Title: WIRELESS RUN-IN POSITION SENSING SYSTEMS AND METHODS

Abstract: A method of performing real-time position sensing includes conveying a tool attached to a tubular string in a borehole. The tool includes a position sensing sub, and the position sensing sub includes sensing devices. The method further includes recording measurements taken by the sensing devices. The method further includes determining, based on the measurements, a position along the borehole of a particular portion of the tubular string. Data from sensing devices having a higher priority overrides conflicting data from sensing devices having a lower priority. The method further includes transmitting the position wirelessly.
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WIRELESS RUN-IN POSITION SENSING SYSTEMS AND METHODS

Background

In the oil and gas industry, some operations require accurate placement of tools downhole. For example, perforation guns should be carefully positioned to control the location of perforation points relative to bed boundaries and relative to each other. In order to achieve such placement, a "dummy run" may be performed. A dummy run refers to performing a round trip in and out of the borehole using a partially completed tool string with the typical objective of confirming the position of a particular portion of the tool string along the borehole for a subsequent actual run using a complete tool string. For example, a dummy run may confirm that the position of perforation guns during the actual run will be within the relatively small range of positions ideal for the perforation operation. Such a range is on the order of a few feet while the borehole may be thousands of feet long.

As borehole lengths increase, the time and cost required for the dummy run also increases. Additionally, rented equipment also adds to the cost. For example, rig rentals may cost up to $1 million per day, and a dummy run may require half of a day or more to complete. Considering only these two variables, the dummy run may cost $500,000. Other variables may also increase the cost of the dummy run, leading to inefficient use of resources.

Brief Description of the Drawings

Accordingly, there are disclosed herein a number of wireless run-in position sensing systems and methods. In the following detailed description of the various disclosed embodiments, reference will be made to the accompanying drawings in which:

Figure 1 is a contextual view of an illustrative perforation environment;

Figure 2 is an external view of an illustrative position-sensing sub;

Figure 3 is a function-block diagram of an illustrative position-sensing sub;

Figure 4 is a flow diagram of an illustrative method for real-time position sensing; and

Figure 5 is a contextual view of an illustrative drilling environment.

It should be understood, however, that the specific embodiments given in the drawings and detailed description thereto do not limit the disclosure. On the contrary, they provide the foundation for one of ordinary skill to discern the alternative forms, equivalents, and modifications that are encompassed together with one or more of the given embodiments in the scope of the appended claims.
Notation and Nomenclature

Certain terms are used throughout the following description and claims to refer to particular system components and configurations. As one of ordinary skill will appreciate, companies may refer to a component by different names. This document does not intend to distinguish between components that differ in name but not function. In the following discussion and in the claims, the terms "including" and "comprising" are used in an open-ended fashion, and thus should be interpreted to mean "including, but not limited to...". Also, the term "couple" or "couples" is intended to mean either an indirect or a direct electrical or physical connection. Thus, if a first device couples to a second device, that connection may be through a direct electrical connection, through an indirect electrical connection via other devices and connections, through a direct physical connection, or through an indirect physical connection via other devices and connections in various embodiments.

Detailed Description

The issues identified in the background are at least partly addressed by wireless run-in position sensing systems and methods. A position-sensing sub that wirelessly transmits position information in real time enables accurate positioning of an operational tool without requiring any extra trips or adjustments of the tool string. Additionally, the tool string need not be pulled out of the borehole for the reading of logs. Accordingly, the dummy run may be eliminated, and as a result, the costs associated with the dummy run may be saved.

The disclosed systems and methods for implementing such position sensing are best understood in terms of the context in which they are employed. As such, Figure 5 shows an illustrative drilling environment. A drilling platform 2 supports a derrick 4 having a traveling block 6 for raising and lowering a bottomhole assembly (BHA) 19. The platform 2 may also be located offshore for subsea drilling purposes in at least one embodiment. The BHA 19 may include one or more of a rotary steerable system, logging while drilling system, drill bit 14, reamer, and downhole motor 26. A top drive 10 supports and rotates the BHA 19 as it is lowered through the wellhead 12. The drill bit 14 and reamer may also be driven by the downhole motor 26. As the drill bit 14 and reamer rotate, they create a borehole 17 that passes through various formations 18. A pump 20 circulates drilling fluid 24 through a feed pipe 22, through the interior of the drill string to the drill bit 14. The fluid exits through orifices in the drill bit 14 and flows upward to transport drill cuttings to the surface where the fluid is filtered and recirculated.

A data processing system 50 may be coupled to a measurement unit on the platform 2 by a wired connection 49 or wireless connection, and may periodically obtain data from the
measurement unit as a function of position and/or time. Software (represented by information storage media 52) may run on the data processing system 50 to collect the data and organize it in a file or database. The software may respond to user input via a keyboard 54 or other input mechanism to display data as an image or movie on a monitor 56 or other output mechanism. The software may process the data to optimize oilfield operations as described below.

Wired telemetry, which uses an electrical line, wireline, or cable to communicate with the surface, has several disadvantages compared to wireless telemetry. First, the line must be installed in or otherwise attached to the drill string. As such, the line is prone to damage in the harsh downhole conditions. As a result, the system is unreliable, which results in costly inspection, servicing, and replacement of the line. Second, the downhole motor should be particularly designed to accommodate the line because the movement of the motor degrades the line without such accommodation. Such customization is expensive.

In various embodiments, wireless methods, such as acoustic and electromagnetic (EM) telemetry, are used for communication with the surface. With regard to acoustic waves, typically, an acoustic signal is generated near the drill bit 14 and is transmitted through the drill pipe, mud column, or the earth. Specifically, the drill string may include an acoustic telemetry transceiver that transmits telemetry signals in the form of acoustic vibrations in the tubing wall of the drill string. An acoustic telemetry receiver may be coupled to the kelly to receive transmitted telemetry signals. One or more repeaters may be provided along the drill string to receive and retransmit the telemetry signals. The repeaters may include both an acoustic telemetry receiver and an acoustic telemetry transmitter.

Electromagnetic telemetry can be employed in a variety of ways. Using one technique, electromagnetic signals are modulated according to a sensor response to represent one or more parameters of interest. In one embodiment, these signals are transmitted from a downhole EM transceiver, through intervening earth formation, and detected as a voltage or a current using a surface transceiver that is typically located at or near the surface. The one or more parameters of interest are extracted from the detected signal. Using another electromagnetic technique, a downhole transceiver creates a current within the drill string, and the current travels along the drill string. This current is typically created by imposing a voltage across a non-conducting section in the downhole assembly. The current is modulated according to the sensor response to represent the one or more parameters of interest. A voltage between the drilling rig and a remote ground is generated by the current and is measured by a surface transceiver, which is at the surface. The voltage is usually between a
wire attached to the drilling rig or casing at the surface and a wire that leads to a grounded connection remote from the rig. Again, one or more parameters of interest are extracted from the measured voltage. Alternately, the one or more parameters of interest can be extracted from a measure of current.

The borehole 17 may be thousands of feet long, and an operational tool such as a perforation sub must be placed accurately within a few feet in the borehole 17. Figure 1 illustrates a position-sensing sub that may be placed on the drill string or a tool string that enables such placement.

Figure 1 shows an illustrative perforation environment 100. (Though these principles are described in terms of a perforation operation, they are also applicable to those other operations requiring accurate placement of tools along the borehole, e.g. positioning of a shear sub or packer, multi-zone testing applications, and completion applications.)

A borehole 118 is cased using multiple concentric casing strings 116, each string having casing joints attached together by casing collars 104 having threaded connectors. To preserve the integrity and rigidity of the casing string 116, the casing collars 104 are made with thicker steel walls. The casing joints have fairly standard lengths, enabling the collars 104 to serve as convenient position markers or "milestones". The thicker steel walls enable the collars to be detected with "casing collar locators", which may employ induction sensors or permeability sensors. Selected casing collars or positions along the drillstring may be additionally tagged with radioactive markers to make them detectable by a gamma ray logging tool.

A tubular string, such as a tool string 102, includes operational tools such as a perforation sub 110 and a position-sensing sub 114. Perforation is a process used to establish a flow path of hydrocarbons from the formation to the borehole by creating one or more holes in the casing and any cement sheath surrounding the casing. The perforation sub 110 includes perforation guns 112 to create such holes. The perforation guns 112 may be a known distance from other portions of the tool string 102, such as the position sensing sub 114, and this distance may be used in order to accurately position the perforation guns 112.

The position-sensing sub 114 includes sensing devices such as an accelerometer, gyroscope, casing collar locator, radiation sensor, roller counter 106, and the like. In various embodiments, different combinations of any or all the sensing devices are included on the position-sensing sub 104. The accelerometer detects inertial movement along the borehole to measure acceleration. The gyroscope includes some form of rotation sensor for measuring the tool's orientation, e.g., a spinning wheel mounted on a gimbal assembly. The casing collar
locator includes two magnetic poles positioned on either side of a central coil. Magnetic lines
of flux in the casing collar locator are temporarily distorted when the position-sensing sub
114 passes the thicker walls of a casing collar. This distortion changes the magnetic field
around the conducting coil, and the change is detected. A radiation sensor such as a gamma
ray log includes a scintillation crystal and a photomultiplier tube to measure gamma-ray
radiation emitted by the tag or marker. The roller counter 106 detects the distance traveled by
the position-sensing sub 116 along the borehole 114, and is described in detail with respect to
Figure 2.

Figure 2 illustrates an external view of the position-sensing sub 200, which includes a
roller counter 201. The roller counter 201 is a sensing device that measures distance traveled
along the borehole, and the roller counter includes extension arms 204 resiliently coupled to
the body of the position-sensing sub 200 by fasteners such as hinges 206 and biased outwards
against the inner walls of the casing string. The hinges 206 enable the extension arms 204 to deploy by extending away from the body of the position-sensing sub 200 such that wheels 202 located at the opposite end of the extension arms 204 contact the
casing string and turn as the position-sensing sub 200 is conveyed along the borehole. In at
least one embodiment, springs on the extension arms 204 keep the wheels 202 in contact with
the casing string. The wheels 202 are coupled to the extension arms 204 by axles, and the
deployment of the extension arms 204 may be initiated and controlled from the surface or
downhole. As the casing string decreases in diameter, the hinges 206 enable the extension
arms 204 to retract such that the wheels 202 maintain contact with the casing string. The
extension arms 204 may also fully retract when the tool string is pulled out of the borehole.
This retraction may also be initiated and controlled from the surface or downhole.

Encoders coupled to the wheels 202 count the rotations of the wheels 202. One
encoder may be used for each wheel 202, and an encoder may include a rotational counter
coupled to the axle of the corresponding wheel 202. In at least one embodiment, the encoder
transmits a signal, such as an electrical pulse, for every rotation of the wheel 202, and the
pulse is detected and recorded by circuitry on the position-sensing sub 200. In other
embodiments, fractional rotations or rotations greater than a single rotation are detected and
recorded.

Multiple extension arms 204 provide centralization of the position-sensing sub 200
within the borehole; redundancy that mitigates failure of a wheel 202, such as a seized
bearing preventing rotation; redundancy that mitigates an electrical connection problem
between the wheel, encoder, and circuitry; and redundancy that mitigates a wheel 202
slipping (not rotating) along the casing string. Because of such redundancies, outliers in the
data measured by the roller counter may be eliminated during real-time processing without
reducing the accuracy of the final data set. Such processing may be performed by the
processor as described with respect to Figure 3.

Figure 3 illustrates a block diagram of a position-sensing sub 302. As described
above, the position-sensing sub 302 includes sensing devices 308 such as an accelerometer,
gyroscope, collar locator, radiation sensor, roller counter, and the like to measure downhole
conditions. The position-sensing sub 302 also includes a processor 304, coupled to memory
306, to process operations, store data, and calculate the position of various portions of the
tools string in real time using data measured by the sensing devices 308.

In at least one embodiment, data from sensing devices 308 having a higher priority
overrides conflicting data from sensing devices 308 having a lower priority during position
determination, and the more accurate sensing device (determined a priori in at least one
embodiment) is given the higher priority. For example, the casing collar locator may be
known to fail to detect some collars while the radiation sensor may be known to detect a
radioactive tag reliably. As such, the radiation sensor is given a higher priority than the collar
locator because the position information of the radiation sensor is more accurate.
Accordingly, when the data measured by the casing collar locator conflicts with the data
measured by the radiation sensor, the latter is given priority during position determination. In
this way, the sensing devices 308 make up a hierarchy of higher and lower priority sensing
devices 308 relative to one another. In at least one embodiment, the radiation sensor has the
highest priority, the casing collar locator has the second-highest priority, and the roller
counter has the third-highest priority. By using a combination of sensing devices 308 and
overriding conflicting data from lower-priority sensing devices, the position of various
portions of the tool string including the position-sensing sub 302 and operational tools such
as a perforation gun may be accurately determined.

The position-sensing sub 302 also includes communication and networking hardware
310 for enabling communications between the position-sensing sub 302 and the surface. The
communication channel between the position-sensing sub 302 and the surface is wireless. As
such, position information can be communicated to the surface in real-time and such
communication may occur continuously, automatically after a threshold amount of time or
inactivity has passed, in response to queries or programmable events (discussed below with
respect to Figure 4), or some combination of the preceding.
Figure 4 is a flow diagram of an illustrative method 400 of real-time position sensing beginning at 402 and ending at 414. At 404, a tool string is conveyed through a borehole. The tool string includes a position-sensing sub, and the position sensing-sub includes sensing devices as described above. The tool string may also include operational tools that should be positioned accurately downhole such as a perforation sub, a packer, a shear sub, and the like. The tool string may be assembled such that the position-sensing sub resides below a packer and above perforation guns when within the borehole.

At 406, measurements taken by the sensing devices are recorded. Specifically, the sensed data may be processed by a processor and stored in memory. Such processing may include pruning sensed data that is unreliable. For example, the accuracy of the wheels on the roller counter may be determined by identifying the wheel that has turned the maximum number of times (or at the fastest speed) over a programmable distance along the borehole. Such a wheel is a "representative" wheel, meaning that the sensed data provided by other wheels along the distance is ignored for purposes of position determination. However, along a subsequent portion of the borehole, another wheel may be selected as the representative wheel. By repeating selection of the representative wheel over several distances along the borehole, the accuracy of the roller counter increases even though various wheels may fail to rotate along different portions of the borehole.

At 408, a query or event trigger is obtained. A query may include a wireless signal or command sent from the surface requesting position information, while an event trigger may include a programmable threshold of time passing, a programmable period of inactivity passing, a programmable distance traveled, detection of a collar, detection of a radioactive tag, and the like. If a query or trigger event is obtained, the current position is determined at 410. If not, the tool string is conveyed further through the borehole at 404.

At 410, a position along the borehole of a particular portion of the tool string is determined based on the recorded measurements. For example, the position of the position-sensing sub may be determined or the position of a particular operational tool, such as a perforation sub or perforation guns, may be determined. A radiation tag detected by the radiation sensor resides at a known location in the borehole. As such, the data sensed by the radiation sensor may be used to determine distance using a database or lookup table. Collars reside at a known distance apart from each other. As such, the data sensed by the collar locator may be used to determine distance by multiplying the amount of collars detected with the distance between the collars. The roller counter may be used to determine distance by multiplying the number of rotations of the representative wheels by the circumference of the
wheels. Finally, the accelerometer and gyroscope may be used to determine distance by using a dead-reckoning algorithm—i.e. the process of calculating a current position by using a previously determined position, or fix, and advancing that position based upon current speeds over elapsed time and course—with the collars or radioactive tag as fixes.

The distance determined from sensed data from the multiple sensing devices may be compared to identify error and update an error factor in any of the sensing devices. For example, using dead reckoning, each time the accelerometer and gyroscope sensors encounter a "fix," the fix distance may be compared with the estimated distance at the location of the fix. A fix is evidence of a known location, in this case, evidence of a known distance along the borehole. The difference between the two values is the error factor, and as more fixes are encountered, the error factor is updated. Ultimately, when no more fixes are encountered, the error factor may be used to adjust the distance measurement derived from the accelerometer and gyroscope measurements. In this way, the lower-priority devices may be recalibrated when presented with conflicting data from higher-priority devices. For example, the collar count is recalibrated every time a radiation marker is detected, and the accelerometer and gyroscope are recalibrated whenever a collar is detected.

The distances determined from sensed data from the multiple sensing devices may be combined to determine the current position of the position-sensing sub and/or the position of an operational tool. For example, the casing collar locator measurements may supplement the radiation sensor measurements because casing collars are more frequently passed than radioactive tags. In the same way, the accelerometer and gyroscope measurements may supplement the casing collar locator measurements for positions between casing collars. Such supplementation may occur if the data does not conflict. If the data does conflict, then data from the higher-priority devices will override data from the lower-priority devices during the combining. For example, the data from the lower-priority devices may be ignored during the combining. As another example, the data from the lower-priority devices may be given less weight during the combining. However, such overriding does not apply to all data from a lower-priority device, i.e. the lower-priority device is not eliminated from providing data entirely. Rather, only those portions along the borehole where a higher-priority device provides conflicting information will be subject to such override.

At 412, the position is reported. For example, the position information is transmitted to the surface wirelessly in real time. After the position information is reported, the operational tool, such as the perforation guns on the perforation sub, is activated without bringing the tool string out of the borehole in at least one embodiment.
A method of performing real-time position sensing includes conveying a tool attached to a tubular string in a borehole. The tool includes a position sensing sub, and the position sensing sub includes sensing devices. The method further includes recording measurements taken by the sensing devices. The method further includes determining, based on the measurements, a position along the borehole of a particular portion of the tubular string. Data from sensing devices having a higher priority overrides conflicting data from sensing devices having a lower priority. The method further includes transmitting the position wirelessly.

The sensing device with the highest priority may include a radiation sensor that detects a radioactive tag. The sensing devices may include an accelerometer and a gyroscope. The sensing devices may include a roller counter. The roller counter may include wheels that turn as the tool is conveyed in the borehole, and recording the measurements may include determining the accuracy of the wheels. Determining the accuracy may include determining the wheel that has turned the maximum number of times over a programmable distance along the borehole and recording that number as a measurement for use in position determination.

The method may include repeating the determining and recording over another programmable distance along the borehole. The tubular string may include perforation guns, and determining the position may include determining the position of the perforation guns. The method may include activating the perforation guns after determining the position without bringing the tool out of the borehole. The tool may be attached to the tubular string at a known distance from the perforation guns. Determining the position may include determining the position of the position sensing sub. The method may include assembling the tubular string such that the position sensing sub resides below a packer and above perforation guns when within the borehole. Programmable events may trigger position determination and updating of an error factor used to calibrate the position. Determining the position may include determining the position repeatedly over programmable distances along the borehole.

An apparatus for performing real-time position sensing includes a hierarchy of sensing devices. The sensing devices measure conditions within a borehole as the apparatus is conveyed along the borehole while attached to a tubular string. The apparatus further includes a processor coupled to the sensing devices. The processor determines position using data from the sensing devices. Data from sensing devices having a higher priority overrides conflicting data from sensing devices having a lower priority during position determination. The apparatus further includes telemetry equipment coupled to the processor, and the telemetry equipment wirelessly communicates the position.
The sensing devices may include a radiation sensor for detecting a radioactive tag, a roller counter, and a collar locator for detecting collars. The radiation sensor may have the highest priority. The processor may determine the position of the apparatus using the data from the sensing devices. The processor may determine the position of perforation guns using the data from the sensing devices. Programmable events, which may include detecting a radioactive tag or detecting a collar, may trigger position determination. The sensing devices may include an accelerometer, pressure sensor, and gyroscope.

While the present disclosure has been described with respect to a limited number of embodiments, those skilled in the art will appreciate numerous modifications and variations therefrom. It is intended that the appended claims cover all such modifications and variations.
Claims

What is claimed is:

1. A method of performing real-time run-in position sensing comprising:
   conveying a tool attached to a tubular string in a borehole, wherein the tool comprises
   a position sensing sub, and wherein the position sensing sub comprises
   multiple sensing devices;
   recording measurements taken by the sensing devices;
   combining the measurements to determine a position along the borehole of a
   particular portion of the tubular string, wherein data from sensing devices
   having a higher priority overrides conflicting data from sensing devices
   having a lower priority; and
   transmitting the position wirelessly.

2. The method of claim 1, wherein the sensing device with the highest priority comprises a
   radiation sensor that detects a radioactive tag.

3. The method of claim 1, wherein the sensing devices comprise an accelerometer and a
   gyroscope.

4. The method of claim 1, wherein the sensing devices comprise a roller counter.

5. The method of claim 4, wherein the roller counter comprises wheels that turn as the tool is
   conveyed in the borehole, and wherein recording the measurements comprises determining
   the accuracy of the wheels.

6. The method of claim 5, wherein determining the accuracy comprises determining the
   wheel that has turned the maximum number of times over a programmable distance along the
   borehole and recording that number as a measurement for use in position determination.

7. The method of claim 6, comprising repeating the determining and recording over another
   programmable distance along the borehole.

8. The method of claim 1, wherein the tubular string comprises perforation guns, and wherein
   determining the position comprises determining the position of the perforation guns.
9. The method of claim 8, further comprising activating the perforation guns after determining the position without bringing the tool out of the borehole.

10. The method of claim 8, wherein the tool is attached to the tubular string at a known distance from the perforation guns.

11. The method of claim 1, wherein determining the position comprises determining the position of the position sensing sub.

12. The method of claim 1, further comprising assembling the tubular string such that the position sensing sub resides below a packer and above perforation guns when within the borehole.

13. The method of claim 1, wherein programmable events trigger position determination and updating of an error factor used to calibrate the position.

14. The method of claim 1, wherein determining the position comprises determining the position repeatedly over programmable distances along the borehole.

15. An apparatus for performing real-time run-in position sensing comprising:

   a hierarchy of sensing devices, wherein the sensing devices measure conditions within a borehole as the apparatus is conveyed along the borehole while attached to a tubular string;

   a processor coupled to the sensing devices, wherein the processor determines position using data from the sensing devices, and wherein data from sensing devices having a higher priority overrides conflicting data from sensing devices having a lower priority during position determination; and
telemetry equipment coupled to the processor, wherein the telemetry equipment wirelessly communicates the position.

16. The apparatus of claim 15, wherein the sensing devices further comprise a radiation sensor for detecting a radioactive tag, a roller counter, and a collar locator for detecting collars, and wherein the radiation sensor has the highest priority.
17. The apparatus of claim 15, wherein the processor determines the position of the apparatus using the data from the sensing devices.

18. The apparatus of claim 15, wherein the processor determines the position of perforation guns using the data from the sensing devices.

19. The apparatus of claim 15, wherein programmable events, comprising detecting a radioactive tag or detecting a collar, trigger position determination.

20. The apparatus of claim 15, wherein the sensing devices comprise an accelerometer, pressure sensor, and gyroscope.
BEGIN

Convey a tool string through a borehole

Record measurements taken by sensing devices

Query or event trigger obtained?

Yes

Determine current position

Report determined position

END

Fig. 4
A. CLASSIFICATION OF SUBJECT MATTER
E21B 47/09(2006.01)i, E21B 47/12(2006.01)i, E21B 12/00(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
E21B 47/09; E21B 47/024; E21B 47/02; E21B 43/118; E21B 43/119; G01V 3/18; G01B 7/28; E21B 47/12; E21B 12/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS/KIPO internal & Keywords: positioning, sensing, borehole, perforating gun, probe, radioactive, roller counter, wheel and priority

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<td>A</td>
<td>US 2549109 A (MCPEE, JAMES W.) 17 April 1991 See column 4, lines 25-column 6, line 29 and figures 1-2.</td>
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<td>A</td>
<td>US 6145378 A (MICROBBIE et al.) 14 November 2000 See claims 1-13 and figures 1-3.</td>
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Further documents are listed in the continuation of Box C. See patent family annex.

* Special categories of cited documents:
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