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Improvement in Sensitivity by Circuit Simulation for Humidity Sensor

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Abstract:
The emerging human comfort life attracts the monitoring of humidity in atmosphere. Particularly, a tiny change in humidity in prosthetic devices alters biological harmony of the living society. However, the tiny change in humidity is very difficult to measure by conventional sensors or hygrometers. Therefore, it is essential to investigate on improvement of sensitivity of a sensor. In resistive type humidity sensors, two electrodes are placed in an interdigitized pattern to enhance the contact area, in which resistivity changes with moisture absorptions in between the electrodes. The present study aimed to further amplify the electric signal to enhance the sensitivity of the sensor by tuning the amplifier-circuit. An operational amplifier (op-amp) is used for the simulation in Proteus software. From the different used op amp, it has been found that without a feedback loop, the op amp works as a comparator. After studying on different feedback loops, we have found that the negative feedback loop used in the present circuit cancels out the noise and varies linearly. Different cases had also taken for all the components in the present circuit to obtain an optimal value, which was maximum by first keeping the input voltage as constant. We considered a certain component value and then changed the input to a very low value keeping the optimum value obtained from the components. Here, we obtained a significant improvement in output for a small change in input signal. Hence, this huge enhancement in amplification () and large sensitivity achieved using the present simulated circuit can be used for humidity sensors.

***Keywords**: Circuit, humidity sensors, prosthesis, stamp, simulation*

I. INTRODUCTION

A humidity sensor senses the humidity at a certain place and particular temperature with respective humidity in air to measure the relative humidity (RH) [1]. It is also dependent on properties such as temperature and the pressure of the system. The temperature and humidity process controlling devices can monitor and control the ambient environmental conditions. In food, medical, pharmaceutical sectors, and laser controlling of RH is vital in the production of moisture-sensitive products [2-4]. An individual use of prosthetic limb for longer duration creates several trauma may [5]. This might have happened due to change in body humidity condition owing to sweating generated in between the skin and the liner [6]. Some people due to their low sensory processing of the skin, they cannot feel this and this can cause skin diseases after prolonged use. It may cause ulcers and even it may lead to skin cancer [5]. Earlier, hygrothermographs had been employed to monitor RH over a long period of time [7]. But now a days, electronic sensing and data acquisition techniques are used to get data easily. After that the sensed analogue signal would be converted into digital signal in order to

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enable and store it in electronic devices such as, electrically erasable programmable read-only memory (EEPROM), random access memory (RAM), and so on. In practical, several types of humidity sensors have been used depending on their sensing principle such as, conductivity, capacitive, resistivity, and etc[1, 8, 9]. In the present experiment, the resistive type is chosen because it has low fabrication cost and size can be small. This type of circuits can be used for remote controlling, i.e., the circuit can be kept far away from the sensor and these can be easily interchangeable as they have low to no calibration standards. However in practical, the change in conductivity, capacitive, resistivity, or etc for tiny change in RH is very small, therefore, signal amplification is essential to detect the small change RH values. Changing sensitivity (i.e., output change in signal/change in input measuring signal) is one of the best methods for signal amplification. Some research group also used sensitive capacitive dependent crystals to measure the high air humidity [10]. Many researchers are trying to increase the sensitivity by simulation, but not achieved the desired values as demanding by the different biomedical fields, particularly in prostheses devices where precise measurement is critical [9, 11, 12].

Aiming to fabricate such humidity sensors which can help the amputees for monitoring the RH in their prostheses and the industries, sensitivity was focused as one of the critical parameters in simulation. The primary goal was to increase the sensitivity of the sensor by simulation using Proteus Design Suit software version 8.6. It would help the manufacturer to detect the small changes in the humidity levels and to get an accurate data by increasing the significant change in output signal voltage in cheap way. This would also help the research to improve prosthetic material and predict the usage it for longer period. In the present study, a high quality economically feasible technique is proposed to measure the RH.

II. The Sensor Circuit Design

2.1. Increasing sensitivity using operational amplifier (op-amp) circuit

The job of any amplifier is to amplify the input to a sensible output value. In the present study an operational amplifier (op-amp) was used to make a potential circuit. The op-amp comprised different resistors and a capacitor as shown in Figure 1. It also performed many mathematical operations like subtraction, addition, and integration to evaluate the output signal. It mainly consists of two inputs and one output as shown Figure 1. The positive side of input terminal is known as non-inverting input terminal. The negative side of the input terminal is known as inverting input terminal. There is also a provision for a terminal for power supply to the op-amp. The used op-amp was differential amplifier with a single output. It amplified the difference between the two signals. The V1 and V2 were two inputs for the op-amp. When the open loop gain of the op-amp was a certain quantity (A) then the output would be $V_{out}= A\times(V1-V2)$.

Without a feedback loop, the op-amp worked as a comparator. Therefore, different types of feedback loops were considered in our simulation. Generally, negative feedback loop and positive feedback loop are used. The basic principle of a feedback loop is to take the part of output voltage and feed it back to the input. Thus, it increases the amount of input voltage and hence, output is amplified even more. In the present study, a negative feedback loop was used. In the negative feedback loop, the inverting terminal was connected to the output, which was directly feeding to the terminal. In a positive feedback loop, the non-inverting terminal was connected to the output, which was feeding directly to the respective terminal. The outputs achieved in both the loops were same but the negative loop will cancel out the noise because of its phase angle 180°and also had linear output. However, the positive feedback loop would also amplify the noise to it. It also has a grater hysteresis effect to the circuit. A positive feedback loop reached a saturation level faster that the

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negative loop. Due to these considerations the present simulation was done on a negative feedback loop.

2.2. Simulation on positive feedback loop

A simulation on a negative feedback loop is created by using Proteus Design Suit software version 8.6. Here, the simulation process was done in two steps: first, to increase the output value and then, to bring it to an optimum value where there was a significant change in output for a small change in input. An external battery source 9V was connected to the power terminals of the op-amp, as shown in Figure 1. In the first stage, an input voltage 5V was considered constant from a humidity sensor. The input voltage correspond to the RH was considered from the maximum voltage 0-5V obtained by the other researchers [2]. Here, a capacitor was provided for storage of charge in case of sudden power cut it can keep the circuit safe. The resistor R1 and R2 were required for the circuit to work. R3 and R4 were the feedback loop resistors. A voltmeter was attached to the output so that output would be measured.

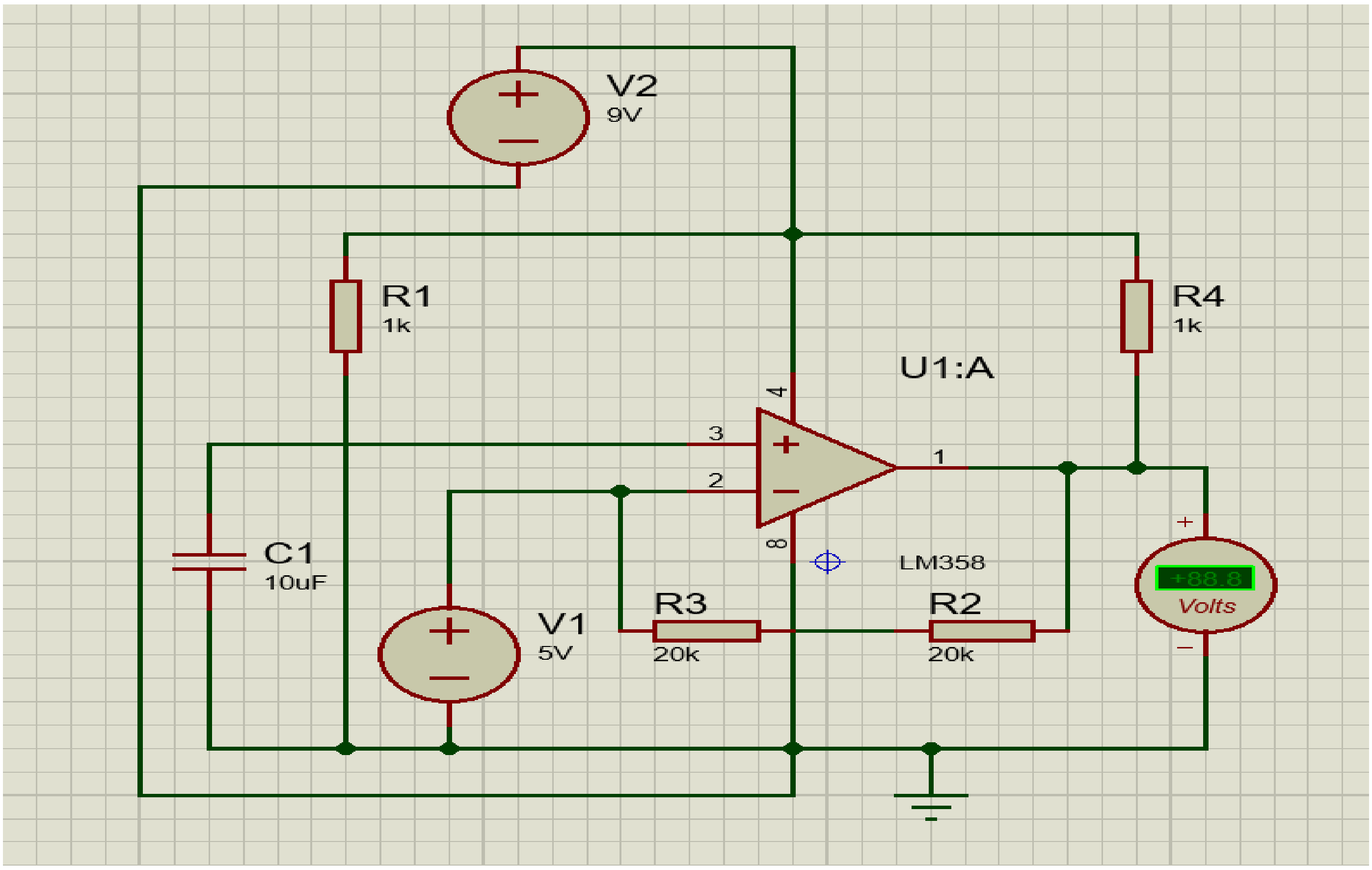

Figure 1: Negative feedback loop operational amplifier.

III. Results and discussion

The tests were done by first keeping R2, R3 and R4 constant at 1kΩ and varying R1 alone. It can be seen that there was no change in the output signal voltage as illustrated in Table 1.

Table1: Simulation done on variation of resistance R1 by keeping other resistances R2, R3, and R4 as constant

Serial No.	Resistance (R1)	Output voltage (V_{out})
1.	1kΩ	7.67V
2.	5kΩ	7.67V
3.	10kΩ	7.67V
4.	50kΩ	7.67V
5.	100kΩ	7.67v

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In the second simulation, we had kept the resistances R2 and R3 as variable. Since the resistors were kept in series and both were changed at once, the remaining resistors were kept constant at 1kΩ and the changes in the output were observed. Now as illustrated in Table 2, from 1kΩ to 10kΩ there was a significant change in output but thereafter from 10kΩ to 400kΩ, the change was very slowly.

Table 2: Obtained output voltage (V_{out}) due to change in resistances R2 and R3

Serial No.	R2	R3	V_{out}
1.	1KΩ	1KΩ	7.67V
2.	10kΩ	10kΩ	8.81V
3.	20kΩ	20kΩ	8.90V
4.	30kΩ	30kΩ	8.93V
5.	40kΩ	40kΩ	8.95V
6.	50kΩ	50kΩ	8.96V
7.	100kΩ	100kΩ	8.98V
8.	400kΩ	400kΩ	8.99V

In the third simulation, we varied R4 while the others were kept constant at 1kΩ. It has been found that as we increased the value of R4 from 1kΩ, the output signal voltage decreases and also as R4 was decreased from 1kΩ to 0.1kΩ, there was a significant change in output signal voltage and it is illustrated in Table 3.

Table 3: Changes in output signal voltage (V_{out}) due to change in resistance R4.

Serial No.	R4	V_{out}
1.	200kΩ	5.04V
2.	100kΩ	5.08V
3.	1kΩ	7.67V
4.	0.5kΩ	8.81V
5.	0.1kΩ	8.9V

Considering all those above obtained values, an optimum value was chosen such that R1 would be 1kΩ, R2 and R3 would be 10kΩ, and R4 would be 0.1kΩ. It gave a output signal value 8.98V. The resistances R2 and R3 were taken as 10kΩ because further increase in resistor value decreased the efficiency in long run. By increasing the resistor value of R2 and R3 from 10kΩ to 100kΩ, the change in output was just only 0.01V it is illustrated in Table 4. Hence, the 10kΩ resistor value of R2 and R3 was kept as optimized value in order to keep the efficiency of circuit high in comparison to the 100kΩ resistor value. Therefore, the optimal 10kΩ values of R2 and R3 was used to obtain a high output signal voltage along with maximum efficiency of the circuit.

Table 4: The optimal value chosen for the op-amp circuit

Serial No.	Component	Value	Value
1.	Resistance R1	1kΩ	1kΩ
2.	Resistances R2 and R3	10kΩ	100kΩ
3.	Resistance R4	0.1kΩ	0.1kΩ
4.	Signal output voltage V_{out}	5 V	8.99 V
5.	Signal output voltage V_{out}	8.98 V	8.99 V
6.	Signal amplification	79.6%	79.8%

Furthermore, different op-amp models available in the software library were tested for the same value of the components as illustrated in Table 5. Since the LM258 is most efficient, simple circuit, and easily available in the market among the all op-amp circuits, it has been selected as best optimal circuit in the present study. It is to be informed that the AD624 circuit has an advantage of having less noise but also one big disadvantage that it has less gain value.

Table 5: Simulation on various operational amplifiers with the same components

Serial No.	op-amp	V_{out}
1.	op-amp 1458	2
2.	op-amp AD642	8.9
3.	LM339	8.9
4.	LM358	8.9
5.	LM258	8.9
6.	LM324	0.5

Since the input value obtained would be very small from the humidity sensor, less than 1 V as per estimated from the literature reported by Moghavvemi et al. 2005 [2] and even may be in millivolt range for prosthesis, for this tiny change in

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input signal we must need to detect the changes of output signals. In the present study, using the LM258 op-amp circuit, the extremely small input signal in the range of millivolts also have been significantly amplified and illustrated in Table 6. According to the computed corresponding RH% value due to change in 0.5V (~1.2 to 1.7 V) was around 36.4% and thus their sensitivity (ΔV/ΔRH%) was only 1.3 V/RH% [2], whereas in the present study, the sensitivity can be computed to 59.332 V/RH%.

Table 6: Simulation on an LM258 operational amplifier circuit for the extremely small input signal, output signal voltage and amplification

Serial No.	Input voltage from sensor (V_{in})	Output voltage obtained (V_{out})	Change in signal amplification
1.	30mV	845mV	2716.66%
2.	35mV	850mV	2328.57%
3.	40mV	854mV	2035.00%
4.	45mV	859mV	1808.88%
5.	50mV	863mV	1626.00%
6.	55mV	868mV	1478.18%
7.	60mV	873mV	1355.00%

IV. Conclusions

The present simulation study designed an innovative circuit to amplify an extremely small signal from several millivolts to several hundred millivolts. It has ability to amplify the millivolt signal up to a range of 1355% – 2328 %. The computed sensitivity of the present circuit was also very high, i.e., 59% (V/RH), which is significantly higher than the reported value.

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