An analysis of the performances of Low Frequency cylinder glass tags for the underwater tracking of pebbles on a natural beach

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***Abstract* - In this paper we provide the results of a two months experimentation of Low Frequency RFID technology for the sediments tracking on a beach close to Ancona, Italy. For this experimentation, cylinder glass tags were used, modifying a previous solution based on the use of plastic disc tags.**
While the use of Low Frequency RFID as a technology to monitor the movements of sediments under and outside water on beaches subject to high coastal erosion phenomenons was already been tested before and described in previous papers, the use of glass tags was not introduced until this last experimentation due to the fragile nature of these devices that discouraged from their use. Anyway, their use was finally encouraged from the goods results obtained from laboratory test concerning their reading range and their ease of use.
The results provided in this paper show that cylinder glass tags are probably the best solution for the tracking of pebbles movements.

I. Introduction

Sediments tracking is a key technique to investigate coastal morphodynamics. Through a better comprehension of the sediment movements on beaches is possible to study all the erosive phenomena that affect several coastal areas all around the world [1, 2].
The necessity to understand the dynamical processes that underlie to the erosion phenomenon have led in the last hundred years to the development of several techniques aiming at the tracking of sediment movements on beaches, concerning both the emerged portion of the beach and then portion of sea close to the beach.
These techniques include the use of different kinds of tracers, that can be roughly subdivided in the following categories:

- Visual tracers. This category encompasses all the solutions that foresee the identification of the tracers from their outward appearance. The easiest visual tracer solution is based on the painting of the tracer [3]: pebbles are usually covered with dye and numbered, in order to allow their identification. Different colors can be used to characterize different tracer categories. Once the painted tracers are positioned on the test site, their recovery is performed by the naked eye: this means that all the tracers sunk below the beach surface are invisible. The same can happen with the tracers dragged under water. Moreover, painted tracers can become unrecognizable due to surface abrasion and subsequent obliteration of the dye layer. These facts limit the use of this technique: the tracers recovery has to be performed at a short time distance from the their deployment because the more time passes, the more tracers can become invisible.
The use of fluorescent dyes is a good alternative to the use of common paints [4], providing additional features and increasing the performances of the tracing solution. Fluorescent dye has the property that, when it is stimulated by a light of a suitable wavelength, it emits a colored light according to the characteristics of the dye. The localization of fluorescent tracers is usually carried out during the night using a ultraviolet lamp that, stimulating the fluorescent dye, allows it to become luminous. This technique is simple and cheap, and allows the monitoring of slowly evolving environments. On the other side the recovery operation can be difficult, while the problem concerning the sinking of the tracer is only partially solved because tracers sunk in depth are also in this case invisible.

- Radioactive tracers. They have been employed for sediment tracking along coasts and on river bed in the sixties and seventies, while their use has been since then discouraged in many countries all around the world. Different kinds of radioisotopes have been used for particles tracing. The detection of the tracers is usually performed using a scintillator probe mounted on a sledge [5–7].

- Magnetic tracers. They have been used to detect the movement of particles along the coasts or on river beds since the eighties [8]. Different techniques have been studied using both natural and artificial tracers. Anyway, all the techniques using magnetic tracers are based on the Faraday Law, that assesses that a magnet moving through or around a coil generates an electromotive force in the coil. The presence of a magnet can be then detected by measuring the voltage peak generated in the coil. Naturally magnetic crystals have been used in some cases while for other applications ad hoc magnetic materials have been introduced inside common pebbles. Artificial tracers are created by digging a hole in the pebbles and then introducing a small magnetic bar in them. While the realization of the tracer doesn't pose particular problems, the development of an efficient detector can be more challenging. Detectors include more coils arranged on one or two rows in order to cover a wide surface: these coils have 25-30cm diameters.

- Radio tracers. The use of electromagnetic devices has been tested several times for the tracing of sediments [9–11]. The first applications appeared at the end of the eighties, when 150Mhz micro transmitters provided with a battery were installed inside natural cobbles to be employed for the tracing of river bed sediment movements. The tracers detection was performed using HB 9 CV antennas arranged in a ow of 12 and positioned on the river bank.

II. The technical solution

The proposed system uses Low Frequency RFID as a mean to trace the movements and identify a set of pebbles turned into tracers by embedding inside them an RFID transponder [12].
RFID technology is able to encompass all the advantages of techniques described before, bypassing all the limitations of the single techniques. In fact, it allows the detection of the pebbles also under water and when the pebbles are sinked under other pebbles and aren't directly visible, and it enables the identification of the single pebbles allowing then their punctual tracking.
Through a punctual tracing of a set of pebble movements it becomes possible to understand the global trend of the movements of sediments along the beach, with a better comprehension of the effects of

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meteorological events on the beach. With an adequate understanding of these dynamics, artificial interventions to halt coastal erosion can be shaped directly on the features of the single beach increasing then their effectiveness.
Low Frequency technology, operating at 125kHz, has been chosen because it provides the best results concerning the under water detection of pebbles. Water attenuation decreases in fact in proportion to the operating frequency: the lower is the frequency, the lower is the attenuation and the larger is the achievable reading range.

2.1 Low Frequency RFID

Low Frequency systems are mainly based on a Reader-Tag inductive coupling, based on the same principle of common power transformers.
Low Frequency transponders are in nearly every case passive ones, and their reading range is typically lower than 1m. Over this distance the field strength decreases with a $1/r^3$ ratio, where r is the distance between the tag and the reader, while the power received by the tag decreases with $1/r^6$ ratio.
The most common operative frequencies in the Low Frequency band are 125kHz, mainly used for access control and for items tracking, and 134,2kHz, used for animal tracking and identification.
Low Frequencies provide a very low data transmission speed, from thousands of bit per second in the best cases down to 200 bits per second in the worst cases. On the other side they provide a high immunity to electromagnetic noise.
Passive transponders use the electromagnetic field generated by the reader as the source of energy to power their circuitry and to transmit their information. This means that the operative distance of these systems is typically very short due to the fact the achievable power by the transponders from the field is very low and it rapidly decreases with the distance. In particular, they don't generate their own carrier frequency to transmit the data, but they modulate part of the energy sent by the interrogating reader through the variation of the impedance of the transponder antenna, that, from absorbent becomes then reflective. This process is similar to the transmission of light signals using a mirror. The first positive consequence of this process is the reduction in the power required for the tag powering, in that no local oscillator is required to generate the carrier frequency.
The communication between reader and tag is based on the physical principle of magnetic inductive coupling in near field conditions. The inductive coupling is based on the phenomenon of electromagnetic induction: this principle is only used when the distance between the reader and the tag is notably lower than wavelength: this happens only at Low Frequencies ($\lambda \leq 2400m$) and at High Frequencies ($\lambda \leq 22.1m$). In this case the systems operates in the Near Field region: the magnetic field component is then prevalent.

2.2 The "Smart Pebble" system

The technical solution foresaw the use of an ad-hoc waterproofed reader and the realization of a set of so-called "Smart Pebbles".
The Smart Pebbles were the effective tracers, basically common pebbles with an RFID transponder embedded inside. They were positioned on the beach in exam, both under and outside water, and their position was recorded through the use of an external GPS device. After a predefined span of time, a recovery campaign was performed using a waterproof reader that was used to detect the presence of the Smart Pebbles and to recover the ID code of the embedded tag, thus allowing their identification. The final position was taken again with the GPS device and these data were used to build a map of all the displacements.
The waterproof reader was built modifying a common reader used for access control. Anyway, the choice of the right reader was a delicate issue, and several key points had to be considered. The most important factor that affected the final choice was the reading range of the reader: due to the characteristics of the application, it was mandatory to achieve the largest range possible: evidently, increasing the reading range, also the chance to recover the Smart Pebbles eventually sinked under other pebbles increases. RFID readers are usually commercialized in three versions, according to their reading ranges. Short range readers are small devices usually connected to a PC through a USB connection, with low costs but also low performances (lower than 10cm). Medium range readers are larger, their price is usually higher, they can be connected to a PC through USB or serial RS232 connection and they provide a reading range lover than 30-40cm. Finally, long range devices are the biggest: they come arranged as gate structures but they can also be found of lower dimensions. Their price is usually very high compared to the one of short range devices (Gate structures can cost up to thousands of Euro), but their reading range can be wider than 1m in ideal conditions.
While a Long Range reader was chosen, it also had to be a portable device: while the best performances are reached using gate readers, these are fixed structures commonly used as antitheft devices, and cannot be employed to perform localization operations as the one planned.
Another feature of RFID readers that was evaluated was their ability to write on tags or only to read the information stored on them. While only the ID code of the tag was used for the identification of the Smart Pebbles, no Read-Write reader was required. Moreover, Read-Only readers are usually cheaper than Read-Write ones, and they are usually more common for Low Frequency systems.
Finally, the choice of a reader with or without an embedded antenna was evaluated. The choice fell then on an integrated device: while the realization of an ad-hoc antenna could have allowed to increase a little the performances of the system in terms of reading range, the presence of two separate devices would have complicated the waterproofing of the reader. Moreover, some solutions can already be found providing a good degree of protection against water, thus improving the reliability of the system in terms of protection against water intrusion.
The final choice fell on the CORE-125 reader by CoreRFID: this device is commonly used for access control, providing a high protection rate against water to allow its use on the outside. In particular, this reader has an IP67 protection rating: this means, according to the International Protection rating, that the device can be immersed in water up to a depth of 1 meter for short spans of time (lower than half an hour). The CORE-125 is a Read-Only reader providing an ideal reading range wider than 70cm, which is nowadays considered one of the highest achievable values. These two features are in accordance with the requirements described before. All the technical features of CORE-125 reader are summarized in Table 1.

TABLE 1 - CORE-125 READER TECHNICAL FEATURES

Feature	Value
Dimensions	265x265x35mm
Weight	1.5kg
Powering	12V DC
Reading distance	80cm
Interfaces	Serial RS232 and Wiegand 26/34
Antenna	Integrated
Protection Rate	IP67

Even if the reader already presented an IP67 protection rating, this wasn't considered sufficient to protect the reader. In fact, while the IP67 could protect the reader for immersions at a maximum 1m depth for short spans of time (Up to 30 minutes), for an efficient tracing system the reader should have been working at depths of up to 4 or 5 meters, with prolonged periods of immersion (Up to 2 or even 3 hours), and in such a situation the protection rate of the reader was clearly insufficient. To overcome this limitation, an ad-hoc waterproof case was studied. The following items were used to build the waterproof case:

- a PVC box;

- a security connector;
- the insulating sponge.

The box was perforated to link the reader to a battery with a powering cable and to a computer with a serial cable: both the cables were introduced into the case through a specific security connector which provided protection against water infiltration (Fig. 1).
To test the efficiency of this structure, it was kept immersed in a bathtub for 24 hours. No evidence of water was found inside the case after this period. Then, to assess the resistance of the case to the sea water pressure, another test was carried out by placing the case on the sea bed at a depth of about 2 meters for 2 hours. This time, it was found that water percolated inside. Therefore, as a final waterproofing, the reader was covered with silicone and this proved successful in preventing water from coming into contact with the reader.
The final device can be easily dragged by a single person, both on the outside- and the under- water sections of a beach. Once realized the

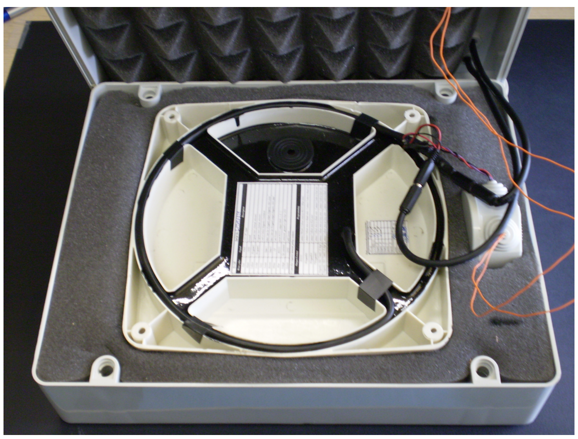

FIGURE 1 - THE READER IN ITS WATERPROOF BOX

waterproof reader, Smart Pebbles had to be developed.
The realization of Smart Pebbles required identification of the right kind of transponder to be employed and on the right way of introducing it into the pebble. For the first prototype 30mm diameter ABS plastic disc tags were chosen. These devices were chosen due to their high resistance against shocks and to their large reading range: laboratory test proved that Smart Pebbles realized using these tags and positioned in a test environment simulating the sea bed were readable at a distance larger than 50cm.

2.3 The first experimentations

Thee first experimentations of the Smart Pebble system took place in 2009 and results proved the effectiveness of the solution. In particular, the system was tested on two beaches in Marina di Pisa, Italy, named Cella 7 and Barbarossa Beach. On these beaches around 100 Smart Pebbles were positioned in March both on the emerged and the submerged portion of the beach. The recovery campaign took place in May: in these two months the Marina di Pisa coast was hit by three severe storms. At the end of the recovery campaign, that required around one week due the necessity to scan carefully both the beaches and the portion of sea close to them with the waterproof reader, a 77% recovery rate for the first beach and a 51% recovery rate for the second were recorded.
Detailed results are shown in Table 2.

TABLE 2 - RESULTS OF THE FIRST EXPERIMENTATIONS

Cella 7				
Site	Underwater	Waterline	Beach	Total
Deployed	32	32	32	96
Localized	25	25	24	74
Barbarossa Beach				
Site	Underwater	Waterline	Beach	Total
Deployed	34	34	34	102
Localized	12	21	20	53

III. THE NEW "SMART PEBBLE" SOLUTION

The Smart Pebble system represents the ideal solution for the sediments tracking because it overcomes all the limitations of the other tracking solutions. It allows to follow the movements of all the single sediment particles, that can be recognized through the ID of the RFID tag, it allows the detection of the pebbles even when they are sinked below other pebbles, it allows the localization of the sediments even if they are under water, and finally, the costs are quite low, being the only expense the price of an RFID tag. Anyway, one of the biggest limitation for a large scale use of this solutions derives from the complexity of the pebble drilling operations: in fact, to insert the disc tag inside a pebble in necessary to make a 3.5cm hole in the pebble, and this operation requires the use of a drill press provided with a cooling system. This kind of device is very expensive, complex to be used and the drilling of the pebbles requires a big amount of time.
The other limitation deriving form the use of disc tags is on the size of the Smart Pebbles: small pebbles cannot be traced with so big transponders.

3.1 The new Smart Pebbles

In order to overcome the limitations listed before, laboratory tests were performed on different typologies of transponder, and cylinder glass tags were identified as the most suitable devices: these transponders can be found in different sizes, according to application requirements, and their insertion inside the pebbles can be performed in an easier way using a common drill [13].
The identified transponders were 34mm long, 4mm large, cylinder-shaped glass tags. Their performances were tested in six different conditions:

- the ideal condition with the tag and the reader in air and in line of sight;
- a test Smart Pebble in ideal conditions;
- a test Smart Pebble under still water;
- a test Smart Pebble under a layer of pebbles in air;
- the previous conditions but under still water;
- the previous condition with salt water, virtually real conditions simulated reproducing the bottom of the sea. It's important to underline that, while the water pressure of the sea is notably higher than in the simulated environment, this feature doesn't affect the reading range, but only the effective waterproofing of the device. Anyway, the resistance to water intrusion could only be tested in sea and this was done directly at the first-field experimentation.

The realization of the Smart Pebble followed these steps:

- A ~4cm deep , 5mm diameter hole was drilled on the pebble surface with a common drill provided with an ad-hoc drill bit;
- The tag was introduced inside the hole;

TABLE 3 - READING DISTANCES OF SMART PEBBLES I

Test conditions	Reading distance
Only Tag	$58 - 65cm$
Smart Pebble	$55 - 64cm$
Underwater	$55cm$
Pebbles Layer	$50cm$
Still water	$44 - 58cm$
Salt water	$48 - 63cm$

- the remaining space in the hole around and over the tag was filled with resin in order to avoid every possible movement of the tag and every contact with the water and the surrounding environment.

With such a solution the tag was virtually melted with the pebble (Fig. 2).

FIGURE 2 - THE TEST SMART PEBBLE

The results of the tests, shown in Table 3, proved that glass tags were suitable to be used for the underwater tracking of pebbles. Anyway, the effectiveness of this kind of transponders had to be tested on a real experiment because, while ABS plastic tags presented a high resistance to shocks, glass tags were evidently more fragile.

3.2 A real scenario

Glass tags were used for a monitoring operation on a beach on the Adriatic Sea in Italy.
The study site is located in the central portion of the Adriatic Sea, just south of the city of Ancona, on the northern edge of the Conero Promontory.
The beach, named Portonovo, is about 500m long and 15-to-35 m wide (Fig. 3). It is bounded by two promontories, which prevent coarse sediment from leaving the system: the northern one is a steep slope that breaks off the continuity of the beach, the southern one is made of a series of large boulders acting as a natural groin. Portonovo beach is characterized by two grain-size fractions: i) medium-to-coarse sands and ii) a coarser fraction mainly constituted by gravel and pebbles. Sands are definitely prevalent over gravel and pebbles.
The experiment was carried out in the spring of 2012. First off, 145 Smart Pebbles were injected along 29 cross-shore transects covering the southern sector of the beach, about 250 m of its whole length, on March, 28. The pebbles were placed on the step crest, on the beachface and on the fair-weather berm, which are the most significant features of the nearshore. Since the step crest and the beachface are highly-dynamic sites, two Smart Pebbles were injected on those positions in order to create aliases useful to check the exact trends of the tracers.

IV. RESULTS

Four recovery campaigns were realized:

FIGURE 3 - THE PORTONOVO BEACH

- The first recovery campaign was performed on the same day of the injection after 6 hours;
- The second one was performed the day after 24 hours;
- The third one was performed around the middle of April, from April 17 to April 19;
- The last one took place on May 29 to June 01 of 2012.

The recovery campaigns were performed using the Waterproof reader to scan both the emerged and the submerged portions of the beach. In particular, for the emerged part of the beach the reader was used as a sort of metal detector: it was moved perpendicularly to the sea from the top of the beach to the waterline and back, repeating this procedure to cover the whole beach surface. The submerged section was scanned in a similar way with the help of a diver. After the first campaign a total of 143 (98,62%) pebbles were localized: very little movements were recorded. After the second one 135 pebbles (93,1%) were localized: pebbles movements were still little but they were more evident than in the previous campaign.
These two campaigns provided interesting geological data, but they presented limited interest for the testing of the technological solution. The third campaign turned in a partial failure due to the bad weather conditions (Strong Wind and heavy sea): a total of 16 pebbles (11,03%) was localized, fearing an inadequacy in the technical solution.
The fourth and last campaign proved that the bad results obtained in the third campaign were mainly due to the difficult working conditions, while the technological solution proved to satisfy the requirements.
A total of 61 pebbles (42,07%) was localized. The position of the Smart Pebbles at the deployment date and after two months is shown in Fig. 4, while in Fig. 5 the total displacements and the global trend of the movements can be seen.
While the number of localized pebbles can appear low, the morphological characteristics of the beach have to be considered. The higher

TABLE 4 - LOCALIZATION RATES AFTER TWO MONTHS

Site	Deployed Pebbles	Localized Pebbles	Rate
Fair-weather Berm	29	9	31%
Beachface	58	25	43,1%
Step Crest	58	27	46,6%

values in the first experimentations held at Marina di Pisa were in fact obtained on artificial beaches, provided with lateral barriers and, in the case of Cella 7 with submerged breakwaters.

The Portonovo beach is a natural one, it is very large and is not provided with any kind of artificial protection. Moreover, only a 10m wide strip of sea close to the beach was scanned, because widening this area would have required the use of a boat for the recovery operations. This means that part of the pebbles have probably been dragged off.

The dimension of the displacements proves that huge movements are possible: the average displacement was 190m, with a maximum of 445m and a minimum of 15m.

The distribution of the localized Smart Pebbles is homogeneous: 9 out of the 29 (31%) pebbles positioned on the fair-weather berm, 25 out of 58 (43,1%) of the ones positioned on the beach face and 27 out of 58 (46,6%) of the ones positioned on the step crest were localized.

All the previous factors can be used as index to evaluate the good performances of the selected kind of tags.

Even with a loss rate close to 60% the obtained data are exhaustive enough to build a dynamic model of the beach evolution.

The only difference in terms of performances between the glass tag solution and the ABS disc solution can be recorded when the Smart Pebbles have to be recovered and not only localized. In this case the new model of Smart Pebble becomes very difficult to be detected because the external aspect of the hole is in this case very similar to the aspect of the unnumbered quantity of holes present on the surface of all the other pebbles: the Smart Pebble can be then recognized only after a careful examination. On the other hand, the Smart Pebbles provided with the ABS tags were easily recognizable due to the large hole that was clearly visible on their surface.

Anyway, the main purpose of the Smart Pebble system is the tracking of the pebbles movements and this can be done also taking just the position of the localized pebbles, without their direct recovery that, once taken the coordinates, becomes useless.

V. CONCLUSIONS

In this paper, the results of a two months experimentation concerning the use of cylinder glass tags as tracers for the sediments tracking on beaches have been presented.

The experimentation carried out from March to May 2012 proved that these devices are the most suitable to be embedded inside pebbles to turn them into tracers. The results prove that this kind of tags also provides a high level of reliability in terms of shocks resistance. Moreover, the insertion of these tags inside the pebble is very easy and then faster than the operations required to insert other typologies of tags. The insertion of a circular ABS tag required the realization of a 30mm diameter hole in the pebble: this could only be made using ad-hoc drilling machines, with timings up to 15 minutes for the drilling of a single pebble. The hole required for the insertion of a cylinder glass tag could be realized with a common drill, in less than 2 minutes.

In addition, the chance to use this kind of tags notably widens the range of possible applications. In fact, smaller glass tags are also available, allowing the use of very small pebbles as tracers. While the tracking of sand is not possible using RFID technology, using 12mm cylinder glass tags, the tracking of gravel becomes possible.

The tracking operations based on the use of glass tags will continue

FIGURE 4 - SMART PEBBLES POSITIONS AT THE DEPLOYMENT DATE AND AFTER TWO MONTHS

then in the next months on Portonovo beach, while new Smart Pebbles will be realized in order to use them also on the Marina di Pisa beach, replacing then the old Smart Pebbles provided with the ABS transponders.

In conclusion, while Low Frequency RFID represents the ideal technology for the sediment tracking, because it overcomes all the limitations present in the other systems, the use of glass tags optimizes at the height this solution, suggesting its use in all the cases when the analysis of the coastal dynamics is required.

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FIGURE 5 - SMART PEBBLES DISPLACEMENTS AFTER TWO MONTHS

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