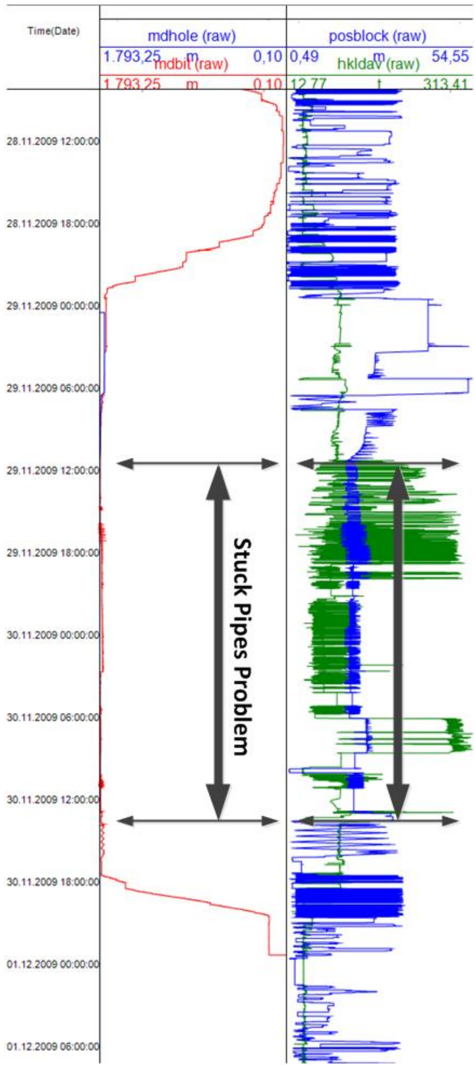

Figure 1. Identifying "Stuck Pipes" problem on a time chart of drilling sensor data

Skewness and kurtosis are used to measure the "asymmetry" and "peakedness" of the measurement distribution, whereas second moment is used to measure the "width" of statistical distribution. Percentiles are used to measure the "position" value, where the p^{th} percentile is a value Y_p such that at most $(100 \cdot p)\%$ of the measurements are less than this value and at most $100 \cdot (1 - p)\%$ are greater. Finally, entropy is used to measure the impurity.

To orient our analysis, we elicited a priori knowledge from drilling experts. Based on their experience, we focused on the sensors measurements of "hookload" and "block position" as the main indicators to monitor the situation of "stuck pipes" problems. This can be interpreted by actions which are usually taken by drilling crew during "stuck pipes" situation. The drilling crew usually tries to move the drill string up and down to make the drill string free. These actions are directly reflected on the sensors measurements of "hookload" and "block position" (see Fig 1).

TABLE 1. THE MAIN SENSOR MEASUREMENTS

Measurement	Explanation
posblock	The distance of the top drive from the floor of drill rig
hookload	The weight which is connected with the hook.
rpm	Rotation speed of the drill string
torque	Torque force which is generated by drill string rotation
mdbit	Measured depth of the drill bit
mdhole	Measured depth of the generated borehole
flowIn	How much fluids are pumped
pumpressure	The pressure of the pumps which is generated in the circulation systems.

Based on these findings, in the next section we exclude all the location statistical features from our analysis process such as: mean, mode, median, maximum and minimum. The reason behind this exclusion is that all these features are heavily related to the ranges and values of the sensors measurements which can be varied and changed from rig to rig. The "hookload" sensor measurements depend on initial top drive weight and weight of each drilling stand. The "flowIn" and "pumpressure" sensors measurements relate to type of circulation pumps. The "block position" sensor measurements influenced by the setup and type of the rig.

We use the descriptive shape statistical features such as: variance, skewness, second moment, kurtosis and entropy for the visual analysis. The reason behind taking these features is because that they can be used for further analysis on different drilling datasets. Another reason is that the drilling process is similar for all drilling rigs, and hence, the shape features of statistical distributions of all sensors measurements are usually similar.

IV. INTERACTIVE VISUAL ANALYSIS

We employ Visual Analytics techniques to analyze drilling problems in sensor measurements. Our purpose is to find the statistical features that are best suited to reveal and identify the "Stuck Pipes" problem from these measurements. For this reason we created small multiples of scatter plots of the statistical features that were determined by domain experts to be the most relevant to the problem (Fig. 2). The items in these plots represent time windows from the drilling process. Items that lie in time ranges classified as "stuck pipes" are colored red. Other items are colored blue.

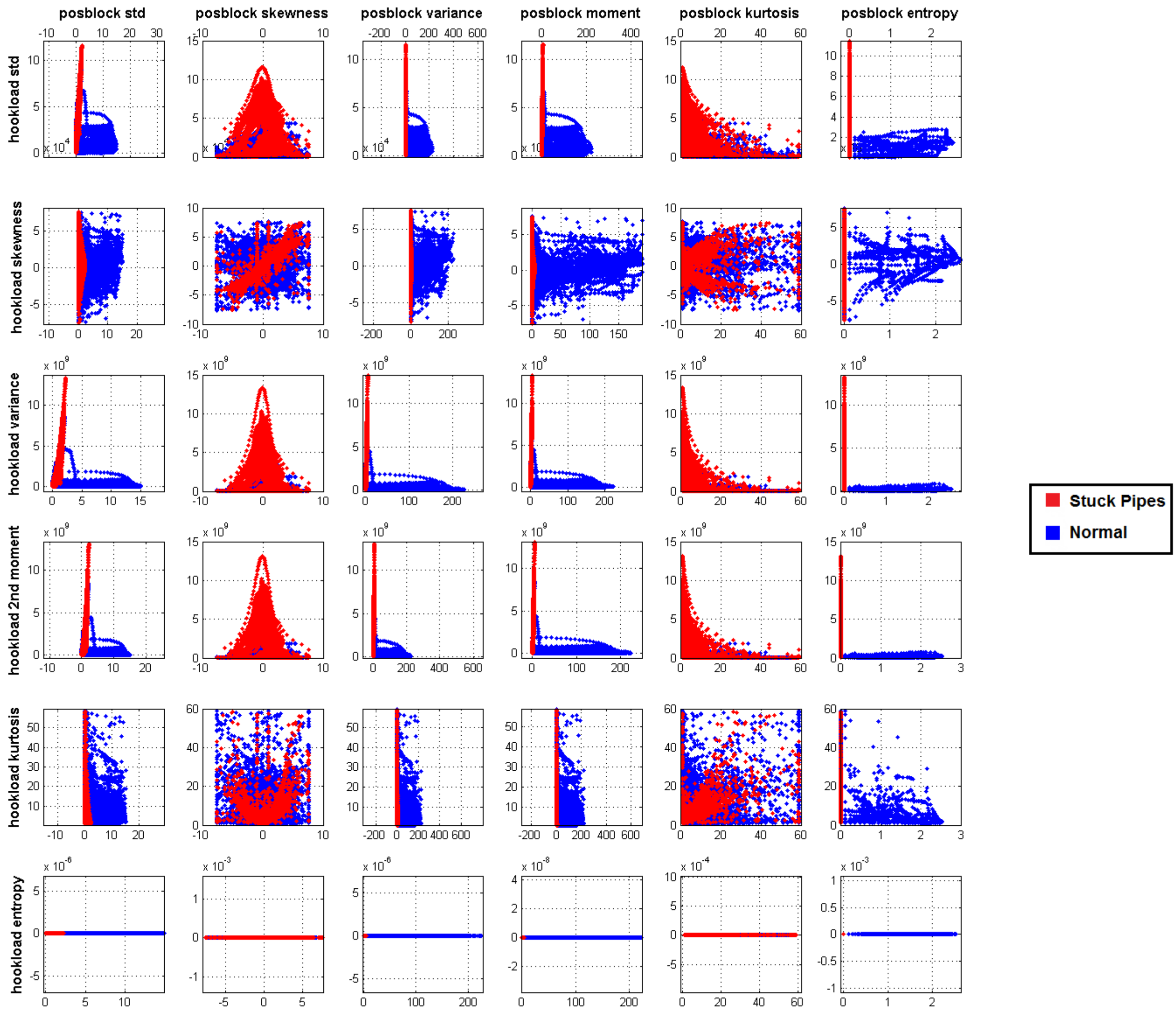

Figure 2: scatter plots of key statistical features selected by the experts as relevant for identifying "stuck pipes" problems.

From the scatter plots of the "posblock" entropy one can notice that when "stuck pipes" occurs the entropy is zero (Fig 3c). Although this could be used as an indicator, the drilling expert suspects that it cannot be generalized to identify "stuck pipe" problems in different sessions and rigs. Using interactive brushing enables selecting data items in one plot to examine how they are distributed in others. Furthermore, the corresponding locations of these items in the time-charts of raw data are highlighted. This helps to relate the features to the temporal patterns in the signal, and to localize detecting patterns in time.

After repeatedly examining the "stuck pipe" patterns in the different plots, the analyst decided that the two plots in Fig. 3a and Fig. 3b are suited for identification. While neither figure exhibits full separation between the two classes, the patterns were consistent in both figures with different instances of the "stuck pipe" problem. This means that data points that correspond to unseen "stuck pipe" instances will most portably exhibit similar distributions in these plots. In Fig. 3d, we observe the skewness of the two channels "posblock" and "hookload" plotted against each other for different windows. While there is no separation between the two classes, they exhibit different trends that can be captured by regression analysis.

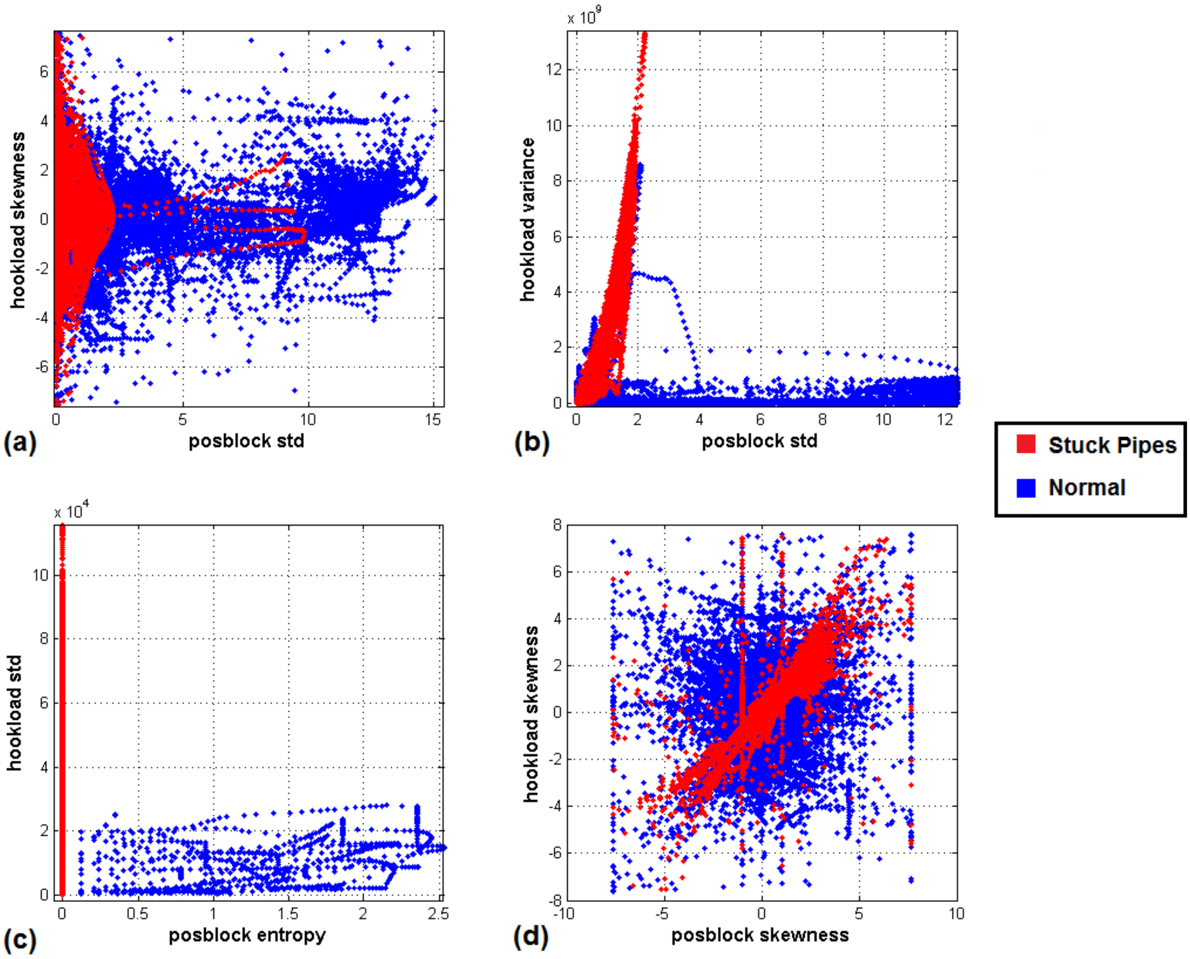

Figure 3. Detail scatter plots views that identify the "stuck pipe" problems. (a, b) different but overlapping distributions for the two classes. (c) the posblock entropy as discriminative but unreliable feature (d) the skewness features exhibit noticeable difference in the trends.

V. Discussion

In this paper we have demonstrated how sensors measurements can be analyzed using Visual Analytics techniques to identify "Stuck Pipes" situation in drilling process. One can generalized this approach and extend it to other types of problems during drilling such as "kicks" or "stick slips". This needs for sure more sensors to be involved in the analysis process. Furthermore, using different views of features is a rigorous step to construct monitoring tools for "stuck pipes" and other abnormal situation in drilling process in real-time.

Moreover, one of the biggest challenges in drilling data management domain is recognizing "stuck pipes" and other abnormal drilling situations in historical data centers. To accomplish this step, the suggested approach in this paper can be used to train classification systems based on the suggested features.

VI. References

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