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New and Improved Time-selective Self-triggering Water Sampler: AUTTLE

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Abstract: Time-selective self-triggering water sampler, AUTTLE developed by Jin *et al.* (1999) has been improved in order to prevent pre-deposition of suspended sediments (SS) before sampling. By using two solenoids, the improved sampler is able to be moored or deployed with inclination. Its position is changed to horizontal position by activating the first solenoid, and then the endcaps of the sampling bottle are closed by the second solenoid that is driven three times to minimize possible failure of sampling. An external control unit for setting sampling time has been also constructed. Additionally, the electric circuit housing of the sampler has been modified to be detached from the sampling bottle when operating manually. Its performance has been confirmed through flume tests and a field experiment. It will serve as a valuable tool in the various fields of oceanography and environmental engineering, especially where seawater sampling synchronized at several sites and/or the information in storm period is important.

Key words: Water sampler, Solenoid, Synchronized sampling, Optical Backscatter Sensor (OBS), Acoustic Backscatter Sensor (ABS), *In-situ* Calibration, Real Time Clock (RTC), Electrically Erasable Programmable ROM (EEPROM).

1. Introduction

Although various instruments have been developed for *in-situ* measurements of marine environmental parameters, seawater sampling is still the primary task for the study that requires shipboard or laboratory experiment for the analysis. However, the prerequisite for seawater sampling with water samplers such as the Van Dorn, Nansen or Niskin sampler is the mild sea condition when vessel cruising is possible.

Suspended sediment concentration (SSC) is usually obtained by measuring total sediments collected by direct sampling with seawater-sampling bottles or pumping units. Solid-state sensors using light attenuation, light scattering, acoustic backscattering or laser dif-

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fraction properties, as related to suspended particulate characteristics, have been also used for *in-situ* measurement of SSC. Because of the fast-time response and relatively low power requirements, optical sensors are ideal for obtaining continuous vertical or horizontal profiles of suspended particulates or time series measurements from moorings or sensors attached to structures within the water column (Sternberg 1989).

However, all the solid-state sensors should be reliably calibrated because they have their own response characteristics according to particle sizes, sediment concentrations and mineralogical composition. Acoustic backscatter sensors (ABSs) can be effectively used in homogeneous sandy environment, however it would underestimate the SSC of sand/mud mixture or muddy suspension (Hay and Sheng 1992) without *in-situ* calibration. The measurement range of a beam transmissometer depends on its path length (Nittrouer *et al.* 1986). The gain (volts per mg/l) of an optical backscatter sensor (OBS) can vary by a factor of 200 according to the particle size (D&A Instrument Co. 1991). Furthermore, the change in the slope sign of the calibration curve due to the blocking of infrared radiation also causes a serious error in the quantitative study of high concentration suspension (D&A Instrument Co. 1991; Kineke and Sternberg 1992). Maa *et al.* (1992) revealed that the maximum operational concentrations of the OBS for kaolinite, illite and montmorillonite are about 0.5 g/l, 0.8 g/l and 1.2 g/l, respectively.

Downing and Beach (1988) and KORDI (1999) constructed apparatuses for the laboratory calibration of the OBS with bottom sediments. In sandy mud or muddy sand environment with strong tidal currents and/or high wave, the OBS calibration with bottom sediments is not appropriate because the sand fraction in the suspension can largely vary with hydrodynamic forcing (Jin *et al.* 2000).

Remote sampling of seawater by a pumping unit such as the RAS 3-48N of McLane Inc. or syringe unit such as the Aqua Monitor-WMS of W.S. Ocean Systems Ltd. is also possible for *in-situ* calibration of an OBS (Sternberg *et al.* 1986; Black and Rosenberg 1994). Important constraints for this method include adjustment of the intake velocity to approximate the ambient fluid velocity, i.e. avoiding fluid accelerations or decelerations while sampling with intake nozzle aimed into the flow (Sundborg 1956; Sternberg 1989).

With special concerns on *in-situ* calibration of turbidity sensors and better understanding of the temporal variations of sand and mud contents in SS, Jin *et al.* (1999) developed an automatic seawater-sampling bottle, AUTTLE, by simple combining a Niskin bottle, two electric circuit boards and a solenoid. Both time-selective self-triggering operation and manual actuation by dropping of a messenger as existing samplers are possible.

Although the AUTTLE's performance was confirmed through a field test, it has inconvenience in setting sampling time and doing manual operation. Jin *et al.* (1999) moored the AUTTLEs horizontally in order to prevent possible disturbance of flow field in the bottle. Thus, there was uncertainty of SS pre-deposition in the Niskin bottles before sampling, especially when using them in high concentration regime.

The old version has been improved in several ways which will be described in this paper.

2. AUTTLE Improvement

Basic Mechanism

The functions of the AUTTLE's two boards are time control, and high power generation with a 9-volt battery and a condenser, respectively. Minimum time to charge the condenser from zero up to the required power of 50 volts for one triggering is 50 seconds. The basic mechanism of the AUTTLE is closing the endcaps of the Niskin bottle by driving the moulded solenoid which pulls the trigger rod.

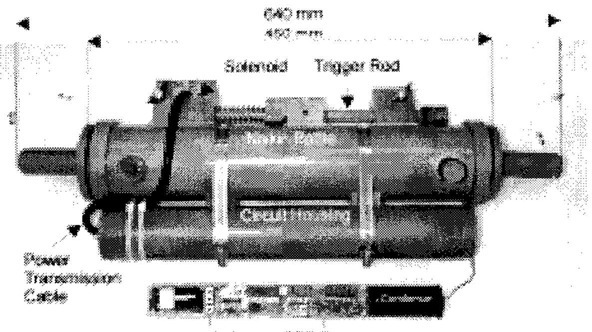
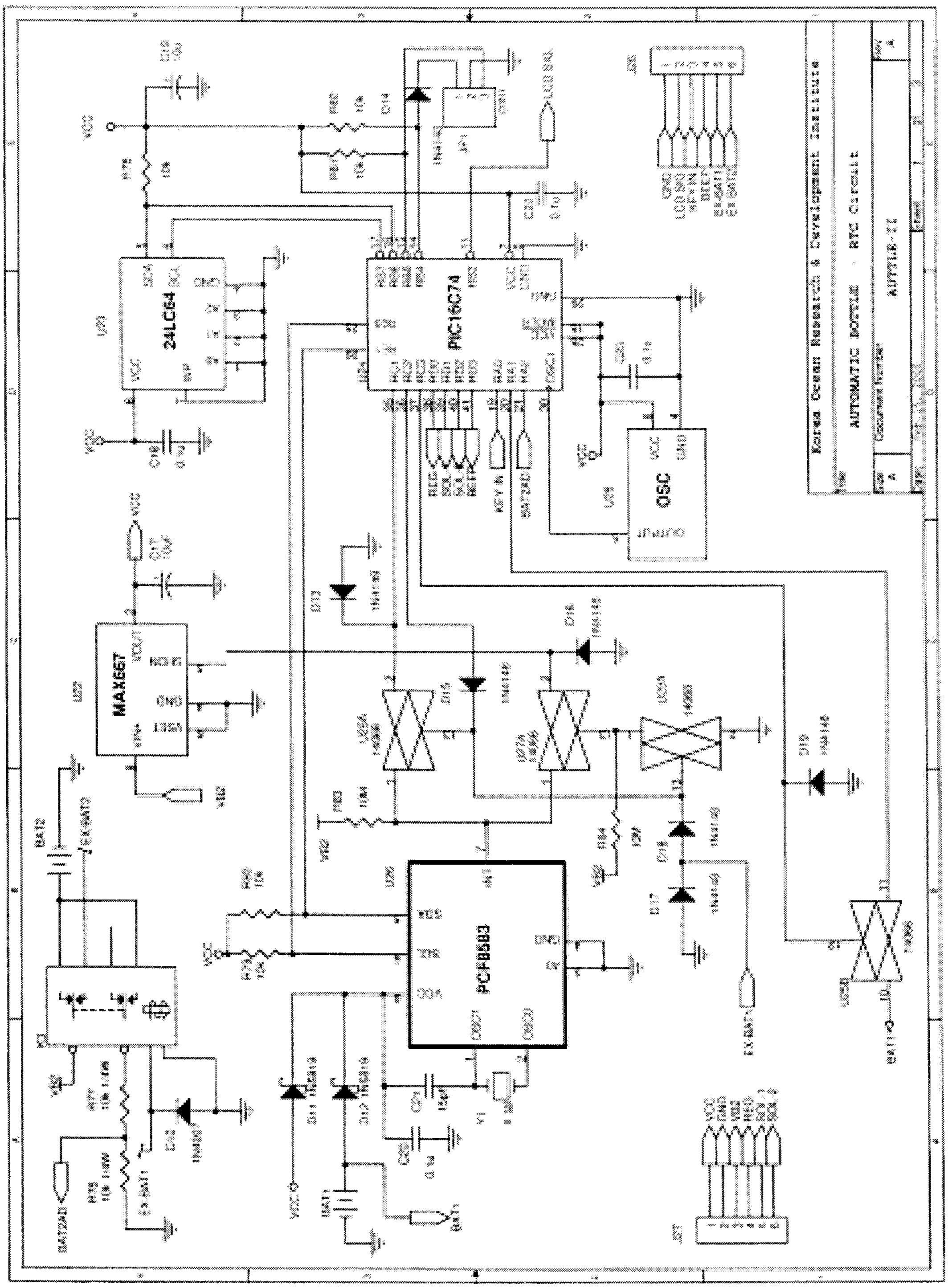
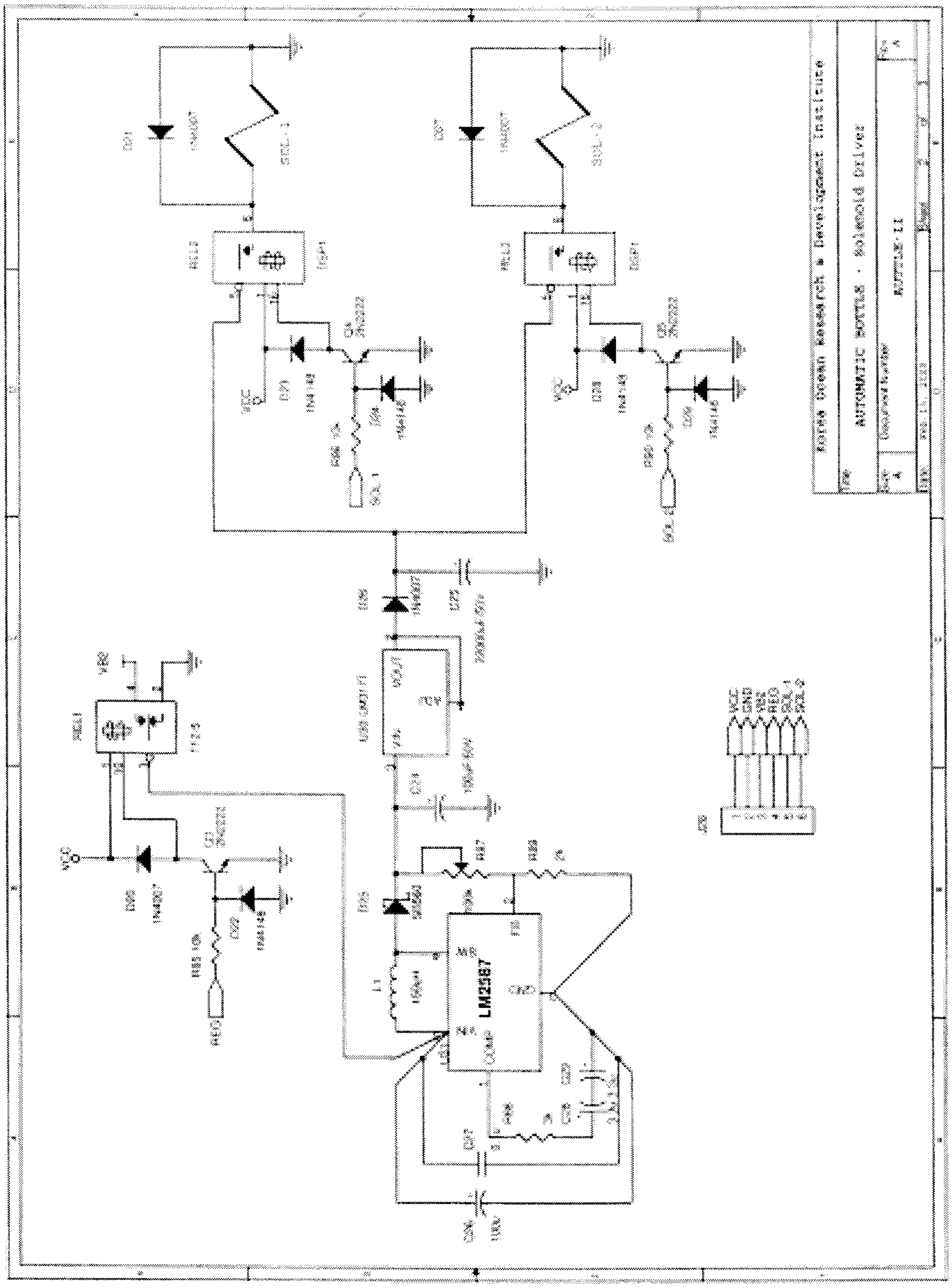


Fig. 1. The old version of the AUTTLE.



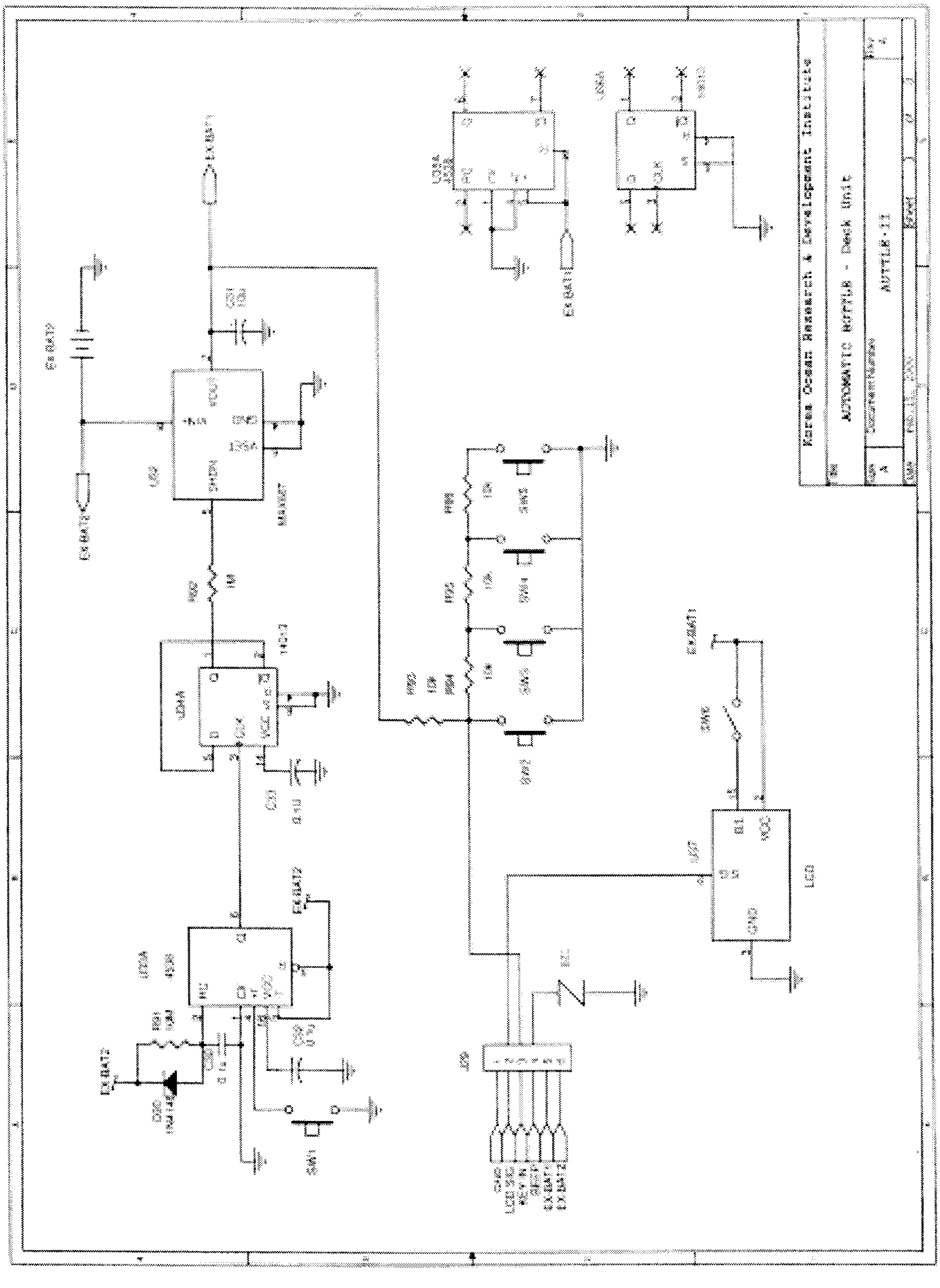
(A)

Fig. 2. Circuit diagrams for (A) real-time clock controller, (B) high-voltage generation, and (C) external control unit.


Korea Ocean Research & Development Institute
AUTOMATIC BOTTLE · Solenoid Driver
LM2587

(B)

Fig. 2. (Cont'd).


Korea Ocean Research & Development Institute
AUTOMATIC BOTTLE - Deck Unit
AUTTLE-II
LCD
MAX667

(C)

Fig. 2. (Cont'd).

New Circuit Boards and External Unit for Setting Sampling Time

The old version which adopted a time counter instead of a real time clock (RTC) has ten switches on the time control board (Fig. 1). The first main switch is for powering on/off, the second is for starting the time counter, and the third is for powering on/off the LED panels. The elapsing time from the start of the time counter to triggering the solenoid is set with the seven binary coded digital (BCD) switches. This configuration has made the procedures of powering on and setting sampling time very troublesome because the circuit board should be pulled out of the housing for that purpose. Additionally, it requires special attention to set the elapsing times of several AUTTLEs.

For the convenience of setting sampling time, the improved AUTTLE replaced the time counter with an RTC (PCF8583) and a non-volatile memory, EEPROM (24LC64). By using the RTC instead of a time counter, the board length could be reduced from 180 mm to 100 mm, and the maximum current consumption for stand-by period was also reduced from 1mA to 10 μA.

Additionally, an external unit (ATU-100) was constructed for checking battery voltage and current time of the RTC, and for setting the RTC and sampling time. It is needless to pull the AUTTLE's boards out of the housing because the RTC board is connected to the ATC-100 through the 6-pin connector.

New circuit diagrams for the real-time controller, high-voltage generation and external unit are shown in Fig. 2.

There are five key pads and two 1.5-volt batteries on/in the ATU-100 (Fig. 3). Four functions can be selected by the mode pad; 1) displaying current time and preset sampling time, 2) setting the RTC, 3) setting sampling time, and 4) setting the interval between the driving of the first and second solenoids. The current voltage of a 9-volt alkaline battery in the AUTTLE can be also checked in the mode 4.

Additional Solenoid and New Design

In order to minimize possible difference between ambient and sampled SSC, the old version was moored horizontally and intended to be parallel to the ambient flow with help of a vane as shown in Fig. 4. However, nobody knows how many sediment particles are deposited within the sampler before triggering.

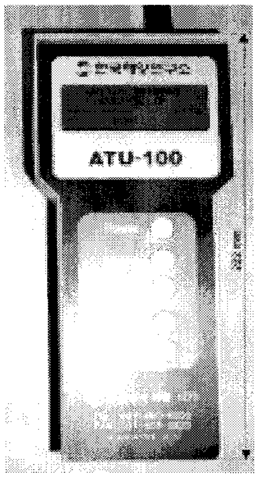


Fig. 3. External control unit, ATU-100.

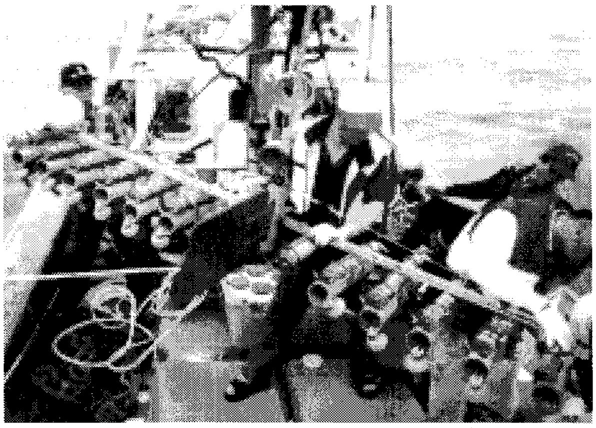
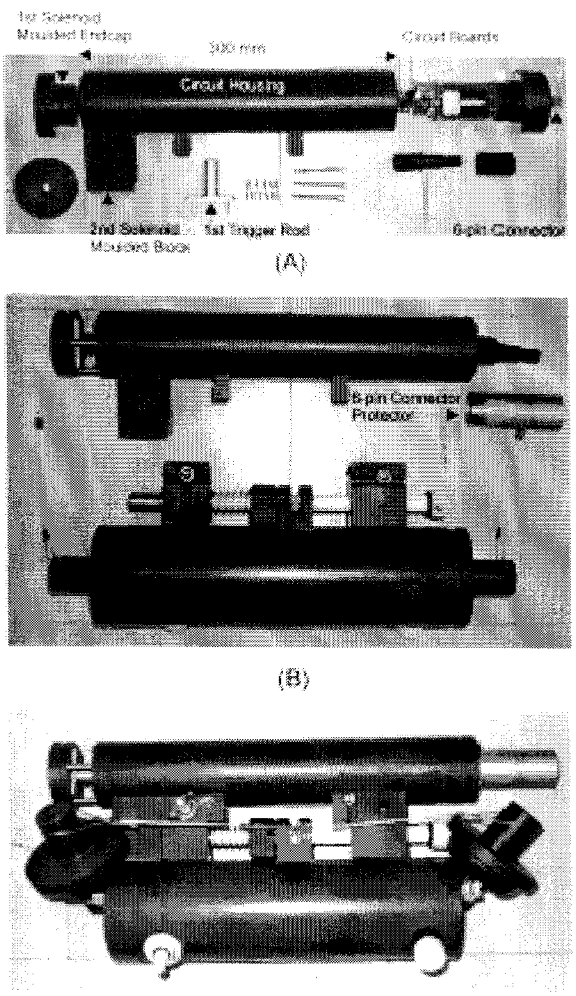


Fig. 4. Horizontal mooring of 13 AUTTLEs and a turbidity meter.

A possible series of procedure to prevent SS pre-deposition may be keeping the endcaps closed, and then opening them just before the preset sampling time, and immediately closing them tightly. This method could not be accomplished by driving a simple solenoid, but requires a motor, a high power supply as well as a more complicated control circuit and program. While the simplest method may be adding another solenoid for changing the AUTTLE's position, which means that the operating method of the old version may not need to be changed.

The new and improved sampler adopted the second method adding another solenoid and trigger rod at the end of the circuit housing (Fig. 5).

Due to a fixed power transmission cable from the



(C)

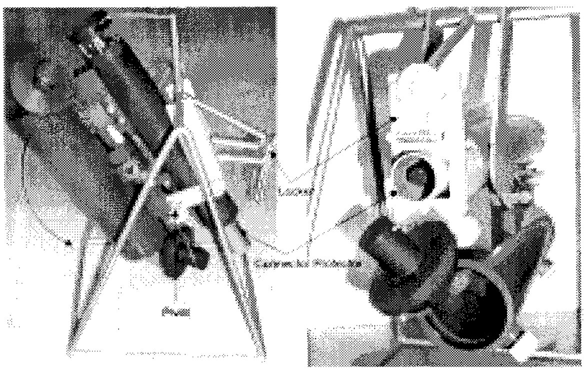
Fig. 5. (A) Elements of new AUTTLE's control part, (B) assembled control part (upper) and a Niskin bottle (lower) for manual operation, (C) assembled new AUTTLE for automatic operation.

condenser to the solenoid moulded in the Niskin bottle as shown in Fig. 1, the circuit housing is still attached to the bottle even during the manual operation of dropping a messenger. The new sampler changed the position of the main solenoid for pulling the Niskin's trigger rod on the circuit housing, by which the housing can be detached from the bottle.

The length and inside diameter of the sampling bottle were reduced by 160 mm and 2.5 mm, respectively. Its sampling volume is now 1 liter which is a half of the old version's.

Successful deployment of the new AUTTLE largely depends on how to install the new AUTTLE with inclination and how to keep its horizontal position after driving the first solenoid.

An installation frame satisfying these two requirements was constructed. With help of a holding hole of the frame, the first trigger rod and a pivot, the AUTTLE can be installed with inclination as shown in Fig. 6A. When the first solenoid is activated, the AUTTLE becomes free from the holding hole, and starts rotating by moment centered at the pivot, then finally its position becomes horizontal by locking the connector protector (Fig. 6B).



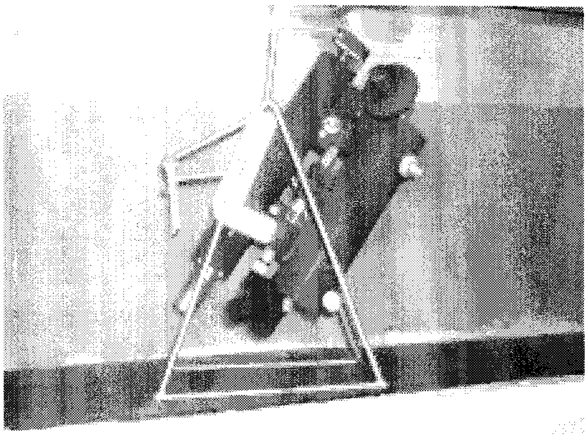
(A) (B)

Fig. 6. Positions of new AUTTLE (A) before and (B) after activating the first solenoid.

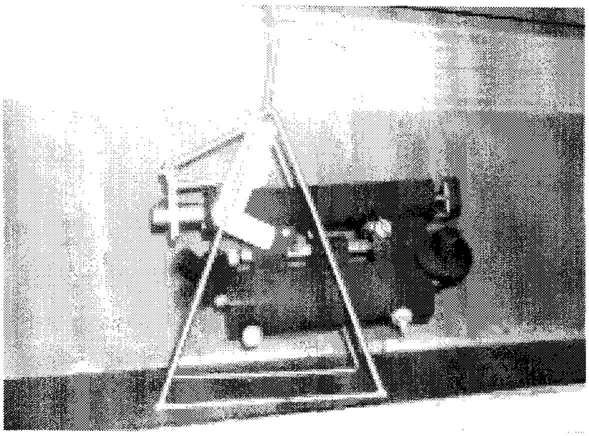
Triggering Procedures

Due to the condenser's length (82 mm), putting two condensers in a line for activating their own solenoids is an obstacle in reducing the dimension of the new AUTTLE. Thus, it was intended to sequentially drive the solenoids with one condenser. For double triggering, the condenser should be charged twice, thus it is necessary to estimate the minimum interval between the successive triggering by checking the voltage drop just after the first triggering.

According to electrical tests, the initial voltage of 50 volts generated for activating the first solenoid drops to about 20 volts just after triggering period of 20 ms. And, it was also found that 30 seconds are required to recharge the condenser up to 50 volts for the next triggering. Thus, the minimum interval between the solenoids' operations, that can be set with the ATU-100,



(A)



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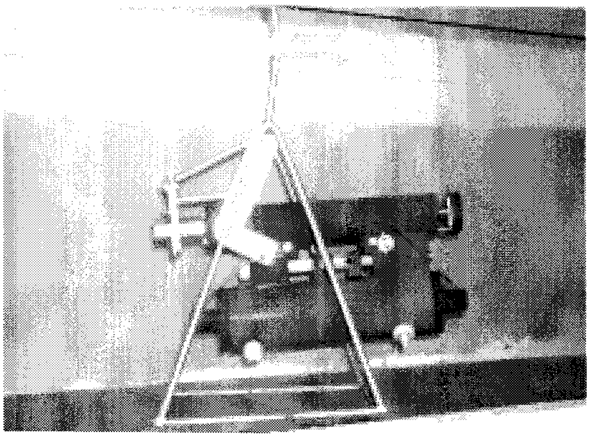


(C)

Fig. 7. Operating steps of new AUTTLE in a flume: (A) Before and (B) after the first triggering, and (C) after the second triggering.

is 30 seconds.

Fine grained cohesive sediments stuck in the narrow gaps between the main trigger rod and the holes which the rod passes through may generate frictional force against pulling the main rod. The worst problem may be the failure to close the endcaps due to this friction, even though the second solenoid may be activated normally. In order to reduce this undesirable possibility, the new AUTTLE was programmed to successively drive the second solenoid three times with an interval of 30 seconds.

The performance of the new AUTTLE and its frame were successfully confirmed in a flume, and its operating steps are shown in Fig. 7.

3. Field Experiment

In order to test the performance of the new version, a field test was carried out in front of the Iwon Tidal Barrier located in a mid-western coastal area of Korea (Fig. 8). The test area belongs to a macrotidal regime with high winter waves.

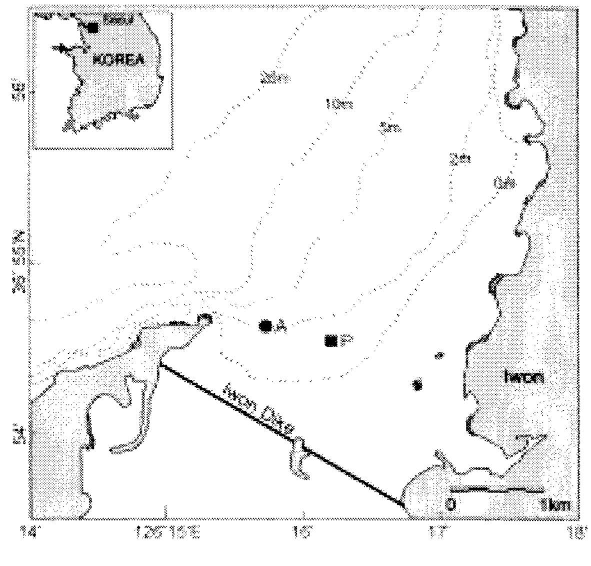
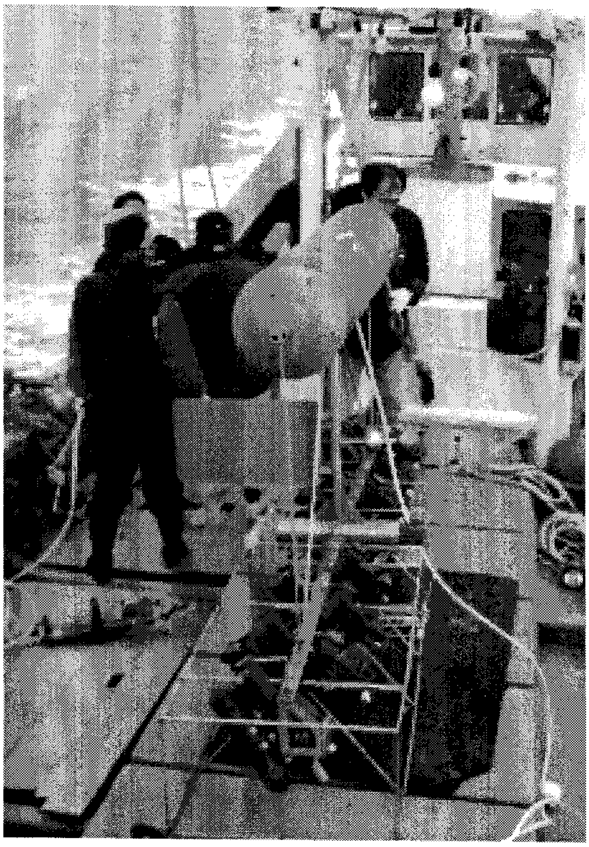
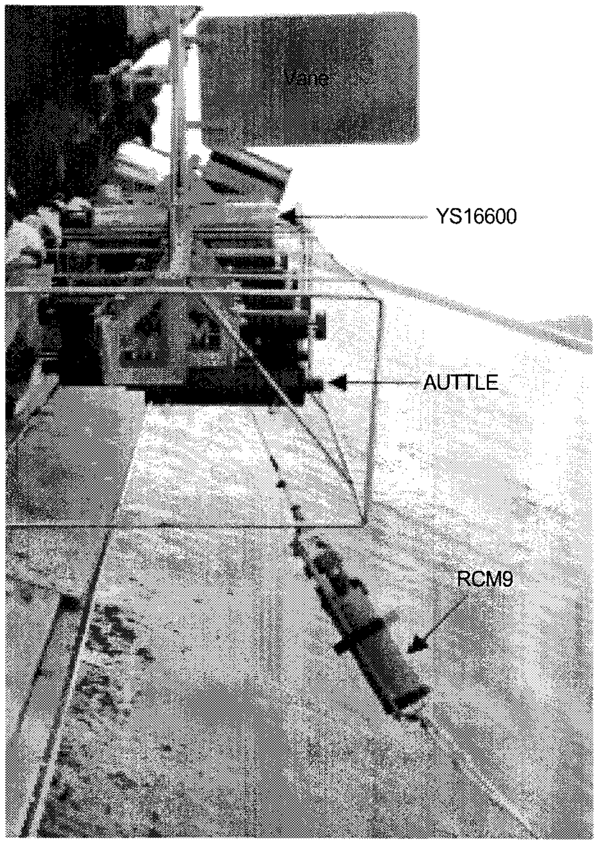


Fig. 8. Location map of the field experiment.

A total of 7 AUTTLEs were moored at about 1.4 m below the sea surface of station A (36° 54′ 39″ E, 126° 15′ 44″ N) with a current meter (RCM9 of Aanderaa Instruments) and a multi-parameter water quality monitor (YSI6600 of YSI Inc.). The YSI6600



(A)



(B)

Fig. 9. (A) Preparation of mooring and (B) retrieval of the instruments.

Table 1. Comparison of SSC from the AUTTLEs and OBS turbidity from the RCM9 and YSI6600 with associated hydrodynamic conditions.

Date and Time	D(m)	V(cm/s)	H_{max}(m)	OBS Turbidity (NTU)	SSC from AUTTLE (mg/l)
09/ 11 22:00	3.35	11.7	0.45	1.8	6.0
10/ 11 00:00	5.56	27.4	0.57	3.0	9.4
02:00	7.79	14.2	0.60	4.3	9.9
04:00	8.15	28.4	0.65	3.2	8.0
06:00	6.10	35.7	0.37	2.0	5.3
08:00	3.54	16.6	0.55	2.3	6.7
10:00	2.82	8.3	0.50	2.7	7.1
22:20	2.68	12.2	0.98	35.5	38.5
23:50	4.09	25.4	1.25	7.1	16.6
11/ 11 01:10	4.56	33.2	1.31	7.0	15.9
04:00	8.31	23.0	0.90	9.0	16.1
05:20	7.42	32.3	1.00	7.7	22.8
09:40	2.40	8.8	0.28	18.8	22.8

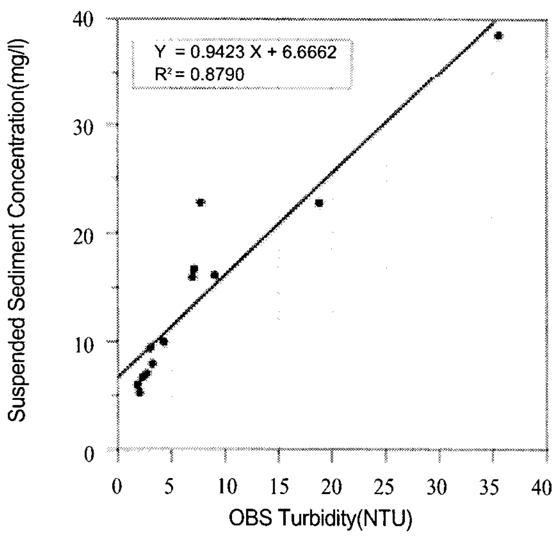


Fig. 10. Correlation between the OBS turbidity and SSC from the AUTTLEs.

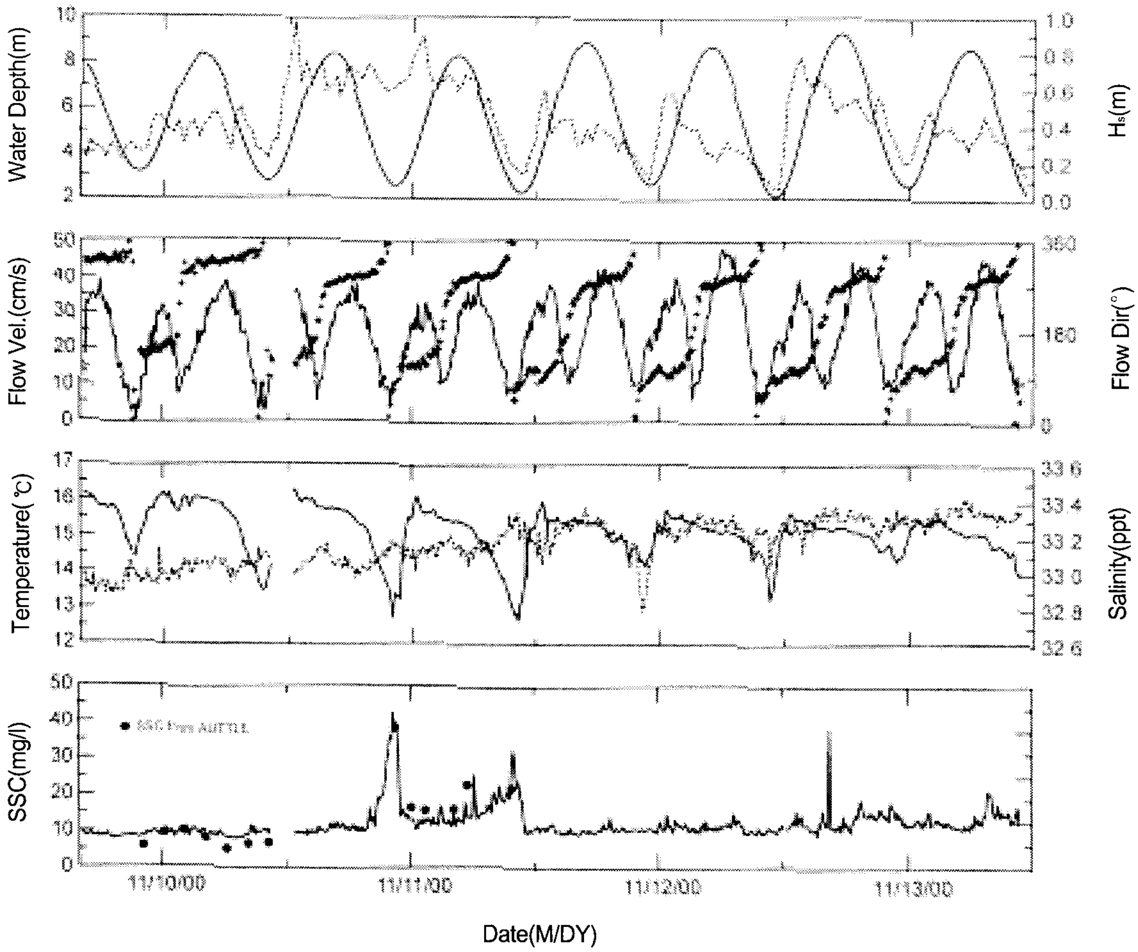


Fig.11. Temporal variation of the SSC, hydrodynamic parameters, seawater temperature and salinity; dotted lines and cross represent variables for right vertical axes.

was fixed horizontally to the same frame of the AUTTLEs, and the sensing depth of the RCM9 was about 0.7 m below the AUTTLEs (Fig. 9). A tide and wave gauge (WTR9 of Aanderaa Instruments) was also deployed at station P (36° 54′ 33″ E, 126° 16′ 13″ N). The test period was about 90 hours from 16:10 November 10 to 10:20 November 13, 2000. Moored instruments were retrieved on November 10 to collect sampled seawaters from the AUTTLEs and then re-moored. AUTTLEs' sampling interval during the first mooring was 2 hours, while it ranged from 1 hour 20 minutes to 4 hours 20 minutes during the second mooring. The RCM9 and YSI6600 measured every 10 minutes, and WTR9 every 30 minutes.

The measurements of the SSC from the AUTTLEs and OBS turbidity from the YSI6600 are summarized in the Table 1 with associated water depth (D), the maximum wave height (H_{max}) from the WTR9 and current velocity (V) from the RCM9. According to the results, the SSC at site A increases at low tidal phase with high waves.

Although the OBS of the YSI6600 was calibrated with two standard solutions of 0 and 100 NTU (nephelometric turbidity unit) before the field experiment, its results must be re-calibrated with SSC (mg/l) obtained from the AUTTLEs for the quantitative study of sediment transport. Figure 10 shows a relatively good correlation between two measurements.

By using the formula in Fig 10, temporal variation of the OBS turbidity was converted to mg/l for the whole mooring period as shown in Fig. 11 with other parameters.

Considering the results shown in Table 1, Figs. 10

and 11, it may be concluded that the AUTTLE's performance in field was successfully confirmed.

4. Conclusions

A new and improved version of the AUTTLE has been developed, and its performance has been successfully confirmed through several electrical and flume tests, and a field experiment. The new AUTTLE has been improved in five ways :

1) Users need not to pull the circuit board out of its housing to power on/off and set its sampling time.
2) Circuit housing can be detached for convenient manual operation.
3) By changing the AUTTLE position just before the seawater sampling with help of an additional solenoid, the uncertainty on the pre-deposition of SS can be minimized
4) Possibility of sampling failure is largely reduced by activating the second solenoid three times.
5) Reduced sampling volume associated with minimizing the circuit board dimension will shorten filtering time of high concentration samples.

The new AUTTLE can serve as a valuable seawater-sampling tool in the various fields of oceanography and environmental engineering. Besides its primary contribution for seawater sampling in predicted storm period, it may be of help for coastal water quality monitoring programs as well as help for a cost-effective calibration of satellite data by mooring and then seawater sampling synchronized at several sites before/at satellite passing, and *in-situ* calibrations of several turbidity sensors.

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