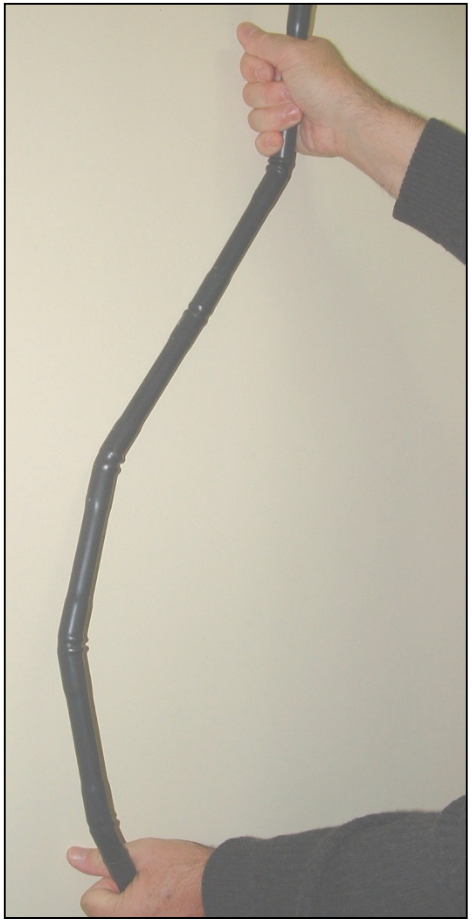
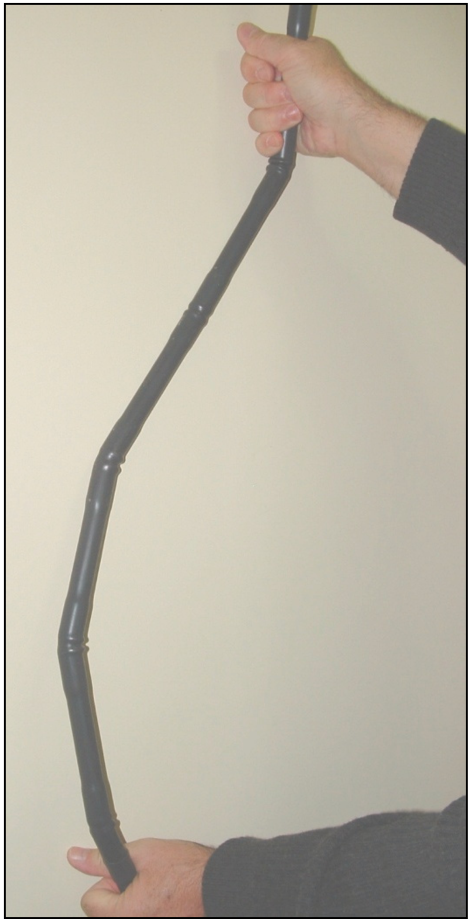


Measurand ShapeAccelArray (SAA)

General Description

This is a broad overview of SAA technology for geotechnical measurements. Please visit our website for more detail:

www.MeasurandGeotechnical.com



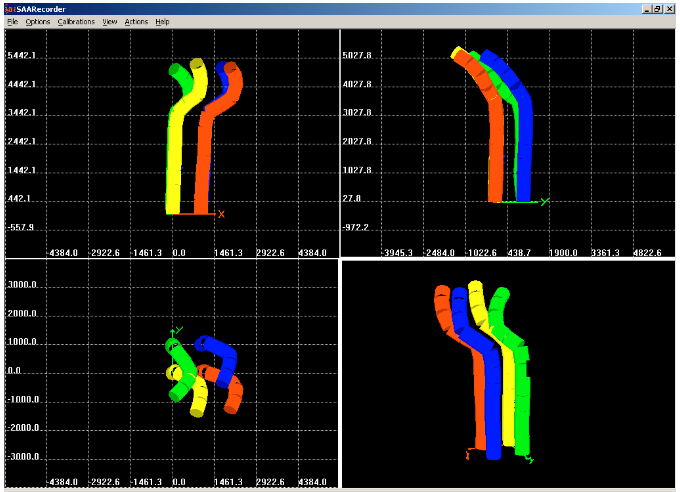
Measurand ShapeAccelArray (SAA)
measures 2D and **3D shape** and **3D vibration** using a compact array of MEMs sensors and proven ShapeTape / ShapeRope algorithms. Unlike collections of tilt sensors or arrays of sensors that bend in a single direction, SAA is a flexible, calibrated 3D measuring system requiring no other guides or fixturing. It bends freely, without a preferred axis, in 2 degrees of freedom and may be mounted **vertically** or **horizontally**. It **rolls up** for shipping and storage.

Versions are available for wireless **field** installation and with enhanced acquisition bandwidth for laboratory **research** installations.

ShapeAccelArray (SAA) is a calibrated "smart array" that "knows its own shape" in 3D when near-vertical, and in 2D when near-horizontal. SAA also monitors vibration in 3D.

Applications

- In-situ monitoring of unstable slopes
- Monitoring of civil structures
- Monitoring of mines and excavations
- Measuring drill-hole shape
- Laboratory research



Advantages

SAA Advantages over manual or in-place inclinometers

- **Higher spatial resolution**
- **Larger tolerance to shearing**
- **Autonomous data collection**
- **Ease of calibration**
- **Vibration data provided**
- **Reusable**
- **Inexpensive casing**
- **Low installation costs**
- **Low maintenance costs**
- **Higher spatial resolution**
- **Fully automated/ fewer errors**

Patents

ShapeAccelArray is covered by patents including

7296363
6127672
6563107
WO 02/055958
WO 02/055958
WO 98/41815
others pending

SAA Design

- Rigid segments connected by joints that bend in any direction
- Stiff in torsion
- Standard segment length is 305 mm, 500 mm is also available
- Segments contain 3 orthogonal MEMS gravity/vibration sensors
- Every eighth segment includes a microprocessor

SAA Installation

Note: Beginning in early 2008, SAAs were being shipped with an over-covering of stainless steel braid, which provides protection against abrasion. A new joint design eliminated the "webbing" used in previous installations.

•SAA slides directly into 27 mm (1.049") ID PVC casing. The SAA may be rotated to align an X mark at the top with a geographical feature (e.g. "North", or "down-slope").

•When compressed axially, SAA coverings expand slightly to snug the SAA into the casing. The casing may be grouted or supported by sand in a larger hole (cased or not).

•Sand allows for extraction even after large shears; grout is often used in construction sites where deformations are expected to be minimal.

•The flexibility and small size of the array, along with this installation method, enables much longer lifetimes and more certain re-use than with other technologies.

Position

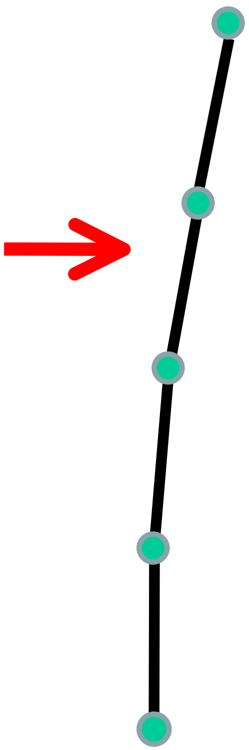
Position Determination

•SAA comprises segments of fixed length (305 or 500 mm)

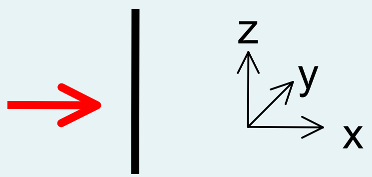
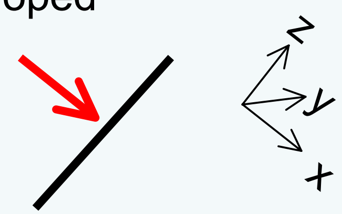
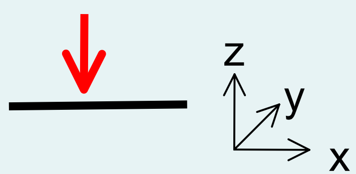
•Gravity measurements by triaxial accelerometers allow 3D shape to be determined if segments are within ~60° of vertical. Otherwise, 2D shape (e.g. settlement) is measured.

•SAA doesn't extend or compress, therefore should be oriented perpendicular to anticipated displacement direction (vertical, horizontal, or in between).

•Measurements are relative to stable ground (e.g. stable soil at end of borehole), or to a survey point.



Displacement Scenario

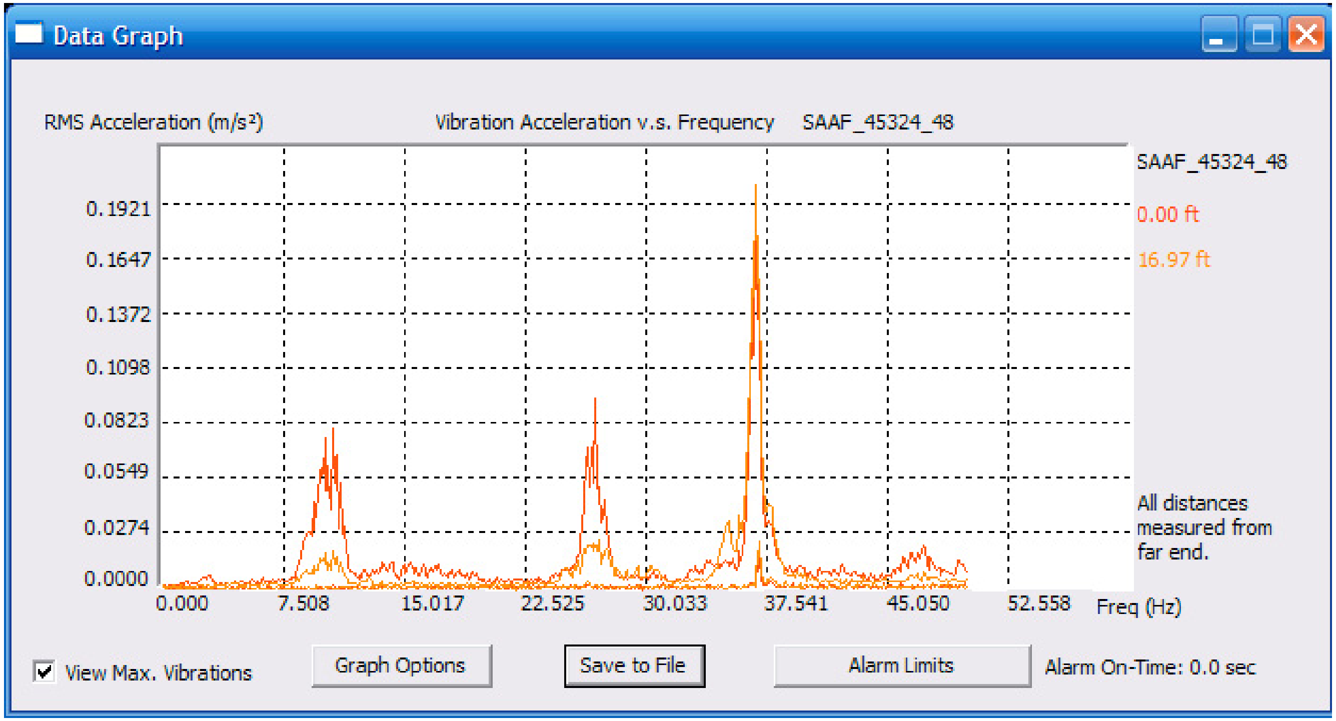
Displacement Scenario	Orientation	Data
Mainly horizontal: 	Near vertical	X,Y displacements at known Z locations
Sloped 	Perpendicular to slope	X,Y displacements at known Z locations. Z axis perpendicular to displacement
Mainly vertical 	Near horizontal	Z displacements at known X locations

Vibration

Vibration Measurement

•SAARecorder software includes 3D real-time vibration capture, display, and export, using FFT algorithms.

•Field installations can be equipped to trigger on earthquakes or other vibration events and record 3D vibration at selected depths.



Versions

Versions of ShapeAccelArray

Field Arrays (SAAF)

Vertical or Horizontal (down-hole, cross-slope, settlement).
Battery-operated, automatic wireless posting of data.
Tilt measurement from all segments.
Rapid vibration measurement from a few segments.

High-Bandwidth Research Arrays (SAAR)

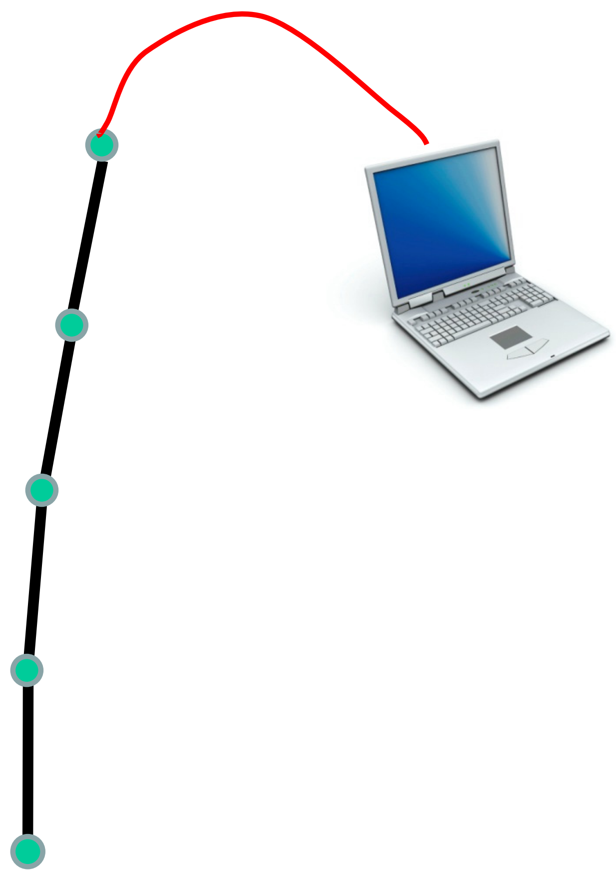
Vertical or Horizontal.
Ideal for Shaker Box research.
Tilt measurement from all segments.
Rapid vibration measurement from all segments, even more rapid from selected segments.

Highly-Flexible Arrays (FAA): See www.MeasurandGeotechnical.com

PODs: See www.MeasurandGeotechnical.com

Interface to PC

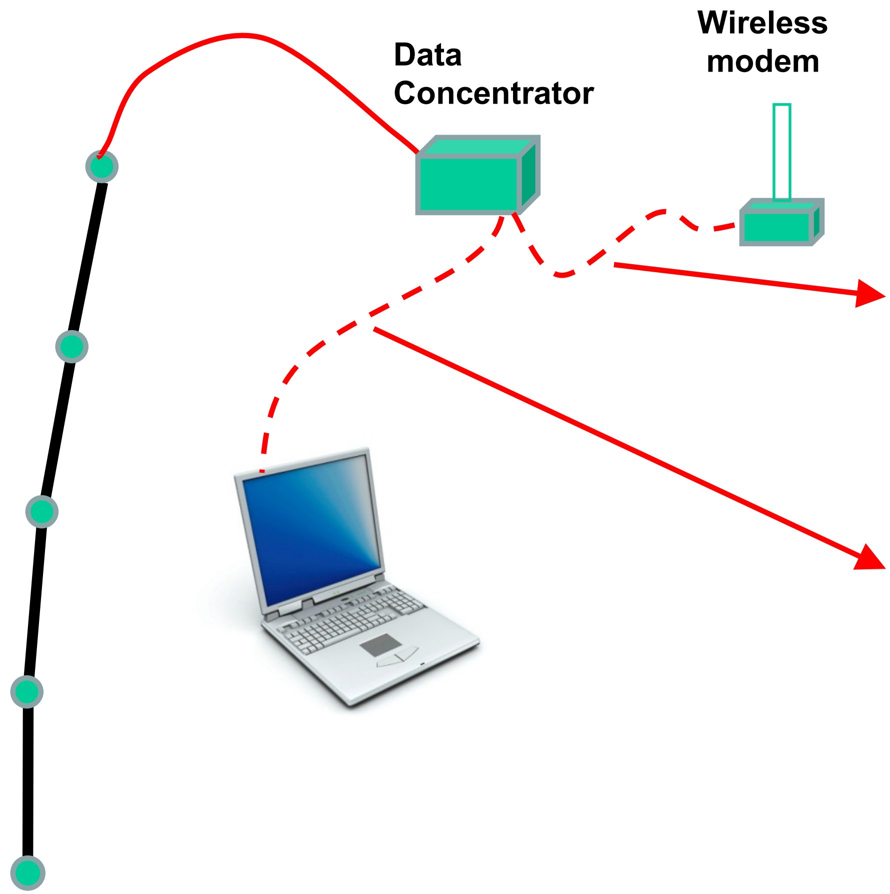
Interface to PC, or...



- Normally used in research installations for real-time acquisition of shape and vibration on demand.
- Capable of automated remote monitoring where it makes sense to use a PC instead of a low-power, automated Data Concentrator.
- SAAs interfaced through USB port or RS 485 card.
- SAARecorder Software.

Interface to DC

...Interface to Data Concentrator

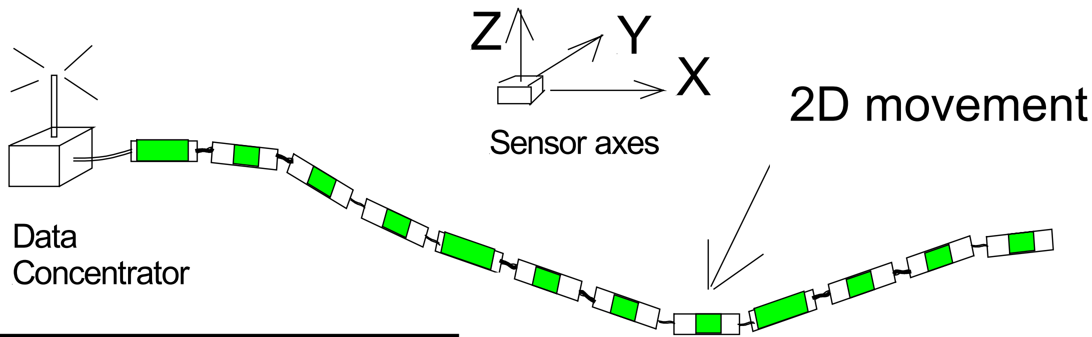


- Data concentrator (DC) useful for unattended field installations. DC is usually solar powered.
- DC stores data automatically, with up to 3-year capacity.
- Typical transfer: DC automatically connects to internet using cellnet or other wireless means. Data are served automatically to customer's internet connection.
- Simplest transfer: PC periodically used to download data via serial port of DC.
- SAA3D Viewer software used to view/export data.
- DC can be configured remotely to change alarm levels, acquisition times, connection times, etc.

For more details on types of SAA and their configurations, see "SAA_Specifications.pdf" and "SAA_Field_Configurations.pdf"

SAA can be used in "horizontal" mode, to monitor settlement or cross-slope slide movement. The hardware is the same; Software is set for "2D" mode (XZ plane).

Data: 2D/3D Shape & 3D vibration



In SAARecorder Software, it is possible to monitor "mixed-mode" shapes in 2D. Mixed-mode means segments can be at any angle, approximately within a vertical plane.

Field or Research Version of ShapeAccelArray (Horizontal application)

Math

ShapeAccelArray
3D shape calculations

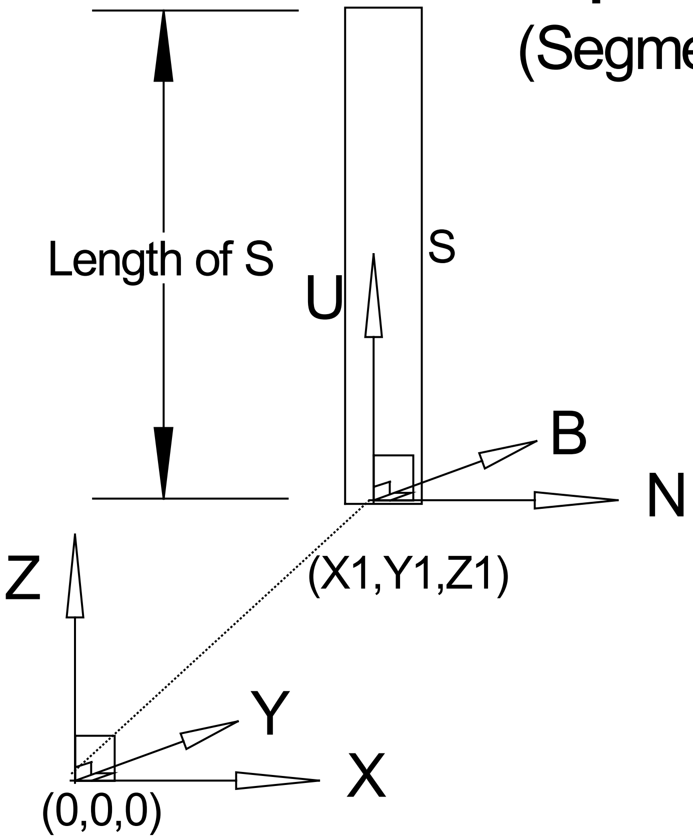
ShapeAccelArrays, like ShapeTapes, measure the shape of an array, expressed as a series of **positions** in x,y,and z and a set of **orientations** associated with the points. The positions form a **polyline** (line segments connected at vertices). The orientations are expressed as sets of unit orientation vectors, which may be converted to Euler angles or quaternions.

Geometrical Rotation Process using Polylines

A polyline may be created by performing rotations on its line segments. In the general case, the polyline may represent connected objects that can be bent in 2 DOFs and twisted in 1 DOF. If the bends and twists are known, the polyline may be calculated by the following geometrical rotation process:

3D Description of a Segment

(Segments are the stiff portions of ShapeAccelArray)



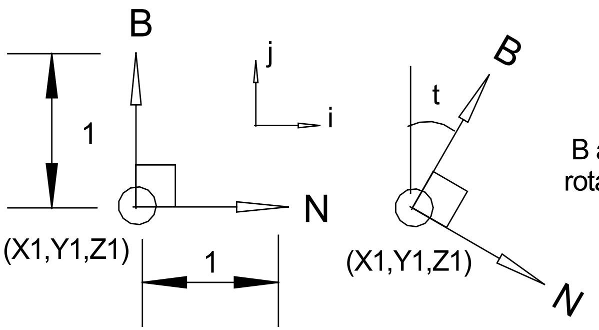
The position of a rigid segment S may be described in an X,Y,Z world coordinate system as (X1,Y1,Z1) relative to the origin (0,0,0).

The orientation of S may be described by a set of mutually orthogonal unit vectors U,N,B in the world coordinate system.

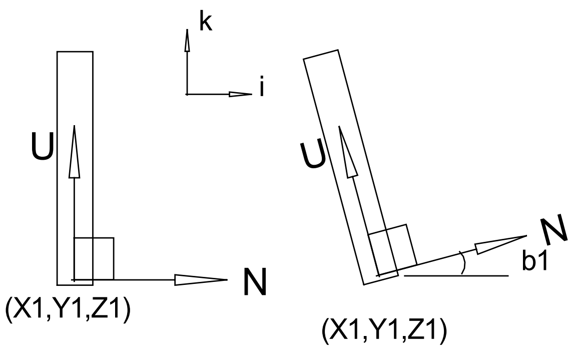
In the simplest case, U,N,B are aligned with X,Y,Z as shown.

However, to transform the simplest case to a more general case, we may rotate a segment within its local coordinate system (i,j,k) in three degrees of freedom:

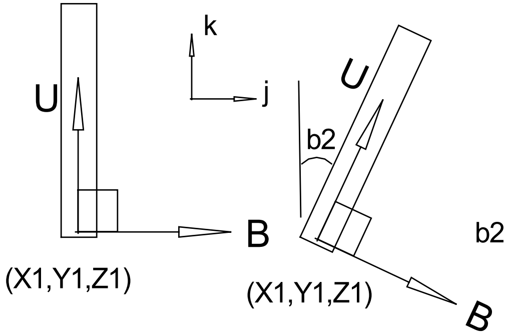
3DOF Rotations



B and N may be rotated about U through a torsional angle t, ...



U and N may be rotated about B through a first bend angle b1, ...



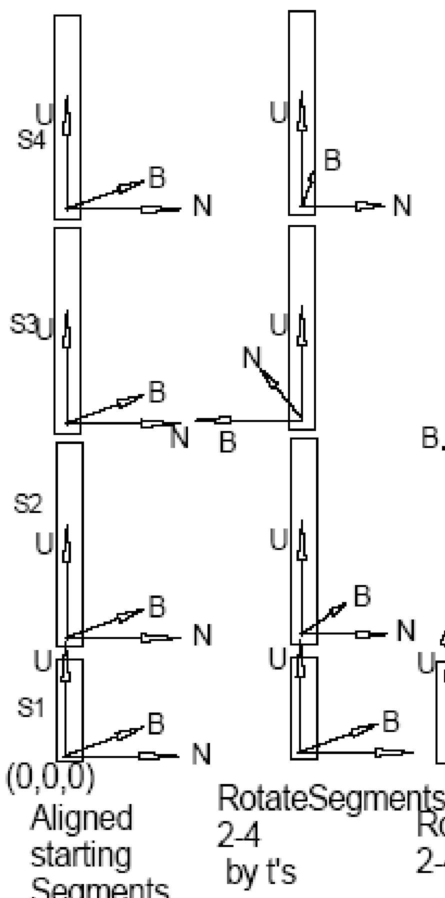
and U and B may be rotated about N by a second bend angle b2.

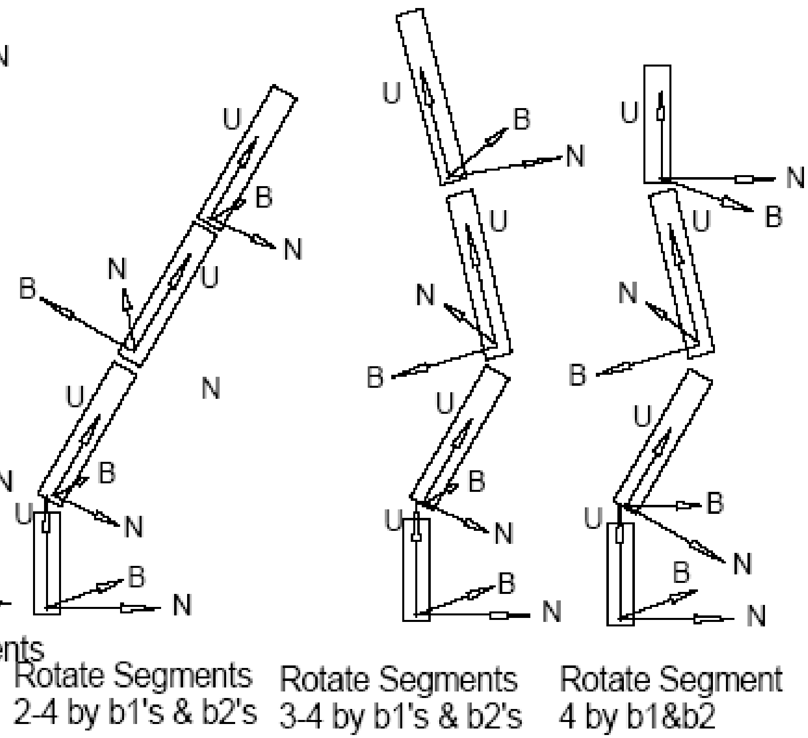
The vectors X1,Y1,Z1 and U,N,B and the length of S completely define the center line of the segment S.

ShapeTape / ShapeRope Calculation

To transform an aligned set of Segments s1…s4 into an arbitrary 3D shape, we can perform a series of rotations by the t, b1, and b2 angles of each Segment relative to the preceding Segments.

Because the rotations are relative to preceding Segments, t's may be thought of as "twists", and b1's and b2's are "bends". In Measurand ShapeTapes and ShapeRopes, twists and bends are measured directly using fiber optic sensors. (In ShapeTapes, only one axis of bend is present).



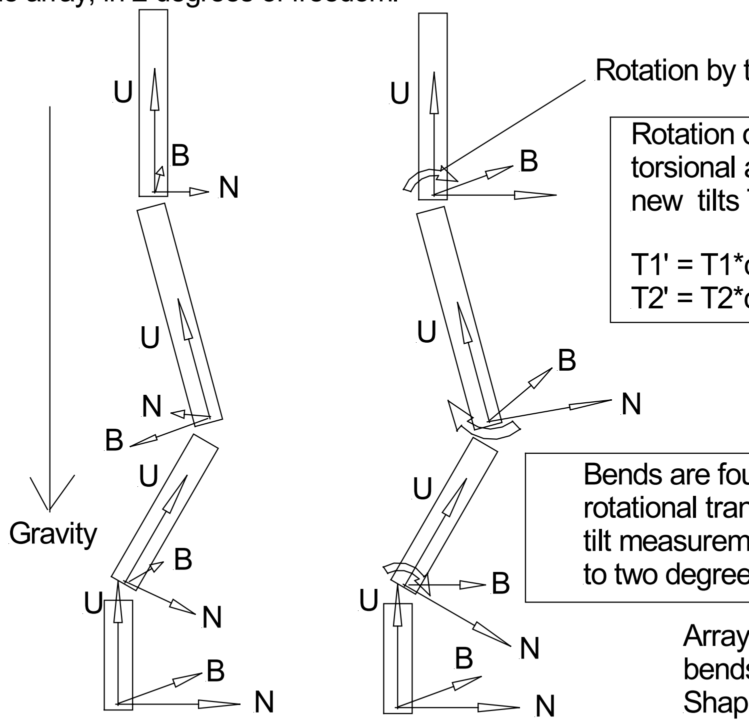


The segments are now in the desired 3D shape

ShapeAccelArray Calculation

In Measurand ShapeAccelArrays, accelerometers are used to sense components of the gravity vector in each Segment. The accelerometers are not aligned torsionally within the Segments during manufacture, but are at known torsional angles (t's) determined after construction. The joints are constrained not to twist, so the calibration t's may be used to "align" the sensor readings torsionally.
Aligned x and y components of the gravity vector represent absolute tilt angles in the world coordinate system.

To determine the 3D shape of the array, the measured x and y components are rotated by the known torsional angles to find a new set of "aligned" tilt components. Then the bend angles are calculated from the differential tilt along the array, in 2 degrees of freedom.



Rotation of T's about U's by torsional angle t to produce new tilts T':

T1' = T1*cos(t) - T2.*sin(t);
T2' = T2*cos(t) + T1*sin(t);

Bends are found using inverse rotational transforms based on tilt measurements, constrained to two degrees of freedom.

Array shape is calculated from bends, using advanced ShapeTape mathematics.

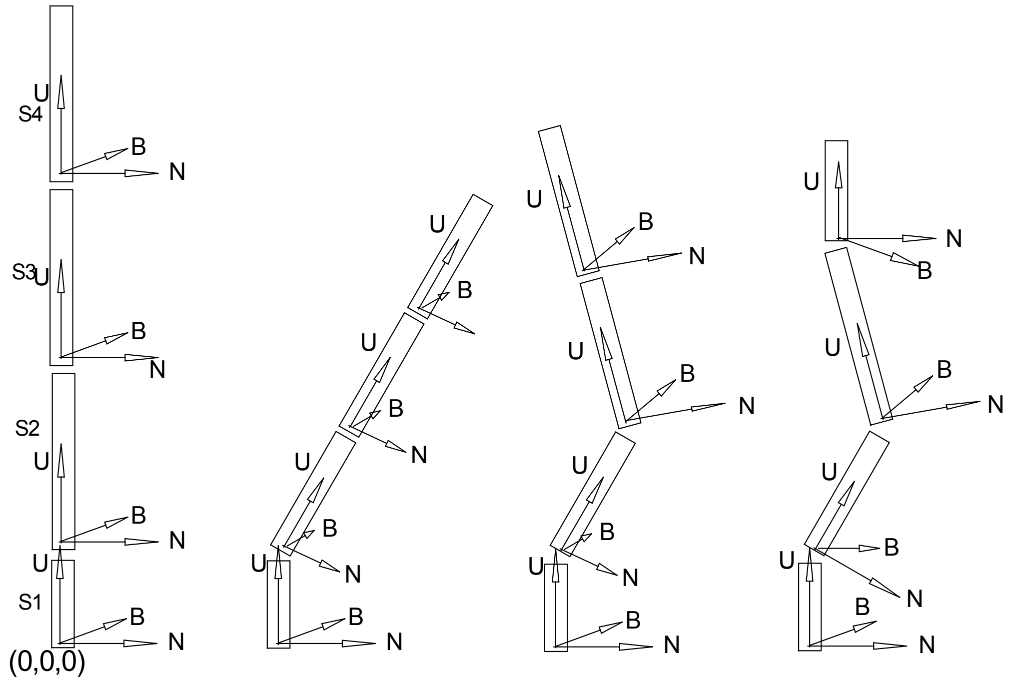
The accelerometers are not aligned torsionally. But the joints do not allow twist, so...

rotations by calibrated twist values about U's are used to find x and y values of tilt within an "aligned" coordinate system.

ShapeAccelArray Calculation

After the alignment process using calibrated torsional values (t's), and after "local" bends (b's) are known from the "absolute" tilts (T's), the calculation of shape can proceed. It is the same as a ShapeTape or ShapeRope calculation, without any twist stage (2DOF bend only).

The physical segment lengthsare specified in a factory calibration file and are used to scale each segment of the calculated 3D polyline. Calculation methods take into account the effects of order of rotation. The result is a 3D polyline with the same shape as the physical array.



Starting Segments that were "virtually aligned" in the previous step

Rotate Segments 2-4 by b1's & b2's determined from virtually aligned accelerometer tilt values

Rotate Segments 3-4 by b1's & b2's determined from virtually aligned accelerometer tilt values

Rotate Segment 4 by b1&b2 determined from virtually aligned accelerometer tilt values