Multi-tank fuzzy level controller system using Kinect

Robinson Jiménez M. Camilo Cáceres. Oscar Avilés. Camilo Gordillo.
GAV-Universidad Militar Nueva granada
Carrera 11 No 101-80, Bogotá, Colombia
{robinson.jimenez, u1801466, oscar.aviles, u1801074}@ unimilitar.edu.co

***Abstract*—This paper presents the development of a level control system using 3D machine vision techniques based on a single level-detector sensor (Kinect), in an arrangement of three tanks. Using image processing algorithms, each one of the tanks is classified within the video sequence as well as each one of the depth measurements is averaged regarding the cross sectional area of the surface of the tanks. This information is used to control the filling level for each tank using a proportional fuzzy controller and a proportional-derivative fuzzy controller. Finally the performance of each controller is compared.**

***Index Terms*—Fuzzy control, level control, 3D vision, Kinect, image processing.**

I. Introduction

NOWADAYS, three-dimensional vision systems are used in many engineering fields. Its development has led to the production of highly reliable and robust products such as Kinect, which using a series of cameras is capable of delivering the color information (RGB) of the scene and the spatial position of the different objects into it (Deepness) [1].

Some of the Kinect applications use the depth information in order to recognize the hand movements of a person [2], which can be applied to control robot hands for tracking or imitation. Similarly, there are some objects identification applications [3], where the characteristics of shape and size can be associated using a combined analysis of the characteristics of color and depth. In [4] a Kinect sensor is used to track a robotic arm on a stage and the possible obstacles in its workspace. In [5] the same sensor is used to control the height of a quadrotor, which shows the functionality of the depth information recollected for the development of all kind of control applications.

On the other hand, fuzzy control systems are very appreciated nowadays because of their capacity to replace the "modeling stage" of the design by a series of rules that describe the behavior and the logic of the controller. In this way, fuzzy controllers are much easier to develop and their performance is usually better. In [6] a classical PID controller was improved connecting a fuzzy system in parallel in order to control the filling and draining cycles of a tank. In this schema, the PID controller operates over the small error variations, while the fuzzy system is in charge of the big ones. In [7] a fuzzy controller was developed, which is able to control the level of a tank in a boiler system in order to avoid the interference effects of warming and maintain the system stability.

In the present work a simple sensor is used (Kinect) as a level measurement system in order to control the liquid level inside a group of three tanks coupled together. Using the deep information measured and applying image processing techniques over the RGB data recollected it was possible to obtain a multi-tank level sensor, which together with a group of fuzzy controllers was able to establish the desired levels of liquid in each tank.

In Engineering applications Kinect is a very recent device, for this reason, no previous studies about its use for tank level measurements could be found. The implementation of fuzzy controllers is already known [8] [9], but there is not a tacit comparison between them. Therefore, two fuzzy level controllers were developed (proportional and proportional-derivative) in order to compare their perdormance.

Next section describes the technique of measuring the liquid level in the three tanks using Kinect. At Section III the design of the fuzzy controllers is presented while the results are showed at Section IV. Finally at Section V the conclusions achieved are presented.

II. Level detection:

The level detection system is based on a Kinect sensor which has an infrared projector that generates a pattern captured by a camera of the same type in order to build a depth map of the objects inside the captured image. Besides, it has a RGB camera with a resolution of 1280x1024 pixels, which allows the system to obtain the color information of the image.

Detecting the liquid level in each tank is performed by using image processing techniques in which by analysis of the video sequences captured by Kinect, it is possible to obtain both, the color information (RGB) for the segmentation of each tank, and the depth measures to establish the current level. The sensor is located so that covers the area occupied by all three tanks from the top, as shown in Figure 1.

Considering the depth measurement technique used by Kinect (infrared), it is not possible to perform the measurement directly on the liquid; therefore, it becomes necessary to use a float in each tank which allows the measure of depth. Each float is highlighted in the scene using a color on its upper surface, which contrast with the surroundings and makes them easier to identify.

A grayscale transformation is performed over the captured RGB image in order to apply a thresholding process and

978-0-7695-4878-4/12 $26.00 © 2012 IEEE
DOI 10.1109/CERMA.2012.77

IEEE computer society

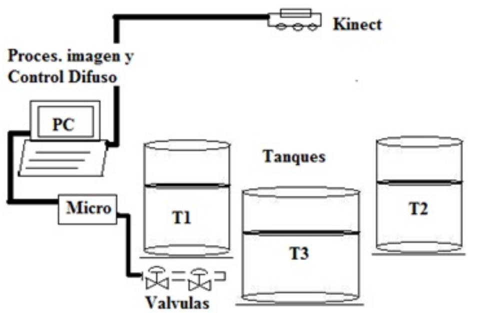


Figure 1. Application diagram

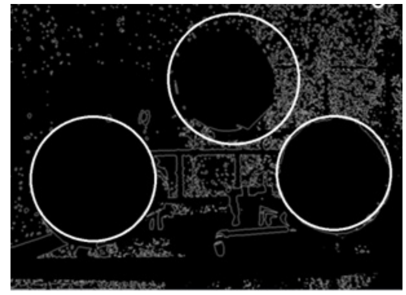


Figure 3. Detection of the tanks

thereby obtain a binary image in which it is possible to detect the edges of the present objects using the Canny algorithm [10]. Figure 2 shows the result of such processing for acquiring the image, Figure 2a shows the top view of the tanks and Figure 2b present s the detected edges.

(a) Top view of the tanks

(b) Image edges

Figure 2. Processing results over the top view image

The location of the tanks is determined by the circular structure of them; therefore, a Hough transformation [11] for detecting circles is applied over the obtained image. Figure 3 illustrates the found circles in the image after applying the transformation.

It is noted that the lateral tanks (tank 1 on the left and 2 on the right) coincide with the centers of the found circles, however, this does not happen with the central tank (tank 3), where the radius calculated was higher, creating a mismatch between the centers. Nevertheless, tank 3 is still contained within the radial area.

The first step is identifying those pixels located between the center of any of the circle found and the perimeter of the respective tank. If a non-black pixel is found within the established perimeter, the center is recalculated as its current position minus half of the distance between the pixel found and the perimeter. This process sometimes generates a smaller circle than the tank, but ensures obtaining only pixels inside it.

The found pixels, which represent the surface of the float, are linked with their own depth measure, averaging each of the values and obtaining the current level of the tank (N_t) using Equation 1.

$$N_t = \frac{1}{n}\sum_{i=0}^{n}\left[d_k - P_i(x,y)\right] \qquad (1)$$

Where $P_i(x,y)$ represents the depth values measured by the Kinect for each pixel of the cross sectional area of the tank, and d_k is a constant as shown in Equation 2. D_t represents the distance between Kinect and the ground; A represents the thickness of the float; B is the thickness of the tank base and C represents the distance from the tank to the ground, as illustrated in Figure 4.

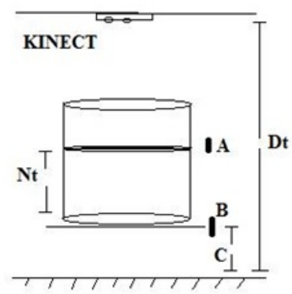


Figure 4. Representative measures

$$d_k = D_t - (A + B + C) \qquad (2)$$

The number of pixels will depend on the radial segmented area for each tank and will be associated with the depth image generated by the Kinect, as shown in Figure 5.

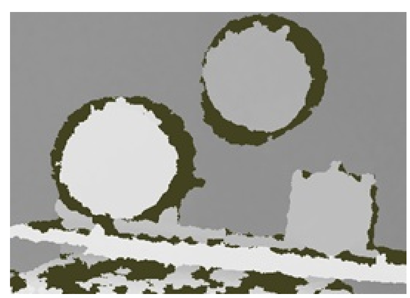


Figure 5. Depth image generated by Kinect

III. Fuzzy control system:

The fuzzy control system developed makes it possible to have an analytical model of the group of tanks. Tanks 1 and 2 in Figure 1 will be controlled by a fuzzy system; A Proportional fuzzy controller will be developed for tank 1 and a Proportional Derivative fuzzy controller for tank 2. On the other hand, tank 3 will be controlled by an ON / OFF controller.

The system operates over a group of proportional control electrovalves, which allow the filling and draining flows. The reference of these electrovalves is FESTO MPYE and their operation range is 0-5 volts (maximum and minimum flow respectively) as shown in Figure 6.

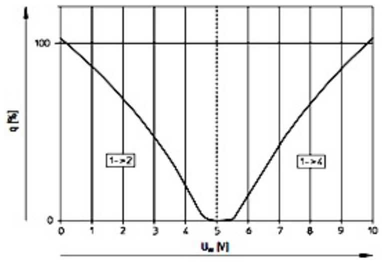


Figure 6. V-Q diagram of the proportional valves

According to the valves response, the membership functions and the universe of discourse of the outputs were deduced. This universe sets the duty cycle percentage (0-100) of a PWM signal, which will be responsible of controlling the actions of the valves.

A. Proportional Fuzzy controller:

The controller input is determined by the difference between the current level of the tank 'N_t' and the reference level 'N_r', which corresponds to the control error (e), as shown in Equation 3 and and as evidenced by the control loop illustrated in Figure 7. The universe of discourse of the input is determined as a percentage between 0 and 100 when 'N_r' is greater than 'N_t' (positive error), and between 0 and -100 when 'N_r' is smaller than 'N_t' (negative error). The percentage relation is given by the filling level of each tank ($N\%$) compared to its maximum capacity (100%), establishing the universe of discourse shown in Figure 8a for each one of the tanks under control.

$$e = N_r - N_t \qquad (3)$$

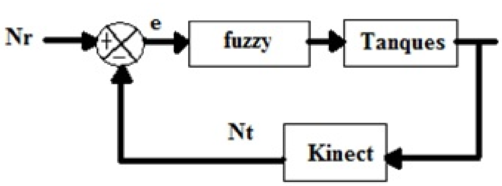
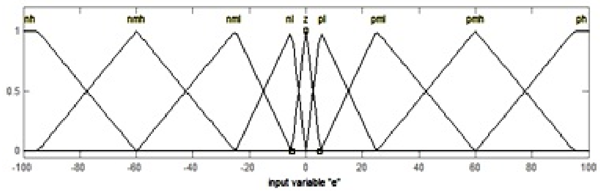


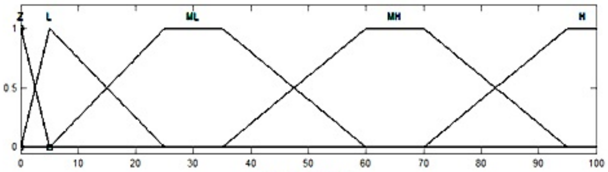
Figure 7. Block diagram of the control loop

The outputs are the control signals of the filling and the drain valves (*Vin* and *Vout* respectively) and they activate the opening and closing of the valves. Therefore, they are set in a range between 0 and 100, generating the universe of discourse for *Vout* and *Vin* (Figure 8b).

The fuzzy set for the input error is *e*={PH, PM, PL, Z, NL, NML, NMH, NH} within the range of *e*={-100,. . . ,0,. . . ,100}. On the other hand, the fuzzy set for both input and output valves is *Vout* = *Vin* = {L,ML,MH,H} within the range *Vout*= *Vin*={0. . . 100}. Where P=Positive, N=Negative, H=High, M=Medium, L=Low and Z=Zero. For example, PH represents a High-Positive error. Each input value will belong completely to one of the membership functions inside the universe of discourse (Ruspini). Table I shows the activation rules for the proportional controller.



(a) Input Fuzzy set



(b) Output Fuzzy set

Figure 8. Fuzzy sets for the proportional controller

Table I
FUZZY RULES OF THE PROPORTIONAL CONTROLLER

if ***e*** is	then *Vin* is	and *Vout* is
PH	H	Z
PMH	MH	Z
PML	ML	Z
PL	L	Z
Z	Z	Z
NL	Z	L
NML	Z	ML
NMH	Z	MH
NH	Z	H

B. Proportional-Derivative Fuzzy controller:

The implementation of the fuzzy proportional-derivative controller involves a new fuzzy set based on the rate of change of the error (de) between a sample K and the immediately preceding (K-1). Because of the 'slow' nature of the system, the error variation is small, therefore the fuzzy set is established in the range of {-10,...,0,...,...,10}. Figure 9 illustrates the membership functions for the error variation.

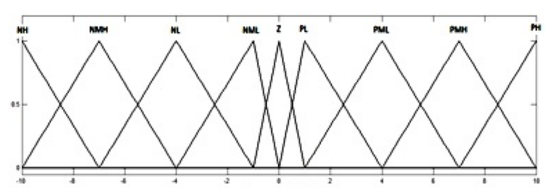


Figure 9. Fuzzy set of the derived output.

Given the controller structure, the fuzzy rules for each valve are determined by each control operation to be performed according to both inputs: the error and its derivative. Table II describes the base rules for the filling valve, while Table III shows the base rules for the drain one.

Table II
FUZZY RULES FOR THE FILLING VALVE OPERATED BY THE PD CONTROLLER.

de/e	NH	NMH	NML	NL	Z	PL	PML	PMH	PH
NH	Z	Z	Z	Z	Z	Z	Z	Z	Z
NMH	Z	Z	Z	Z	Z	Z	Z	Z	L
NML	Z	Z	Z	Z	Z	Z	Z	L	L
NL	Z	Z	Z	Z	Z	Z	L	L	ML
Z	Z	Z	Z	Z	Z	L	L	ML	ML
PL	Z	Z	Z	Z	L	L	ML	ML	MH
PML	Z	Z	Z	L	L	ML	ML	MH	MH
PMH	Z	Z	L	L	ML	ML	MH	MH	H
PH	Z	L	L	ML	ML	MH	MH	H	H

Table III
FUZZY RULES FOR THE DRAINING VALVE OPERATED BY THE PD CONTROLLER.

de/e	NH	NMH	NML	NL	Z	PL	PML	PMH	PH
NH	H	H	MH	MH	ML	ML	L	L	Z
NMH	H	MH	MH	ML	ML	L	L	Z	Z
NML	MH	MH	ML	ML	L	L	Z	Z	Z
NL	MH	ML	ML	L	L	Z	Z	Z	Z
Z	ML	ML	L	L	Z	Z	Z	Z	Z
PL	ML	L	L	Z	Z	Z	Z	Z	Z
PML	L	L	Z	Z	Z	Z	Z	Z	Z
PMH	L	Z	Z	Z	Z	Z	Z	Z	Z
PH	Z	Z	Z	Z	Z	Z	Z	Z	Z

The defuzzification method uses the center of gravity procedure, described by equation 4, which is the one that best matches the fuzzy set type [12].

$$y = \frac{\sum_{j=1}^{F} \mu_b^{'}(y_j) * y_j}{\sum_{j=1}^{F} \mu_b^{'}(y_j)} \qquad (4)$$

IV. RESULTS:

The experimental framework of the fuzzy system is done using the Open Source Fuzzy Logic Library (DotFuzzy); the image processing algorithms are developed using OpenCV 2.1, and all the development is implemented under Microsoft Visual C# 2010 Express Edition. The tester computer has a 2.4GHz processor and 2GB of RAM.

The control signal of each tank is supplied by a PIC18F2550 microcontroller, which generates a PWM output for tanks 1 and 2 and an ON/OFF signal for tank 3. At the same time, this microcontroller receives a main control signal from C#.

Figures 10 and 11 show the measurement result with Kinect compared to the manual measurement of the level of each tank. From these, an average error of 0.89% was obtained, which generally denotes a good performance of the sensor used.

It can be seen that tank 3 presents the greater error, because of its distance to the sensor. This is expected, given the Kinect resolution and its degradation with distance. For tanks 1 and 3, the error is mainly presented because of disturbances produced by the float and the tank walls, which can be solved by making the diameter of the floats smaller.

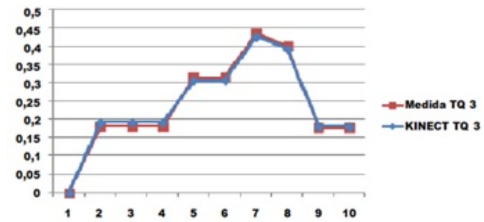


Figure 10. Level measurement of tank 3.

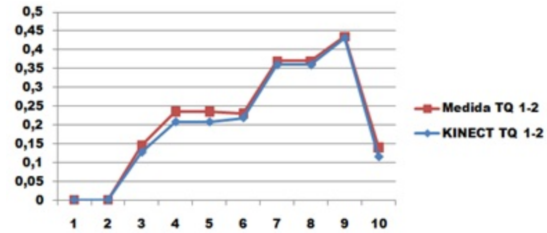


Figure 11. Level measurement of tank 1 and 2.

Figure 12 shows the control action results for a filling cycle when the same reference level is set for tanks 1 and 2; Figure 13 shows the same results but for a draining cycle.

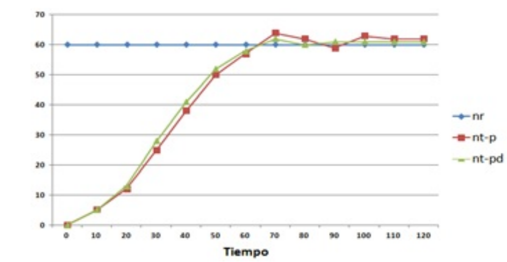


Figure 12. Controllers response to the filling process.

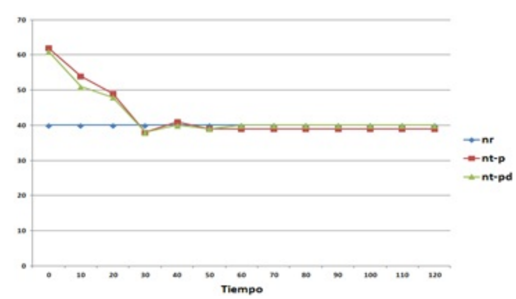


Figure 13. Controllers response to the draining process.

It can be seen that the 'PD' controller generates a filling and draining responses slightly higher, which makes the system responds in a shorter time. For different reference levels the response time is about 1.5 seconds.

The system presents a maximum overshoot of 6.6% and steady-state error of 4.2%. Borderline cases of these two parameters are given for small control actions in which the valves do not close completely due to the defuzzification method (center of gravity), which keeps a remaining voltage on the valves input. For this reason, a correction signal is generated by software on the microcontroller in order to bring this value to zero.

V. Conclutions

It was possible to develop a level measurement system using Kinect, which using image processing techniques is capable of sensing efficiently the filling rate from three different tanks in order to apply this information in an automation system. Thus decreasing the number of sensors, the respective communication lines and the acquisition times associated with each sensor.

Regarding the performance of the fuzzy proportional and the fuzzy proportional-derivative control systems implemented in the level control loop, very similar results were obtained. Given the slow nature of the process, the improvement in time of the 'PD' controller (1.5 seconds avg.), does not represent a significant advantage over the 'P' controller, but since the structure of the first one (PD) is more complex and does not generate an additional computational load to the system, this controller is ultimately more efficient.

References

[1] Smisek, J.; Jancosek, M.; Pajdla, T.; "3D with Kinect," Computer Vision Workshops (ICCV Workshops), 2011 IEEE International Conference on, vol., no., pp.1154-1160, 6-13 Nov. 2011.

[2] Raheja, J.L.; Chaudhary, A.; Singal, K.; , "Tracking of Fingertips and Centers of Palm Using KINECT," Computational Intelligence, Modelling and Simulation (CIMSiM), 2011 Third International Conference on, vol., no., pp.248-252, 20-22 Sept. 2011.

[3] Saenko, Kate; Karayev, Sergey; Jia, Yangqing; Shyr, Alex; Janoch, Allison; Long, Jonathan; Fritz, Mario; Darrell, Trevor; , "Practical 3-D Object detection using category and instance-level appearance models," Intelligent Robots and Systems (IROS), 2011 IEEE/RSJ International Conference on , vol., no., pp.793-800, 25-30 Sept. 2011.

[4] Rakprayoon, P.; Ruchanurucks, M.; Coundoul, A.; "Kinect-based obstacle detection for manipulator," System Integration (SII), 2011 IEEE/SICE International Symposium on, vol., no., pp.68-73, 20-22 Dec. 2011.

[5] Stowers, J.; Hayes, M.; Bainbridge-Smith, A.; , "Altitude control of a quadrotor helicopter using depth map from Microsoft Kinect sensor," Mechatronics (ICM), 2011 IEEE International Conference on , vol., no., pp.358-362, 13-15 April 2011.

[6] Li Liang; "The application of fuzzy PID controller in coupled-tank liquid-level control system," Electronics, Communications and Control (ICECC), 2011 International Conference on, vol., no., pp.2894-2897, 9-11 Sept. 2011.

[7] Zhuo Wang; Qiang Wang; "Application of fuzzy controller in drum water-level control," Mechatronic Science, Electric Engineering and Computer (MEC), 2011 International Conference on, vol., no., pp.174-176, 19-22 Aug. 2011.

[8] G.Wang, H.Song, Q.Niu, "Mine Water Level Fuzzy Control System Design Based on PLC", Second International Conference on Intelligent Computation Technology and Automation, Vol.3, pp130- 133, 2009.

[9] L.Chen, C.Wang, Y.Yu and Y.Zhao, "The research on Boiler drum Water Level Control System based on Self-Adaptive fuzzy-PID", Control and Decision Conference (CCDC), pp1582-1584, May2010.

[10] J.Canny, "A Computational Approach to Edge Detection," IEEE Transactions on Pattern Anal. and Machine Intell., vol.PAMI-8,no.6, pp. 679-698, Nov. 86.

[11] Chan, R.; Siu, W.-C.; , "A new approach for efficient Hough transform for circles," Communications, Computers and Signal Processing, 1989. Conference Proceeding. IEEE Pacific Rim Conference on, vol., no., pp.99-102, 1-2 June 1989.

[12] Babuska Robert, "Fuzzy and Neural Control DISC Course Lecture notes". Delft University of Technology. Sept 2004.