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Technical specifications of low-frequency radio identification bedload tracking from field experiments: Differences in antennas, tags and operators

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ABSTRACT

Low-frequency passive integrated transponders (PIT tags) have been increasingly used for tracking bedload transport in gravel-bed rivers. Prior studies have reported high recovery rates in small streams, while recovery rates remained much lower in large systems, in large part because of the limited reading distance of the tags (<1 m). Some laboratory tests have identified controlling factors for detection ranges (tag and antenna size, tag orientation, burial, submergence, etc.). Beyond these tests, improving our understanding of PIT tag functioning, using different equipment within different environments, is still needed in order to select the most suitable device for each geomorphic context. We address this knowledge gap with technical specifications for a low-frequency radio identification (RFID) device by working for the first time with real fluvial constraints, i.e., the gravel deposits and the aquatic channel. The three-dimensional detection envelopes of two types of tags and three types of antennas are quantified as well as the effect of practices (interoperator bias, battery power) on the detection. The interoperator variability and the intertag variability can be considered as negligible. The influence of burial in dry and water-saturated sediment and the influence of water immersion are shown to be minor. Finally, we summarize practical implications for RFID bedload tracking through these experiments.

1. Introduction

The transport of coarse sediments is particularly important in determining channel morphology and habitat structure of gravel-bed rivers. Measuring the path of the transported grains provides essential information for defining bedload transport rates, explaining morphological features (Pyrce and Ashmore, 2003), to then be integrated in coarse sediment management plans or in river restoration projects (Liedermann et al., 2013). Among the techniques classically used to track bed particle displacements (see Sear et al., 2000; Hassan and Ergenzinger, 2003), radio frequency identification (RFID) technology with the insertion of passive integrated transponders (PIT) in pebbles has been increasingly used in recent years. The PIT tags allow an operator to locate individual buried or exposed particles. They are durable as they contain no battery and are inexpensive compared with active transponders (<US$ 5/passive tag versus >US$ 100/active tag; Burke and Jepson, 2006). The technique was employed successfully on small and shallow-water rivers of North America and Western Europe, with recovery rates ranging from 78 to 100% according to field sites and research teams (Lamarre et al., 2005; Camenen et al., 2010; MacVicar and Roy, 2011; Biron et al., 2012; Bradley and Tucker, 2012; Houbrechts et al., 2012; Liébault et al., 2012; Olinde et al., 2012; Milan, 2013; Phillips et al., 2013). Applications in large and deep-water rivers (i.e., flow channel more than 80 m wide and 60 cm deep) followed. For example in France, PIT tag studies provided encouraging results, coupled with other techniques for bedload monitoring (recovery rate of 36% on the Ain River: Rollet et al., 2008; 42% on the Rhine River: Arnaud, 2012; 40% on the Durance River: Chapuis et al., 2015).

The RFID technology currently used in bedload research concerns low-frequency electromagnetic waves (125–135 kHz) because these are much less impacted by the water column than high-frequency ones (13.56 MHz). Indeed, the latter undergo a significant reduction in the reading distance (up to 80%) caused by the properties of water attenuation $a = 0.0173\sqrt{f\sigma}$ (in dB/m, with σ as the water conductivity); the lower the frequency f, the lower the attenuation a (Reaz, 2013).

Typical low-frequency tags are glass cylinders of 3.8 mm diameter and 23 or 32 mm long operating at 134.2 kHz, distributed by Texas Instruments (TI-RFID, 2001, 2006). The PIT tags were originally used for fish monitoring (Prentice et al., 1990; Skalski et al., 1998; Roussel et al., 2000; Zydlewski et al., 2001). They were then chosen for tracking bedload as their small size allows insertion into pebbles too. Common equipment used by research teams is from simple drilling refilled with resin or from a groove on the pebble surface (Houbrechts et al., 2012).

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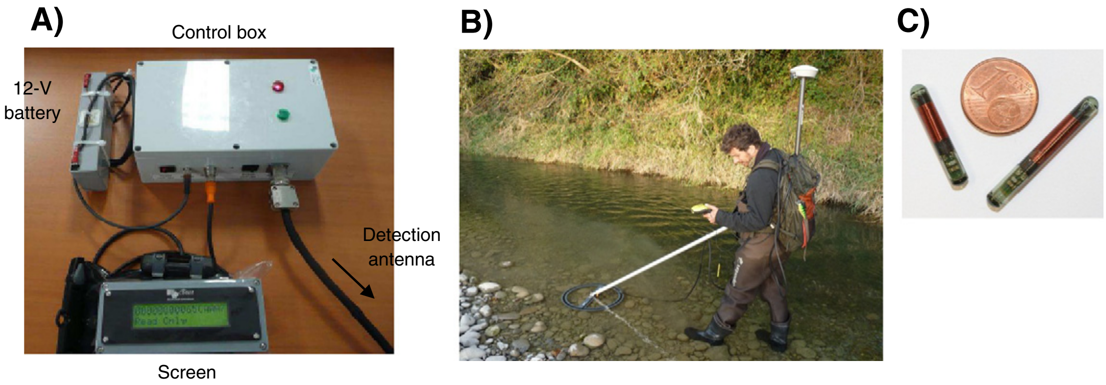

Fig. 1. (A) RFID equipment tested in this study; (B) field technician using RFID tracking over bars and shallow-water areas with a 0.46-m-diameter loop antenna; (C) 23- and 32-mm-long glass cylinder tags.

Circular tags of 3 cm diameter operating at 125 kHz have also been tested recently for tracking sediment movement on coarse-grained beaches (Bertoni et al., 2012).

The number of tracers recovered after floods is critical for ensuring robust statistical observations on distances and trajectories of particle displacement. This is highly dependent on the reading range which differs according to field conditions and equipment used. For instance, Lamarre et al. (2005) and Rollet et al. (2008) estimated from field observations a maximum reading distance of ~25 cm with 23-mm-long tags detected with a 0.5-m-diameter *loop* antenna. From laboratory tests performed in a plastic box filled with water and sediment, Schneider et al. (2010) measured reading distances of ~30 and ~40 cm with 23- and 32-mm-long tags, respectively, detected with a 0.5-m-diameter antenna, and reading distances of ~50 and ~60 cm detected with a 0.8-m-diameter antenna. Burial and submergence appeared to cause no more than 1- to 4-cm decrease in the reading distance compared to open-air conditions. Other laboratory experiments by Benelli et al. (2011) demonstrated a decrease of up to 15 cm. Finally, a detailed study testing different transponder and antenna (*loop* and *stick* shapes) combinations recently provided additional understanding of RFID use (Chapuis et al., 2014). The authors examined the effect of the tag orientation (i.e., the angle between the tag and the plane of the antenna) and of the sweep direction (i.e., the tag position into the plane of the antenna), on the reading distance in open air as well as in buried and submerged conditions in a laboratory *sandbox*. Optimum distances were obtained using vertical cylinder tags placed at the center of the 0.5-m-diameter loop antenna (e.g., ~70 cm for a 23-mm-long tag). No significant effect of tag burial on the detection was found.

Such variability in reading distances supports the need to improve our understanding of RFID functioning using different equipment within different environments, while most researchers currently employ RFID systems that are commercialized by industrial companies that do not provide any specific information for environmental applications such as fluvial monitoring. The challenge is to select the device (type of tag, type of reader, operating frequency) that should be most effective for specific geomorphic contexts (channel width, bedload sheet thickness) in order to maximize recovery rates and assess particle mobility and path lengths more accurately.

The objective of this study is to advance our technical understanding of low-frequency RFID tracking systems by testing the effects of operational practices (interoperator bias, battery power) and equipment (two types of tags, three types of antennas) on detection ability. We aimed to go beyond the constraints of indoor laboratory procedures, which are limited in scale and potentially affected by surrounding metallic structures that are known to modify the electromagnetic field (Bradley and Tucker, 2012; Chapuis et al., 2014). We thus worked in real fluvial conditions; our test system is the aquatic channel and coarse alluvial deposits of the Ain River (France). The results are compared with previous experiments, and some practical implications for RFID bedload tracking are deduced.

2. RFID equipment

The RFID reader used in this study is commercialized by the company CIPAM (Clermont-Ferrand, France). It is composed of an electronic control box and a digital screen powered by a rechargeable 12-V DC lead–acid battery (2.1 Ah) (Fig. 1A). The components of the control box are manufactured by Texas Instruments (Series 2000, half-duplex transmission, power module RI-RFM-008B, control module RI-CTL-MB2B and antenna tuning module RI-ACC-008B). The operating frequency is 134.2 kHz. The device is usually contained in a backpack carried by an operator who scans exposed gravel surfaces and shallow-water areas with a detection antenna connected to the control box. The antenna is maintained in contact with the river bed surface for maximizing chances to detect buried tracers (Fig. 1B). The control box buzzes when a tag is detected and the identification number is displayed on the screen. The PIT tag position is then recorded using a GPS.

We compared tracking capabilities of 23- and 32-mm-long glass cylinder tags (Fig. 1C) and three coil inductor loop antennas. The first antenna is 0.46 m in diameter (Figs. 1B and 2A), manufactured by CIPAM and fairly similar to the pioneering model used by Lamarre et al. (2005) (hereafter referred to as the *small antenna*). Two additional antennas were designed following discussions with CIPAM to reduce prospection efforts on large flow channels, in the context of a project on the upper Rhine River (INTERREG 'Redynamization of the Old

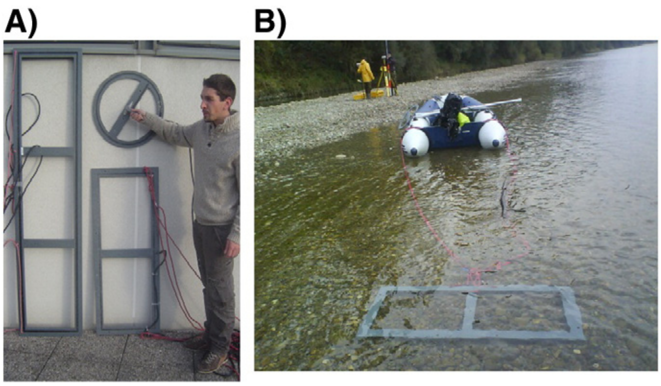

Fig. 2. (A) The three antennas tested in this study; (B) boat RFID tracking with the medium antenna.