Claims

What is claimed is:

1. A method of actuating a downhole tool in a wellbore, the wellbore having casing collars that form a physical signature for the wellbore, comprising:

acquiring a CCL data set from the wellbore, the CCL data set correlating recorded magnetic signals with measured depth, thereby forming a first CCL log for the wellbore;

selecting a location within the wellbore for actuation of a wellbore device;

downloading the first CCL log into a processor on-board the downhole tool;

deploying the downhole tool into the wellbore such that the downhole tool traverses casing collars, the downhole tool comprising the processor, a casing collar locator, and an actuatable wellbore device;

wherein the processor is programmed to:

continuously record magnetic signals as the downhole tool traverses the casing collars, forming a second CCL log;

transform the recorded magnetic signals of the second CCL log by applying a moving windowed statistical analysis;

incrementally compare the transformed second CCL log with the first CCL log during deployment of the downhole tool to correlate values indicative of casing collar locations;

recognize the selected location in the wellbore; and

send an actuation signal to the actuatable wellbore device when the processor has recognized the selected location; and

sending the actuation signal to actuate the downhole tool.

2. The method of claim 1, wherein:

the method further comprises transforming the CCL data set for the first CCL log by applying a moving windowed statistical analysis;

downloading the first CCL log into a processor comprises downloading the first transformed CCL log into the processor on-board the downhole tool; and

the processor incrementally compares the second transformed CCL log with the first transformed CCL log to correlate values indicative of casing collar locations.

3. The method of claim 1, wherein:

the first CCL log represents a depth series;

the second CCL log represents a time series; and

incrementally comparing the second transformed CCL log with the first CCL log uses a collar matching pattern algorithm to compare and correlate individual peaks representing casing collar locations.

4. The method of claim 3, wherein applying a moving windowed statistical analysis comprises:

defining a pattern window size (W') for sets of magnetic signal values; and

computing a moving mean m(t+1) for the magnetic signal values over time.

5. The method of claim 4, wherein:

the moving mean m(t+1) is in vector form and represents a mean of magnetic signal values for a pattern window (W); and

applying a moving windowed statistical analysis further comprises:

defining a memory parameter μ for the windowed statistical analysis; and

calculating a moving covariance matrix $\Sigma(t+1)$ for the magnetic signal values over time.

6. The method of claim 5, wherein:

the moving mean m(t+1) is an exponentially weighted moving average for the magnetic signal values for a pattern window (W); and

calculating a moving mean m(t+1) for the magnetic signal values is done according to the following equation:

$$m(t+1) = \mu\, y(t+1) + (1-\mu)\, m(t)$$

where $y(t+1)$ is a collection of magnetic signal values in a most recent pattern window (W+1), and

m(t) is the mean of magnetic signal values for a preceding pattern window (W).

7. The method according to claim 6, wherein calculating a moving covariance matrix $\Sigma(t+1)$ for the magnetic signal values comprises:

computing an exponentially weighted moving second moment A(t+1) for the magnetic signal values in a most recent pattern window (W+1); and

computing the moving covariance matrix $\Sigma(t+1)$ based upon the exponentially weighted second moment A(t+1).

8. The method of claim 7, further comprising:

defining m(W) = y(W) when the downhole tool is deployed,

where m(W) is the mean m(t) for a first pattern window (W), and y(W) is a transpose for m(W);

and

defining y(W) = $[x(1), x(2), \ldots x(W)]^T$ when the downhole tool is deployed,

where $x(1)$, $x(2)$, . . . x(W) represent magnetic signal values within a pattern window (W).

9. The method of claim 7, wherein:

computing an exponentially weighted second moment A(t+1) is done according to the following equation:

$$A(t+1) = \mu\, y(t+1) \times [y(t+1)^T + (1-\mu)\, A(t)$$

and

computing the moving covariance matrix $\Sigma(t+1)$ is done according to the following equation:

$$\Sigma(t+1) = A(t+1) - m(t+1) \times [m(t+1)]^T .$$

10. The method of claim 9, wherein applying a moving windowed statistical analysis further comprises:

computing an initial Residue R(t) for when the downhole tool is deployed;

computing a moving Residue R(t+1) over time; and

computing a moving Threshold T(t+1) based on the moving Residue R(t+1).

11. The method of claim 11, wherein:

the initial Residue R(t) is only computed if $t > 2 \times W'$

where t represents the number of magnetic signals that have been cumulatively obtained, and

W' represents the number of samples, or size, of each pattern window (W);

and

computing the initial Residue R(t) is done according to the following equation:

$$R(t) = [y(t) - m(t-1)]^T \times [\Sigma(t-1)^{-1} \times [y(t) - m(t-1)]$$

where R(t) is a single, unitless number

y(t) is a vector representing a collection of magnetic signal values for a present pattern window (W), and

m(t–1) is a vector representing the mean for a collection of magnetic signal values for a preceding pattern window (W).

12. The method of claim 11, wherein computing a moving Threshold T(t+1) comprises:

defining a memory parameter η for the threshold calculations; and

defining a standard deviation factor (STD_Factor).

13. The method of claim 12, wherein:

the moving Threshold T(t+1) is only computed if t > 2 x W'; and

applying a moving windowed statistical analysis further comprises marking a time (t) as a potential start of a collar location if:

$$t > \frac{W}{\mu},$$

R(t–1) < T(t), and

R(t) ≥ T(t).

where R(t) is a single, unitless number for a present pattern window,

R(t–1) is the Residue for a preceding pattern window (W),

W is a pattern window number, and

μ is the memory parameter for the windowed statistical analysis.

14. The method of claim 13, further comprising:

defining MR(2 * W'+1) = R(2 * W'+1) when the downhole tool is deployed,

where R represents the Residue,

MR represents the Moving Residue, and

(2 * W'+1) indicates a calculation when t > 2 * W',

defining SR(2 * W'+1) = $[R(2 * W'+1)]^2$ when the downhole tool is deployed,

where SR represents the second moment of Residue,

defining STDR(2 * W'+1) = 0 when the downhole tool is deployed,

where STDR represents the standard deviation of the Residue,

and

defining T(2 * W'+1) = 0 when the downhole tool is deployed.

15. The method of claim 14, wherein:

computing the Moving Residue (MR) is done is done according to the following equation:

$$MR(t+1) = v\,R(t+1) + (1-\mu)\,MR(t)$$

where MR(t) is the Moving Residue at a preceding pattern window, and

MR(t+1) is the Moving Residue at a present pattern window,

computing the Second Moment of Residue (SR) is done is done according to the following equation:

$$SR(t+1) = \mu\,[R(t+1)]^2 + (1-\mu)\,SR(t)$$

where SR(t) is the Second Moment of Residue at the preceding pattern window, and

SR(t+1) is the Second Moment of Residue at the present pattern window,

computing the Standard Deviation of the Residue (STDR) is done is done according to the following equation:

$$STDR(t+1) = \sqrt{SR(t+1) - [MR(t+1)]^2}$$

where STDR(t+1) is the Standard Deviation of the Residue at the present pattern window,

and

computing the moving Threshold T(t+1) is done is done according to the following equation:

$$T(t+1) = MR(t+1) + \text{STD_Factor} \times STDR(t+1).$$

16. The method of claim 3, wherein the collar matching pattern algorithm comprises:

establishing baseline references for depth from the first CCL log, and for time from the transformed second CCL log;

estimating an initial velocity v_1 of the autonomous tool;

updating a collar matching index from a last confirmed collar match, indexed to be d_k for the depth, and t_l for the time;

determining a next match of casing collars using an iterative process of convergence;

updating the collar matching index based on a best computed match; and

repeating the iterative process.

17. The method of claim 16, wherein estimating an initial velocity v_1 of the autonomous tool comprises:

assuming a first depth d_1 matches a first time t_1;

assuming a second depth d_2 matches a second time t_2; and

calculating the estimated initial velocity using the following equation:

$$v_1 = \frac{d_2 - d_1}{t_2 - t_1}$$

18. The method of claim 16, wherein the iterative process of convergence comprises the following steps:

(1) If $v = \left(\frac{d_{k+1} - d_k}{v_{l+1} - v_l}\right)$ satisfies $(1 - e)\,u < v < (1 + e)\,u$, match d_{k+1} with t_{l+1};

(2) Else, if $(d_{k+1} - d_k) < v\,(t_{l+1} - t_l)$, delete d_{k+1} from the index and reduce all later indices by 1 so that the next depth number in sequence is d_{k+1}, and return to step (1);

(3) Else, if $(d_{k+1} - d_k) > v\,(t_{l+1} - t_l)$, delete d_{l+1} from the index and reduce all later indices by 1 so that a next time number in sequence is t_{l+1}, and return to step (1);

wherein u represents a last confirmed velocity estimate; and

e represents a margin of error.

19. The method of claim 18, wherein the margin of error e is no greater than 10 percent.

20. The method of claim 1, wherein incrementally comparing the second transformed CCL log with the first CCL log uses a collar matching pattern algorithm to compare and correlate more than two individual peaks at a time.

21. The method of claim 1, wherein acquiring a CCL data set from the wellbore comprises:

running a casing collar locator into the wellbore on a wireline; and

pulling the casing collar locator to record magnetic signals as a function of depth.

22. The method of claim 1, wherein the downhole tool further comprises a fishing neck.

23. The method of claim 1, wherein:

the actuatable wellbore device is a fracturing plug configured to form a substantial fluid seal when actuated within the wellbore at the selected depth;

the fracturing plug comprises an elastomeric sealing element and a set of slips for holding the location of the downhole tool proximate the selected depth; and

sending the actuation signal actuates the sealing element and the slips.

24. The method of claim 23, wherein:

the fracturing plug is fabricated from a friable material; and

the fracturing plug is configured to self-destruct a designated period of time after the fracturing plug is set in the wellbore.

25. The method of claim 1, wherein:

the actuatable wellbore device is a perforating gun having charges; and

sending the actuation signal actuates the perforating gun to detonate the charges.

26. The method of claim 25, wherein:

the perforating gun is substantially fabricated from a friable material; and

the perforating gun is configured to self-destruct after the charges are detonated.

27. A tool assembly for performing a tubular operation in a wellbore, the wellbore having casing collars that form a physical signature for the wellbore, and the tool assembly comprising:

an actuatable tool;

a casing collar locator for sensing the location of the actuatable tool within a tubular body based on the physical signature provided along the tubular body; and

an on-board controller configured to send an actuation signal to the actuatable tool when the location device has recognized a selected location of the actuatable tool based on the casing collars;

wherein:

the actuatable tool, the casing collar locator, and the on-board controller are together dimensioned and arranged to be deployed in the tubular body as an autonomous unit;

the on-board controller has stored in memory a first CCL log representing magnetic signals pre-recorded from the wellbore; and

the on-board controller is programmed to:

continuously record magnetic signals as the tool assembly traverses the casing collars, forming a second CCL log;

transform the recorded magnetic signals of the second CCL log by applying a moving windowed statistical analysis;

incrementally compare the transformed second CCL log with the first CCL log during deployment of the downhole tool to correlate values indicative of casing collar locations;

recognize a selected location in the wellbore; and

send an actuation signal to the actuatable tool when the processor has recognized the selected location in order to perform the tubular operation.

28. The tool assembly of claim 27, wherein:

the actuatable tool is a fracturing plug configured to form a substantial fluid seal when actuated within the tubular body at the selected location; and

the fracturing plug comprises an elastomeric sealing element and a set of slips for holding the location of the tool assembly proximate the selected location.

29. The tool assembly of claim 27, wherein:

the tool assembly is a perforating gun assembly; and

the actuatable tool comprises a perforating gun having an associated charge.

30. The tool assembly of claim 27, further comprising:

a fishing neck.

31. The tool assembly of claim 27, wherein:

the actuatable tool is a bridge plug configured to form a substantial fluid seal when actuated within the tubular body at the selected location; and

the bridge plug comprises an elastomeric sealing element and a set of slips for holding the location of the tool assembly proximate the selected location.

32. The tool assembly of claim 27, further comprising:

an accelerometer in electrical communication with the on-board controller to provide a velocity estimate of the tool assembly when comparing the transformed second CCL log with the first CCL log.

33. The tool assembly of claim 27, wherein:

the casing collar locator comprises a first casing collar locator proximate a first end of the tool assembly;

the tool assembly further comprises a second casing collar locator proximate a second opposing end of the tool assembly, separated a distance d; and

the on-board controller is further programmed to:

calculate velocity based upon the distance (d) divided by time (t) in which the first and second casing collar locators respectively traverse a casing collar to provide a velocity estimate of the tool assembly when comparing the transformed second CCL log with the first CCL log.

34. The tool assembly of claim 27, wherein:

the actuatable tool is a casing patch, a cement retainer, or a bridge plug; and

the actuatable tool is fabricated from a millable material.

CLAIMS

1. An invention not claimed in any divisional application.