ENABLING TETHERED OCEAN WORLD VEHICLES BY SHARING POWER AND COMMUNICATION CONDUCTORS.

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Introduction: This abstract proposes the concept of establishing high-bandwidth communications links over power-supplying conductors as an area meriting further research to enable ocean world exploration. Such a concept could greatly reduce tether burden by using only two conductors to supply power and communications. This would allow design of reduced tether cross-sections to minimize diameter, a key attribute in a tether, on which coil volume, mass, and range depend.

Remotely-operated vehicles (ROVs), underwater vehicles mechanically connected to a base station supplying the vehicle with power and control signals and receiving sensor data via tether cable, are an attractive option for detailed exploration of icy ocean worlds owing to their success in exploration of Earth analogs [1, 2]. The tethered benefits of power supply and high-bandwidth communication on other worlds may come at a steep cost owing to tether mass and volume if using traditional tether techniques.

ROVs are most often deployed from ships; traditional ROV tethers use separate conductors to supply power and communications and are heavily armored to resist abrasion and provide tensile strength potentially required during ship operations. Communications often take place over optical fibers instead of electrical conductors, the delicacy of which requires even more protection and drives up tether diameter further.

To date, the authors are aware of only one fielded example in which power and communications were supplied on conductors: a family of ROVs known as SCINI (Submersible Capable of under Ice Navigation and Imaging) [2, 3]. These ROVs were designed to accommodate deployment to ice-covered marine environments by helicopter; design constraints led to the use of commercial off-the-shelf power line networking adapters of the kind conforming to, e.g., the IEEE 1901 standard [4] to a establish a high-bandwidth data connection over a traditional AC power line.

Shortcomings of Current Technology: The SCINI network-over-power line solution was suitable for deployment on Earth but has a number of disadvantages for ocean world exploration that must be investigated and solved.

The tether included significant armoring to protect it during handling. In addition to the thick jacket needed to prevent damage if stepped on, mis-wound, or otherwise mishandled, the SCINI tether contained four conductors when only two were necessary.

Commercial powerline transceivers restricted useful tether length to approximately 350 m on the SCINI project. The team found by iterative experiment that a longer tether would fail to sustain a network connection of any speed. Ocean worlds may be covered in over 10 km of ice and a 350 m limit would necessitate inline repeaters, greatly increasing potential points of failure. Depending on repeater dimensions, repeaters may also greatly complicate an autonomous unspooling operation.

The powerline networking community has advanced since the SCINI started development in 2007 by using 100 Mbps adapters. Modern adapters are capable of communication at 1-2 Gbps and it is unknown how a custom-designed tether would interact with such transceivers.

Cabled ROV Advantages Over Tether-free AUV Operations:

Autonomous underwater vehicles (AUVs) can conduct missions over tens of thousands of kilometers for weeks or months and require no mechanical connection to a base station to perform scientific surveys [5]. These missions require careful planning and must be informed by expected bathymetry, available magnetic field for heading, known ocean currents, etc., none of which are understood to the extent necessary on ocean worlds.

Of particular importance in AUV operations is buoyancy control: the AUV has no tether and therefore no way to be recovered if it becomes locked in a state where its density is higher than the surrounding fluid. Ocean world densities may be different from what we expect and a mechanical tether to an in-ice base station would provide engineers with insurance against a deployed vehicle simply sinking.

A tethered vehicle does not need its own internal power supply, reducing its necessary size -- particularly in settings where a radioisotope thermoelectric generator (RTG) is the only source of power available -- and thereby reducing the amount of thermal energy required to melt its way through the ice.

An ocean probe will be only one part of a mission consisting of many instruments. A high-bandwidth cabled link from an ocean probe to a central base station would accommodate streaming of, e.g., high-resolution video for autonomous processing and selection of frames for transmission to Earth via limited bandwidth radio link. An AUV, conversely, would likely be limited to a low-bandwidth acoustic link on the order of 100s of bps [6].

Improvements over Existing Work: A purpose-designed tether would include only two conductors and minimal outer jacketing due to a specialized ocean world application environment and autonomous unspooling.

Existing work investigating custom tether types for autonomous through-ice operations on Earth targets up to ~3.5 km range [7]. Cable types under investigation incorporate more than two conductors and include strength members capable of withstanding extremely high tensile forces [7, 8] making these cables also impractically large for use on ocean worlds. Furthermore, existing work does not appear to take full advantage of the data handling potential of these custom-designed cables. We suspect the dedicated communications conductors in these works are capable of sustaining high bandwidth data transfer but communications in [8] are only described as "a baud rate of 115 200" over a custom cable 550 m long, and communications in [7] are not described. This suspicion is based on existing product capabilities; for instance, a commercial transceiver for coaxial cable specifies up to 144 Mbps for a 550 m link and 64 Mbps for links up to 2400 m [9].

Conclusions: This enabling technology will let engineers of ocean world-exploring underwater vehicles surpass mission limitations imposed by today's technology. Engineers are currently forced to choose among a set of non-ideal options: very low bandwidth wireless acoustic link, delicate optical fiber data link, or unsuitably bulky power and data cable. Establishing long-distance, high-performance communication over power conductors will allow us to create custom robot tethers with minimum diameter, thereby enabling deployment of more capable through-ice underwater vehicles on ocean worlds.

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