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Antileaks: A device for detection and discontinuation of leakages in domestic water supply systems

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Abstract Water losses in supply systems create difficult problems to water economy. The currently available approaches to this problem are inadequate and do not provide a comprehensive solution. The device built in this project is designed to detect leakages in water systems and stop them. First, the system analyzes based on a mathematical model the consumer's average water consumption over a period of time. Then, the system keeps measuring and analyzing the water consumption in real time. In case it detects a great deviation from the average or steady water consumption over a period of time, it alerts the consumer by cellular communication – and if necessary disconnects the leaking system from the water supplier. Additionally, the system can send data about the consumption to a nearby computer by wireless communication.

1 Preface

In Israel, and in countries around the world such as Spain, Britain, Australia, France and the United States, there are areas experiencing severe water shortages that are getting worse from year to year. In comparison, the demand for water is constantly growing, both due to the steady growth of population, and the rising standard of living. In addition, the rapid urbanization causing less water to infiltrate through the ground while the amount of water flows to sea increases.

In the last decade, Israel's population has grown by the almost fixed rate of 1.8% per year (CSC, 2009a). Consequently, during the years 2000–2007, the water consumption of the domestic economy went up by 15.86% to a total of 767 million m^3/year, while the estimations of water consumption in 2015 fluctuates between 853 to 910 million m^3/year (CSC, 2009b). However, the quantity of water for industrial usage remained practically the same, and the quantity of water supplied to agriculture decreased (due to increase in the amount of treated wastewater). Therefore, reducing the water consumption of domestic households may have a critical impact on the reduction in overall water consumption.

In Israel, a parliamentary commission of inquiry stated in 2001 that the required solution for the crisis is the expansion of the water supply by artificial means, and the government decided that Israel should be able to desalinate 400 million $m^3/year$ by 2005.[1] Still, according to state commission of inquiry in 2009–10[2], "(w)e are in the midst of an acute water crisis, where we do not have enough

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[1] Israeli Government Decision 1682 (PM/32), April 4th 2002

[2] *Efficient Use and Saving*, State Commission of Enquiry About the Administration of Water in Israel, March 12th 2009.

desalination plants to answer water demands", and there is a quest for immediate solutions that will lead to savings in the use of water.

Motivated by the situation in Israel and around the world, an immediate solution for the domestic households was sought. The problem this project was chosen to focus on is water loss, which has not yet been solved satisfactorily.

2 Presentation of the problem

2.1 Water loss and unobserved leakage

Water loss in supply systems is one of the most difficult problems of the water economy, which has numerous reasons (see Farley and Trow, 2003). Outdated infrastructure and poorly maintained pipelines, mechanical damages, unauthorized uses and frozen pipes are some of the factors contributing to leakage. Leakages reduce pressure in the supply system, while raising pressures to make up for such losses involves increased energy consumption, and has adverse environmental impacts (Lahlou, 2005). The financial damage caused to the property should be taken into account as well. Apart from the direct implications of water loss, an untreated leakage can be a serious health hazard, due to mold residuals and dangerous and toxic fungus growing in its vicinity. Many of these hazards are not even visible. The treatment for such damages can require evacuation of the house, and may take several months.

Visible leakages do not necessarily cause a great loss of water, since they are usually detected and treated quickly. Unobserved leakages, even small ones, may result in the loss of much larger amounts of water, due to the time it takes to detect them.

2.2 Water loss around the world

Towards the end of the 2000s, worldwide water loss was estimated to be around 30% of the total amount that passes through the water supply networks in the domestic economy (de Millers, 2000). In some places, even in developed countries, the water infrastructures are dated to the late 19th century, and the water loss rate reach 50% (see e.g. van der Leeden, Troise and Todd, 1990; Twort, 1994).

2.3 Water loss in Israeli

The state commission of inquiry made an initial estimate of over 100 million m^3/year of water leaks from fresh water pipes and the sewage.[3] The Israel Water Authority stated in response that only 60–80 million m^3/year are lost through leaks, but that estimation was later rejected in the final report.[4] It was mentioned that there is significant water depreciation, probably through unobserved leakage.

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[3] State Commission of Enquiry About the Administration of Water in Israel, March 12th 2009.

[4] Office of the Director, Water Authority, State of Israel, April 7th 2009.

2.4 Proposed solutions and their suitability

It seems clear that there is a need for solutions designed to treat leakages or unobserved drips and to address the problem in a versatile manner. Several solutions have been suggested by the water companies and providers. The first one is to frequently replace all the plumbing in the houses. This solution is expensive and impractical. A second solution that has been suggested by the water authority is a localized warning by the water supplier.[5] This solution is problematic, because the warning would arrive after a long delay through a third party (mostly through the post, with the monthly/bimonthly water bill) even though in the case of a leakage, the water balance exceeds the regular reading in a matter of hours. A third solution is to order a leakage survey from external firms, that use geophone and others devices that are able to find leakage by the intensity of the noise and the change of pressure. The main problem is the high cost. Also, the testing is not done on a regular basis and has to be ordered.

Another approach is to use a digital water meter that aims to detect leakages. However, the meters on market are relatively expensive (100-150$), they require the construction of special centers, and they are not designed to stop leakages.

3 The system's operation

3.1 General description and system components

The system we developed is meant to answer all aforementioned problems. It adjusts itself to the individual water usage habits of every household, alerts the consumer when a leakage is detected and closes the leaking pipe system, if necessary. The components and the mode of operation of the demonstration system we devised are presented in figure 1. It has four basic parts:

1. **Command and Control:** A microcontroller makes up the core of our system and controls all its actions, together with a few additional electronic circuits.
2. **Consumer:** A sub-system that emulates a regular water consumer (a household), and also contain a display circuits that show the amount of water consumed.
3. **Cellular Communication (alerting):** A GSM modem that send a text massage to the consumer phone. The consumer can respond to the system.
4. **Wireless Communication (reporting):** An RF communication device that sends the data about the water consumption to a nearby computer.

Electrical chart of the system (core and consumer simulation) and the system communication units can be found in Appendix A.

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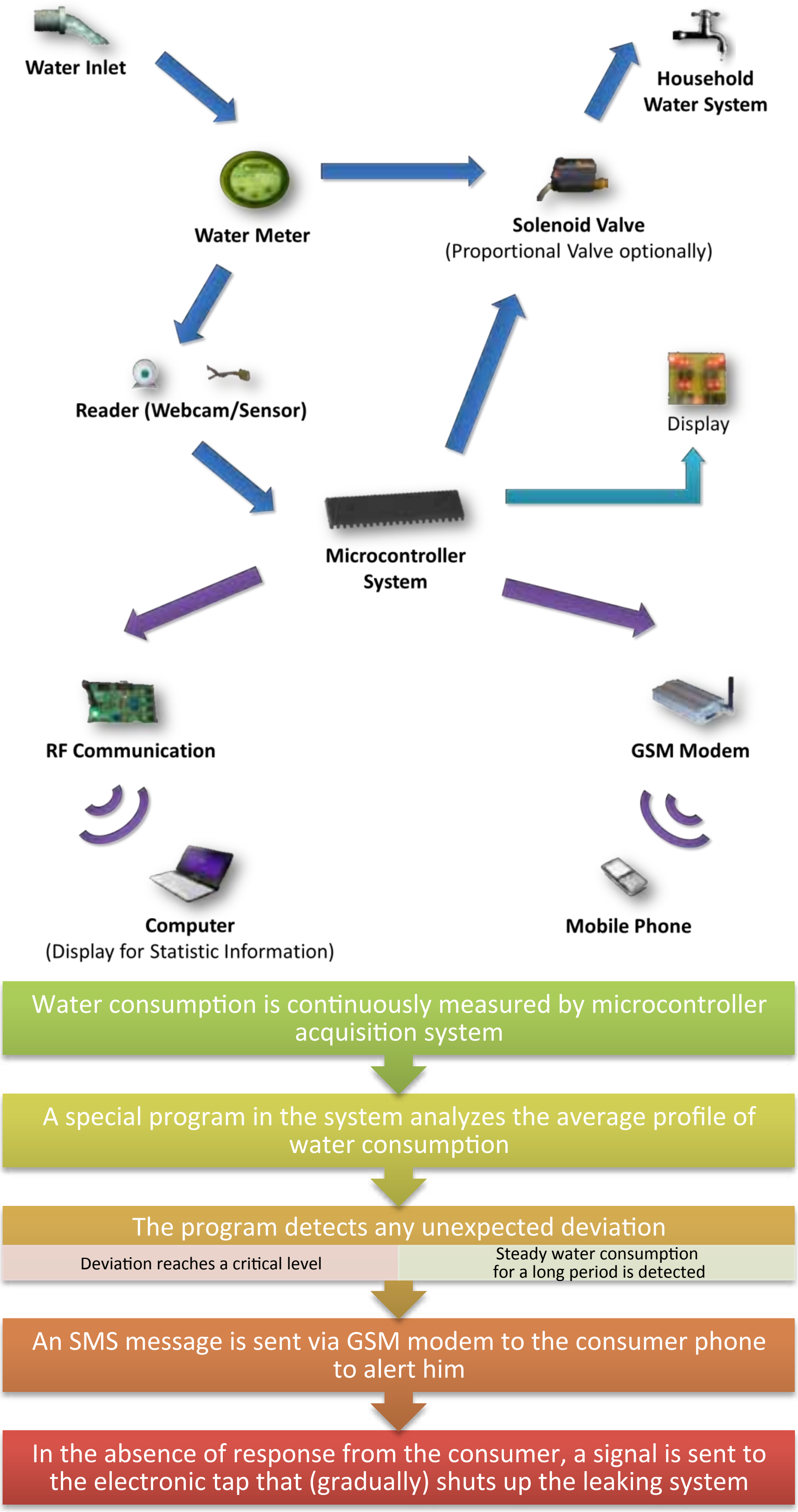
[5] Operation Department, Water Authority, State of Israel, May 17th 2009



Water consumption is continuously measured by microcontroller acquisition system

A special program in the system analyzes the average profile of water consumption

The program detects any unexpected deviation

Deviation reaches a critical level

Steady water consumption for a long period is detected

An SMS message is sent via GSM modem to the consumer phone to alert him

In the absence of response from the consumer, a signal is sent to the electronic tap that (gradually) shuts up the leaking system

Figure 1 Diagram of the system (on top) and mode of operation (below)

3.2 Command and control

3.2.1 Microcontroller

The *89S52 microcontroller* made by ATMEL is the controller of our whole system.[6] It receives data coming from an *A/D converter* about the ongoing water flow of the tap, so it controls the intensity of the electric current that goes to the *pump*. The consumption data come to the microcontroller through a *light sensor* or a *webcam* connected to the *water meter*. The leakage detection process is based on a mathematical model, which was transformed into C language program code, and burned into the microcontroller.

3.2.2 A/D Converter

Electronic circuit that converts analog signal to digital signal.[7] In our system, it converts the analog signal that comes from the tap (which is proportional to the water discharge) to a digital signal in voltages suitable to logic levels of '1' or '0', and sent it to the microcontroller.

3.2.3 Motor control

A *transistor* controls the magnitude of the water discharge by adjusting continuous electric current to the pump. To enable it to function under high electric currents – approximately 0.8A – it was connected to a *L293D Driver*.[8] The PWM (*Pulse-width modulation*) generator of the microcontroller, by external interrupts, was used to command the pump's motor. The idea of this method is to change the duty cycle of a PWM square wave, by which way the overall power and the speed of the motor shall be changed (Meir, 2008).

3.2.4 Sensor and Unstable Multi-Vibrator

One way to read the data from the *water meter* is by a light *sensor* that responds to the rotating arrow present in water meters. The rotation speed is proportional to the discharge.

To quantify the sensor changing data, it has to be compared to other fixed data, generated using an *unstable multi-vibrator*, constructed of *NAND gates*.[9] This circuit can be the source for a fixed square wave since it has two semi-stable positions, and it does not require an external trigger to move from one position to the next.

3.2.5 Webcam

Another way to read the consumption is to use a *webcam* that shoots the meter's needle rotations. It enhances the reliability of the data, yet it is slightly more expensive and consumes more electricity.

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[6] 8-bit Microcontroller with 8K Bytes In-System Programmable Flash – AT89S52, ATMEL, Rev. 1919A-D7/1

[7] Data Sheet, ADC0803/0804 – CMOS 8-bit A/D Converters, Philips Semiconductors, 2002

[8] L293D – Push-Pull Four Channel Driver, Unitrode Integrate Circuits

[9] Data Sheet, HEF4093 gates, Philips Semiconductors, Jan. 1995

A C# program was written to perform the *image processing*. The image is represented on *bitmap* and it was analysed using RGB model. The program uses a *timer* to capture an image from the camera in fixed time periods. First we define a *vertical strip* around the region between the cursors of 5 (*half rotation*) and 0 (*full rotation)* (see figure 2). Then the system is calibrated and defines MAX_RED as 'the maximum number of red pixels in the *vertical strip*'. During the real time consumption, an ongoing check whether the numbers of red pixels in the strip equal to MAX_RED is performed. If the check is positive, then a *half rotation* has been detected, and when a *full rotation* is detected, an interrupt will be sent to inform the microcontroller.

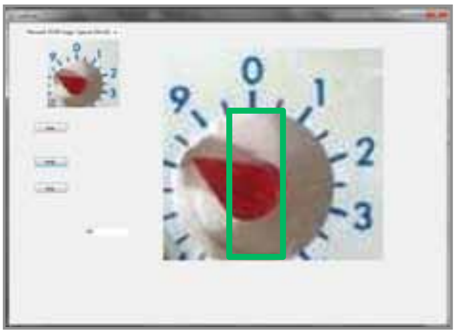

Figure 2 From the left, the continuous input of the webcam (*dynamic image*), and from the right, a capture of the image for a specific moment (*static image*) with a vertical strip.

3.3 Consumer

3.3.1 Plumbing infrastructures

To draw water from a *container* to the *water meter* and vice versa, a *pump* was used (see figure 3). The magnitude of the water flow was controlled by a tap's handle. The *analog water meter* that was used is the most common water meter in the developing countries. As mentioned above, the data can be read from it by sensor and webcam.

Figure 3 Simulating a water consumer installation: water meter, pump, container and electrical tap

3.3.2 Electric tap

In reality, the leaking system should be closed by a *solenoid valve*, a tap that opens and closes by electrical signals. It is possible to use a *proportioning valve*, which can also control the magnitude of the water flow.

3.3.3 Display

The system stores the statistics of water usage for two different periods: *learning period*, and *regular period*. In this project, several *seven-segment displays* were used to show the quantity of water that passed through the pump during these periods (i.e. the water used by the consumer), and LEDs were connected to signify the specific period of time (Figure-4). In order to operate these displays, a *4026 Counter*[10] with *decoders* for seven segment screens was used. It gets the instructions from the microcontroller and serves as a BCD counter, namely, it is used to present the digits 0-9.

Figure 4 *Seven segment displays* for the *learning period* and the *regular period*, together with LEDs signify the specific time period.

3.3.4 Voice system

In an effort to create a work-friendly and convenient interface, the system reports on the device status using *loudspeaker* and voice messages that were recorded on *ISD-4004* circuit.[11] The SPI (Serial Peripheral Interface) bus of the microcontroller enables it to be controlled.

3.4 Cellular communication

A *GSM modem*[12] was connected to the microcontroller and provided it with a cellular number to which a text massage can be sent. The consumer can respond and inform the system if it was a false alarm, and thus assist its operations.

3.5 Wireless communication

The Nordic *nRP9E5* transmitter/receiver[13] is connected to the system, so the consumption data can be sent by *RF communication* to a nearby computer, from where it is possible to deliver it to a relevant party. The data is displayed on graphs using a simple *Microsoft Excel* program. This device already contains the microcontroller, and in real life it is possible to deploy all the system's programs into it.

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[10] Decade Counters/Dividers with Decoded 7-Segment Display Outputs, SGS-Thomson, Jun. 1989

[11] ISD4004 Series, Winbond Electronic Corp. 26 Oct. 2005, Rev. 1.2

[12] Fastrack Go Cellular Modem, Wavecom

[13] nRF9E5, Nordic Semiconductor ASA, Apr. 2008

4 Mathematical model to detect leakages

4.1 Leakage detection criteria

To simplify the explanation, the following will focus on each criterion separately, even though the system takes into account all the criteria together. After that several situations of leakages will be demonstrated, and their graphs will be used to illustrate the system operation.

First, an important and simple criterion for *non-existence of leakage* characterized by a certain moment in which the level of consumption is 0 (or pseudo-0, since there may be a slight deviation in analog water meter measurements). Practically, we defined it as a detection of a very short time slot with no consumption.

4.2 Leakage detection based on average consumption

4.2.1 General description

Because a leakage was detected by this criterion, it is necessary to collect data about the *average consumption* (*avg*), length of the *time period* in which the average was measured (T_x), and the *maximum deviation level* (MD_{Tx}), which the consumer allows the consumption to exceed from the average consumption.

The time periods for the model were defined in advance (such as: 15 *min,* 30 *min,* 2 *hour,* 5 *hours,* 12 *hours,* 1 *day,* 1 *week,* and 1 *month*). Potential leakage is defined as the first deviation for a specific time period T_1 above the *MD*. Thereafter, if there is another deviation over a longer time period T_2, then this criterion will detect a leakage. Hence, an alert will be made if:

$$\mathrm{MD}_{T_1} < \mathrm{Consumption}(T_1) \text{ and } \mathrm{MD}_{T_2} < \mathrm{Consumption}(T_2)$$

4.2.2 Time periods for averaging

Time periods shorter than or equal to a full day will be referred to as *short time periods*. In these cases, there might be radical changes in consumption levels relative to time (*e.g.* 5 *min* with certain consumption followed by *200min* with no consumption at all), that will cause large variance and significant downward of the averages, hence, the distribution of consumption will not be normal.[14] Therefore, these *short time periods* are defined not only by their length, but also by their *starting point* and *ending point* (*e.g.* a single average for the *30min* from 07:00 to 07:30 in each day). Such distributions behave like a normal distribution.

Over *long time periods* (longer than a full day), the changes that might be in the consumption are not radical, but these periods fit the human consumption pattern (1 *day*, 1 *week*, and 1 *month*). It is more efficient to use that pattern, and thus a *starting point* and *ending point* were defined for them as well (e.g. a single average for all Sundays).

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[14] Limpert E., Stahel W.A., Abbt M. (May 2001), Log-normal Distribution across the Sciences: Keys and Clues, *Bioscience*, 51 (5) 341-352.

4.2.3 Deviation level

The value of the MD is determined using *statistical hypotheses*. Several simulations of water consumption situations were preformed to decide the initial hypotheses, but they still require testing and optimization in reality. The system could change the *MD* in extreme cases, so there is a *minimal standard* (*MinMD*) that the *MD* cannot reach below, but that will not be discussed it here. The length of the *initial learning period* is two weeks, during which detection of leakage will be carried out using other criteria (see section 4.3). Also a numerical *MD* was set for situations where the consumption average is 0 even after the learning period.

4.2.4 Data representation and calculations

The consumption data represented in *histogram* with k categories (classes) was normalized to display the *relative frequencies*. Statistical measures were calculated by *maximum likelihood estimation* and *confidence interval*.

In the following simulations (see subsections 4.2.5 and 4.3.2), the *confidence level* is:

$$1 - \alpha = 0.99$$

The mean estimator $\bar{X}$ and the standard deviation estimator $\hat{S}$ are given by the known formulas 1 and 2 (when n is the size of the sample):

$$\bar{X} = \frac{1}{n}\sum_i x_i f_i \tag{1}$$

$$\hat{s}^2 = \frac{\sum_i (x_i - \bar{X})^2}{n-1} \tag{2}$$

Leakage detection means detection of deviation above the average only, that is to say the right-tailed null hypothesis:

$$H_0: \mu \leq \bar{X},\ H_1: \mu > \bar{X}$$

According to the confidence interval for a mean μ of a normal population when the variance is unknown, the upper critical value is:

$$K = \bar{X} + t_{1-\alpha}^{n-1} \cdot \frac{\hat{S}}{\sqrt{n}}$$

The *t-scores* are calculated in advance using Student's t-distribution using equation 3 (see table 1).

$$F(t) = \int_{-\infty}^{t} \frac{\Gamma\left[\frac{1}{2}(n+1)\right]}{\sqrt{\pi n}\,\Gamma(n/2)\left(1+\frac{x^2}{n}\right)^{(n+1)/2}}\,dx \tag{3}$$

Table 1 Student-T distribution table (relevant data)

n	15 16	17 18	19 20	21 22	23 24	25 26	27 28	29 30
$t_{1-\alpha}^{n-1}$	2.624 2.602	2.583 2.567	2.552 2.539	2.528 2.518	2.508 2.500	2.492 2.485	2.479 2.473	2.467 2.462

If n > 30 we can substitute the $\hat{s}^2$ for σ^2 and use Z-test (where $Z_{0.99} = 0.8389$). The general formula of the MD is given by equation 4.

$$(4) \qquad MD_T = \begin{cases} c, & K = 0 \\ aK + b\hat{S}, & 0 < K \end{cases}$$

$a, b, c \geq 0$ determines for each time period (T) in advance, based on our simulations.

4.2.5 Simulation of leakage detection based on averages consumption

Following is a simple simulation with: $T_1 = 15min$, $T_2 = 30\ min$, $1 - \alpha = 0.99$, and MD formulas for each time period of the day (see table 2).

Table 2 Maximum deviation *(MD)* level formulas

Time	Consumption pattern	T1 (*15min*)	T2 (*30min*)
05:00-08:00	stable	$MD_{T1} = \begin{cases} 40, & K = 0 \\ 3K, & 0 < K \end{cases}$	$MD_{T2} = \begin{cases} 60, & K = 0 \\ 2.5K, & 0 < K \end{cases}$
08:00-17:00	mutable	$MD_{T1} = \begin{cases} 40, & K = 0 \\ 3K + \hat{S}, & 0 < K \end{cases}$	$MD_{T2} = \begin{cases} 60, & K = 0 \\ 2.5K + \hat{S}, & 0 < K \end{cases}$
17:00-24:00	stable	$MD_{T1} = \begin{cases} 40, & K = 0 \\ 3K, & 0 < K \end{cases}$	$MD_{T2} = \begin{cases} 60, & K = 0 \\ 2.5K, & 0 < K \end{cases}$
24:00-05:00	low consumption	$MD_{T1} = \begin{cases} 40, & K = 0 \\ 6K + 3\hat{S}, & 0 < K \end{cases}$	$MD_{T2} = \begin{cases} 60, & K = 0 \\ 4.5K + \hat{S}, & 0 < K \end{cases}$

The daily activity in this case is such: there are 3 people in the consumer's family, who wake up between 06:00-06:30. The mother is a housewife; the child goes to school in the morning, returns home at 15:00, takes a shower every day, and goes to sleep around 19:00; the father goes to work and returns at 18:00; and both parents shower several times a week and go to sleep between 22:00-01:00.

The focus is put on two events that happened on day 40: A potential leakage that has proven to be false, and a real leakage that was detected at 03:00 in the system (a partially cracked pipeline was simulated at 2:00, and it was completely broken by 02:30; See figures 5 and 6 for time periods T_1 and T_2 respectively).

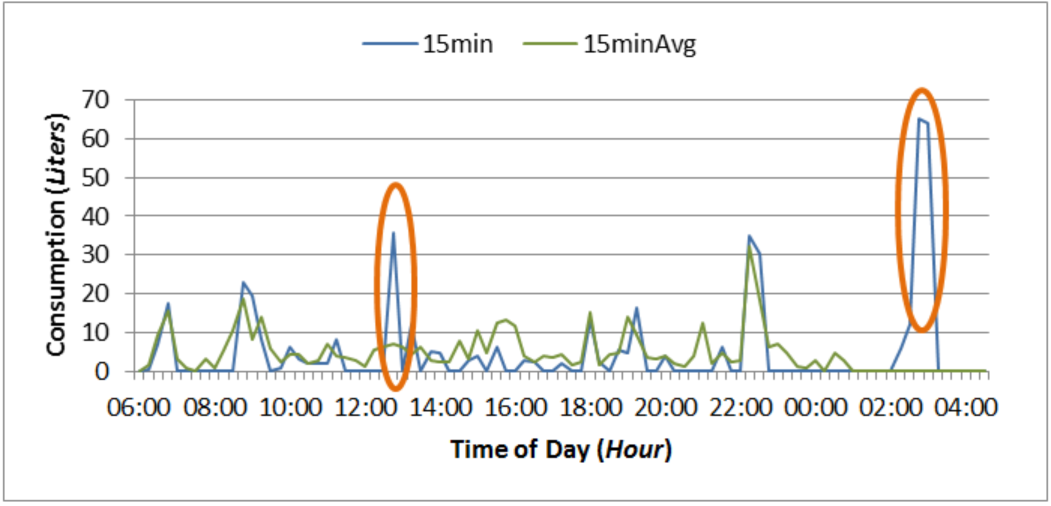

Figure 5 Graphic measure of the general consumption averages and the specific consumption on the leakage day, for time period T_1 (15 min), and the potential leakages that were detected.

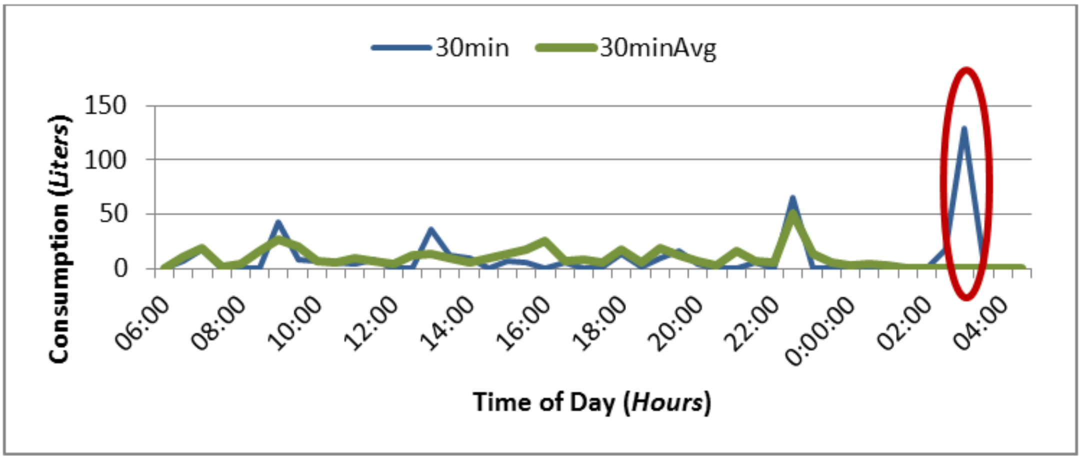

Figure 6 Graphic measure of the general consumption averages and the specific consumption on the leakage day, for time period T_2 (30 *min*), and the leakage that was detected.

At T_1 from 12:45 to 13:00 the system detected consumption of $35.8\ l$ which is potential leakage, since according to the histogram (see table 3), we get:

$$\bar{X}(n) = 7.157,\ \hat{S} = 7.285,\ K = 8.141, MD_{T1} = 3K + \hat{S} < 35.8$$

Table 3 Frequency table for time period 12:45–13.00.

Classes (consumption)	**0-2**	**2-8**	**8-14**	**14-20**	**20-40**	**40-80**	**80-160**
Frequency	6	26	4	1	3	0	0
%	15	65	10	2.5	7.5	0	0

At the following time period T_2 from 13:00–13:30, consumption of $12\ l$ was detected and thus the suspicion proved to be false, since according to the histogram (see table 4) we get:

$$\bar{X}(n) = 10.625,\ \hat{S} = 10.767,\ K = 12.053,\ MD_{T2} = 2.5K + \hat{S} > 12$$

Table 4 Frequency table for time period 13:00–13:30

Classes (consumption)	**0-4**	**4-12**	**12-26**	**26-60**	**60-100**	**100-150**	**150-300**
Frequency	11	20	6	3	0	0	0
%	22.5	52.5	17.5	7.5	0	0	0

At T_1: 02:30-02:45 consumption of $65\ l$ and a potential leakage was detected since $avg = 0$. At T_2: 02:30-03:00 consumption of $129\ l$ and another deviation was detected, and the system alerted on leakage.

4.3 Leakage detection based on steady water consumption over time

4.3.1 General description

Steady water consumption will be referred to as a *time period* (*TP*, that begins in T_0) with no discontinuing of the consumption. The *interval time* (*IT*) between the samples needs to be short. By this criterion, a leakage can be detected even in the learning period.

In the consumer house, the chances for a long steady consumption are very low (even devices such as washing machine consume water in several pulses); however, in networks that connect a lot of consumers to the supplier, the chances are higher, so this criterion is less significant.

Practically, there might be regular consumption parallel to the leakage in the system. This case will be referred to as *steady water consumption of AC wave riding DC wave*. A primitive yet effective way to detect a leakage in such case is to check if the majority of the water consumption samples (more than 50%) revolve around the *median* (*med*) – namely, the minimal sample value – with a *slight deviation* (*sd*). Hence, for group of samples:

$$X = \left\{ x_i = Consumption\ (T_0 + IT \cdot i) \,\middle|\, 0 \le i,\ IT \cdot i \le T \right\}$$

An alert will be made if:

$$\frac{\sum_{i=0}^{n} x_i \in [Med(X) \pm Med(X) \cdot SD]\ and\ x_i > 0.1}{n} > \frac{1}{2}$$

A more effective method is to use Fourier analysis, that decomposes a signal into its constituent frequencies. By using *fast Fourier transform* (FFT) method, which takes advantage of the special properties of the complex roots of unity, we can compute the discrete Fourier transform $DFT_n(a)$ in time $\theta(n \cdot \lg n)$. Because of that efficiency we still can use economical microprocessor, despite its limitations, to do this calculation as needed.

4.3.2 Simulation of leakage detection based on steady consumption over time

In the following simulation:

$$TP = 2h, IT = 20sec, SD = 3\%, n = \frac{2h}{20sec} = 360$$

In the discussed case, at T_0 14:02 an underground pipe cracked and a small unobserved leakage was created, while regular consumption continued as usual (see figure 7). The leakage was detected at 16:02, the consumer alerted, and the supply system blocked a few minutes later.

At the time period 14:02-16:02, steady water consumption was detected. According to the samples: $Med(X) = 1.22$, and thus the rate of samples around the median is:

$$\frac{\sum_{i=0}^{360} x_i \in [1.1834,\ 1.2566]\ and\ x_i > 0.2}{360} = \frac{321}{360} = 89.1\%$$

Thus, the system alerted on leakage.

4.3.3 Leakage detection by consumption pattern of plumbing fixtures

According to the theory of the criterion, characteristic consumption of each *plumbing fixture* at the consumer house will be identified and classified for

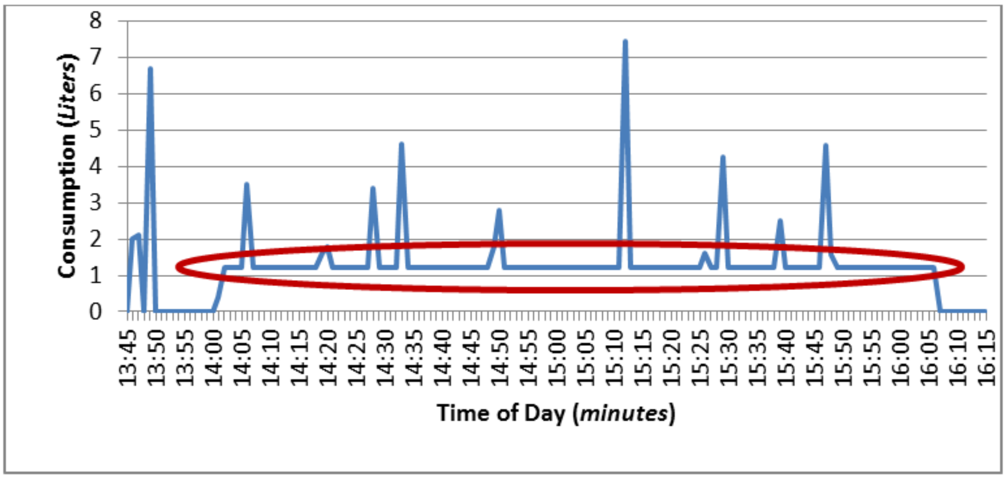

Figure 7 Graphic measure of the consumption during 13:45-16:15.

immediate detection of non-standard consumption. The criterion should take into account that other fixtures can be added, although this rarely occurs.

4.4 Discussion of issues related to the detection process

4.4.1 Leakage adjacent to the learning period

In the case, the distortion of the consumption averages should be explored. There might be a need to repeat the learning period, and make use of other criteria during it.

4.4.2 Increased water consumption due to fires

Fire alarms, as *building management systems (BMS),* are common in large buildings. The consumer may not respond to the system due to an emergency situation, and the water supply can be shut down. Therefore, it is necessary to analyze these systems' consumption patterns. If no special pattern is found, the mechanism of the system should be changed so that a leaking system will be shut down only after approval from the consumer (and not in the absence of it). It is also necessary to synchronize the fire alarm systems with our system in case the consumer is outside the house he cannot approve that there is a leakage.

4.4.3 Airflow in water meters

In damaged water meters air sometimes flows through it, causing 'fake' water consumption. A general characteristic for these flows is a sequential rising and falling wave, and, on the basis of future research, the impact of these flows, if any, has to be discovered.

4.4.4 False respond of the consumer

If the consumer responds that the deviation is due to normal consumption, the system will not rely completely on that reply in case there is still an unobserved leakage.

5 Conclusions

5.1 Benefits and contribution to society

From this comprehensive study of water losses in Israel, and elsewhere, the specific problem of reducing household leakages was addressed. The device that was developed, offers a direct and immediate solution to the discussed problem.

The entire system can be embedded into one electronic circuit, which is minimized to a few square cm using a printing circuit boards method. It is possible to market the entire system inside an analog/digital designated water meter, or to mount it on existing water meter, as has been done in the case of the model device.

The final cost of the system, after the development, is estimated to 20-40$, and it includes the cost of the GSM modem, a small battery (that can function for several years) and a small solar panel. The cost of a simple solenoid valve is about 20$.

5.2 Future directions

After the final prototype was developed, an optimization and empirical validation of the hypotheses is needed, in addition to a future research on the issues discussed above.

Groups of investors have already been in contact, attempting to mass-market the device. A patent registration of several parts of the device is still possible, and *Hagichon Ltd – Jerusalem Water & Waste Water Works Corporation* already showed an interest in using the device throughout their jurisdiction.

During the project, we have lectured about the issue of water loss in few primary schools to be able to raise awareness of the water economy’s situation, and to encourage young students to be involved in research and development in the future.

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