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Research Article

Development of a Local Flood Alarm System (LOFAS) for Riverine Flood Forecasting: A Prototype

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ABSTRACT

The incessant cases of flooding which is one of the consequences of climate change and global warming aroused our interest on the development of a local flood alarm system (LOFAS) for riverine flood forecasting. The LOFAS consists of the level sensing unit, the alarm unit and the communication unit. The level sensing unit is made-up of three level sensing probes locally designed to sense the rise in water stage of a river, the alarm unit consist of three alarms that triggers-on in response to the rise in water stage of the river and the communication unit houses the trained personnel that disseminates the water level information to the host community through bell, mobile phone or computer. It was tested to be highly sensitive with a sensitivity of about 1.01 and has a very little lag-time of about 0.19secs. If fully implemented, the LOFAS will give a real-time flood warning of riverine flooding which will encourage timely evacuation of lives and properties of people living in flood prone areas.

Keywords: Incessant, Riverine, Forecasting, Lag time, Sensitivity, Nigeria Flood.

INTRODUCTION

Due to the issue of climate change and global warming, the world should expect more cases of flood and flooding. Throughout the world, floods and flooding occur as natural phenomena which, in most cases, are not much appreciated by people living in the affected areas. Consequently, flood management and flood control measures are introduced in many places to prevent the negative consequences of this flooding. Flood-control includes those aspects of flood management involving structural measures and their operation. The balances of the measures available to limit the adverse effects of flooding are then the "non-structural" aspects (Duivendijk, 1999). Generally, flooding causes damages to the community it affects. These damages can be materially, emotionally, socially or economically related. For instance, the Nigerian flood of 2012 affected the socioeconomic wellbeing of the citizen. These damages in turn were aggravated by the complete lack of flood awareness of the general public. Here, the (false) perception of safety created by the long period without any significant flooding becomes apparent. Finally, the knowledge that extreme floods will cause flooding and that this is unavoidable have encouraged the introduction of a wide range of, what are called, "non-structural measures", of which this local flood alarm system (LOFAS) is a type. The major objective is to develop a local flood alarm system (LOFAS). Flood protection measures can be structural ("hard") or non-structural ("soft") and with non-structural measures, flood risk reduction is often indispensable (Menzel, 2003). White (1942) in his dissertation described the non-structural measures as one protecting the occupants of floodplains against floods, of aiding them when they suffer flood losses and of encouraging more intensive use of floodplains. As a way of encouraging the non-structural measures, Myers (1995), suggested that "When selecting materials for building in flood prone areas, care must be taken to study their hydraulic properties." Myers (1995) also suggested three ways new buildings can be flood-proofed. Andjelkovic (2001) also suggested other non-structural measures (NSM). According to the National Weather Service (NWS), "Determining the most effective type of Local Flood Warning System (LFWS) for a community is a complicated problem." It also described two basic types of LFWSs: manual systems and automated systems." Automated LFWSs have been designed, developed and implemented by the NWS, other Federal agencies, state and local governments, and private vendors; and they vary in design, capability and operation. A community must assess its needs to determine the level of sophistication (and associated costs) required.

Hernando (2007) gave general guidelines for setting up a community based flood forecasting and warning system (CBFFWS). The CBFFWS is a locally based operational flood forecasting and warning activities of a community that aids them in mitigating the effects of flooding in their area. The system is basically composed of a set of monitoring instruments, staff gauges along the target river channel and rain gauges installed at strategic locations within the watershed area encompassing the community (Hernando, 2007). Though the CBFFWS is simple in design and operation, relatively cheap and easy to sustain (Hernando, 2007), the river stage information is not collected automatically rather manually by trained personnel from the community.

MATERIALS AND METHOD

LOFAS response to the rise in level of water stages by triggering on alarms in the alarm unit. It is made up of three units; the level sensing unit, the alarm unit and the communication unit. The materials for the development of the different units of the LOFAS were selected after certain considerations. The materials used for the development of the level sensing unit are listed in the Isometric view (Figure 3). The level probe is a sensitive part of the LOFAS. In developing the level probe, copper material of good electrical conductivity 5.96×10^7 S/m (Wikipedia, 2012) was used for the terminals of the level probe. Also, a float of plastic material of density 0.95g/ml less than the density of water, 1.0g/ml (Wikipedia, 2012) was attached to the slider of the level probe. The float produces a buoyant force that buoys the slider's terminal to make contact with the other terminal (static terminal). For easy maneuvering, 1mm flexible electric wire was selected. The two ends of the wire were connected to the terminals of the level probe. They help to transmit signal from the level sensing unit to the alarm unit as shown in Figure 3. The Alarm unit is composed of three alarms. Based on availability, functionability, loudness (70dB) and effectiveness, Shenba electric horns purchased from Bicycle line in New Market, Owerri were used. The alarms were connected to the terminals of the level probe through electric wires. The alarm uses two (2) 1.5V batteries. For the communication unit, depending on the community, any of the following can be used; internet facilities, GSM phone or a local bell in addition to trained personnel. A laptop computer connected to the net will be very useful in information dissemination to the host community. With this device, when the alarm is sensed by the trained personnel, bulk SMS will be sent across. Before now, the phone numbers of every member of the host community will be uploaded to the phone book of the system using PC suites. Also, if it is a place where people are close to their PC'S, electronic mail (E-mail) might be sent to the host community. In places where people have no access to internet facilities, communication is facilitated through GSM. When the trained personnel receive the signal from the alarm unit, he sends SMS through his phone to the inbox of the members of the host community. The phone must be properly charged at all times especially during peak periods of flood. For communities that culturally respond to local bell, the trained personnel will pass the signal across through the ringing of a local bell to a pre-informed tune. Two or more persons who must not be suffering from any sound related problems must be provided in the communication unit. They sense the signal and disseminate the information to the host communities. The operational design drawings of the LOFAS are shown in Fig1 – Fig3 below

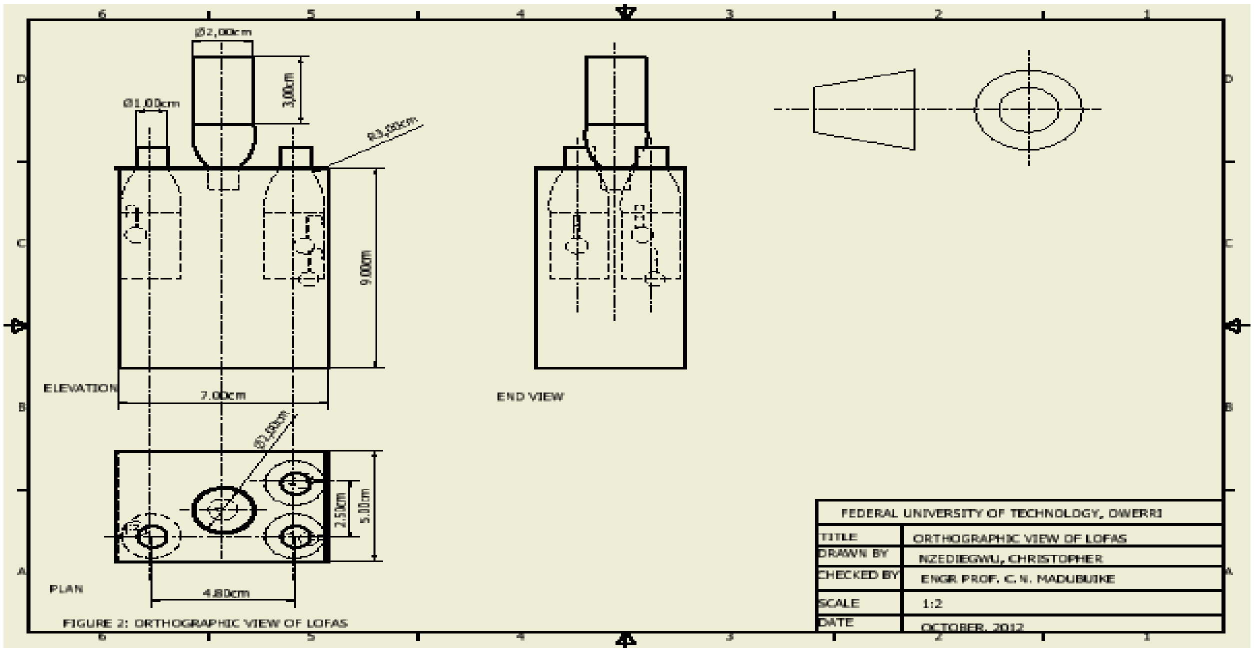

Figure1 Orthographic view of LOFAS

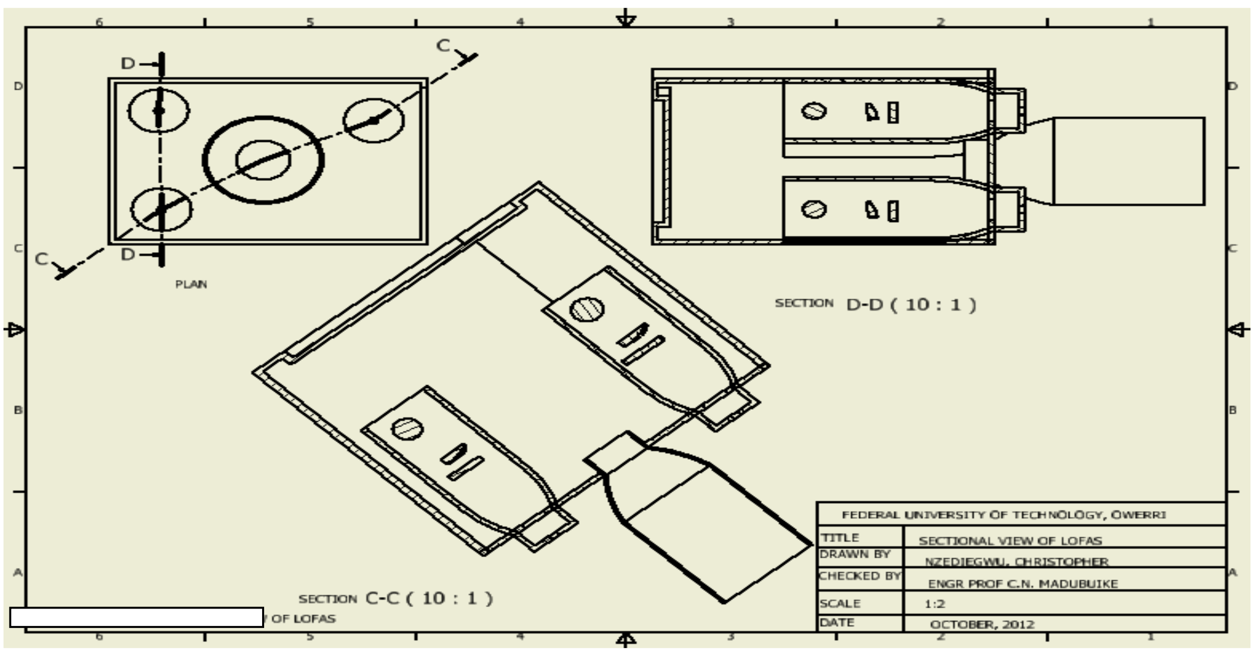

Figure2: Sectioned View of LOFAS

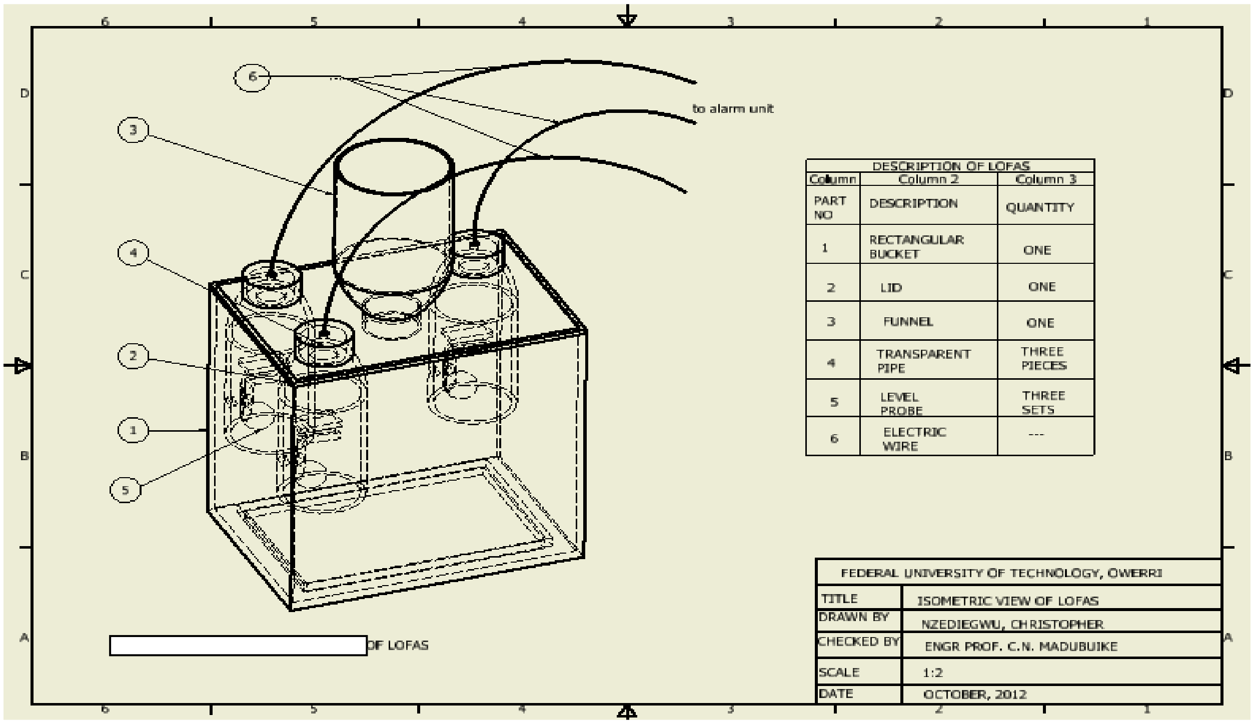

Figure3: Isometric View of LOFAS

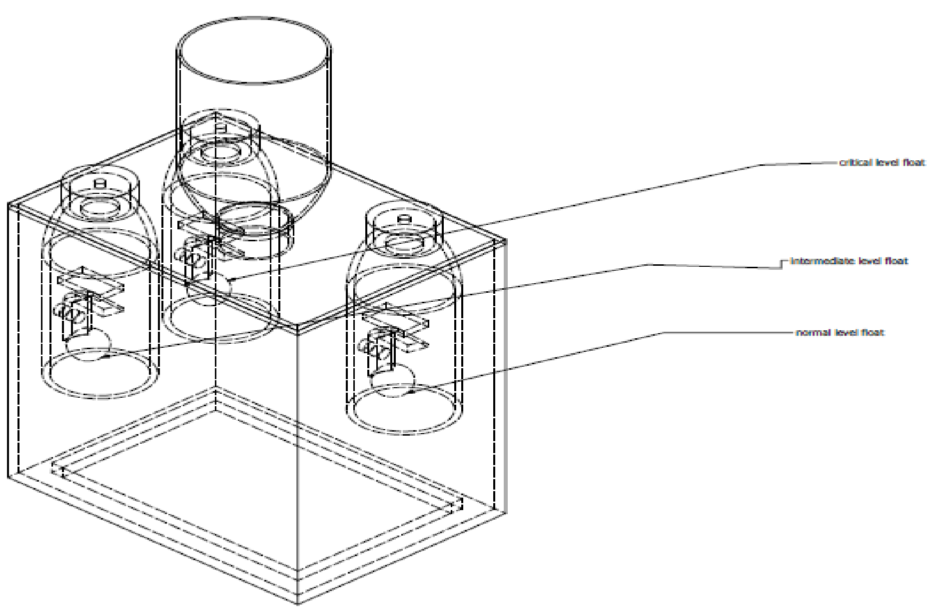

Figure 4: Isometric view showing the Three Levels of the Level Sensing Unit.

Some existing mathematical and geometrical formulae were considered during the design of the various parts of the LOFAS. The transparent pipes were spaced radially along the lid of the rectangular bucket. The spacing between each of the pipes was obtained using Equation 1.

$$S_p = \frac{2}{n}\pi r_\rho \text{ ------------ } \mathbf{1}$$

Where, S_p = pipe spacing in metric unit.

r_p = radius of the smallest circle circumscribing the pipes.
n= number of pipes to be circumscribed.

For this special case, n=3. Thus, Eqn1 becomes

$$\mathbf{S_p = \frac{2}{3}\pi r_p}\text{-----------------------}\mathbf{2}$$

The circumference of the transparent pipe's slot was obtained using Eqn 3 as

$$S_c = \pi d_s - - - - - - - 3$$

Where,
S_c = circumference of the slot in metric unit.
d_s = diameter of lid-end of the transparent pipe with the thread inclusive.
The circumference of the funnel's slot on the bucket lid was obtained using Eqn 4.

$$S_f = \pi d_f - - - - - - - - - 4$$

Where,
S_f = circumference of the funnel's slot in metric unit.
d_f = diameter of the lid-end of the funnel fastened to the bucket's lid.

In order to determine the minimum length of wire to buy, Equation 5 was considered.

$$T_L = T_n + T_i + T_c \text{ - - - - - - - - - - - - - - - - } 5$$

Where,
T_L = total length of wire required.
T_n = length of wire for the normal part.
T_i = length of wire for the intermediate part.
T_c = length of wire for the critical part.

Where,

$$T_n = \pi d_b + \frac{4}{5}h + 1.1d_{LA} - - - - - - - - 6$$

$$T_i = \pi d_b + \frac{1}{2}h + 1.1d_{LA} - - - - - - - - 7$$

$$T_c = \pi d_b + \frac{1}{3}h + 1.1d_{LA} - - - - - - - - 8$$

Where,
d_b = diameter of bolt at level probe terminal.
d_{LA} = distance between the level sensing unit and the Alarm unit.
h = height of the transparent pipe before cutting it. Eqn 5 - Eqn 8 are in metric unit.

The critical height, intermediate height and normal height as shown in Fig.4, corresponds to three pre-set river stages of a river. Any river prone to flooding, in spite of the return period of the flood, must have a critical height beyond which the river overtops its bank (Arora, 2009). Likewise, there is also a depth called the normal depth at which the river is safe. These heights are not uniform for any two rivers and therefore must be determined by any of the methods described by Arora (2009). For the development of LOFAS, these heights were chosen arbitrarily as h_n (normal height), h_i (intermediate height) and h_c (critical height). It is at these heights that the level sensing unit trigger-on the alarm in the alarm unit. Each of these heights has its own unique sound that can be interpreted by the trained personnel.

Two major tests were carried-out using the LOFAS. The tests were aimed at determining the following: the lag-time and the sensitivity. The concept of lag-time in an instrument is important as it helps to ascertain its ability to respond quickly to signals. The lag-time for the LOFAS is the time it takes the alarm unit to respond to the signal sensed by the level sensing unit. During the Lag-time test, a datum was established on the river model at a point 5cm below the normal level and the following time where observed:

a) Time of water rise (T_{lsu}) between datum and h_n, h_i and h_c.
b) Time elapsed for the alarm to trigger (T_{au}) between datum and h_n, h_i and h_c.

The test was repeated for forty two times (42) and the results are tabulated in Table 1 and Table 2.

Mathematically, the equation for calculating the lag-time was developed as:

$$T_L = T_{au} - T_{LSU} \text{ ------------------------ } 9$$

Where,
T_L = lag-time in seconds, T_{LSU} = time at level sensing unit in seconds.
T_{au} = time at alarm unit in seconds

According to Haslam et al. (1986), sensitivity of an instrument is the ratio of change in output to change in input. The sensitivity of the LOFAS is a function of its time of response. It is mathematically given as:

$$S = \frac{T_{au}}{T_{LSU}} ------------ 10$$

Where,
S = sensitivity. From Eqn. 10, a sensitivity of 1.0 signifies highly sensitive.

RESULTS AND DISCUSSION

The pictorial views of the LOFAS are shown in Plate 1 to Plate 4.

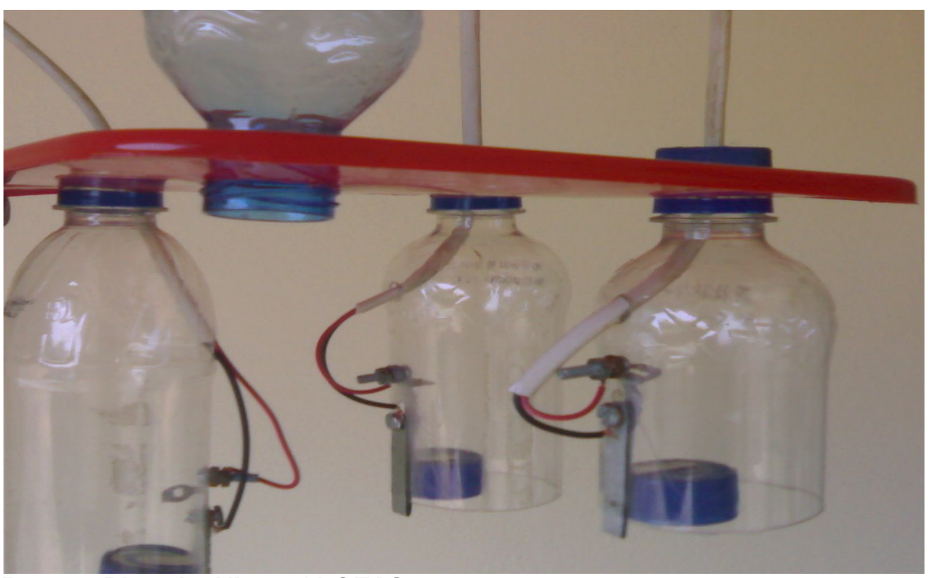

Plate 1: Pictorial View of LOFAS

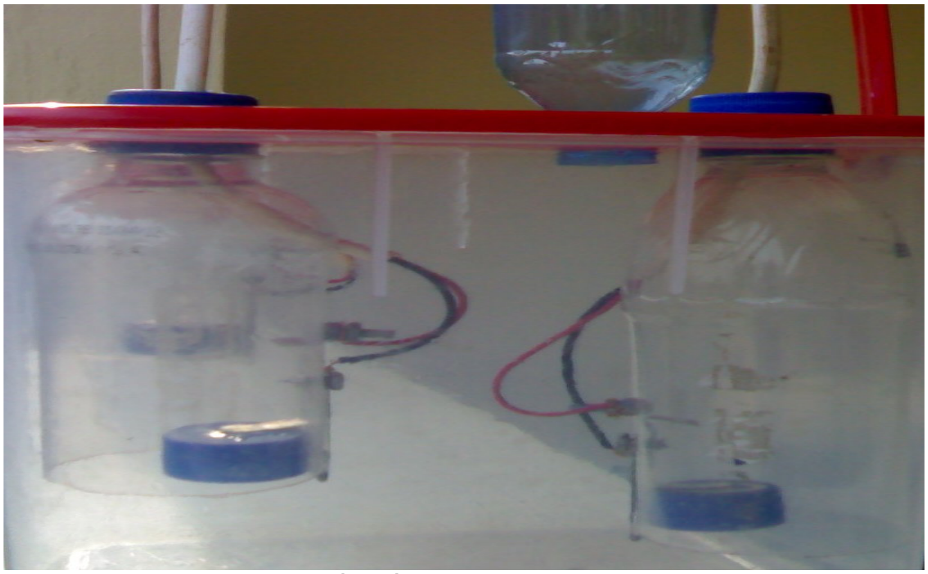

Plate 2: Pictorial View of LOFAS during Testing

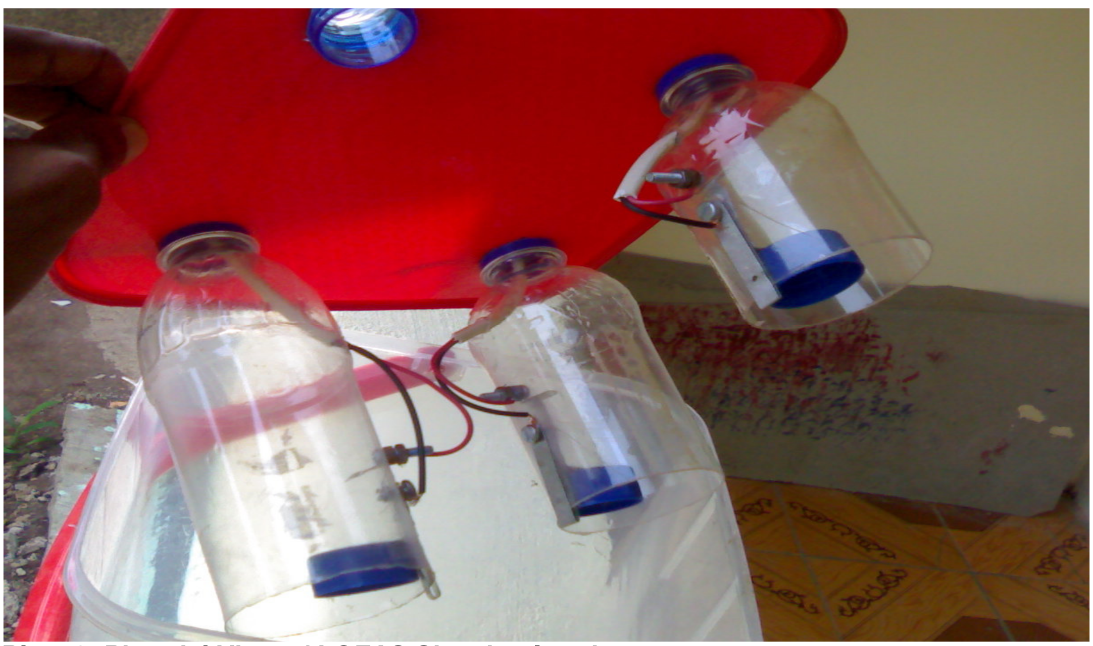

Plate 3: Pictorial View of LOFAS Showing Interior

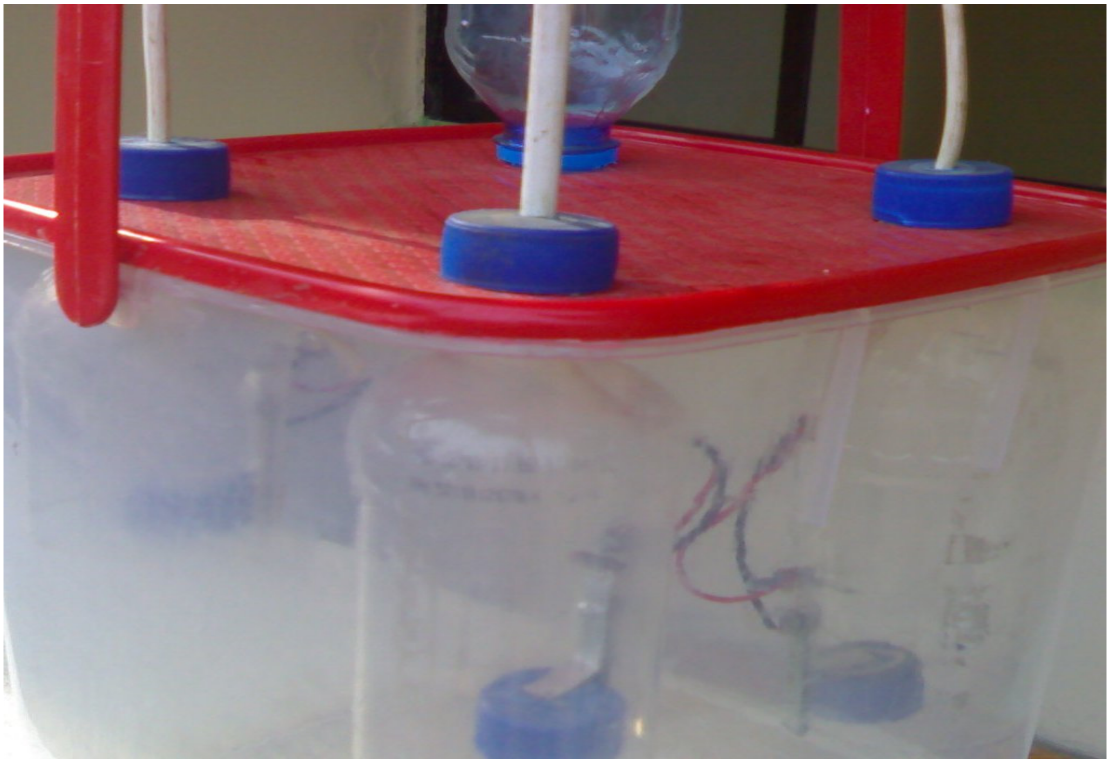

Plate 4: Pictorial View of Assembled LOFAS

The Lag-time and sensitivity test result are shown in Table 1 and Table 2 below.

Table 1: Lag-time at Normal(NS), Intermediate(IS) and Critical(CS) Level.

Case 1	T_{lsu} (s)	T_{au} (s)	T_l (s)	Case 2	T_{lsu} (s)	T_{au} (s)	T_l (s)	Case 3	T_{lsu} (s)	T_{au} (s)	T_l (s)
	10	10.5	0.5		15	16	1		20	20	0
	10	10	0		15	15.5	0.5		22	22.5	0.5
	11	11	0		15	15	0		21	21	0
	9	10	1		14	14	0		21	21.5	0.5
	9	9.5	0.5		16	16	0		19	19	0
NS	11	11	0	IS	16	16	0	CS	19	19	0
	10	10	0		14	15	1		21	21.5	0.5
	10	10.5	0.5		14	14	0		21	21	0
	11	11	0		15	15	0		22	22	0
	9	9	0		14	14	0		20	20.5	0.5
	11	11	0		16	16	0		20	20	0
	10	10	0		14	14.5	0.5		20	20	0
	9	9	0		15	15	0		20	20	0
	11	11	0		15	15	0		21	21.5	0.5
MEAN			**0.1786**				**0.2143**				**0.1786**
MEAN of MEANS (sec) = **0.1905**											

Table 2: Sensitivity at Normal (NS), Intermediate (IS) and Critical (CS) level.

Case 1	T_{lsu} (s)	T_{au} (s)	S_n	Case 2	T_{lsu} (s)	T_{au} (s)	S_i	Case 3	T_{lsu} (s)	T_{au} (s)	S_c
	10	10.5	1.05		15	16	1.07		20	20	1
	10	10	1		15	15.5	1.03		22	22.5	1.02
	11	11	1		15	15	1		21	21	1
	9	10	1.11		14	14	1		21	21.5	1.02
	9	9.5	1.06		16	16	1		19	19	1
NS	11	11	1	IS	16	16	1	CS	19	19	1
	10	10	1		14	15	1.07		21	21.5	1.02
	10	10.5	1.05		14	14	1		21	21	1
	11	11	1		15	15	1		22	22	1
	9	9	1		14	14	1		20	20.5	1.03
	11	11	1		16	16	1		20	20	1
	10	10	1		14	14.5	1.04		20	20	1
	9	9	1		15	15	1		20	20	1
	11	11	1		15	15	1		21	21.5	1.02
Mean			**1.019**				**1.015**				**1.008**
Mean of Means=1.014											

From Table 1, the mean lag-time at normal position, T_{ln} is 0.1786secs; mean lag-time at intermediate position, T_{li} is 0.2143secs and mean lag-time at critical position, T_{lc} is 0.1786secs. Also, the Lag-time of LOFAS (T_t), the mean of means was obtained as 0.1905secs with a standard error of 0.0119. This value is an indicator that the system is reliable to a high extent. From Table 2, the mean sensitivity at normal position, S_n is 1.019; mean sensitivity at intermediate position, S_i is 1.015 and mean sensitivity at critical position, S_c is 1.008. The Sensitivity of LOFAS (S_t), mean of means is 1.014 with a standard error of 0.003062. This value shows that the LOFAS is highly sensitive.

INSTALLATION

For full implementation of LOFAS, it should be installed on the downstream side of a pier (Hernando, 2007) and surrounded by a wave breaker mechanism that can subsidize any little wave generated in the river. The pier can be that of an existing bridge or a new pier can be constructed. Also, care must be taken to align the instruments' heights (hn, hi and hc) with the corresponding river stages.

CONCLUSIONS

Local flood alarm system (LOFAS) was designed using Autodesk Inventor. Design calculations were made, local materials were selected and the LOFAS was developed. The sensitivity and lag-time of the LOFAS were determined following several test-running of the LOFAS. With these data, the following conclusions were drawn about the LOFAS:

i. It will be able to give real-time flood warning with a very little time lag of about 0.19secs.
ii. It will help the communities living in flood prone areas take timely precautive actions to save their lives and properties.
iii. It will help the government to hasten the strengthening of structural flood control measures such as levees, embankments, reservoirs, etc.
iv. It can only be used for forecasting riverine flooding.

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