System Development Life Cycle Document

For The

Benthic Event Detection System

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Content

1. Scope and Methods

1.1. Acronyms and Abbreviations

AUV– Autonomous Underwater Vehicle
BED – Benthic Event Detector
ROV – Remotely Operated Vehicle

1.2. Abstract

We propose developing a Benthic Event Detector (BED) to measure the down-canyon movement of the sediments within Monterey Canyon during mass transport events. This project will be structured as a hybrid feasibility-development project whose goal is to determine the feasibility of constructing a self-contained sensor system (the BED) that detects seafloor sediment motion, and to build a prototype unit ideally in the latter half of 2012, if feasibility is adequately demonstrated. The BED will be equipped with a yet-to-be-determined suite of motion sensors (most likely tilt and/or acceleration) and a pressure transducer, and will be buried just below the sediment surface. This unique sensor will aid in evaluating the new hypothesis that sedimentary fill within submarine canyon floors may move downslope as large masses, not primarily in suspension in the water column above the seafloor or as bed load moving over the surface of the seafloor. If it is conclusively demonstrated that substantial sub-seafloor movements are occurring, this promises to overturn existing paradigms that explain how sediment moves down submarine canyons.

1.3. Summary of Problem

Multibeam mapping of Monterey Canyon has revealed the existence of crescent shaped bedforms in the axial channel extending from the canyon head (~11 m) down to ~1900 m water depth. AUV multibeam mapping surveys of other submarine canyons along the California continental margin show that these features are characteristic of active submarine canyons. The occurrence of these bedforms has captured the attention of the marine geologic community and the origin of these features is already controversial. Our recent efforts to determine the origin of these bedforms have included monitoring the movement of buried homer beacons, repeated AUV-multibeam mapping surveys, and ROV vibracoring in upper Monterey Canyon. Results obtained so far have clearly demonstrated that the bedforms are generated during brief, energetic sediment transport events that occur a few times each year, which are capable of moving boulder-sized objects hundreds of meters down-canyon. What actually happens in these sediment transport events is less clear. The initial assumption, which logically extended from the existing paradigm, was that the wave-like bedforms are produced by suspension and redeposition of sediments during high-energy turbidity events. In contrast, our data suggest that large sections of the canyon floor appear to move in a slump-like fashion during these events, somewhat analogous to movement of ice within a glacier. This new model challenges the turbidity current model and forces us to re-interpret old data and assumptions. At issue is whether the sediment transport events are turbidity currents that exhume material from the canyon floor and carry it either suspended in the water column, as bedload over the seafloor before it is redeposited further down canyon, or as down-canyon translations of large coherent segments of the seafloor. The depth to which the bottom movements penetrate is unknown, but sustained translation of the seafloor down-canyon is a potential mechanism for carving the canyon into its host rock. An instrument buried in the seafloor designed to record motion during the down-canyon sediment movement would aid in discriminating between the turbidity current, bedload, or coherent-slab transport models.

1.4. Proposed method

The goal of detecting and characterizing sediments motion to be implemented by means of the following principles:

- Benthic Event Detector (BED), a compact, self-contained autonomous motion detection and data transmission system, to be developed in-house.
- BED system to be deployed by embedding on the surface or into the top portion of the sediment layer; alone or potentially in groups.
- In order to record representative motion data, BEDs shall stay attached to the sediment mass. As a variation, BEDs hydrodynamic properties shall be tunable with the goal of mimicking the behavior of representative sediment layer objects.
- During course of deployment BEDs shall transmit motion dynamics of surrounding sediments by means of (TBD) parameters.

2. Requirements

2.1. User Requirements

Listed below are top level requirements captured with participation of the end users of the system:

- Motion detection. Resolve the motion of the BED to the extent possible (TBD); using a combination of one or more of the following parameters, their static values, and their rate of change: Translation, Orientation, Acceleration, Depth (water pressure)

- Time scale. Resolve and record fast motion (event) on a scale of minutes (required); and slow creeping/turning motion (“context”) on a scale of hours-days-months (desired)

- Event record. Entire event should be recorded continuously and consistently from the start to the end.

- Operate in a water depth up to 500 meters.

- Temperature range. Operation over a temperature range of -3 to 20 degrees Celsius; transportation up to 50C (-3°C Arctic water; 50 °C deck temperature).

- Be operational for at least 12 months or (**TBD)** hours of debris flow event time data transferred off the instrument; whichever occurs first (previous data suggests that at least one ‘large’ event occurs every 12 months).

- Be able to locate BEDs (or hardware module containing full data set) for 12 months after functional life of the BEDs has expired (desirable)

- Communicate and offload data underwater via an acoustic interface without tethered communications device and without excavation, from the depth of up to 3m beneath the sediment. (Excavation is logistically challenging and any tether would alter dynamics of BED.)

- Package to have a default density comparable to the top 3m of sediment: between 1.5 and 1.8 G/CC. (This will keep package from sinking below the depth where data can be retrieved remotely).

- Ability to alter package such that density could be increased to 3 times the default package density so that self-burial can occur.

- System core shall be as small as possible to allow deployment stand alone or attached to a larger physical interface in order to change dynamics and/or density.

- Be deployable and recoverable from an MBARI ROV.

- Allow end user to select specific data subsets for offloading.

- Timestamp data collected during a sediment transport event with < 1 sec resolution and < 1 min precision over the whole length of the deployment.

- Allow motion event detection thresholds to be varied over the deployed communications link.

2.2. System Requirements

Listed below are derived requirements. They can be changed as long as top level requirements are met. Some of the requirements, also captured in discussions group, particularly those that can be traced back to the top level user requirements, also had been sorted into this section. Each requirement is marked with a unique ID for traceability.

BEDS-0010: Start of the event shall be identified by detecting motion exceeding Event Detection Thresholds with a time delay (“Record Delay”) not to exceed 1-2 seconds.

BEDS-0015: End of the event shall be identified by detecting motion parameters below no motion thresholds.

BEDS-0020: Recording of the event shall continue beyond End of the event to ensure motion had stopped (“No Motion Timeout”)

BEDS-0025: System shall log orientation data (Euler angles) and depth periodically (every hour), for context and creeping / slow turning detection

BEDS-0030: Data storage. The system shall store collected data onboard.

BEDS-0035: The system shall be able to send the system health status (battery capacity/voltage, current, time/date, memory, humidity, temperature, events detected, etc) by request.

BEDS-0040: Clock drift limit. The system shall limit clock drift to less than 1 minute per year.

BEDs-0050: The system shall be able to survive tumbling and potential localized impacts during sediment transport events.

BEDS-0055: The system shall be “ruggedized” to withstand vibration of TBD g at TBD Hz. to TBD Hz. (currently working with engineering department from avalanche transceiver manufacturer to determine if their specs would be reasonable)

BEDS-0060: Orientation data. The system shall record orientation in 3 rotational axes with resolution of at least 0.1 degree.

BEDS-0065: Translation data. The system shall record linear acceleration in 3 axes with resolution of at least TBD.

BEDS-0070: Pressure data. The system shall record pressure with resolution of at least 0.016 dbar (16 mm).

BEDS-0075: Communication orientation. The system shall communicate at any package orientation.

BEDS-0080: Recording orientation. The system shall measure and record data at any package orientation.

BEDS-0090: Pre-deployment activation. TBD if needed (e.g. Hall, reed, wireless, nothing)

BEDS-0095: Pre-deployment systems check. System shall be able to verify subsystems status on initial boot-up; and store report for transmission by user request.

BEDS-0100: System shall require authentication on acoustic link especially for “write access” so garbled or accidental unauthorized transmission would not be able to alter system settings or damage data.

BEDS-0105: Protected system parameters. System time, among other parameters (TBD) shall be set in pre-deployment phase and cannot be altered by means of acoustic link.

BEDS-0110: Remotely variable parameters. Event Detection Thresholds, No Motion Threshold; Data Sampling Rate (other parameters, TBD), shall be variable by means of acoustic link.

BEDS-0115: Extended Transponder. System shall be equipped with a transponder, sufficient for operation 12 months beyond main battery pack, or 24 months total.

BEDS-0120: The design of the system and deployment manner shall adhere to the regulations of Monterey National Marine Sanctuary including lost (not recoverable) instrument.

2.3. Optional requirements / future improvements

- Onboard linear displacement calculation.
- Adaptive TX power reduction. To save the energy, the transmission power of the acoustic modem might be automatically adjusted to the minimum level needed for reliable communication.
- Adaptive baud rate.
- Acoustic frequency hopping scheme could be implemented to increase acoustic communication reliability. Dependent on Benthos release schedule.
- Clock drift reporting. To enhance synchronization of event data to world time, the records of time offset between system time and GPS time, obtained during communication sessions, could be used for post processing.
- Adaptive Decimation (zip?). The orientation/ acceleration data processing could be modified in such a way, that only changes from previous values are stored and transmitted thus reducing the data amount requirement.
- System could be equipped with a drop weight, allowing surface recovery after functional life has expired.
- A method for determining height of sediment above the BED would be useful
- Some method of detecting the viscosity or density of the sediment could be added

2.4. Alternatives/existing similar systems

2.5. Constraints

- Battery capacity limits length of deployment and data transmitted
- Depth of burial for reliable communications
- Depth of burial limits ability to recover instrument

2.6. Interfaces

- Acoustic communication link between BEDs system on the ocean floor, and a modem in the water column.
- Logical user interface, allowing access to the BEDs file system, low resolution data, system parameters, etc.
- Pre-deployment activation and programming (electrical) interface.
- Physical attachment interface, allowing recovery by ROV from any orientation, partially buried (loop, u-bolt, studs, etc, perhaps several of them to allow attachment from any orientation)

2.7. Assumptions identified

- The relative value of each sample collected during an event is assumed to be constant (i.e. the first samples are no more valuable than the last)
- Discrete nature of sediments transport events when beginning and end of the event can be clearly identified
- The frequency and duration of events will align with limited data that we have
- Sampling data rates are high enough to bound and event

3. Design concept

3.1. Algorithm of system operation

Based on the assumption of discrete nature of the sediment transport events, and to save energy/ bandwidth, the operating algorithm of BED can be split into the following modes of operation. *Italics represent transition between modes*:
(REFERENCE) **Please refer to: BEDs-Operation-Flowchart.pptx**

1. **Watch cycle mode:**
   a. Activate sensor package.
   b. Creep detection and contextual data. Store orientation, depth, and environmental data (humidity, temperature) at predefined rate (once per hour)
   c. Event detection: Wait for motion detection interrupt from sensor and initiate Record Cycle
   d. Activate modem at predefined duty cycle, listen for acoustic communication, and initiate Command Mode if detected.

2. **Event recording mode:**

a. Log linear acceleration in earth coordinate system (3 parameters), orientation in earth coordinate system (3 parameters), depth (1 parameter) at rate of (100-200Hz)
b. Calculate and log magnitude of motion in energy units.
c. *Return to Watch Cycle after motion parameters falls below no motion thresholds; and No Motion Timeout has expired.*

3. Command mode (default mode on power-up):

a. Activated acoustic link and respond to user input:
  i. Enable/disable subsystems
  ii. Set thresholds for future data acquisition.
  iii. Read system status string (voltage, current, time/date, memory, humidity, temperature, events detected, etc)
  iv. Set Data Upload Range (in time).
  v. Set data items to upload (if desired different from default).
  vi. Upload decimated data directory
  vii. Upload user defined range of data
b. Activate Watch Cycle on communication time-out (30 min) or by deployment command.

3.2. System structure of deployable BEDs unit

(REFERENCE) **Please refer to: BEDs-System-Architecture.pptx**

- CPU board
  - IMU, Invensense MPU 6050 (I2C) OR MPU 6000 (SPI)
  - Mass data storage
    - SPI to SD card if Atmel or PIC CPU
    - On-board CFM if Persistor CF2
    - 32GB cards are cheap, and would provide storage for > 2000 hours of event recording, or 1000 hours of events plus > 1 year of watch cycle
  - RTC (SPI to CPU)
    - Drift up to 63 seconds per year
    - Software calibration?
    - Systematic frequency offset (~.2 sec/day delta)
    - Temp correction for constant temp
  - Health sensing (Analog to ADC)
    - Temperature
    - Humidity
  - Analog V and I measurements
  - ADC 16 bit
  - Misc. Digital I/O
  - Console serial port
- Acoustic modem: Benthos ATM-885-4G
  - RS-232 to CPU board
  - Power from power management board, low resistance path
- Power Distribution

    - Power from battery pack
    - V and I monitoring
    - Load switching
- Pressure sensor (Analog to ADC)
- Transponder (designed to outlast main system)
- Battery pack

3.3. Real Time Clock possibilities

- DS3234 Temperature compensated RTC from Maxim is specified at 2 ppm, which is 63 seconds/year. We may be able to do better than that by writing software to calibrate it offline versus a GPS. We will investigate that option.

- Symmetricom SA.45S Atomic clock is good to .05 ppb when factory calibrated, with 1 ppb/year of drift. 1 ppb corresponds to 31 milliseconds/year. However, it's (a) expensive, at $1500, and (b) power hungry, at 120 mW. The latter point would disqualify it, greatly reducing our run time, unless extreme clock accuracy were needed. The power requirements can be mitigated at the expense of accuracy by using "ultra low power mode"; i.e., run it intermittently. For example, by having it on for 5 minutes/hr, we can reduce the power to 20 mW, and maintain an accuracy of ~5 ppb, or 158 ms/year.

3.4. Energy and data budget

- (REFERENCE): Please refer to document: **EnergyBudgetv2.3-Electrochem14cells.xls**

3.5. Mechanical structure

- Instrument housing
    - 7" x 10.5" cylinder with electronics
    - Material
        - Carbon or steel
    - Fits 14 DD batteries

- Trim/ballast
    - 15" flotation sphere
- Transducer guards
    - UHMW

3.6. Software structure

3.6.1. Onboard software

The on-board (aka embedded) software is implemented as a single-threaded state machine which will operate in one of the three modes described in section 3.1, "Algorithm of system operation".

- **Command mode**
  At start-up, and whenever serial traffic is detected on either the acoustic modem port or the console serial port, the software will be in command mode. This is a simple menu-driven user interface. While in command mode, the software will not be acquiring sensor data. Command mode will have reasonable timeouts for all user input; e.g. a few minutes. If this mode times out, the system will proceed to Watch Cycle mode. The exception to this rule is when the system first starts up. In that case, it will remain in command mode until the user commands it to run sensor acquisition, at which point it will enter Watch Cycle mode.
  Command mode will allow the user to perform all the actions outlined in section 3.1, including but not limited to:
  - Upload data to supervisory system. Data to upload may be specified by event or range of date/time.
  - Upload decimated data
  - Upload entire data files
  - Set thresholds for future data acquisition
  - Enable/disable subsystems
  - Get system status (date/time, voltage, current, memory usage, environmental parameters, events detected, etc).
  - Explicitly go to Watch Cycle mode.
- **Watch Cycle mode**
  In Watch Cycle mode, the system is acquiring data from the sensor package and recording it to mass storage, although at reduced data rates (e.g. 10 Hz in watch cycle vs 100 Hz in event recording). In this mode, the system will also: a) periodically acquire data from contextual and engineering sensors (depth, humidity, temperature, etc); b) monitor the motion detection indicator from the sensor and initiate Event Record mode if found; c) periodically activate the modem and monitor it for input, entering Command mode if found; and d) monitor the console serial port, entering Command mode if found (possibly not needed ???)
  Watch Cycle mode continues until:
  - motion is detected, at which point the system enters Event Record mode, or
  - serial traffic is detected on the acoustic modem (or console port?), at which point the system enters Command Mode.
- **Event Record mode**
  In Event Record mode, the system is acquiring data from the sensor package at high data rates (e.g. 100 Hz) and recording it to mass storage. The system continues in this mode until no-motion is detected for the duration of the No Motion Timeout.

3.6.2. Post processing software

- Software runs on shore-side workstation, to operate on data downloaded from deployed system.
- Algorithm to reconstruct linear motion (displacement) from orientation and acceleration data
- May be dedicated app written in C, Java; or may be MatLab

3.6.3. Visualization

- Software runs on shore-side workstation, to operate on data downloaded from deployed system.
- Low-resolution (contextual) data panel with data, magnitude, orientation, time scale, and event start/end identifiers
- Event data panel to represent high resolution data
- VRML can provide 3D modeling

4. Implementation and Specifications

4.1. System Specifications

- (REFERENCE): Please refer to the document: **BEDs-Concept-Datasheet.ppt**

4.2. Limitations of design concept

- Limited ability to detect motion, falling in time and scale between Fast motion ("Event) and low time resolution data ("Context").

- Limited ability to detect slow linear displacement (for instance < 1m per minute) if orientation remains constant. Exception is vertical displacement where water pressure can provide independent information about the absolute depth.

- Onboard linear displacement calculations will not be implemented at this time

- Selected IMU sensor does not provide data for magnetic heading

5. Qualification and Testing

5.1. Test Procedures, Calibration procedure.

(REFERENCE): **Newport-TestJig-Datasheet-2012-05-25.ppt**

- Motion thresholds, Event Start, Event Stop: can be performed using test jig, in X axes with fully assembled unit, or X-Y or X-Y-Z with the subassembly (CPU/ IMU board)

- Acceleration, full range: drop on the calibrated spring-loaded platform.

- Rotational testing: rolling on the ramp.

- Calibration of RTC with GPS in environmental chamber at constant temperature.

5.2. Test Data

6. Applicable Documents

(REFERENCE): **BEDs File Formats** – September 2011, MBARI Doc #TBD

Note: Unless otherwise noted, references to applicable documents are to the latest version published.