Probing while driving for oil well surface profile measurement

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Abstract— **Gas/oil well often stretches several miles underground. Due to various extreme conditions such as high temperature, high pressure, and highly corrosive environment, or even land movement due to earthquake, the well will have many possible problems that cause interruption to gas/oil drilling/production, or even accident. Thus one of the frequent well measurements is to check the well deformation, well surface irregularity so that preventive actions may be taken. One major indicator is the circularity measurement as a perfect well has circular casing. In this paper, a novel robot and a built-in well surface measurement method is developed. The robot has a driving mechanism that is capable of moving miles inside a well. A toggle mechanism is designed as both a robot stabilizer and a probe to measure the radius of a point. The current design has four such toggle mechanisms which means four points can be measured at the same time. If needed, the number of measurement points can be easily increased. The proposed system is simple and robust. It can record data while traveling inside a well that stretches miles underground.**

Keywords—caliper log; in-pipe robot; surface profile; probing.

I. INTRODUCTION

Oil wells are tubular in shape. However, due to corrosion, scaling, pitting, and deformation from other forces to the tubular casing, oil wells need frequent measurements. It is desirable to measure the diameter of a borehole along a well's complete depth. Some special features of oil well measurement are the long range (can be as long as five miles) and hostile environment (high temperature, high pressure, and corrosive fluid). Because of these features, such measurements are usually performed mechanically, with only a few using sonic devices. Fig. 1 shows a simple diagram of an oil well. It may have several branches which make measurements even more complicated.

Any oil well measurement and maintenance are very expensive (can be more than one hundred thousand dollars per hour), because such operations require both expensive equipment and human expertise, suspension of oil/gas production. Therefore, quick measurement must be done in order to reduce cost. In this paper, a robot that may carry heavy load and move very fast is developed for both equipment transportation and oil well surface measurement. A special feature is that the measurement is designed as part of the robot. Even though this paper has used circularity as a special measurement case study, yet the proposed system is also applicable for measurement of enclosed unknown environment.

Even though oil well surface measurement has been done for many years, yet robot based measurement is a recent development. In today's oil/gas wells, they may not be straight. They may have many possible paths, such as a spiral path. Many wells even have some branches. The measurements for such wells are best done through a robot.

Even though there are many studies on autonomous measurement of un-known environment in the last twenty years [1], yet they almost all use range sensors such as cameras, laser, sonar or ultrasonic) that provide large and time-efficient data collection [2,3]. However, these methods may not be applicable to the proposed well measurement as the harsh environment prohibits the use of such instruments. Mazzini et al [4] have developed a tactile arm to map the well surface so that well rehabilitation can be done cost effectively. However, the reported work uses only one probe. The probe itself is an articulated robotic arm which is exposed to a harsh environment thus probe to problems. It is also very slow as it has only a single probe with a complicated structure. The accuracy is also limited due to its long arm design.

Recent studies have also reported some robot based circular surface measurement results. A snake like robot has been used to map simulated 2D circular pipes with known diameters [5]. Research related to robotic touch probing [6,7], grasping and haptic [8,9] and even reverse engineering of the whole surface [10].

The above mentioned methods are either can't be used in harsh environment, or are very complicated and slow. The work reported in this paper has integrated the measurement instrument into a multi-purpose robot design that is simple, and efficient. The proposed design can work in harsh, unknown enclosed near circular environment.

II. THE BASIC SYSTEM CONCEPT

The proposed measurement must have a robot that can move inside a near circular pipe space. Fig. 2 shows the proposed design. The design has a driving section where three gear wheels rotate to move the robot forward or backward.

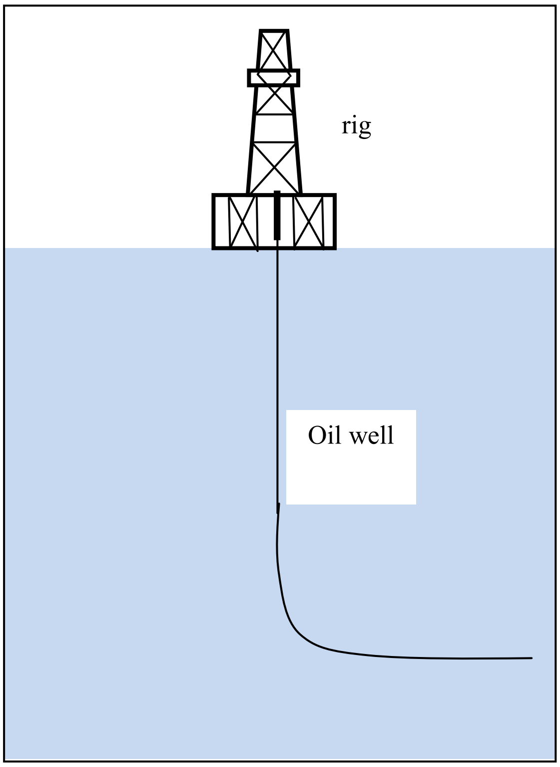


Fig. 1. A typical oil/gas well structure

The driving wheels are driven by a motor. The whole robot is stabilized by a stabilizer design which has four wheels each of the wheels is supported by a toggle mechanism. The toggle mechanism is also designed as a probe for measurement of pipe radius. Fig. 3 shows the robot inside a pipe.

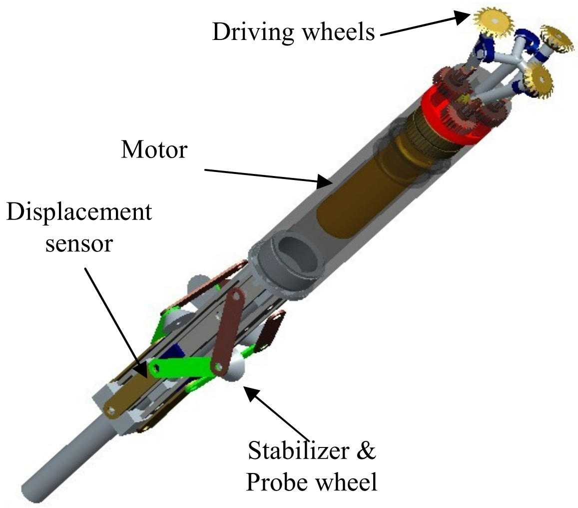
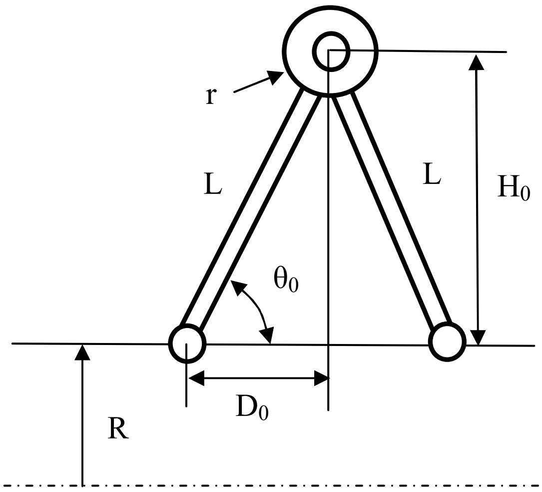


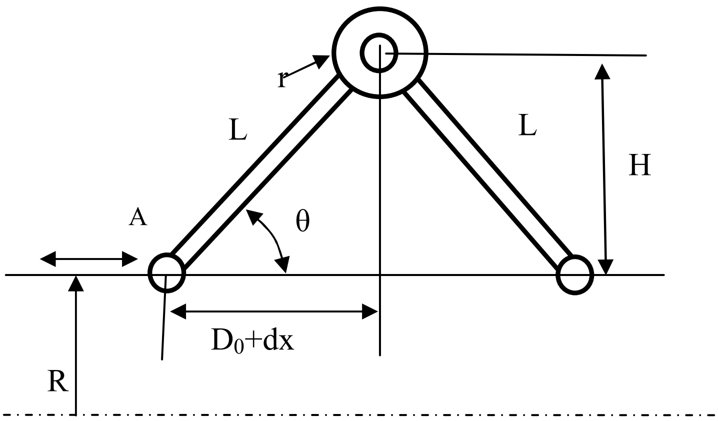
Fig. 2. The basic concept of the proposed robotic measurement system

Fig. 3. The robot working inside a transparent pipe

For each of the toggle mechanism, it serves as a stabilizer for the robot so that the robot can be centered inside the well. The stabilizer also prevents the robot from spinning itself as the driving gear wheels will generate a torque which has the tendency to rotate the robot. At the same time, the radial distance of a point inside the well can be measured because each toggle mechanism has a displacement sensor that measures the linear displacement of a toggle point which is explained in Fig. 4. In Fig. 4.(a), the toggle can be calibrated at certain position. The actual calibrated position can be different from application to application. For a given position as in Fig. 3(a), once calibrated, the parameters H_0, D_0, and θ_0 will be considered as known parameters.



(a) Calibrated position



(b) Any given position

Fig. 4. The toggle mechanism as a stabilizer and a probe

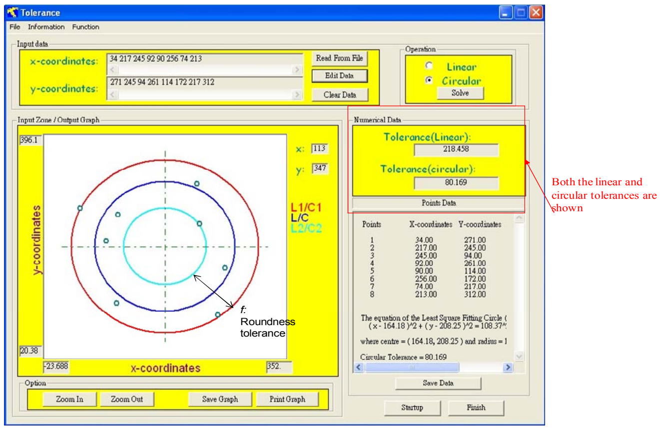


Fig. 5. Least Square circle fitting and circularity tolerance

Fig. 3(b) shows a any given position. This position is achieved due to the linear motion of point A. The displacement relative to the calibrated position is dx. In actual applications, dx can be both positive and negative. The actual displacement can be measured using any potential meter based linear displacement sensor. From Fig.4(b), Eqn (1) can be established.

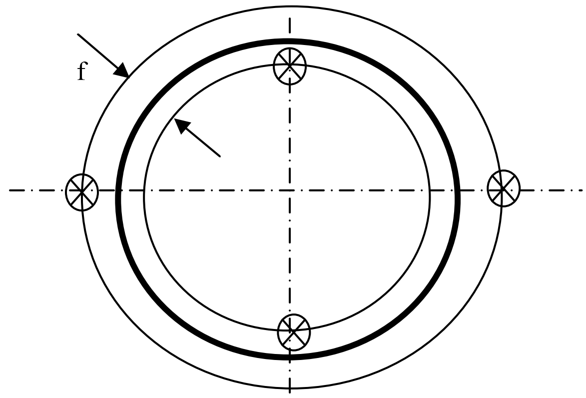
$$sin\theta = \frac{D_0 + dx}{L}, or\ \theta = s \qquad (1)$$

Now, the toggle mechanism's extended length H can be found from the following

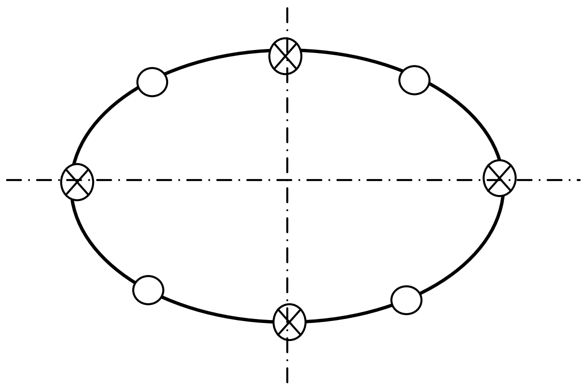
$$H = L\ sin\theta \qquad (2)$$

The measured radius at the given position is $R+H+r$. Where R is the radius of the robot, H is the extended length and r is the radius of the probe wheel. For any given, position, the measurement of radius is fast as only simple calculation is needed.

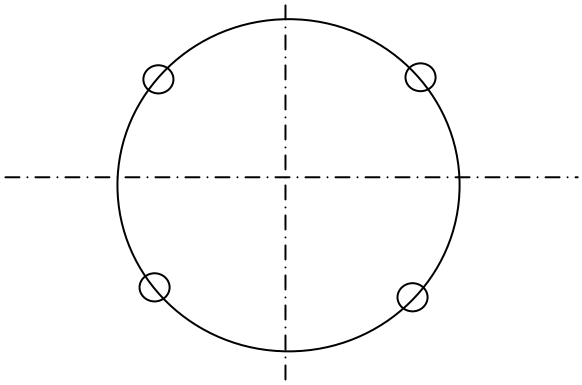
For any four measurement points, it is possible to fit the points into a circle using least square method. Fig.5 shows the implementation of least square fitting method for measurement points and roundness tolerance analysis. For generality, any number of points can be fitted using the least square method. It will also fit points into surfaces so that when more measurement points are collected, it is possible to constructed the entire surface profile of an oil well. In Fig.6 (a), the 4 measurement points can be fitted as a circle shown as dark thick line. Once the least circle is found, the circularity tolerance f can be found as in the figure. However, in many cases, a circular section of an oil well is not a circle. It might be an ellipse as shown in Fig. 6(b). In this case, the measurement results may have large error. If the 4 measurement points are as those shown as small circles, the fit circle will be small as in Fig.6(c). If the 4 measurement points are as shown with a cross inside small circles, the fit circle will be very large as in Fig.6(d). Thus the measurement results will be subject to unpredictable error.



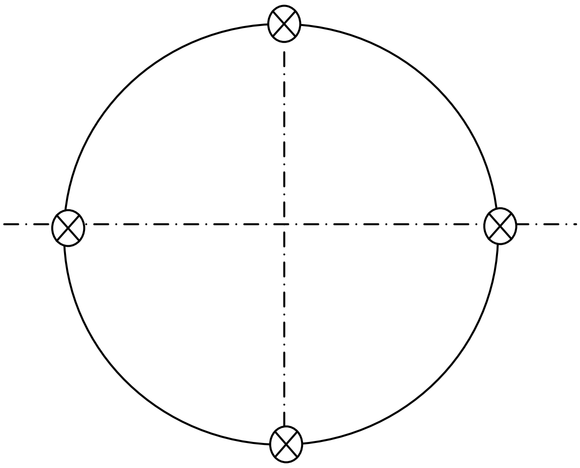
(a) least square fitting



(b) ellipse well cross section



(c) circle with the least radius



(d) Circle with the max radius

Fig. 6. Measurement points and their fitting

In order to overcome this kind of error, it is desirable to measure more points so that the entire interior surface of a well can be constructed. Fig. 7 shows the surface patches of a small portion inside a well. If this is to be done, many more points need to be measured. To achieve this, future work will be focused on designing two rotating probes instead of four fixed probes. When the robot is travelling inside a well, the two probes will rotate so that as many points as possible on the circumference of the well can be measured. This will greatly improve the measurement accuracy.

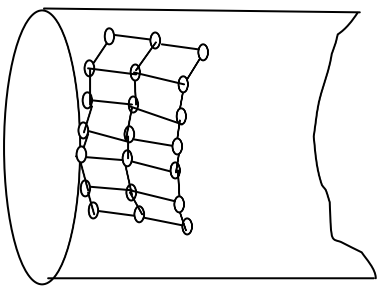


Fig. 7. More measurement points with surface patches

III. CONCLUSSIONS

This paper has presented a robotic well surface measurement concept and prototype. Currently, the analytical part of the concept has been completed. Field measurements will be performed when the robot design is perfected. It is expected that the four point measurement method may yield some errors when the well surface are not circular. Future research will focus on a rotating probe measurement method and the relevant mathematical or geometrical analysis methods that can easily yield correct results.

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