ISCWSA
Prediction of Wellbore Position Accuracy when surveyed with Gyroscopic Tools

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A simplified error model for estimation of wellbore position accuracies when surveyed with gyroscopic tools

Torgeir Torkildsen, Statoil

ISCWSA meeting, Amsterdam March 2nd, 2001

Presentations/Discussions

- ISCWSA meetings
  - 2001, March 2nd, Haarlem
  - 2001, June 7th, Denver
  - 2003, February 18th, Amsterdam
  - 2003, October 9th, Denver
  - 2004, April 2nd, Paris

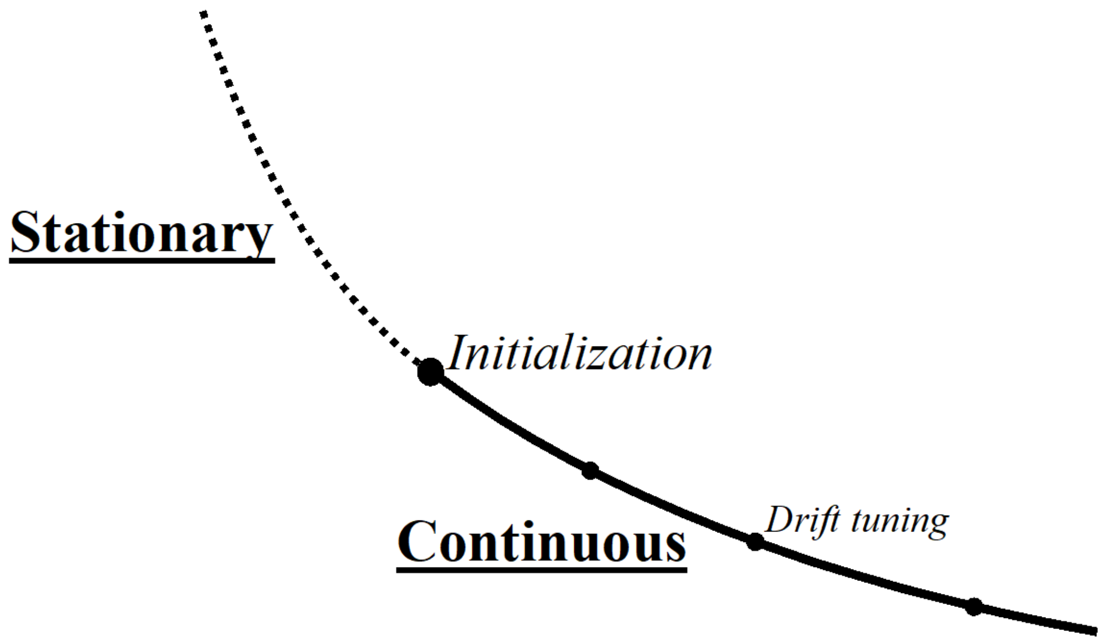
Gyro Group

- Gyro Group meetings
  - 2002, June 12th, Stavanger
  - 2003, February 17th, Amsterdam
  - 2003, October 8th, Denver
- Author meetings
  - 2003, May 6th, Aberdeen
  - 2003, December 3rd-4th, Trondheim
  - 2004, January 29th, Final proposal

Objectives

- Estimation of wellbore position accuracies
- General gyro error model
- Standard for the oil industry
- Easy to implement in software products for well planning and survey management

Survey modes



Error terms for Tool Inclination

- **Stationary**
  - Accelerometer Biases
  - Accelerometer Scales
  - Gravity Bias
  - Sensor Misalignments
- **Continuous**
  - Accelerometer Biases
  - Accelerometer Scales
  - Gravity Bias
  - Sensor Misalignments

Error terms for Tool Azimuth

- **Stationary**
  - Gyro Random Biases
  - Gyro Biases
  - Gyro Spin Mass Unballances
  - Gyro Input Mass Unballances
  - Gyro Scales
  - Sensor Misalignments
  - ~~Tool Inclination~~
- **Continuous**
  - Azimuth Reference
  - Gyro Random Walks
  - Gyro Drifts

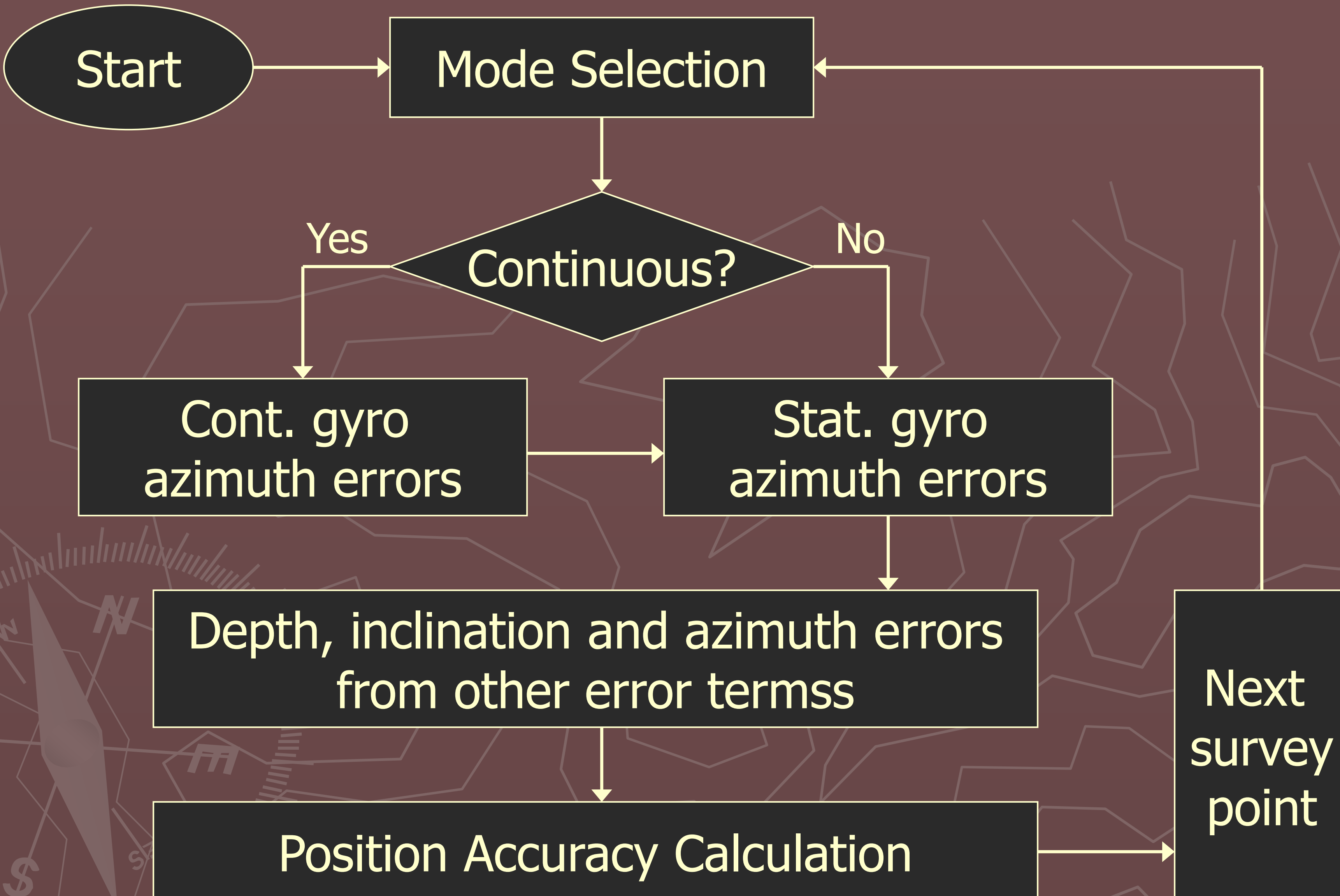
Error terms for Wellbore Inclination and Azimuth

- Inclination
  - Tool Inclination
  - xy Misalignments
  - Vertical Sag
- Azimuth
  - Tool Azimuth
  - xy Misalignments

Sensor Packages

- Accelerometer
  - xy g-sensitive
  - xyz g-sensitive
- Gyro
  - xy rotation sensitive
  - z rotation sensitive
  - xyz rotation sensitive

The General Gyro Error Model covers any combination of these


Start
Mode Selection
Continuous?
Yes
No
Cont. gyro azimuth errors
Stat. gyro azimuth errors
Depth, inclination and azimuth errors from other error termss
Position Accuracy Calculation
Next survey point

Error Term Groups
General mode

- Depth
- Tool Misalignment
- XY Accelerometer
- XYZ Accelerometer

Error Term Groups Stationary mode / Initialisation

- External Reference
- XY Stationary Gyro
- XYZ Stationary Gyro

Error Term Groups Continuous mode

- Z Continuous Gyro
- XY Continuous Gyro
- XYZ Continuous Gyro

Error Term Groups (10)

- On/Off
- Inclination interval
- Other parameters:
  - Misalignment alternative
  - Cant angle
  - Running speed
  - ....

General mode

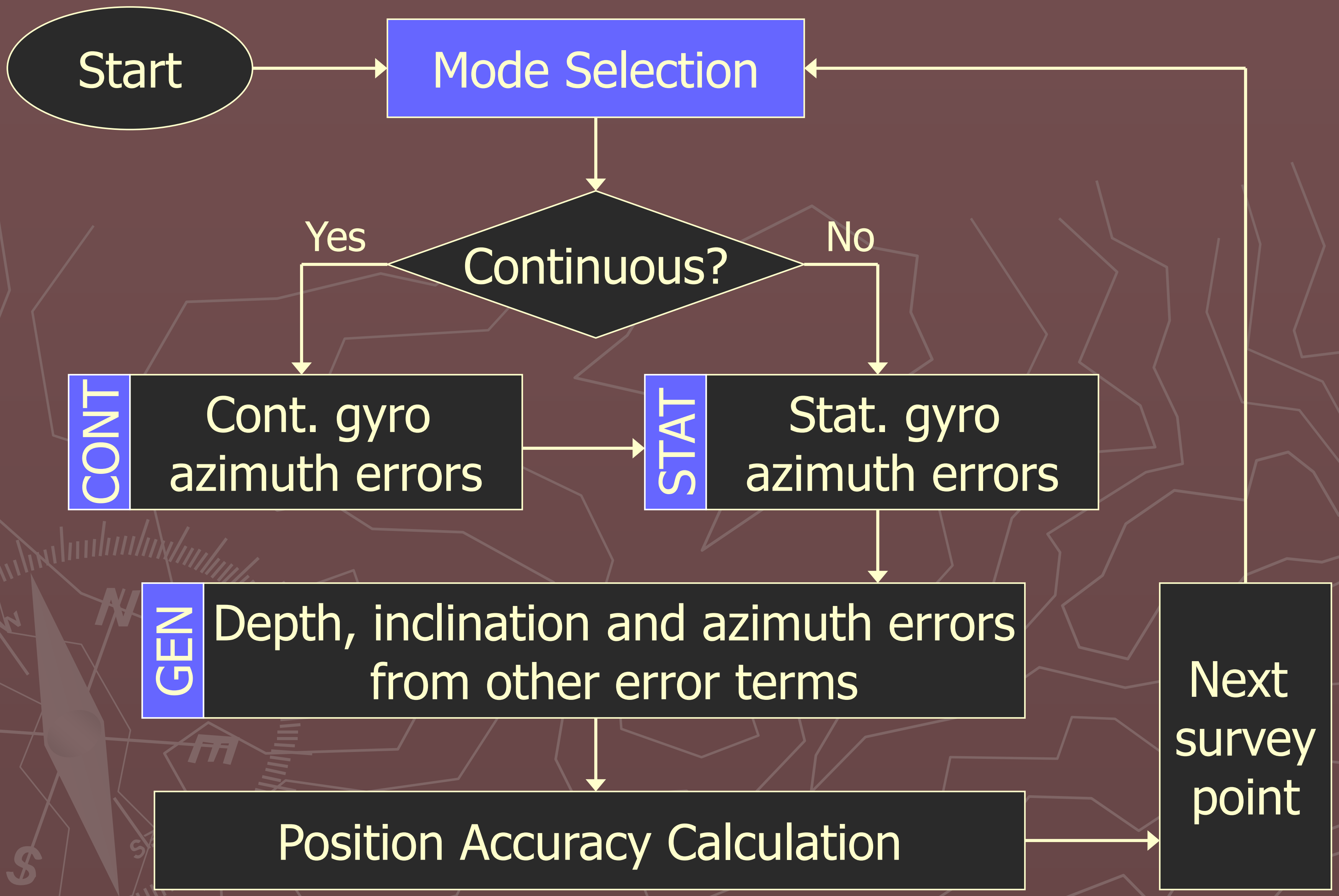
Error term groups (mode)		*Used (yes/no)*		*Definitions / Parameters*			
Depth Error (GEN)							
Tool Misalignments (GEN)	**Alt. #1**		**Select one of these**				
	Alt. #2						
	Alt. #3						
XY Accelerometer (GEN)			**Select one of these**	**Cant angle →**		**Switching (5) →**	
XYZ Accelerometer (GEN)							

Stationary mode / Initialisation

<table>
<tr><td colspan="2">Error term groups (mode)</td><td colspan="2">Used (yes/no)</td><td colspan="3">Definitions / Parameters</td></tr>
<tr><td colspan="4"></td><td>start_inc</td><td>end_inc</td><td>init_inc</td></tr>
<tr><td rowspan="2">External Reference (STAT)</td><td>Foresight</td><td></td><td rowspan="4">Select one of these</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>Tie-on</td><td></td></tr>
<tr><td colspan="2">XY Stationary Gyro (STAT)</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">XYZ Stationary Gyro (STAT)</td><td></td><td></td><td></td><td></td></tr>
</table>

Continuous mode

Error term groups (mode)	*Used (yes/no)*		*Definitions / Parameters*		
			start_inc	*end_inc*	*running speed*
Z Continuous Gyro (CONT)		**Select one or more of these**			
XY Continuous Gyro (CONT)					
XYZ Continuous Gyro (CONT)					
Minimum distance along well bore between initialisations (min_D)			**Noise reduction factor for gyro noise at initialisation**		


Start
Mode Selection
Yes
Continuous?
No
CONT
Cont. gyro azimuth errors
STAT
Stat. gyro azimuth errors
GEN
Depth, inclination and azimuth errors from other error terms
Position Accuracy Calculation
Next survey point

Error Terms (48)

- Value
- Propagation: R/S/W/G

- All terms are independent variables
- All azimuth initialisation errors are propagated systematically (S) in continuous mode

Error Terms

Depth (GEN)

Error term	Mode	Value
Depth Random Error	R	0.50 m
Depth Systematic Reference	S	0.50 m
Depth Scale	W	0.001
Depth Stretch-type	G	5.0×10^{-7} /m

Tool Misalignment (GEN)

Error term	Mode	Value
xy Misalignment 1	S	0.1 deg
xy Misalignment 2	S	0.1 deg
xy Misalignment 3	S	0.2 deg
xy Misalignment 4	S	0.2 deg
Vertical Sag	S	0.1 deg

XY Accelerometer (GEN)

Error term	Mode	Value
xy accelerometer bias		
Accelerometer scale factor error		
Accelerometer misalignment		
Gravity bias		

XYZ Accelerometer (GEN)

Error term	Mode	Value
xy accelerometer bias	S	0.005 m/s2
z accelerometer bias	S	0.005 m/s2
Accelerometer scale factor error	S	0.0005
Accelerometer misalignment	S	0.05 deg.

Error Coefficients
Weighting Functions

$\Delta\omega_x = (\Omega\cos\phi\cos A\cos I + \Omega\sin\phi\sin$ …

$\Delta\omega_y = -\Omega\cos\phi\sin A \;\; s_y$

Substituting for $\Delta\omega_x$ and $\Delta\omega_y$ in equation A …
error:

$\Delta A = \dfrac{\sin A(\Omega\cos\phi\cos A\cos I + \Omega\sin \ldots}{\dfrac{\cos A\sin I}{\Omega\cos\phi} \quad \Omega c \ldots}$

$= (\sin A\cos A + \tan\phi\,\sin A\,\tan I)\, s$ …

Hence

Error term	Mode	Error coefficient
xy gyro bias 1 (High side bias)	S/R [1]	$\dfrac{\sin A}{\Omega\cos\phi\cos I}$ [2]
xy gyro bias 2 (High side right bias)	S/R [1]	$\dfrac{\cos A}{\Omega\cos\phi}$ [2]
xy gyro random noise	R	$f\cdot\dfrac{\sqrt{1-\cos^2 A\sin^2 I}}{\Omega\cos\phi\cos I}$ [3]
xy gyro g-dept error 1 [A,B] (Input/Quadrature mass unbalance)	S	$\dfrac{\cos A\sin I}{\Omega\cos\phi}$
xy gyro g-dept error 2 [C,D] (Input mass unbalance)	S/R [1]	$\dfrac{\cos A\cos I}{\Omega\cos\phi}$ [2]
xy gyro g-dept error 3 [D] (Input mass unbalance)	S/R [1]	$\dfrac{\sin A}{\Omega\cos\phi}$ [2]
xy gyro g-dept error 4 [A-D] (Spin/Direct mass unbalance)	S	$\dfrac{\sin A\tan I}{\Omega\cos\phi}$

Numerical Examples

- Example Error Models (6)
- Wellbores: ISCWSA #1, #2, #3

- Position Covariance Elements to coincide within �1% or �2m² (ft²)

Numerical Examples

Example Model, #2

Depth [m]	NN	NE	NV	EE	EV	VV
1200	19	0	0	18	0	2
2100	1446	-376	-2	144	-6	9
5100	86999	-23272	-18	6400	-49	137
5400	-	-	-	-	-	-
8000	-	-	-	-	-	-

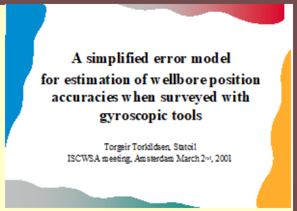
Example Model, #3

Depth [m]	NN	NE	NV	EE	EV	VV
1200	19	0	0	18	0	2
2100	923	-235	-2	106	-6	9
5100	45445	-12136	-13	3408	-38	120
5400	54685	-14608	-14	4085	-39	136
8000	181521	-48567	-16	13296	-38	289

Upcoming Actions

- Some minor corrections will be placed on the ISCWSA/SPE web-site (week 16)
- SPE paper 90408 to be prepared for presentation at the ATCE in Houston, September 2004

General Gyro Tool Error Model
Wellbore Position Accuracy Estimation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- ***Can Position Accuracies be properly estimated with the proposed model when the well is surveyed with Your Gyro Tools?***
- ***Do we need another Propagation Methodology?***
- ***Do we need any additional Error Term(s)?***
- ***Can we remove any of the proposed Error Term(s)?***
- ***Are you able to serve oil industry with Reliable Values for Error Terms which are actual for Your Gyro Tool(s)?***