ACTA MECHATRONICA

2019 Volume 4 Issue 3

International Scientific Journal about Mechatronics

electronic journal
ISSN 2453-7306

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(SEPTEMBER 2019)

doi:10.22306/am.v4i3.48

DIDACTIC MODEL OF CONTROLLED WATER TANK SYSTEM

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Keywords: mechatronics, education, water tank, embedded systems
Abstract: The paper deals with didactic model of water tank, which is controlled via using of microcontroller as embedded system or other control system. System consists of water tank, water level sensor, water pump, transistor-relay module and control system. The aim is to use function model of system for practical exercises on mechatronic courses for bachelor and master students. Students have to complete system, make a testing of all components, make a hardware completed structure and make a software for microcontroller.

1 Introduction

Actually, many application with tank or cistern are around as. It is necessary to store any medium as water, gas, gasoline, diesel or other medium for various purposes (Figure 1). The level of medium should be controlled by any operator or automatically controlling system.

This paper is focused to water tank used as didactic model for students. The water level should be keep between the low and up limits. When water level is low, then it is necessary to start pump to refill tank up to high limit. Any operator has to look at the water level and has to stop pump, when level tank is full. Situation is complicated when tank is invisible or it is situated underground and operator cannot to follow water level. Any sensing system is needed for signalization of level inside tank. If tank is full and pump is still turned on, than there is a risk of tank damage or breakage of other systems. Other situation is when water consumption is too large and pump is not able to refill tank to desired level. Other problem is when damage of any component occurs (pump damage, sensor malfunction, breakdown of transistor-relay unit etc.) It seems to be easy, but there are many activities and therefore there is a place for using of mechatronic system, which will has several functions. Students will have training with real system in laboratory and it is best preparing them for real situation in practice.

Figure 1 Water tank examples

2 Concept of water level model

Model of system (Figure 2) consists of water tank with outlet valve, sensors for level sensing, transistor-relay module, controller, pump, and reservoir of water for refill and emptying of water tank. Water tank will be as controlled plant.

The water tank has connected outlet valve for simulation of water consumption – opening of valve causes the water level decreasing and total emptying of tank (in real situation water consumption is represented by user in home or office in kitchen, toilets, bathroom, or industrial application like cooling of reactor, water the garden, washing manufactured parts etc.) Some cases are very important like power plants, where insufficiency of water can causes the total destroying of nuclear reactor and there is a risk of very dangerous disaster. Redundancy of automation and mechatronic system is for this reasons actually frequently used in practice.

System can work as sequential logical system. When water level is lower than low limit, then pump is started up to moment of reaching of upper limit. After reaching of upper limit pump is stopped. When water level is decreased, pump is not started up to the moment when it is less than low limit.

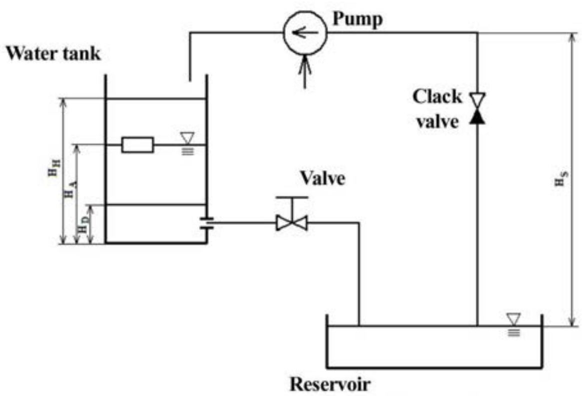

Figure 2 Concept of water tank model

Water tank will be transparent because of easy visibility and good visual demonstration for students.

On the base of previous notes, the control diagram can be shown on figure 3.

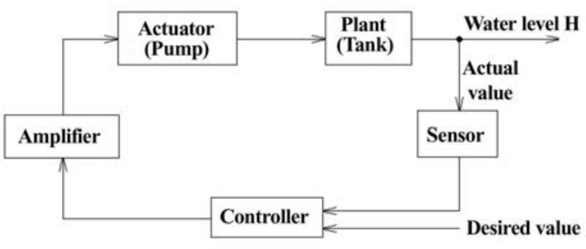

Figure 3 Control block diagram of water tank model

Water tank with level of water is plant and water consumption is as disturbance of controlled system. Actuator is pump and amplifier is transistor-relay switch. Regulator can be realized via using of microcontroller, PLC or any other control board. For every case it is necessary to use accessories board for signal processing and power amplifier in accordance with used control platform.

There are two basic selected choices for water level sensors. First choice is analogue output distance sensor, which will sense distance to float swimming on water level. The advantage is that in every time there is an information about water level value. The second choice is binary two state float sensor based on reed switch with permanent magnet inside plastic float also called as water level reed switch. Proposed system needs two these sensors (binary two state sensing of low limit and up limit). These sensors are very cheap and simple to use, but we have information only in binary expression.

Figure 4 Sensors for water tank model (analogue distance sensor and two state float reed sensor)

There are only four states of this system from the viewpoint of logical operations:

- Water level is less than low limit.
- Water level is between limits and it is going up.
- Water level is more than up limit.
- Water level is between limits and it is going down.

Pump is powered with low voltage because of safety. The proposed solution is automotive water pump for front and back window splashing. It is powered with voltage 12V or 24V.

Figure 4 Automotive pump for windows splashing

3 Water level tank math description

Water level tank can be demonstrated as graduated cylinder with output escape hole (Figure 5).

It can be described with Bernoulli equation for expressing of water outflow:

$$h_1 + \frac{p_{at}}{\rho \cdot g} + 0 = 0 + \frac{p_{at}}{\rho \cdot g} + \frac{v_t^2}{2 \cdot g} \qquad (1)$$

Where h_1 is water level height, ρ is density of water, p_{at} is atmospheric pressure, v_t^2 – velocity of output water flow.

Velocity output water flow can be derived as:

$$v_t = \sqrt{2gh_1} \qquad (2)$$

For special cases it is possible to use two coupled water tanks (Figure 6).

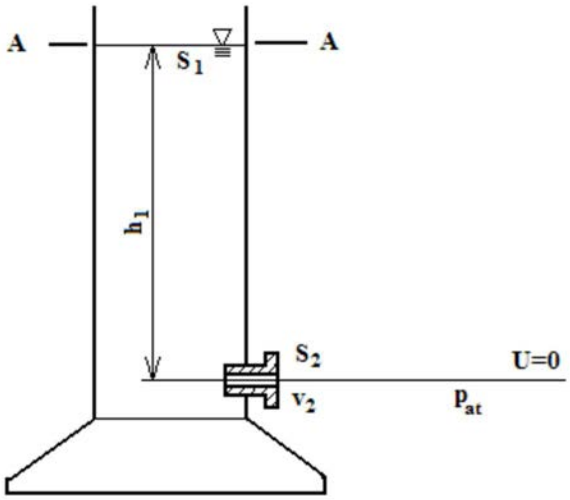

Figure 5 Water level tank with output escape hole

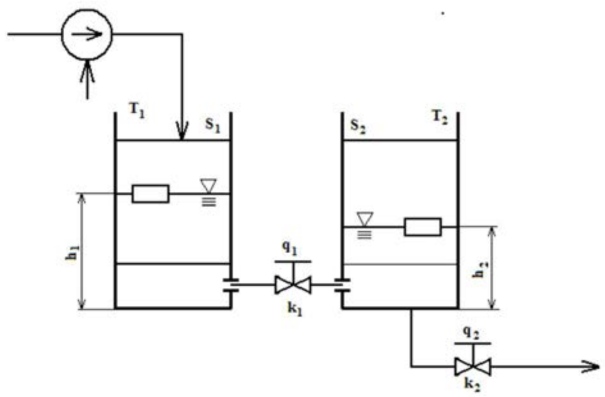

Figure 5 Two coupled water tanks

For this system with two tanks, it can be notes equations:

$$S_1(t)\frac{dh_1(t)}{dt} = Q_1(t) - S_v v_1(t)$$
$$S_2(t)\frac{dh_2(t)}{dt} = S_v v_1(t) - S_v v_2(t) \qquad (3)$$

Velocity of output water flow can be derived as

$$v_1(t) = \sqrt{2g(h_1(t) - h_2(t)}$$
$$v_2(t) = \sqrt{2gh_2(t)} \qquad (4)$$

Analogically it is possible arrange three water tanks or more and make more sophisticated system (Figure 6).

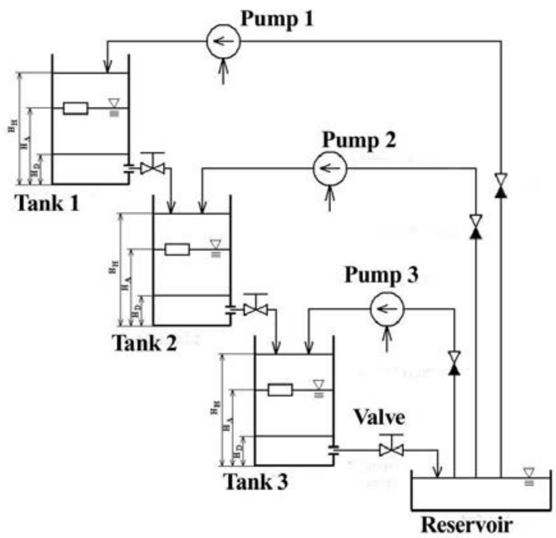

Figure 6 Design of three coupled water tanks

Currently, measurement of water level can be realized with reed float switch (two state sensor) or analogue optical distance sensor.

Figure 7 Distance sensor for measurement of water level

Transformation characteristic of sensor has been obtained experimentally as it shown on figure 8. Approximation equation can be modified for using of measurement via using of controller.

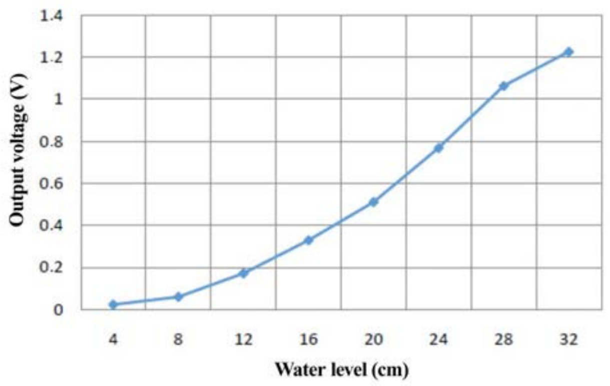

Figure 8 Transformation characteristic of distance sensor for measurement of water level

4 Algorithm of water level controlling

Flowchart of algorithm (Figure 9) shows the possible simple algorithm of controlling water level with using of two state float reed switch. There are two sensors. First is used for detection of water level on low limit and second is for detection of reaching of upper limit

First step in flowchart (Figure 9) is obtaining data from both sensors and saving them into memory. Next step is decide block, where a condition is tested "Is the water level lower than upper limit?" If yes, than the pump must be turned off. If no, than it continues to next decide block, where a next condition is tested "Is the water higher than lower limit?" If yes, than it continues to starting point A. If no, than the pump must be activated and it continues to starting point in infinity loop.

Students can improve it with additional testing of functionality of sensors or pump. It is possible to add another sensors or any other parts.

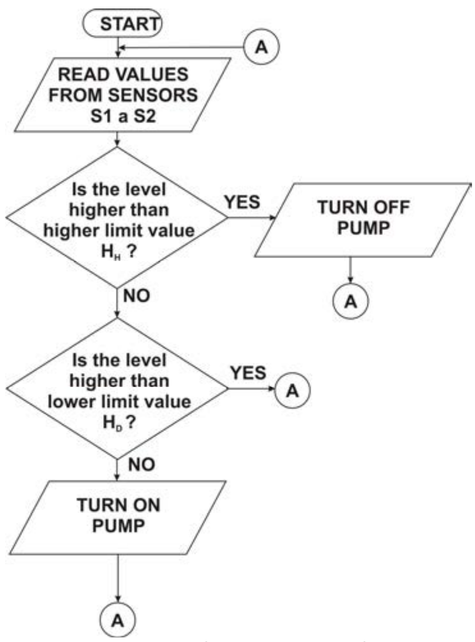

Figure 9 Flowchart for controlling of water level

Finally the six pieces have been realized for laboratory experiments as didactic model. Also it is possible to compose multi-tank system as various combinations of water tanks with more complicated logic functions.

Figure 10 Realisation of functional model of water tank

5 Conclusion

It looks very simple but this model enables to make more complicated systems. Also simulation model can be arranged and simulation results can be verified with experiments. Students will see, that there are several problems with real systems like saturation of actuators, dead zone of sensors, signal noise, low robustness of actuators and others relative problems. As control systems can be used microcontroller, PLC, time relay or standard PC with data acquisition card.

These didactic model are prepared for supporting of creativity of students. The theory presented on lectures are perfect but the best choice is to verify it on exercises on practical model. It means that mechatronics should go through the hands of students [3-17].

Acknowledgement

The authors would like to thank to Slovak Grant Agency – project KEGA 018TUKE-4/2018 supported by the Ministry of education of Slovak Republic.

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Review process

Single-blind peer review process.

JOURNAL STATEMENT

Journal name:	**Acta Mechatronica**
Abbreviated key title:	Acta Mechatron
Journal title initials:	AM
Journal doi:	10.22306/am
ISSN:	2453-7306
Start year:	2016
The first publishing:	March 2016
Issue publishing:	Quarterly
Publishing form:	On-line electronic publishing
Availability of articles:	Open Access Journal
Journal license:	CC BY-NC
Publication ethics:	COPE, ELSEVIER Publishing Ethics
Plagiarism check:	Worldwide originality control system
Peer review process:	Single-blind review at least two reviewers
Language:	English
Journal e-mail:	**info@actamechatronica.eu**

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Publisher:	**4S go, s.r.o.**
Address:	Semsa 24, 044 21 Semsa, Slovak Republic, EU
Phone:	+421 948 366 110
Publisher e-mail:	**info@4sgo.eu**

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