Mem. Natl Inst. Polar Res., Spec. Issue, **58**, 196–202, 2004

Technical report

Little Leonardo digital data logger: its past, present and future role in bio-logging science

Hiroyuki Muramoto[1]*, Mitsuhiro Ogawa[2], Michihiko Suzuki[3] and Yasuhiko Naito[4]

[1]*Marine Micro Technology Co., 102 Wakamiya Haitsu, 12-1, Takakura 4-chome, Iruma 358-0021 (*mura-mmt@jade.dti.ne.jp)*
[2]*Institute of Biomaterials and Bioengineering, Tokyo Medical and Dental University, 3-10, Kanda-Surugadai 2-chome, Chiyoda-ku, Tokyo 101-0062*
[3]*Little Leonardo Co., Asahi-Syouten-Bldg., 4-4, Honkomagome 1-chome, Bunkyo-ku, Tokyo 113-0021*
[4]*National Institute of Polar Research, Kaga 1-chome, Itabashi-ku, Tokyo 173-8515*

(Received July 29, 2003; Accepted August 25, 2003)

Abstract: For over 10 years, Little Leonardo has been developing digital data loggers for use in diverse research on marine animals. In this paper, the authors give an overview of Little Leonardo digital data loggers, the difficulties of designing a digital data logger and the possibilities for future improvements. Current data loggers are adequate to monitor animals in the field but several improvements are needed and the performance of Little Leonardo loggers will improve as future technologies are incorporated.

key words: data logger, design of data logger

The contribution of digital data loggers to bio-logging science

Over the past two decades, it has become increasingly clear that data-logging devices deployed on animals could substantially advance biological studies that wish to investigate the behavior of free-ranging individuals in an ecosystem. This is especially true for marine vertebrates that cannot be tracked by researchers over a long period of time while at sea. In this regard, the usefulness of a data-logging approach has been exemplified by the work of several research teams, most of whom attended the International Symposium on Bio-logging Science, held at and organized by the National Institute of Polar Research (NIPR), Tokyo, Japan, in March 2003. As progress is made, questions become more complex, involving new animal species that, in return, bring new challenges to the technicians. Since 1992, the Little Leonardo company in association with Marine Micro Technology has developed digital data loggers of internationally recognized quality and efficiency. Most of these loggers were developed to answer the specific needs of biological researchers at NIPR. The following references illustrate the various approaches and results of the collaboration between our company and the biology group of NIPR (Naito *et al.*, 1989; Otani *et al.*, 1998; Kuroki *et al.*, 1999; Ropert-Coudert *et al.*, 2000a, b; Watanuki *et al.*, 2001; Sato *et al.*, 2003; Watanabe *et al.*, 2003).

For the researcher working on animals that exploit remote environments, digital data loggers offer three main advantages: small loggers can be easily produced; the data collected are per se digitized and, therefore, easy to handle; and technological improvements can be implemented through hardware upgrades of the data logger. This flexibility explains the success of digital data loggers in studies aimed at investigating the behaviour of marine animals in their natural environment. In this paper, we describe the basic characteristics of our company's standard digital data logger and discuss some of the anticipated future improvements.

The standard digital data logger

Our digital data loggers consist of the following elements: case, battery, sensor(s), A/D converter, MPU, memory, real-time clock and interface (Fig. 1). Figure 2 shows an example of a data logger.

1) Case

In the majority of our models, the logger case is made of aluminum (A6061B-T6), protected by hard-anodizing. Cylindrical shapes are preferred because they are easy to produce

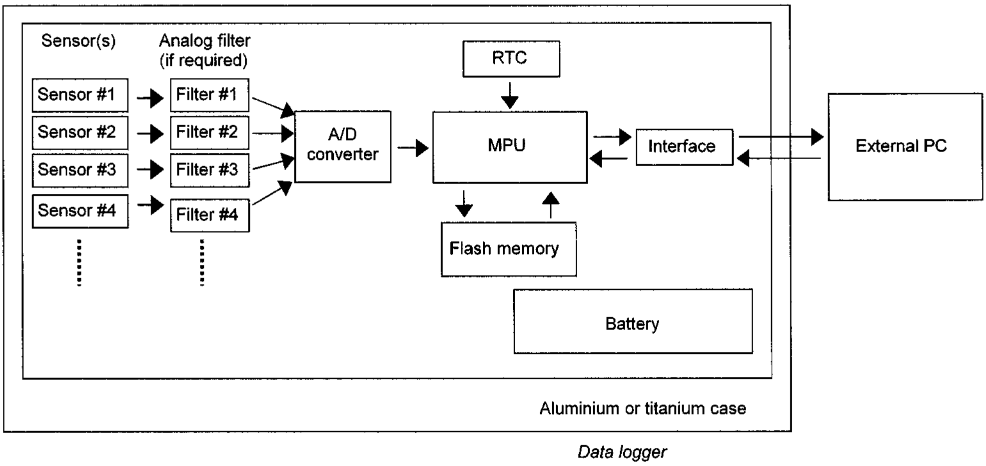

Fig. 1. Schematic diagram of Little Leonardo data logger.

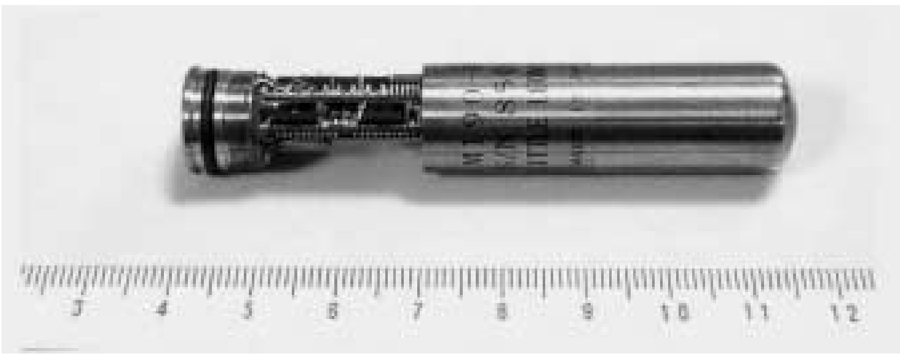

Fig. 2. An example of a data logger (Model M190-DT).

and offer appropriate strength. For instance, a 1 mm thick casing with outside diameter of 15 mm can withstand pressures of about 4×10^7 Pa (400 atmospheres). For long-term studies, where the logger must stay on animals for several months or years, the case is made of titanium (TAB6400). With this material, cases do not corrode over several years of deployment. Cases are sealed with "O" rings to be waterproof and the insides of the cases are filled with air at 1 atmosphere pressure.

2) Battery

Lithium manganese-dioxide batteries are chosen because they can operate at low temperatures–a determinant parameter since our loggers are primarily meant to be deployed on polar, marine animals–and have high energy density. Currently, a non-rechargeable battery is used for actual data sampling and storing because it has a much higher energy density than a rechargeable battery. The data logger's design uses CMOS (Complementary Metal Oxide Semiconductor) components for all devices in order to minimize power consumption. With the MPU (Main Processor Unit) operating in Standby mode most of the time (where the MPU operates with very low power consumption) and with the sensors working at reduced power, power consumption is kept as low as possible. The design of the battery box of our data loggers allows the batteries to be easily changed. The operating voltage of the internal circuits is 3.3 V. Because the operating voltage of a lithium manganese-dioxide battery is 3 V, voltage boosting by a DC-DC converter is used to obtain 3.3 V in data loggers operated by a single battery. In loggers operated by 2 or > 2 batteries, batteries are connected in series and a voltage regulator is used to obtain 3.3 V.

3) Sensor

Many sensors have been introduced allowing researchers to record various parameters, as shown in Table 1. Overall, the features of our loggers result from the need to balance miniaturization with the researcher's desire for multi-sensor sampling. Where several sensors

Table 1. There were several variations in each model. Digital data loggers were produced by Little Leonardo and the National Institute of Polar Research, Japan (minor variations in each model are not included).

Type	Size (mm)	Memory size	Parameters
NIPR-200	14×70	349 kbit	Depth and temperature
NIPR-101-4T	14×77	349 kbit	4 temperature points
KS-200DT	19.5×70	8 Mbit	Depth and temperature
KS-200DTC	19.5×75	8 Mbit	Conductivity, depth and temperature
KS-200PDT	19.5×75	8 Mbit	Swim speed, depth and temperature
W380M-DT	20×67	16 Mbit	Depth and temperature
W400M-4T	20×87	16 Mbit	4 temperature points
W380L-PDT	20×116	32 Mbit	Swim speed, depth and temperature
W190L-PD2GT	21×116	256 Mbit	2 acceleration axes, swim speed, depth and temperature
W380TL-3MPDT	24×189	128 Mbit	3-axes geomagnetic compass, swim speed, depth and temperature
W400-ECG	21×109	2 Gbit	Electrocardiogram
M190-DT	15×48	32 Mbit	Depth and temperature
M400-2T	15×70	32 Mbit	2 temperature points
M190L-D2GT	15×52	128 Mbit	2 acceleration axes, swim speed, depth and temperature
DSL-1000DV	52×230*	512 Mbit†	Still image, depth
DSL380-DTV	22×128	2 Gbit††	Still image, depth, temperature

* Flash and camera; † equivalent to 700 images; †† equivalent to 1000 images.

need to be monitored simultaneously, size or shape may be increased accordingly. Conversely, the number of parameters that can be recorded may be limited in the case of smaller devices, depending on the sensor types.

4) A/D converter

In most cases, output from the sensors is digitized with an A/D converter (Analog-to-Digital converter) with 12-bit resolution, after being amplified and filtered with an analog circuit. Although A/D converters with more than 14-bit resolution are commercially available, it is inappropriate to use these products because of the comparatively low signal-to-noise ratio of measurements made on wild animals. In some models, an A/D converter is included within the MPU.

5) MPU

A C-MOS 8-bit RISC MPU (PIC17C Microcontroller Family, Microchip Technology, USA) is used to control sensing procedures, store and compress data and communicate with other computers.

6) Memory

Data are compressed using an MPU data compression procedure, before being stored semi-permanently in a NAND-style flash memory. Data are retained even after the battery life has expired, which would not be possible with a DRAM (Dynamic Random Access Memory) or a SRAM (Static Random Access Memory). The capacity of the flash memory varies among models, ranging from 16-Mbit to 2-Gbit.

7) Real-time clock

A real-time clock (RTC) provides a time reference for the system. Timekeeping information includes thousandths of seconds, seconds, minutes, hours, days, months and years. The date at the end of the month is automatically adjusted for months <31 days, including correction for leap years. The average error of RTC is 5 ± 23 ppm (an error of 23 ppm corresponds to *ca.* 1 min per month).

8) Interface

Communications with the logger (protocol setup and data download) are carried out using communication cables that are connected to an interface based on the RS-232-C protocol. This interface box is then connected to a desktop or laptop computer. The achievable transfer rate of data is about 130 Kbps.

9) Difficulties in designing digital data logger

We mentioned previously the advantages of digital data loggers, but it should be noted here that there are also several constraints that control the design of a digital data logger. For instance, long-term deployments, or the need to collect larger amounts of data, require bigger batteries and, thus, greater logger size and mass. This, in return, reduces the range of animal species on which such enlarged loggers can be deployed. Similarly, long-term deployments require use of A/D converters, MPU and memories with lower power consumption. However, lower power devices stabilize more slowly and this means that the data sampling speed becomes relatively slow. High impedance sensors can also reduce power consumption because the electric current flowing through them is decreased. However, the signal-to-noise ratio generally decreases, limiting accuracy. Finally, measuring data with higher accuracy generally means that bigger sensors—and again, a larger logger—are needed.

Expected technological improvements

Obviously, technological progress will help to increase the performance of data loggers. Improvements can be obtained by two different approaches: improving each element of the logger separately or developing a new logger based on totally new concepts.

Improving each element separately

This approach is the easiest and quickest way to improve logger performance but this also means that progress will be gradual. Technological improvements occur on a nearly day-to-day basis: smaller RTC packages and lower power consumption A/D converters or MPUs should be commercially available soon. Technological enhancements can be expected from companies that develop portable devices (*e.g.* PDAs, cellular phones, notebook computers). For instance, commercial models of "fuel cell" batteries that contain much more energy than ordinary batteries are currently under development in several of these companies. Alternatively, electric circuits that run on 1.8 V could be used to reduce the power consumption of data loggers. Companies producing portable devices are also a potential source for lower power consumption and small-sized memories. In the near future, a new generation of nonvolatile memories will probably replace the classical flash memories. For instance, Ferroelectric Random Access Memory (FeRAM; 10 times faster and more reliable than the current flash memory), Magnetoresistive Random Access Memory (MRAM) or Resistance Random Access Memory should be available soon.

While new sensors can be introduced at any time, it is rather difficult to develop new sensors exclusively for data logger usage. Practically, data logger makers select their sensors from those that are commercially available. None-the-less, the number of sensors in a unit can be increased, or new higher-performance sensors can be used, if other elements of the logger become smaller or consume less power.

Additionally, a new communications interface will be developed in order to cope with large-volume data transfer. Among the promising interfaces, USB 2.0, whose maximum transfer rate is 480 Mbps, bears our highest hopes.

New concepts for future data loggers

We propose here three (non exhaustive) directions that could revolutionize the way data loggers work:

Rechargeable battery with a generator:

The introduction of a rechargeable battery with a high energy density, would enable us to use a dynamo as a power source. A miniaturized propeller installed in the logger would rotate a coil inside a magnet (or a magnet inside a coil, like a bicycle dynamo), which would transform kinetic energy into electric energy. This would allow researchers to perform long-term deployments, without the size limitations of a traditional battery.

Developing the "intelligent" data logger:

In parallel with the expected increase in the performance of MPU units, data loggers will become more "intelligent" and data logging periods will be extended. For example, future loggers may be able to interpret data from sensors autonomously, make decisions on the timing of data samples, shift to low-power mode, select algorithms for data compression, etc.

Although a single MPU is used to process data in the current models, a high performance DSP (digital signal processor) may become available to assist the MPU units, helping to calculate digitized data more rapidly.

Fabrication of device for exclusive use in data loggers:

On a commercial basis, the minimum number of electronic devices that can be economically produced is in the range of 10000–100000 units. The specifications of such a device must be carefully determined so that its design is suitable for several applications. Most of these specifications are constrained by the types of products available on the market. For example, it is difficult to design a logger with five sensors because most of the A/D converters have four or eight, not 5, channels. Therefore, we should use either one 8 channels converter or two 4 channels converters (but then 3 channels would be unused). The fields of micro-machining and nano-technology are maturing and promise high-variety, low volume manufacturing of electronic devices. These emerging fields could make it economical to produce 100 (or even fewer) custom electronic devices. Thus, it would become possible to purchase devices that are designed exclusively for data loggers at a low price, which in turn will improve the performance of data loggers.

Conclusions

Collaboration between biologists and engineers will become more important for developing new data loggers. For example, in the medical engineering and telemedicine/telecare fields, a medical doctor who has good understanding of engineering contributes to the technological development of a device and to its evaluation. Similarly, interactions between biologists (who are aware of engineering issues) and companies should help develop data loggers with higher performance, at a lower cost and much more quickly.

Acknowledgments

The authors would like to thank A. Kato, Y. Ropert-Coudert and R.H. Hill for their helpful comments on the manuscript.

References

Kuroki, M., Kato, A., Hayama, S. and Naito, Y. (1999): Preliminary report of new method for ECG measurement of exercising birds. Polar Biosci., **12**, 40–46.

Naito, Y., Le Boeuf, B., Asaga, T. and Huntley, A.C. (1989): Long-term diving records of an adult female northern elephant seal. Nankyoku Shiryô (Antarct. Rec.), **33**, 1–9.

Otani, S., Naito, Y., Kawamura, A., Kawasaki, M., Nishiwaki, S. and Kato, A. (1998): Diving behaviour and performance of harbour porpoises, *Phocoena phocoena*, in Funka Bay, Hokkaido, Japan. Mar. Mammal Sci., **14**, 209–220.

Ropert-Coudert, Y., Baudat, J., Kurita, M., Bost, C.-A., Kato, A., Le Maho, Y. and Naito, Y. (2000a): Validation of oesophagus temperature recording for detection of prey ingestion on captive Adélie penguins (*Pygoscelis adeliae*). Mar. Biol., **137**, 1105–1110.

Ropert-Coudert, Y., Sato, K., Kato, A., Charrassin, J.-B., Bost, C.-A., Le Maho, Y. and Naito, Y. (2000b): Preliminary investigations of prey pursuit and capture by king penguins at sea. Polar Biosci., **13,** 101–112.

Sato, K., Mitani, Y., Cameron, M.F., Siniff, D.B. and Naito, Y. (2003): Factors affecting stroking patterns and body angle in diving Weddell seals under natural conditions. J. Exp. Biol., **206**, 1461–1470.

Watanabe, Y., Mitani, Y., Sato, K., Cameron, M.F. and Naito, Y. (2003): Dive depths of Weddell seals in relation to vertical prey distribution as estimated by image data. Mar. Ecol. Prog. Ser., **252**, 283–288.

Watanuki, Y., Mehlum, F. and Takahashi, A. (2001): Water temperature sampling by foraging Brunnich's guillemots with bird-borne data loggers. J. Avian Biol., **32**, 189–193.