Instruction for 'ThreeD_path'

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'ThreeD_path' is a customized macro compliant with IGOR Pro (Wavemetrics). It is programmed to calculate three-dimensional paths from tri-axis magnetisms, tri-axis accelerations, swimming speed and depth data based on algorithm introduced in Johnson & Tyack (2003).

Contents:

1. Before using 'ThreeD_path' (Data preparation)

'ThreeD_path' is a customized macro is used for reconstruction of three-dimensional paths by calculating heading, pitch and roll (Fig. 1). Tri-axis magnetisms, tri-axis accelerations, swimming speed and depth data are required to use 'ThreeD_path'. Note that the directions of tri-axis must be set as Fig. 1 for correct estimations.

Upon calculation, 'ThreeD_path' automatically changes the sampling interval to the lowest interval if the sampling intervals differ among the data. For example, 32 Hz tri-axis acceleration data and 1Hz other data are used in 'ThreeD_path', acceleration data are automatically down-sampled to 1Hz before the calculation. As a consequent, the resulting estimations are at 1 Hz.
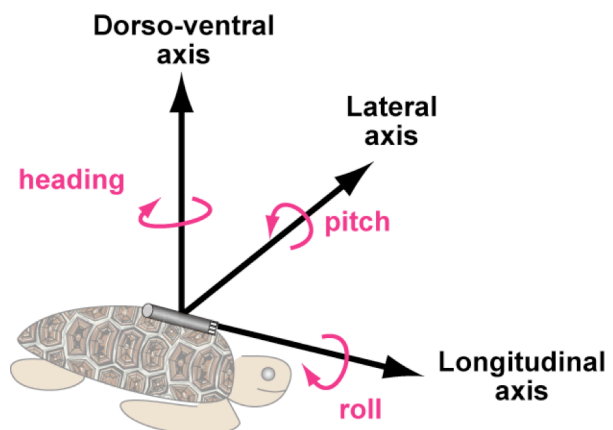

Fig.1 Directions of tri-axis and rotation for 'ThreeD_path'

Many data loggers (e.g. 3MPD3GT produced by Little Leonardo) record tri-axis accelerations and magnetisms as relative values. Therefore, such relative values must be converted into absolute values with appropriate units (m/s^2 or G for accelerations, and nT for magnetisms) before using 'ThreeD_path'.

See Fig.2 as an example: a data logger was set still horizontally, directing toward magnetic north. At this situation, the acceleration sensor at the dorso-ventral axis records relative values equivalent to $-$ 9.8 m/s^2 (or -1 G). Similarly, the magnetic sensor at the dorso-ventral axis records relative values equivalent to $-$ F・sin(i) nT, where F and i are total magnetic force and inclination at the study site, respectively. Geomagnetic information at the study site can be obtained from websites, such as NOAA National Geophysical Data Center (http://www.ngdc.noaa.gov/geomagmodels/IGRFWMM.jsp).

We recommend conducting a calibration experiment to convert relative recording values into the appropriate units, and also to check the estimations resulted from 'ThreeD_path'. Please refer appendix for details of the calibration experiment.
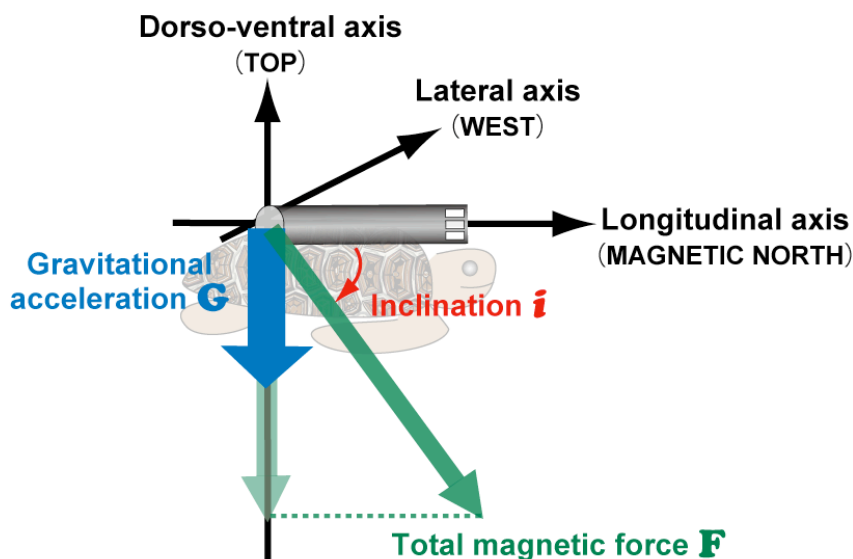

Fig.2 Gravitational acceleration and magnetism recorded by a data logger

In addition, acceleration data recorded by data logger include both gravity-based accelerations (e.g. change in response to changes in body posture etc) and dynamic accelerations (e.g. reflect strokes etc). To use 'ThreeD_path', gravity-based acceleration must be extracted by low-pass filter. For methods and precautions about extracting gravity-based acceleration, please see Shiomi et al. (2010).

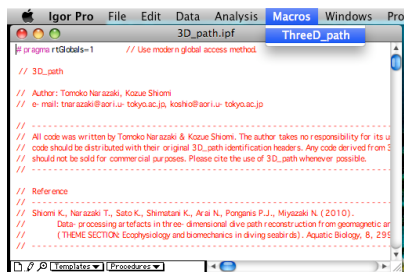## 2. How to use 'ThreeD_path'

(1) Download '3D_path.ipf' from the page 'Reconstruction of 3-D path' in the homepage of Japanese Society of Biologging Science (http://bre.soc.i.kyoto-u.ac.jp/bls/index.php?3D_path).

(2) Run Igor Pro (later than ver 5.05) and open the file '3D_path.ipf'.
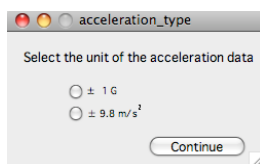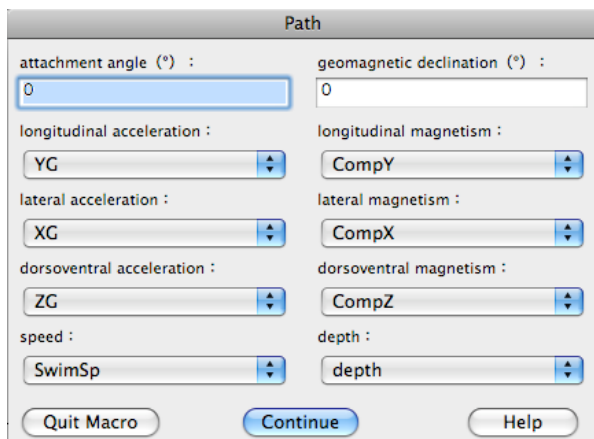
(3) Compile the '3D_path.ipf'.
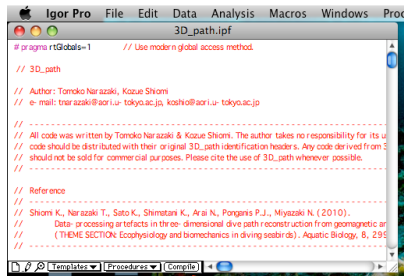
Click

(4) Run 'ThreeD_path' by selecting the 'ThreeD_path' in the 'Macros' tab.

(5) Select the unit of your acceleration data (G or m/s^2). Click 'continue'.

(6) Input attachment angle and geomagnetic declination at the study site. Select the appropriate waves, and click 'continue'.


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(7) Reconstruction of three-dimensional path.

The following waves are created after running the 'ThreeD_path'.

- **Head** – Heading. Rotation angle around dorso-ventral axis (°). 0°, 90°, -90° indicate north, east and west, respectively.
- **Pitch** – Rotation angles around lateral axis (°). Show negative values when animals headed downward.
- **Roll** – Rotation angles around longitudinal axis (°).
- **X3** – Accumulated eastward distance (m)
- **Y3** – Accumulated northward distance (m)
- **Z3** – Accumulated upward distance (diving depth) (m)
- **delX** – Eastward distance moved at each sampling interval (m)
- **delY** – Northward distance moved at each sampling interval (m)

X3 vs Y3 indicate the animal's horizontal travel path (Fig. 3).
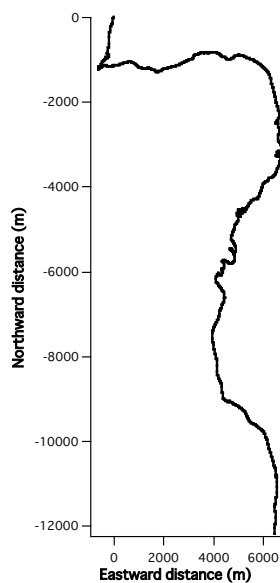
Fig. 3 Example of horizontal path traveled by a loggerhead turtle.

By using X3, Y3 and Z3, three-dimensional paths can be displayed by using various programs, such as *Gizmo* ('Window' → 'New' → '3D plot' → 'Other…') in Igor Pro and *scatterplot3d* in R.

3. References & recommended papers

【Algorithms】

Johnson, M.P. & Tyack, P.L.(2003). A digital acoustic recording tag for measuring the response of wild mammals to sound. *IEEE Journal of Oceanic Engineering*, **28**: 3-12.

【Methods and precautions】

Shiomi, K., Narazaki, T., Sato, K., Shimatani, K., Arai, N., Ponganis, P.J. & Miyazaki, N. (2010). Data-processing artefacts in three-dimensional dive path reconstruction from geomagnetic and acceleration data. *Aquatic Biology*, **8**: 299-304.

【Analysis of 3-D path】

Shiomi, K., Sato, K., Mitamura, H., Arai, N., Naito, Y. & Ponganis, P.J. (2008). Effect of ocean current on the dead-reckoning estimation of 3-D dive paths of emperor penguins. *Aquatic Biology*, **3**: 265-270

Narazaki, T., Sato, K., Abernathy, K.J., Marshall, G. J. & Miyazaki, N. (2009). Sea turtles compensate deflection of heading at the sea surface during directional travel. *The Journal of Experimental Biology*, **212**: 4019-4026.

Appendix: Calibration experiment (Confirmation of the resulting estimation)

We recommend conducting a calibration experiment to convert relative recording values into the appropriate units, and also to check the estimations resulted from 'ThreeD_path'. Here, the calibration experiment using 3MPD3GT (Little Leonardo Co., Tokyo, Japan) were introduce
This experiment must be conducted outdoor where minimum magnetic disturbances exist (e.g. beaches, open spaces).

(1) Calibration of sensors at the longitudinal axis

Set the data logger with its impeller to be at the top (Fig. 4 left). Keep the logger still for approx. 30 seconds. During this period, the relative values recorded by the acceleration and magnetic sensors at the longitudinal axis are equivalent to -9.8 m/s^2 (-1G) and -F・sin(i) nT (*), respectively.

Next, set the data logger upside down like the right figure of Fig. 4. Again, keep the logger still for approx. 30 seconds. The relative values recorded by the acceleration and magnetic sensors at the longitudinal axis are equivalent to 9.8 m/s^2 (1G) and F・sin(i) nT

Longitudinal axis

Fig. 4

(*), respectively. Then, a regression line is obtained from these values for each of acceleration and magnetic sensor at the longitudinal axis, and is used to convert the relative values into m/s^2 (G) and nT, respectively.

(* F = Total magnetic force at the study site, i = inclination at the study site)

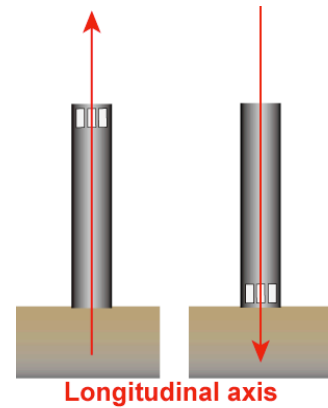**(2) Calibration of sensors at dorso-ventral and lateral axes**

Set the data logger horizontally. Keep the logger still for approx. 30 seconds with the arrow of the dorso-ventral axis heading upward (Fig. 5, left) and donwnward (Fig. 5, right), respectively.

Follow the similar procedures for lateral axis: set the data logger horizontally and keep the logger still for approx. 30 seconds with the arrow of the lateral axis heading upward (Fig. 6, left) and downward (Fig. 6, right), respectively.
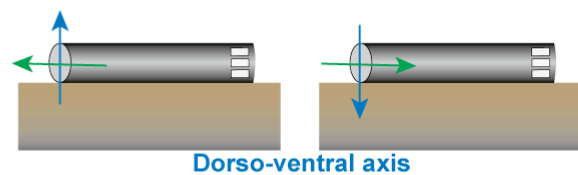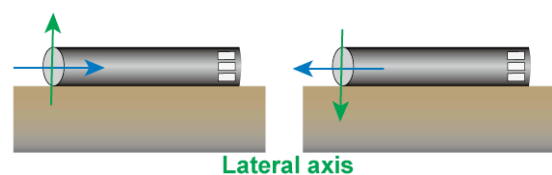
While each arrow heading upward, the

**Dorso-ventral axis**

Fig. 5

Lateral axis

Fig. 6

acceleration and magnetic sensors record relative values equivalent to -9.8 m/s^2 (-1G) and -F・sin(i) nT. While each arrow heading downward, the acceleration and magnetic sensors record relative values equivalent to 9.8 m/s^2 (1G) and F・sin(i) nT.

(3) Check the estimated heading

It is very important to set the direction of tri-axis correctly (Fig. 1) when using 'ThreeD_path'. If direction of tri-axis are not set correctly (e.g. the direction of longitudinal axis are set at opposite direction etc), headings estimated by 'ThreeD_path' are incorrect. Therefore, to check the accuracy of heading estimation, we recommend to slowly rotate the data logger clockwise from magnetic north, with various pitch and roll angles (Fig. 7). If correctly estimated, time-series heading data can be seen as Fig. 8

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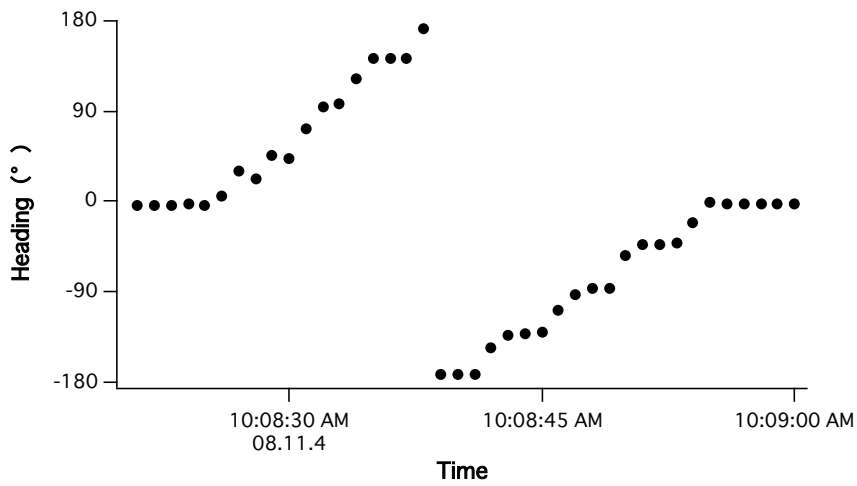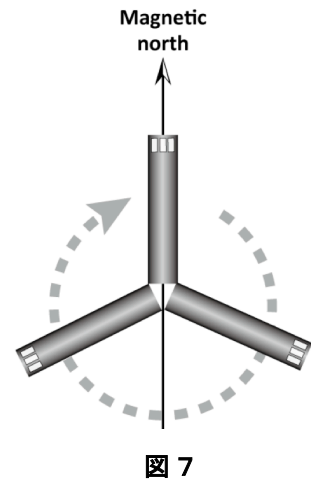
Fig. 8 Time-series heading data while the data logger rotate clockwise from magnetic north

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