Bed Profile Tracking and Data Acquisition System for Hydraulics Physical Models

João Palma, Luís Guilherme, Elsa Alves

Abstract--**A practical solution for the control of a bed profiler system with automatic data transfer to a computer is presented. The system is intended for recording the profiles of variable shape sediment bottoms in hydraulics physical models. The new instrument corresponds to a modern design of a classic one, with better performance. New features include higher robustness and speed, improved power drive and motor control in the vertical motion control, as well as a microcontroller based unit for x, y coordinate recording and serial communication with a PC. The new system has been used in an experimental hydraulic flume for the study of reservoir sedimentation, in order to characterize both high grain sediment (delta deposition) and low grain turbidity currents for the validation of mathematical models. Experimental results are shown to demonstrate the appropriate performance.**

Index Terms--**bed profiler, instrumentation, hydraulics model, motion control, reservoir sedimentation.**

I. Introduction

SINCE long ago [1, 2] Laboratório Nacional de Engenharia Civil (LNEC) and other hydraulics research institutions have developed servo-controlled devices for recording bed profiles in flumes and hydraulics basins [e.g. 3, 4]. Such instruments consist usually of a vertical position controller driven by a small electric motor and mechanical transmission actuating a rod as depicted in Fig. 1. In the lower extremity of the rod there is a probe which is the bottom sensor used for the tracking function under water. The longitudinal profile recording is performed by the horizontal translation of the above device placed in a carriage or chariot, with rail or beam guidance, either by motorized motion or manual displacement.

A delicate part in this application is the capability of detecting the bottom very closely but with no contact and with quite good stability to avoid sand penetration and destruction. Bed materials in hydraulic basins or flumes consist mostly of sediments with a variety of granular sizes which are not electrically conductive.

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J. Palma and L. Guilherme are with the Scientific Instrumentation Centre, Laboratório Nacional de Engenharia Civil, Av. do Brasil, 101, 1700-066 Lisboa, Portugal (e-mail: jpalma@lnec.pt, lguilherme@lnec.pt).

E. Alves is with the Department of Hydraulics and Environment, Laboratório Nacional de Engenharia Civil, Av. do Brasil, 101, 1700-066 Lisboa, Portugal (e-mail: ealves@lnec.pt).

Contactless bottom sensing can be made with a multi-electrode probe at the lower end of the vertical rod, by the variation of resistance between electrodes. Rough bed surface, variable granular sediments, water conductivity variations due to temperature and salinity, and also electromagnetic interference, are among the most disturbing effects that influence the sensing and servo-control performance.

In the following sections some design and implementation aspects of a bed profile tracking system are presented as well as the experimental results from its application to a particular hydraulics study.

II. Bottom Sensing and Tracking Control

A. Bottom Sensor

The sensing probe with three electrodes (see Fig. 2a) plays an important role in the process. The distance from the probe to the bottom is transduced by the unbalance between impedances R_A and R_B. Under homogeneous temperature and salinity R_A increases when the probe approaches the bottom (crushing current lines), while R_B remains constant.

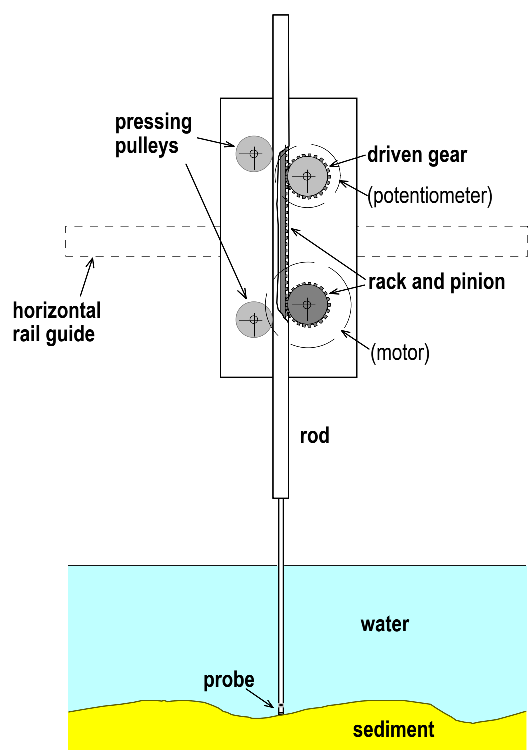

Fig. 1. Pictorial description of the mechanism for vertical motion of a bed profiler.

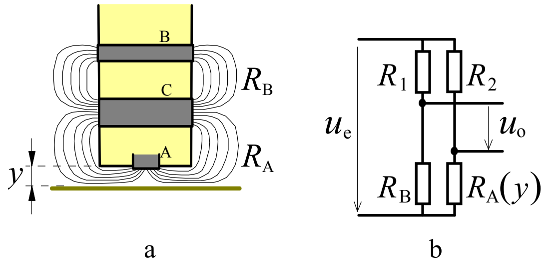

Fig. 2. (a) Details of the bottom proximity sensor probe with three electrodes. (b) Bridge circuit for transducing the distance y to the bottom with temperature and salinity compensation.

Bridge circuits are widely used in instrumentation to obtain transduction solutions with the capability of self-compensation for certain disturbing effects [5, 6].

The bridge circuit shown in Fig. 2b provides a fair compensation for water conductivity variations due to temperature and salinity. In fact, conductivity variation affects simultaneously R_A and R_B, still yielding an equilibrium condition:

$$R_1 R_A^* = R_2 R_B \rightarrow R_1 \alpha R_A^* = R_2 \alpha R_B \quad (1)$$

Bridge excitation is made in high frequency (10 kHz) ac voltage in order to avoid electrolytic polarisation of electrodes. The bridge output is then dc decoupled, rectified, peak detected, amplified and filtered. The resulting voltage u_y, although varying nonlinearly with the distance y to the bottom, may be linearised in the working range (i.e. close to the bottom) and suitable for linear control design techniques [7].

Far from the linear region the output signal saturates thus demanding maximum actuating torque. This effect requires current limitation in the inner motor control loop as explained in the next section.

When the probe is reaching the water surface a reciprocate effect occurs with R_B increasing while R_A remains constant. If this condition is exploited the system becomes a surface follower (or *limnimeter*).

B. *Tracking Control System*

Older versions of bed profile followers had stability problems due to the dc motor control method by direct armature voltage adjustment. In fact, the brush contact voltage drop is quite significant in a 12 V motor giving rise to a strong nonlinearity. The new system was designed with a subordinate current control loop [8] allowing to overcome the above difficulty and giving explicit torque control, with less than 2 milliseconds settling time.

Fig. 3 shows the block diagram of the servo system used for bed profile tracking, with the inner current control loop. The tracking controller is of lag-lead type in order to have a compromise between response speed and error. The reference signal to the subordinate loop represents the reference value of current demanded by the position control loop and allows the application of a limiting device in order to protect the motor and the amplifier against over-currents.

The bed tracking system is adjusted to keep the probe at a constant distance of 1 to 3 mm from the bottom. This adjustment is made at resistor R_2 (Fig. 2b).

Bottom tracking was implemented with analogue electronics, as shown in Fig. 4.

A switching converter operation would be essential for higher power machines [8], due to efficiency reasons and also for the sake of semiconductor rating and heat dissipation. In this particular application, however, movable parts are relatively light thus allowing for a very low power motorisation (10 watts). In many instrumentation applications with delicate transduction processes the interference caused by the harmonics generated by switching converters are a major concern. Thus a linear amplifier was preferred instead of a chopper given the almost insignificant heat losses involved in order to reduce the electromagnetic noise and interference in the sensing process.

A current control solution was adapted to the full bridge power amplification (formerly a half bridge), using a probe resistor R_p for current sensing, in a triple operational amplifier arrangement shown in Fig. 4.

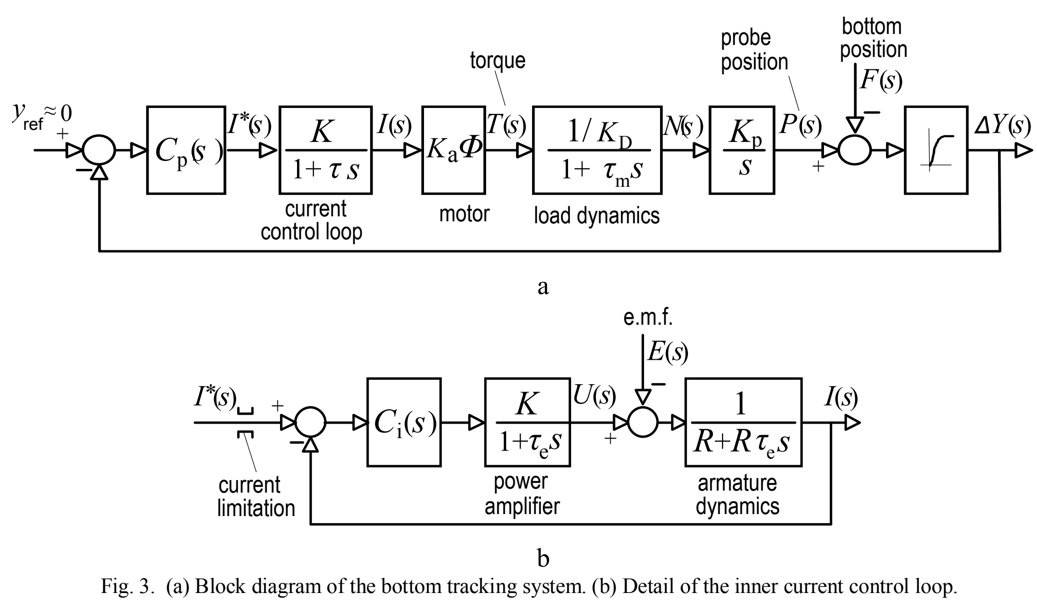

Fig. 3. (a) Block diagram of the bottom tracking system. (b) Detail of the inner current control loop.

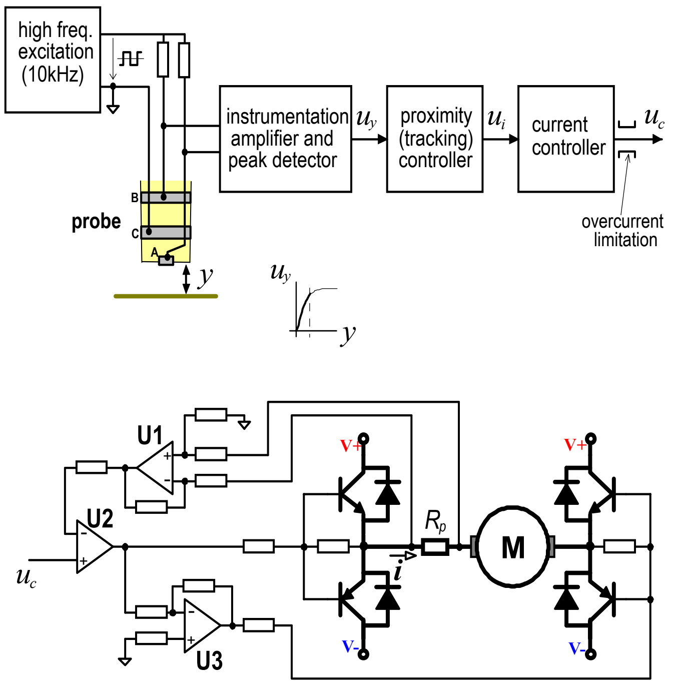

Fig. 4. Sensing and controller block diagrams and electric drive circuit schematic for current control.

In Fig. 4 subtractor U1 provides the current measurement signal from the voltage at R_p terminals, U2 performs as the linear current source controller driving directly the left bridge arm and U3 creates the inverted signal for the right bridge arm. The bridge is formed of BD 680 PNP and BD 681 NPN Darlington transistors.

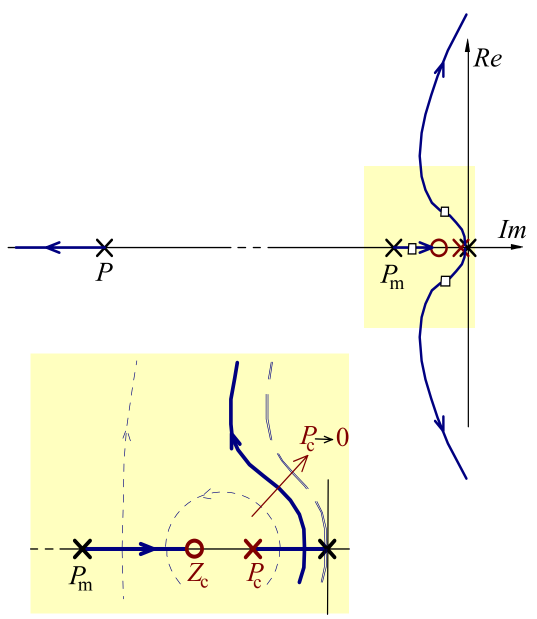

Fig. 5. Root locus trend of the closed-loop control system with an enlarged detail showing the effect of varying the controller pole (from *lag-lead* to *PI* controller).

This represents an improvement to the half-bridge topology of previous versions [1], yielding double voltage supply to the motor with he same +15V, 0, -15V source, especially useful for transient capabilities (acceleration and deceleration).

Simple controller structures are especially welcome for practical purposes whenever possible, in order to have a minimum number of parameters to adjust. In this particular case two-parameter controller structures were seek.

The controller synthesis is described with the aid of the root locus tendency draw roughly depicted in Fig. 5. The design is based on linear modelling, where three major poles are found: a fast electrical one (P) due to the inner current control loop (with aprox. 1 ms time constant), a slow mechanical pole (P_m) modelling the motor and load (with aprox. 40 ms time constant), and a pole at the origin resulting from the integration of speed yielding the position.

The controller consists of a pole P_c and a zero Z_c in a lag-lead arrangement. In fact the pole-zero placement may be chosen such that different emerging locus patterns can be found (see the enlarged detail in Fig. 5) ranging from the *lag-lead* type to the *PI* type controller (when P_c is placed at 0). Stability is possible – and was verified in experimental tests – with both types.

The PI controller gives no steady state (i.e. accumulated) error with two dominant complex poles yielding moderate overshoot. But a faster speed response with still less overshoot was found with P_c slightly displaced from 0. Final parameters were experimentally adjusted.

Although a more complex controller structure with one pole and two zeroes has been studied and tested in laboratory with good results, the simpler versions are preferred for the sake of future adjustment needs.

III. Computer Data Acquisition

A. Specifications

Bed profile data consist of a sequence of coordinate pairs $\{x_i, y_i\}$ in a considerable number of points. These data is recorded by moving the profiler, either manually or automatically, along a given direction.

The vertical coordinates are obtained from a multi-turn potentiometer (see Fig. 1) as an analogue signal. The horizontal coordinate is obtained from an incremental encoder actuated by a system of two pulleys and a thin steel cable. This method requires an initial zero positioning of the carriage in order to produce absolute x coordinate values.

Since the system may be at rest for long periods the power supply for the amplifier and motor should be de-energized by a relay through a computer command. The mechanical reductor coupled to the motor prevents gravity downwards movements after de-energisation.

During rapid carriage travel (e.g. for return to origin) the bed tracking operation may be suspended and in such case the profiler should be commutated for surface tracking.

Data acquisition, as well as activation and initialization of the system are made from a computer (PC) communicating in series with a specific digital unit as explained next.

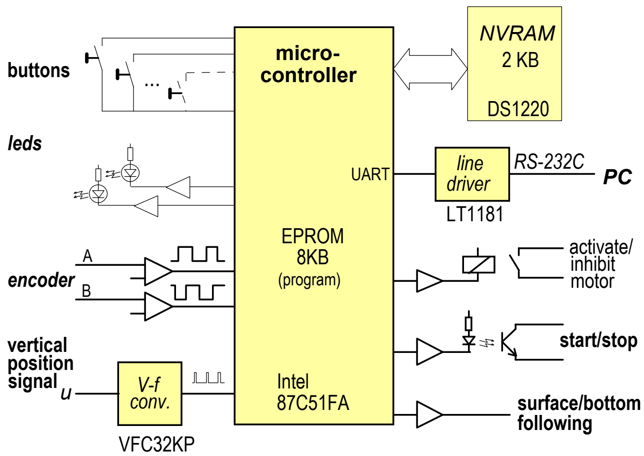

Fig. 6. Block diagram schematics of the microcontroller based unit.

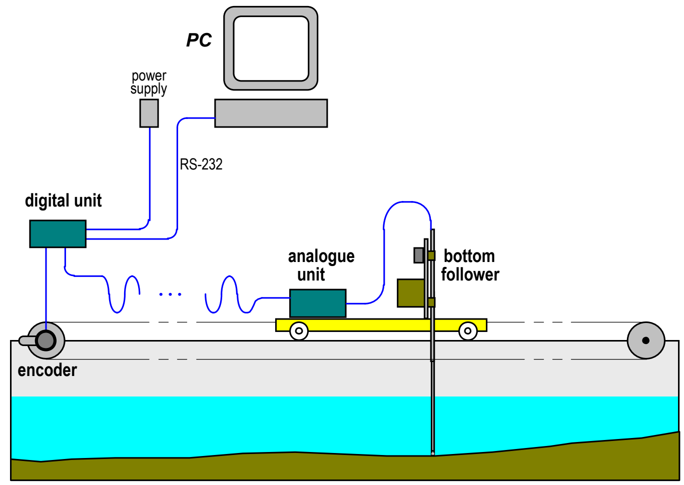

Fig. 7. Synoptic description of the measurement and data acquisition system used in the flume.

B. Digital unit description

A digital programmable unit was developed for the above tasks, as described in Fig. 6, using an 8-bit microcontroller (Intel 8751FA) with internal EPROM for program, external NVRAM for data, and internal UART for serial communication.

The data acquisition of the horizontal coordinate is made by up-down pulse counting of two quadrature-output signals of the encoder, with NVRAM retention. The vertical coordinate data acquisition is made after voltage to frequency conversion of the analogical potentiometric signal and pulse counting in the microcontroller at regular 40 ms intervals.

Communication with the computer is made by serial, asynchronous mode, 9600 b/s rate, using RS-232C interface. Media access control is master-slave and error control is made by BCC with retransmission mechanism. A very short protocol allows the master (PC) to send a few commands, namely:

energize or de-energize actuator,
memorise the zero position,
commutate to bottom or surface following,
request state and data.

The encoder has 1024 pulses/turn and the horizontal resolution is 1320.12 pulses/m with les than ±1 mm dead beat. Vertical resolution after V/f conversion and pulse counting is 13.5 pulses/mm.

Coordinate pairs (x, y) are requested by the computer at a rate of 5 points/sec and recorded in a file as shown below:

```
* 2006/10/11  11:23:34 *
  8.214 242.37
  8.217 244.89
  8.220 246.30
         ...
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Since manual chariot motion was required for the application reported in section IV, i.e. with uncontrolled translational speed, over-acquisition had to be avoided by excluding points less than 2 mm horizontally apart. This precaution is not needed with automatic horizontal motion.

Fig. 7 has a schematic drawing that shows a synoptic overview of the whole system.

The analogue unit remains in the carriage close to the bed profile follower mechanism while the digital unit is outside the flume. The PC is kept inside a cabinet for channel service and works with a simple program for communication with the digital unit and data archiving in disk.

IV. Experimental Application

The system described was used in a flume of the Department of Hydraulics and Environment of LNEC for the study of the sedimentation process in dam reservoirs, by making successive profile surveillances [9, 10]. The flume has 10.60 m length, 0.30 m wide and 0.75 m maximum height.

Fig. 8. Photograph showing the external appearance of the instrument block in a flume chariot.

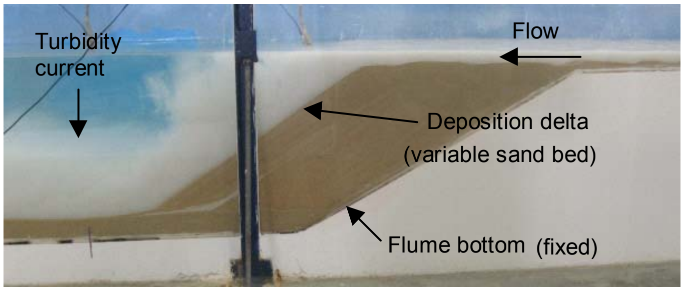

Fig. 9. Photo showing the delta deposition of sand and the turbidity current (white cloud) seen through the transparent acrylic wall of the flume.

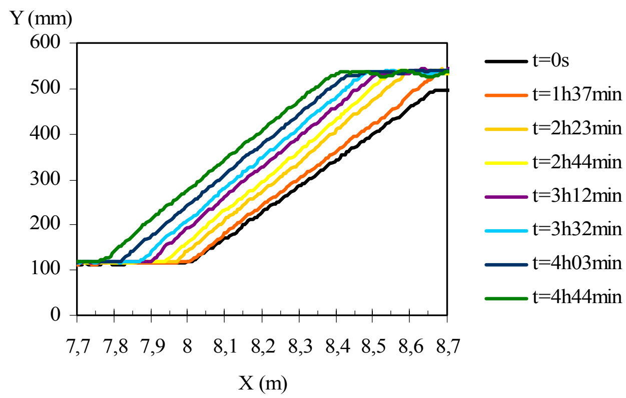

Fig. 10. Successive bed profiles along time in the region of interest corresponding to the portion shown in fig. 9.

Fig. 8 shows a photo of the instrument apparatus in a carriage over the flume. The shape of deposited sediment in the region of interest after 4 h 44 min of test can be seen in Fig. 9. Fig. 10 shows the diagrams of collected data corresponding to several profiles at given time intervals, showing the progress of the delta front edge. The equilibrium tilt angle of this front edge is approximately 33º and was attained 2 h and 23 min after the test start.

From the hydraulics point of view the experimental study aims at characterizing both high grain sediment (delta deposition) and low grain turbidity currents for the validation of mathematical models.

V. Conclusion

The new bed profile tracking system allows digital communication with a computer, and brings a number of advantages for command, diagnostics and data acquisition.

Significant robustness and performance improvements were achieved in the vertical motor control as well as in the tracking system in terms of higher stability, response speed and force capability (due to the bridge topology of the amplifier). The inner current control loop that was introduced in the control structure proved to be useful for the attenuation of the nonlinearity created by the collector-brush voltage drop, as well as for establishing a self-protection scheme against overcurrents in the motor and the amplifier.

Occasional penetration of the probe tip in the sand with immediate loss of tracking capability was a destructive kind of event that has been effectively avoided with the new system, owing both from servo controller response improvements and from a re-shaping of the geometry of electrodes at the probe tip. This improvement in robustness is an important feature in order to avoid local destruction of delicate bottom sediments.

After initial tests and adjustments the system has been used with success in a study of sedimentation caused by turbidity currents, with the progress of the delta front edge with an approximate tilt angle of 33º.

Experimental results demonstrated the appropriate performance of the system.

VI Acknowledgement

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VII. References

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VIII. Biographies

João Palma was born in Luanda, Angola, on 1956. He received the diploma of Licentiated, M.Sc. and Ph.D. degrees in Electrical Engineering from the Technical University of Lisbon, Portugal, in 1980, 1989 and 1994, respectively.
Since 1983 he has been with the Laboratório Nacional de Engenharia Civil (LNEC) in its Scientific Instrumentation Centre (CIC), now as a Senior Research Officer. He is also an Invited Coordinator Professor at the Department of Electrical and Automation Engineering of Instituto Superior de Engenharia de Lisboa. His research interests include instrumentation design, static power conversion, variable speed drives and automation used in scientific equipment applied to Civil Engineering.

Luís Guilherme was born in Santarém, Portugal, on 1977. He graduated in Electrical Engineering at the Instituto Superior Técnico (IST) of the Technical University of Lisbon, Portugal in 2002. Currently he is finishing his MSc in Electrical Engineering at the same University.
Since 2003 he has been with the Laboratório Nacional de Engenharia Civil (LNEC) in its Scientific Instrumentation Centre (CIC), with a Research Grant. His research interests include scientific instrumentation, metrology, industrial automation, systems control and renewable energies.

Elsa Alves was born in Lisbon, Portugal. Graduated in Civil Engineering at the Instituto Superior Técnico (IST) of the Technical University of Lisbon in 1993. Received her MSc degree in Hydraulics and Water Resources (IST) in 1997.

Since 1993 she has been with the Laboratório Nacional de Engenharia Civil (LNEC) at the Environment and Hydraulics Department (DHA). Her main areas of interest are fluvial hydraulics, hydrology and water resources.

Within fluvial hydraulics she performed an experimental study on turbidity currents on reservoirs as part of her PhD thesis to be presented at IST in 2008.