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A PID Controller Design for 6 Degree Robotic Arm Control

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ABSTRACT: This paper studies the experimental control of multi-joint robotic arm (Geomagi Touch haptic device) via a fuzzy PID controller. First, the system of Geomagi Touch haptic device is introduced, and the hardware-in-loop control scheme is established through Matlab Simulink. Then, fuzzy logic is utilized to update PID controller gains, where the parameters can be updated adaptively such that the performance of multiply joints can be optimized. Finally the effectiveness of the presented fuzzy controller is validated through real experiment.

KEYWORDS: PID control, robotic arm, multi-joint, Simulink, 2-DOF

I. INTRODUCTION

Robotic arms with multi joints play an essential role in various engineering fields such as industrial production lines [1, 2], medical treatment [3, 4], and service [5, 6]. They are often used in repetitive actions to improve production efficiency and reduce the occurrence of artificial accidental injuries. The key to the flexible movement of the multi-joint mechanical arms lies in advanced control strategies. Proportional-integral-derivative (PID) is known as a popular control method in mechanical manipulators [7,8]. Determine suitable control gains in PID control is capital to achieve the implement ability and safety of the mechanical arms. In traditional PID controllers, the control gains are chosen offline and fixed during operation. Modern robotic manipulators are time-varying, nonlinear, strong coupling and subjected with uncertainties, which make the pre-determined control gains not always meet the demand. Therefore, updating PID control gains adaptively is investigated in recent work (e. g. [9-11]). Fuzzy logical algorithm is an advanced intelligent control suitable for nonlinear complex system [12-14]. With appropriately designed membership function and fuzzy rules, control parameters and be updated adaptively online. Therefore, it is motivated to integrate fuzzy logic and PID controller for robotic arms such that the performance can be guaranteed even under time-varying, highly nonlinear and uncertain conditions. Recently, fuzzy controller has been applied to real system such as biomass microwave pyrolysis[15] and hydraulic system [16].

In this paper, a fuzzy PID control technique is developed for a robotic arm with three domains of freedoms, such that the joint behaviors can be optimized simultaneously. Specifically, the robotic arm under investigation is a touch haptic robot which has been widely used in the research of medical treatment and remote control. Two-dimensional fuzzy rules are designed for three actuated joints to optimize control gains adaptively in real time. Furthermore, the proposed control strategy is validated through real experimental work.

II. ROBOTIC ARM MODEL

Robotic arm is constructed by connecting different joints using links. The robotic arm can be modeled as an open-loop chain with many links connected in series by joints that are driven by stepper motors. Robot kinematics is related to the study of the geometry of the motion of a robot. Being more complex, difficult to solve, more common to be exist in research papers, the author choose the 5 DOF to be the testbed for simulation and implementation. Fig. 1 shows a five link robot which will be used to study theSoft-Computing based tool methods for solving the IK problem, its simulation results and experimental study. Fig. 3 shows link frame assignment for robot arm. Table 1 shows the DH parameters for the robot arm. Where ai-1 is the length of the common normal, ai-1 is the angle about common normal, from old Z-axis to new Z-axis, di is the off- set along previous Z-axis to the common normal and bi is the angle about previous Z-axis from old X-axis to new X-axis. For the 5 DOF robot arm, the forward kinematic equations are [15]:

$$r = l_1 \cos(\emptyset_2) + l_2 \cos(\emptyset_2 + \emptyset_3) + l_3 \cos(\emptyset_2 + \emptyset_3 + \emptyset_4) \quad (1)$$

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$$Z_E = l_0 + l_1 \sin(\emptyset_2) + l_2 \sin(\emptyset_2 + \emptyset_3) + l_3 \sin(\emptyset_2 + \emptyset_3 + \emptyset_4) \quad (2)$$

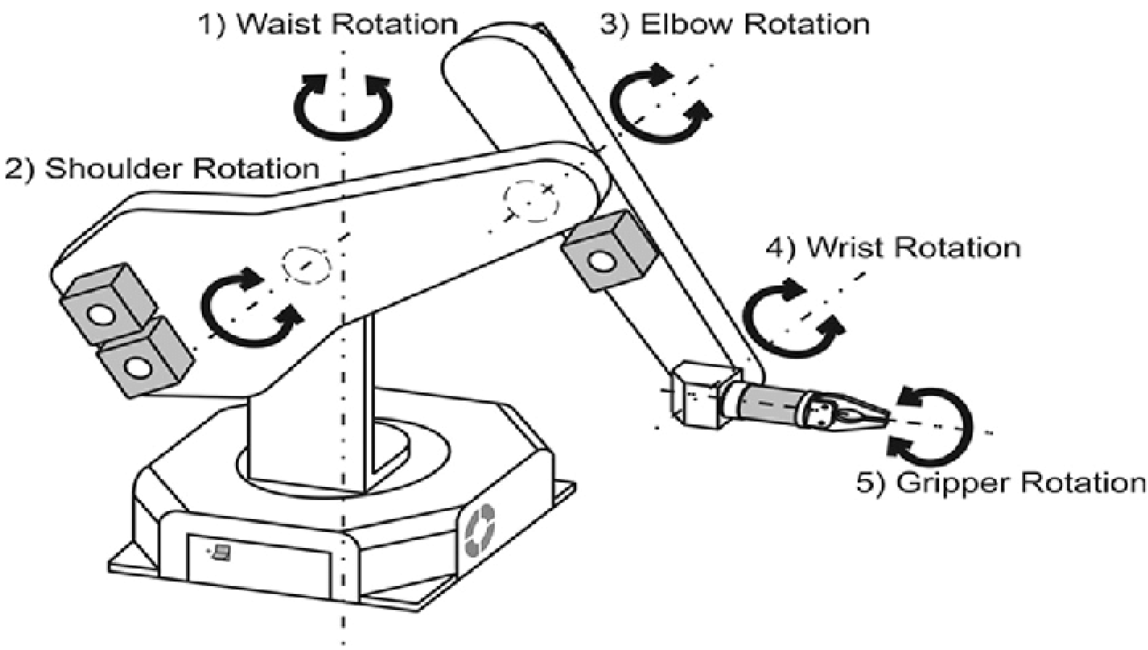

Figure. 1: Robotic arm with five degree of freedom

Table 1: DH Parameters

Link	a_{i-1}	α_{i-1}	d_i	$\emptyset_i$
1	0	0	l_0	$\emptyset_1$
2	l_1	-90	0	$\emptyset_2$
3	l_2	0	0	$\emptyset_3$
4	l_3	-90	0	$\emptyset_4$
5	0	90	0	$\emptyset_5$

$$X_E = r\cos(\emptyset_1) \quad (3)$$

$$Y_E = r\sin(\emptyset_1) \quad (4)$$

$$\emptyset_{E_X} = \emptyset_5 \quad (5)$$

$$\emptyset_{E_Y} = \emptyset_5 + \emptyset_5 + \emptyset_5 \quad (6)$$

$$\emptyset_{E_z} = tan^{-1}\left(\frac{Y_E}{X_E}\right) \quad (7)$$

where l_0 is Base link length, $\emptyset_1$ is joint 1 angle, l_1 is link 1 length, $\emptyset_2$ is joint 2 angle, l_2 is link 2 length, $\emptyset_3$ is joint 3 angle, l_3 is link 3 length, $\emptyset_4$ is joint 4 angle. The joint movements are limited with the following: $0 \le \emptyset_1 \le 360$, $0 \le \emptyset_2 \le 90$, $-90 \le \emptyset_3 \le 0$, $-90 \le \emptyset_4 \le 90$, and $0 \le \emptyset_5 \le 180$.

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III. PID CONTROLLER SUBSYSTEM

The "Controller" subsystem consists of five digital PID controllers (one per joint). Each PID controller is implemented using the "2-DOF PID Controller" block from the Simulink library. The control sample time is Ts=0.1 (10 Hz). Typically, such multi-loop controllers are tuned sequentially by tuning one PID loop at a time and cycling through the loops until the overall behaviour is satisfactory. This process can be time consuming and is not guaranteed to converge to the best overall tuning. Alternatively, we can use systune or looptune MATLAB functions to jointly tune all five PI loops subject to system-level requirements such as response time and minimum cross-coupling.

In this paper, the arm must move to a particular configuration in about 1 second with smooth angular motion at each joint. The arm starts in a fully extended vertical position with all joint angles at zero except for the Bicep angle at ninety degrees. The end configuration is specified by the angular positions: Turntable = 60 deg, Bicep = 80 deg, Forearm = 60 deg, Wrist = 90 deg, Hand = 90 deg, and Gripper = 60 deg. Figure 2 represent the block diagram of the Simulink implementation of the proposed PID controller sub system.

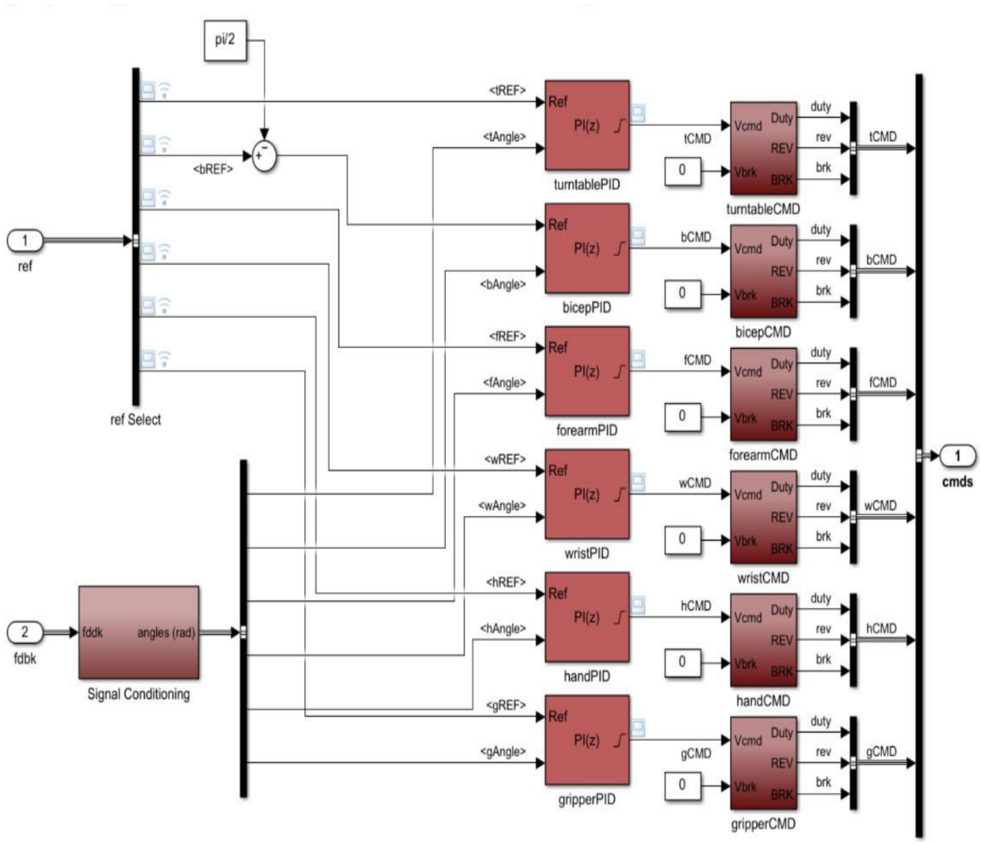

Figure 2: Block diagram of the proposed PID controller in Simulink

IV. RESULT AND DISCUSSION

While running due to bad tuning of the proposed PID controller, clearly the response is too sluggish and imprecise. This imprecise response is represented in figure 3.

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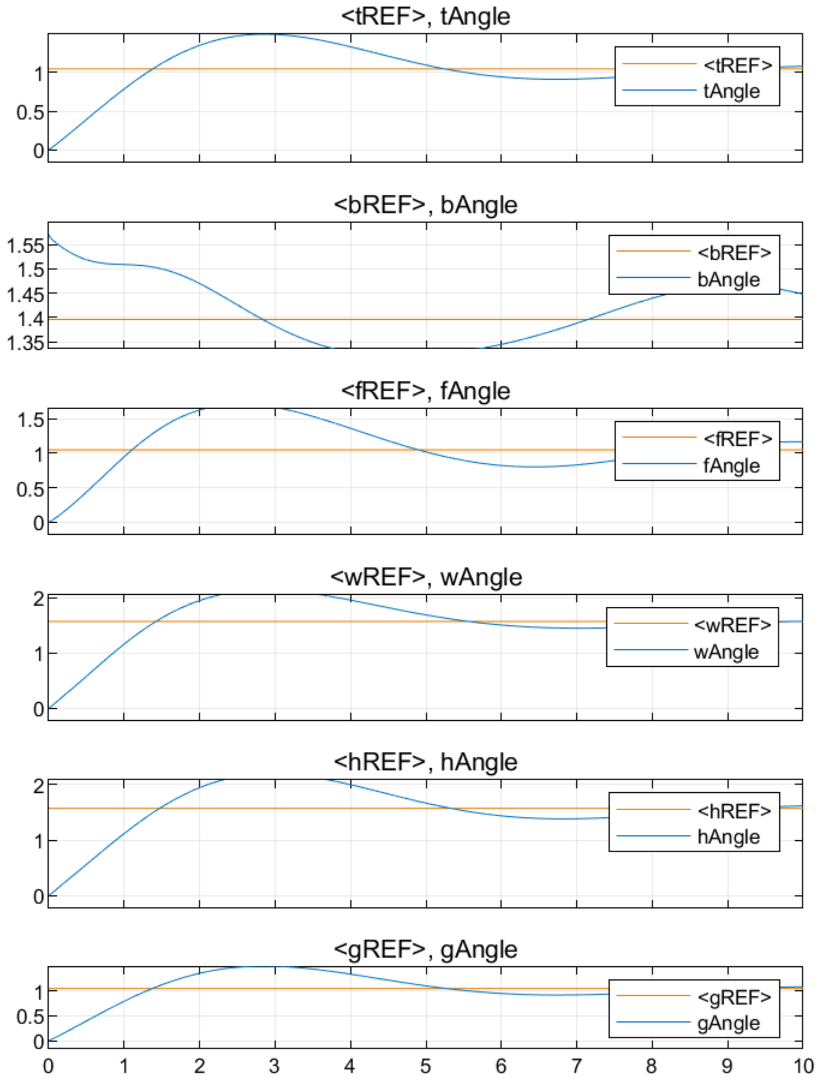

Figure 3: Response of the PID Controller without Tuning

In order to make the proposed PID controller more precise, we follow following steps:

A. Linearizing the Plant

The robot arm dynamics are nonlinear. To understand whether the arm can be controlled with one set of PI gains, linearize the plant at various points (snapshot times) along the trajectory of interest. Here "plant" refers to the dynamics between the control signals (outputs of PID blocks) and the measurement signals (output of "6 DOF Robot Arm" block).

B. Tuning the PI Controllers with LOOPTUNE

With looptune, you can directly tune all six PI loops to achieve the desired response time with minimal loop interaction and adequate MIMO stability margins. The controller is tuned in continuous time and automatically discretized when writing the PI gains back to Simulink. Use the slTuner interface to specify which blocks must be tuned and to locate the plant/controller boundary. In its simplest use, looptune only needs to know the target control bandwidth, which should be at least twice the reciprocal of the desired response time. Here the desired response time is 1 second so try a target bandwidth of 3 rad/s (bearing in mind that the plant dynamics vary least near 10 rad/s). A final value near or below 1 indicates that looptune achieved the requested bandwidth. Compare the responses to a step command in angular

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position for the initial and tuned controllers. To improve overshooting, we have used 2-DOF tuning. The 2-DOF tuning eliminates overshoot and improves the Bicep response. The response after 2-DOF tuning is shown in the figure 4.

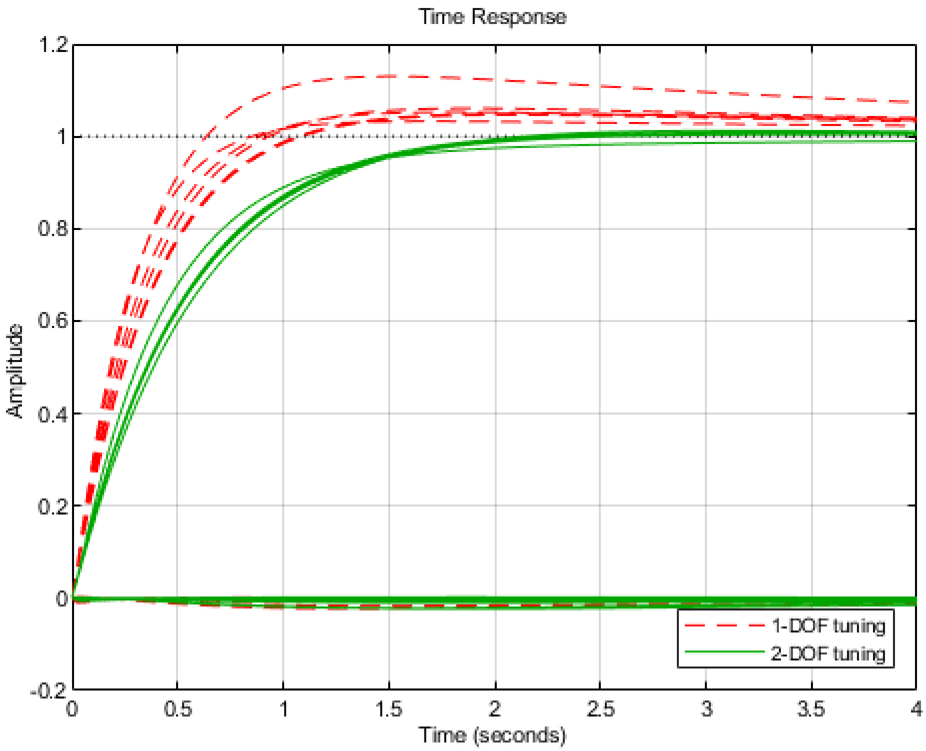

Figure 4: Time response of the proposed controller after implementing 2-DOF tuning

V. CONCLUSION

In this paper, an autotuned PID controller is designed for a multi-joint robotic arm. Two-dimensional PID controller with modified 2-DOF membership functions are designed for three actuated joints to determine PID control gains adaptively. The performances of f2-DOF PID controller and fixed-parameter PID controller are compared through Matlab simulation work. From the results, the developed 2-DOF PID controller has better accuracy to track the desired signal. This work provides a foundation of our future research, where the proposed PID controller will be used to control an industrial robot remotely.

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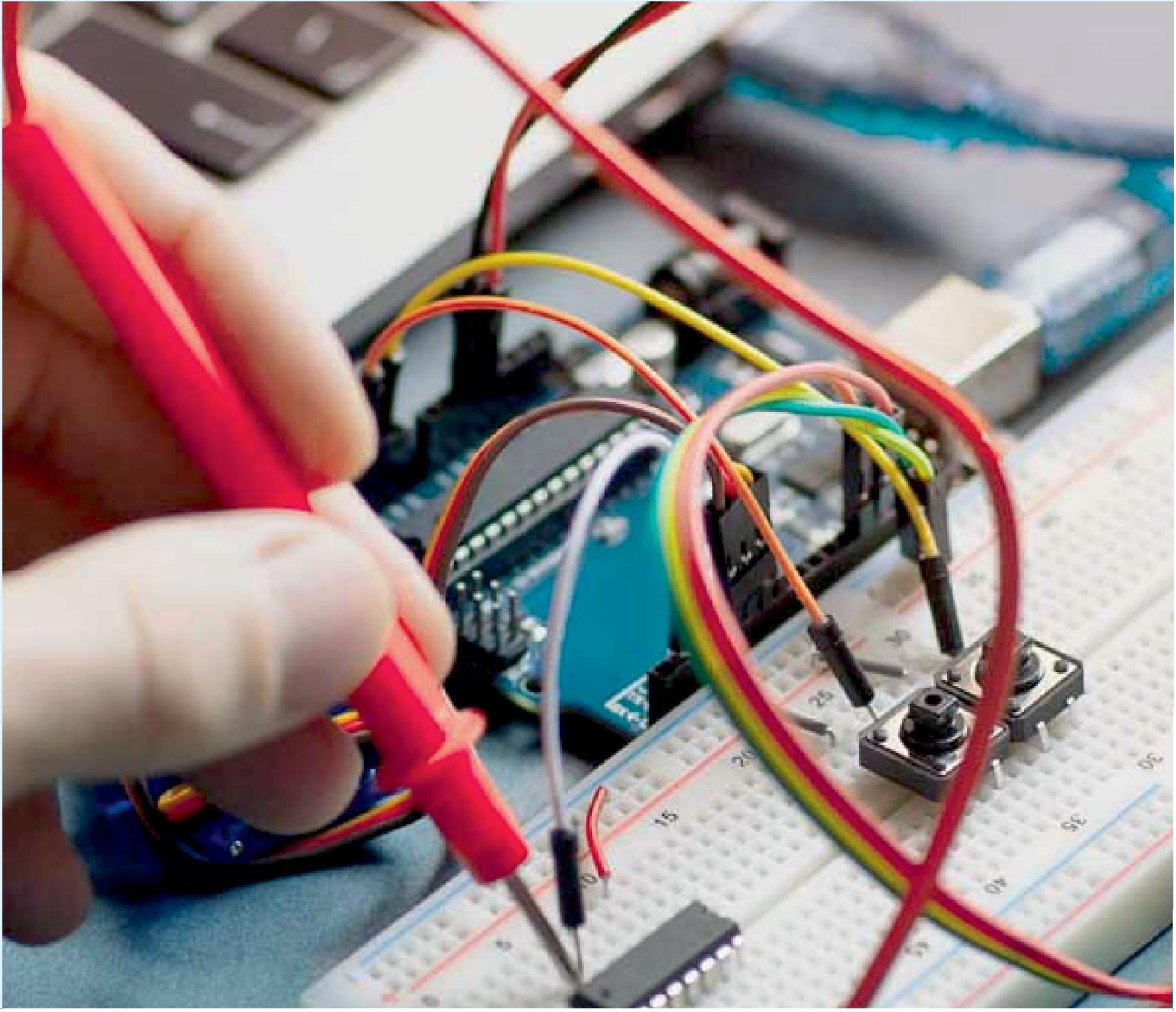

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