Wireless technology applied in 3-axis filament winding machine control system using MIT app inventor

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Ma Quanjin[1, 2], M.R.M.Rejab[1, 2], M.S.Idris[1], Bo Zhang[2], M.N.M.Merzuki[1], Nallapaneni Manoj Kumar[3]

[1]Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
[2]School of Mechanical Engineering, Ningxia University, Yinchuan, 750021, China
[3]School of Energy and Environment, City University of Hong Kong, Hong Kong

[*]Corresponding author: neromaquanjin@gmail.com

Abstract. Filament winding technique is a traditional composite fabrication process, which is generally used in filament winding machine with different axes motions. Current several filament winding machines have complicated and expensive control systems, which are used wire connection method to control. However, the main problem of filament winding machine system is that it is mostly controlled by the sophisticated systems using traditional connection method. The aim of this paper is to design a mobile software application to control the 3-axis filament winding machine with wireless connection using open-source platform. The 3-axis filament winding machine is briefly fabricated using aluminium profile for structure frame. The mobile application is designed to control several parameters such as winding angle, length and thickness. The mobile software is used to produce filament wound tubes, which is performed using Bluetooth. Bluetooth module is successfully applied to filament winding machine control system, which makes a significant contribution to winding machine control system methods.

1. Introduction

1.1. Filament winding technique

Filament winding technique is a classic automated fabrication method to produce filament wound composite products like tubes, vessels and domes [1-3]. The main procedure is briefly shown in Figure 1, which can demonstrate related device function and process design. The process is commonly designed to pass the fibre through a resin bath, and impregnated fibre can be wound on the mandrel with tension device [4]. Different fibre spools are placed on creel device and mounted on the horizontal carriage. It can be controlled using different relative speed to ensure filament winding angle or fibre orientation [5, 6]. Filament wound composite product can be removed from the mandrel after the curing process accordingly, which may use hydraulic rams to remove completely [1]. In some cases, the mandrel can become an integral part of the assembling product [7]. Filament winding technique can provide a higher fibre volume fraction compared to other composite fabrication processes, which is one of strengthens in this processing technique.

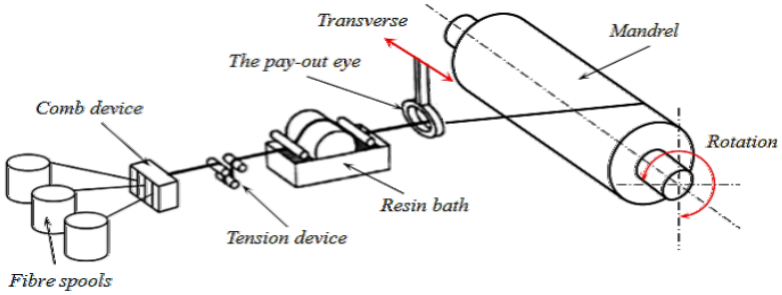

Figure 1. Schematic diagram of filament winding technique

Filament winding technique is typically used to produce tubes, storage tanks, and vessels products, which has expanded to non-systematic composite products with sophisticated machine and software system. This process can use in many application fields, which refers to infrastructure, military & defense building & construction and mass transportation [8-10]. The highlighted advantage of this technique is the highly automated manufacturing process, which can produce different fibre orientation with different mechanical properties. Filament winding technique can have three patterns, which are the hoop, helical and polar winding patterns [11]. Wet, dry and semi-dry and semi-wet winding methods are typically three winding methods applied in winding technique, which used dry and wet winding methods generally.

There are several composite fabrication processes to produce composite products, which are summarized distribution of composite market in Indian in Figure 2 (a). Filament winding technique is the second popular process in basic composite manufacturing processes, which can provide an automated technique compared to traditional hand layup process. Cost of composite production is an essential factor to restrict process development [12]. Therefore, relative composite process equipment with the comparative analysis is shown in Figure 2 (b). It is concluded that filament winding process is used a relative lower equipment cost, which can have a potential composite market in filament winding technique.

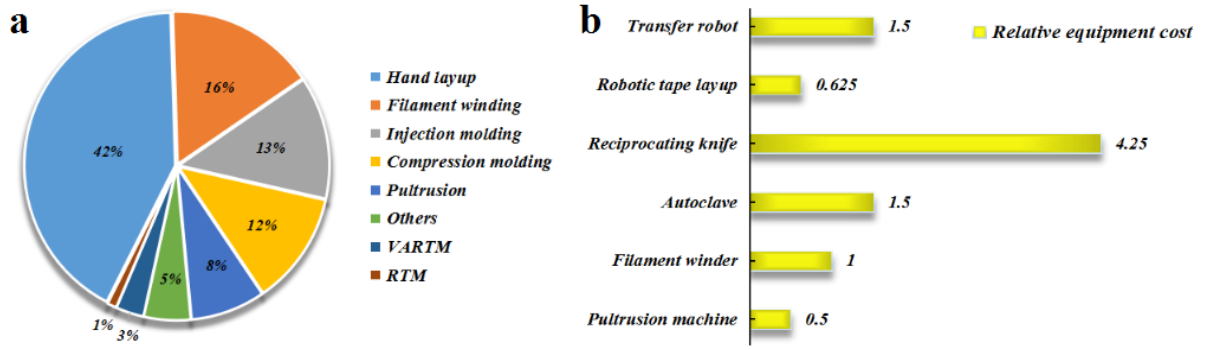

Figure 2. Composite fabrication processes: (a) distribution of composite market in Indian; (b) relative equipment cost of composite manufacturing process (Source:http://icerpshow.com/industry-trends) [12]

1.2. Filament winding machine development trend

In the previous research study, several researchers have studied the low-cost filament winding machine, which refers to machine structure design, control system development, machine performance and composite product fabrication [12-18]. Filament winding machine structure and control system type are summarized in Table 1, which refers to numerical controlled axes, control system type, machine size and product structure. Filament winding machine is developed to provide a low-cost and automatic control system with 2, 4 axes or more than.

Table 1. Filament winding machine structure and control system type

Machine control system	Machine size	Axis	Product shape	Ref
Servo-motor control system	—	2	Tubes	[13]
Automatic control system	Medium	2	Pipe/round shape	[14]
CAM system	—	4	Elbow/tubes	[15]
Manual system	Medium	4	Tubes	[16]
PIC 18F452 micro controller	Medium	2	Tubes	[17]
D2-260 PLC master controller	Medium	2	Tubes	[18]

1.3. Machine control system method

Currently, filament winding technique is the reasonably mature process, and different companies have studied its unique characteristics on machine control system method. Software pattern is used for winders with 4 or more axes to produce complex structure products, which includes Cadwind, FiberGraphix, and Cadfil with its personal strengths [19]. Machine market research for filament winding machine is summarized in Table 2, which refers to machine view, machine control system type and application. Based on current machine market fields, winding machines are mostly selected traditional wire connection method, which has a lower mobility and flexibility compared to the wireless connection. The wireless connection can provide a higher reliability and mobility, which can reduce machine system costs and space limits. Therefore, it is significant to develop wireless technology in filament winding machine control system, which can design a more advanced, portable and efficient control system.

Table 2. Filament winding machine market comparison results (Sources: http:// pultrex.com, http://www.xwinder.com, http://www.entec.com/en-US/)

Machine view	Machine control system type		Numerical axes	Application
	Software section	Connection method		
	Programmable software	Wire connection	4 NC	Composite fabrication processes industries
	PLC control system/CNC control system	Wire connection	2 NC	Educational, R & D facilities
	X-Winder 2.0 (Industrial software)	Wire connection	2/4 NC	Aerospace composite industries
	Technical controller	Wire connection	2 NC	R & D facilities

The aim of the paper is to adopt mobile wireless technology in the 3-axis portable filament winding machine, which can be controlled using customized mobile application. The mobile software can control the machine to produce filament wound products according to customers' demands. Compared to traditional wire connection control system in filament winding machine, it primarily applies wireless method connection in filament winding technique, which can enhance control system development trend.

2. Materials and methods

Carbon and kevlar fibres were obtained in winding experiment using mobile wireless technology using the 3-axis filament winding machine. Two kinds of fibres have wound on the mandrel using the mobile application as the control system, which can qualify the portable winding machine capability. The properties of carbon fibre, kevlar fibre, and epoxy resin are summarized in Table 3, which can

provide related specifications. The study was used experimental method, which involves wet and dry winding patterns. It can analyze the portable winding machine, mobile control system and filament wound products comprehensively.

Table 3. Carbon fibre, kevlar fibre and epoxy resin properties

	Carbon fibre	Kevlar fibre	Epoxy resin
Type	TR 30S 3K	956 K29	D.E.R™ 331™
Elongation/%	1.80	2.2	—
Tensile strength/MPa	4120	75.1	—
Tensile modulus/GPa	234	591	—
Density/g/cm^3	1.79	1.61	1.16
Width/mm	3	3	—
Number of filaments	3000	3000	—

3. Machine fabrication and mobile application design

3.1. Fabrication of the 3-axis filament winding machine

The 3-axis filament winding machine can be briefly divided into two sections, which are mandrel rotation and linear movement motions. Machine main structure frame is assembled using aluminium profiles (20×20 mm), which are cut to the required length to fabricate base and carriage frames. Figure 3 is shown the two machine frame sections, and other components are embedded in related frame.

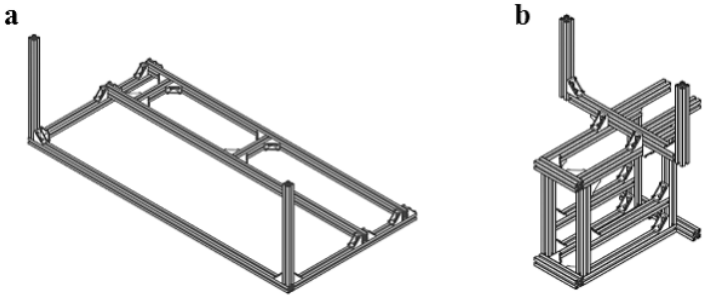

Figure 3. Machine main structure frame: (a) base frame; (b) carriage frame

The other rest of the accessories for fabrication procedure are shown in Figure 4, which includes aluminum profiles, buckets, bracket bearing, steel rods, pulleys, T-nuts, belts, bearings and limit switch. 18 and 20 teeth pulleys are applied to set with the NEMA17 type stepper motor, which is used to transmit rotation or linear motion through closed GT2 timing belts.

Figure 4. Related essential components

The 3-axis filament winding machine is designed and fabricated using machine frame and related essential components based on machine motions [20]. The 3-axis filament winding machine assembling procedure is shown in Figure 5, which illustrates machine other devices details. The realized machine prototype is shown in Figure 5 (a), which is completely based on the 3D machine design prototype in Figure 5 (b).

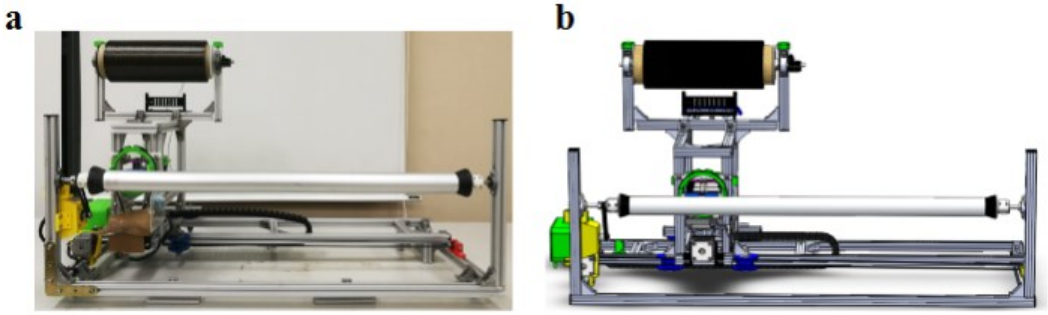

Figure 5. Machine assembling procedure of the 3-axis filament winding machine prototype: (a) realized machine prototype; (b) 3D machine design prototype

3.2. Wireless technology control system

The 3-axis filament winding machine can embed with the wireless control system, which shows the wireless connection schematic in Figure 6. The machine can insert the IWinder key, which is the Bluetooth module receiver connected with a machine control system. IWinder software can be installed in a mobile phone to send the commands to IWinder key through the Bluetooth connection. Wireless technology machine control system procedure is presented in Figure 7, which can exhibit whole winding procedure to fabricate filament wound products. Bluetooth connection is needed to successfully connect using a mobile phone, and the IWinder software can be firstly opened and settled product details in the software interface. The IWinder software can send the G-codes to Arduino Uno, which is mounted with a CNC v1 shield through pins. Then the machine can perform the winding process using three stepper motor motions based on G-codes commands. Filament wound tubes can be fabricated successfully, which have the customized product dimension.

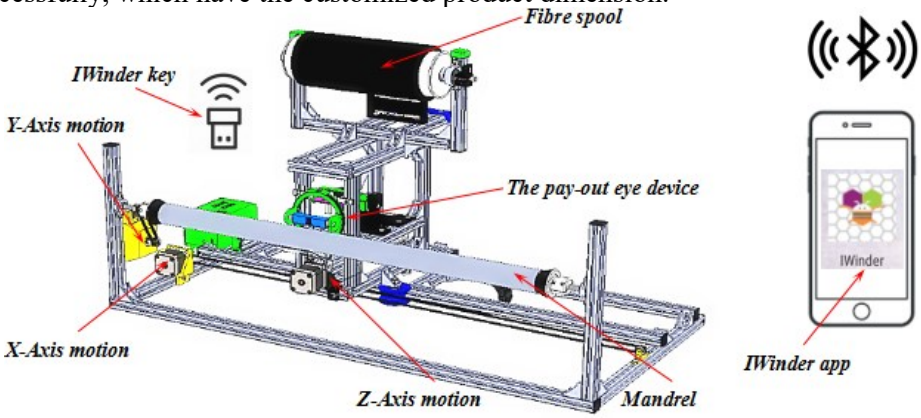

Figure 6. Schematic of the 3-axis filament winding machine using wireless connection method

3.3. Design mobile IWinder software

MIT App Inventor is an open-source web application, which allows users to create software applications for the Android operating system [21]. It adopts a graphical interface, which allows users to drag-and-drop visual objects to create the specific application that can run on Android devices. The block-based coding program can inspire the intellectual and creative environment, which can provide real empowerment for users to make different software applications [22]. In order to apply the wireless technology in the 3-axis filament winding machine, IWinder software is designed and programmed using MIT App Inventor.

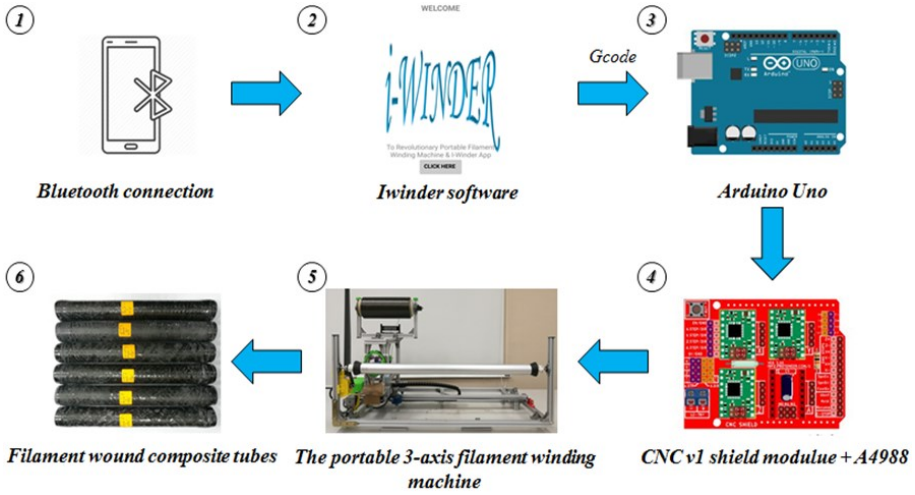

Figure 7. Wireless connection control system procedure

When the Bluetooth module is connected, the IWinder apk is opened using a mobile phone, which can have two user interfaces are shown in Figure 8. The first user interface was presented in Figure 8 (a), which involves the star button, the homing button, and manual control button in Figure 8 (b). The second user interface was designed to input product details, which refers to product thickness, length, bandwidth, winding angle, cycle time and federate. Related parameter values can be input based on customers' requirements, and it can send commands to perform filament winding process.

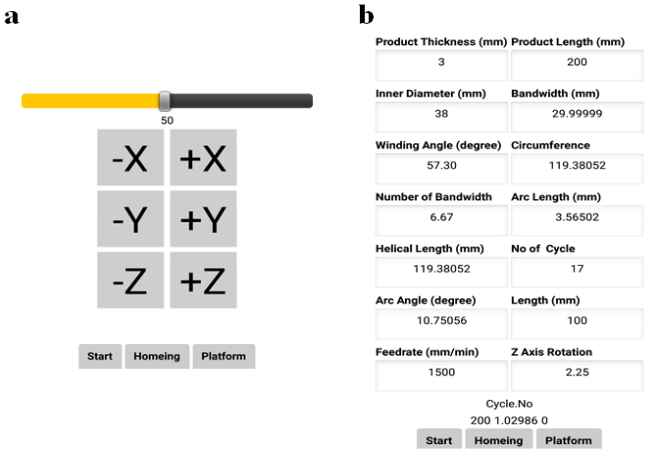

Figure 8. IWinder software screen interface: (a) first user interface; (b) second user interface

Two user interfaces were designed in designer section of MIT App Inventor, and several blocks were designed in editor block section. The flowchart of blocks in IWinder software was shown in Figure 9, which included Bluetooth connection block, homing block, timer and delay block, parameter definition block and winding code block. Related blocks are discussed in details, and each block function is mentioned as follows.

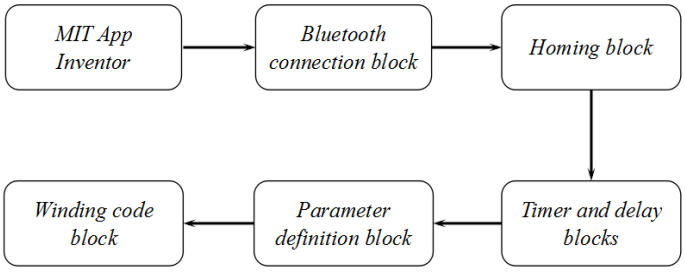

Figure 9. Flowchart of blocks in IWinder software

The *"ListPicker1"* block is programmed to connect the Bluetooth module with Bluetooth symbol, which is shown in Figure 10. When an operator touches the Bluetooth system in the first user interface, it can call the *"BluetoothClient1"* to connect in *"AfterPicking"*. The Platform block was designed to associate with *"Start, Homing, and Platform"* buttons, which can perform the related functions. The *"Homing"* block is designed to call the machine to move to the initial position in *X* axes, which is automatically connected with Bluetooth module. The *"Homing"* block is indicated in Figure 11, which provides programming code in details.

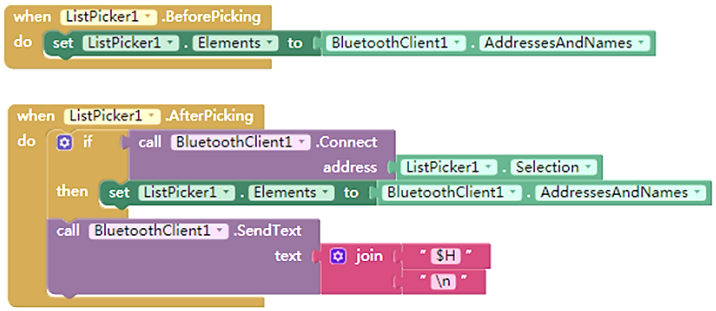

Figure 10. Bluetooth connection block

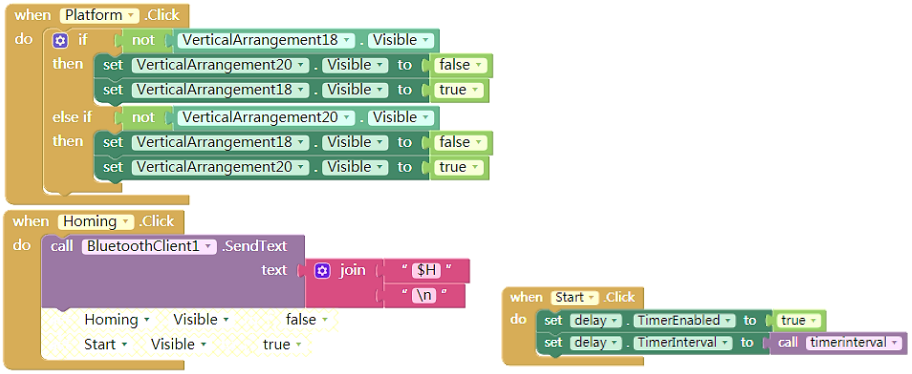

Figure 11. Homing block

The *"Clock1 Timer"* is designed to use time block to count initial time and cycle time, which has a red or green colour to report Bluetooth connection state, and it is shown in Figure 12. The *"Delay"* is programmed to warm up the machine, sending G-code commands and machine preparation with 17 seconds, which refers to fibre attachment, resin bath volume, fibre tension adjustment and machine safety checkups. The *"Delay Timer"* is presented in Figure, which can provide 7 cycles times to repeat the single winding loop.

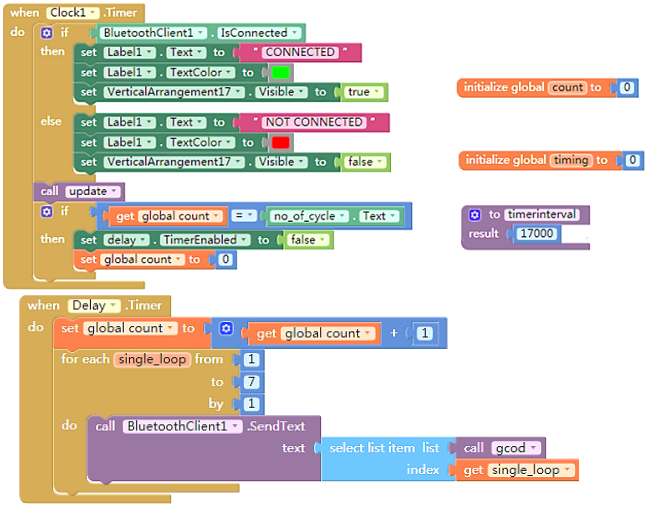

Figure 12. Timer and delay blocks

The winding parameters are designed in parameter definition block, which refers to program bandwidth, circumference, helical length, arc length, arc angle, cycle time, *X, Y* and *Z* axes movements. The related parameters are programmed using math blocks with mathematical equations, which are mainly shown in Figure 13. The winding codes are programmed using G-code format, which has 7 sub-blocks to combine the winding process. The winding process can be successfully wound with the single winding loop code, which is performed based on *X* and *Y* axes length movements at the same time as shown in Figure 14. Filament wound composite tubes are cured at room temperature with constant mandrel rotation for 2 hours using this portable winding machine.

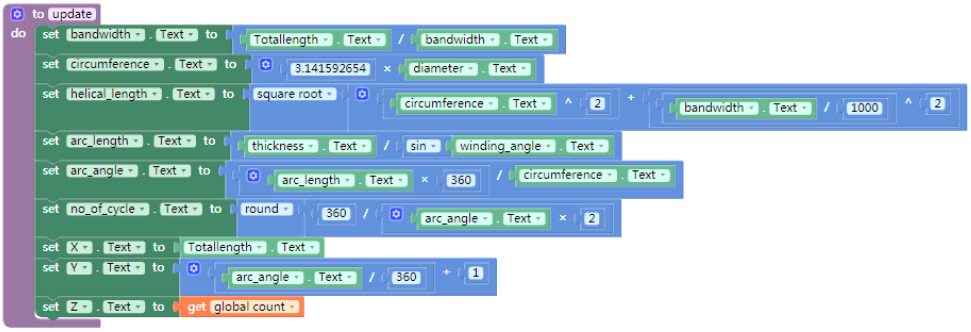

Figure 13. Parameter definition block

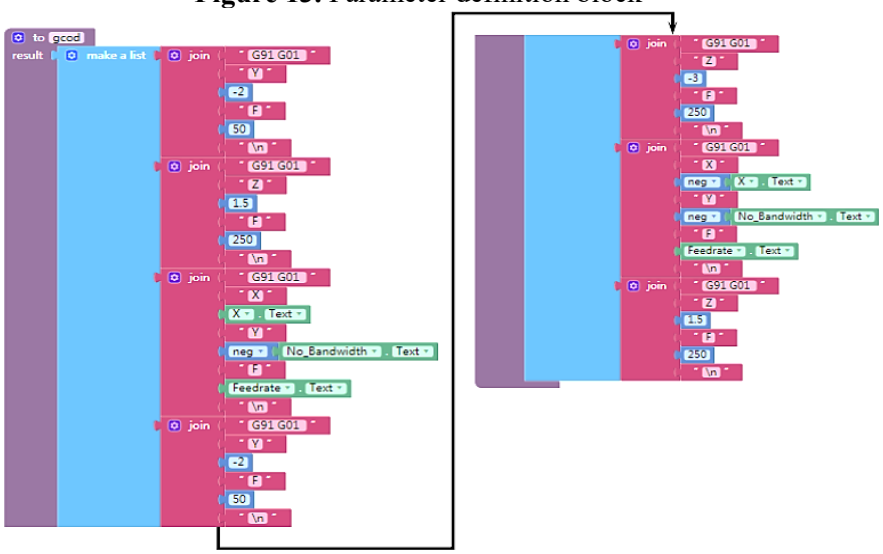

Figure 14. Winding code block

4. Results and discussion

The 3-axis filament winding machine can be performed using dry and wet winding methods, which is designed to control using IWinder application. Different winding method results are shown in Figure 15, which can test IWinder software operability. The two winding condition products have a smooth outer surface, and the mandrel can be fully covered using carbon or kevlar fibres. It is concluded that IWinder software can perform sufficient winding codes, which do not have potential error or bugs in wet and dry winding processes. This portable filament winding machine also has some limitations, which refer to 20° to 90° winding angle ranges, manual adjustable tension device and limited control distance.

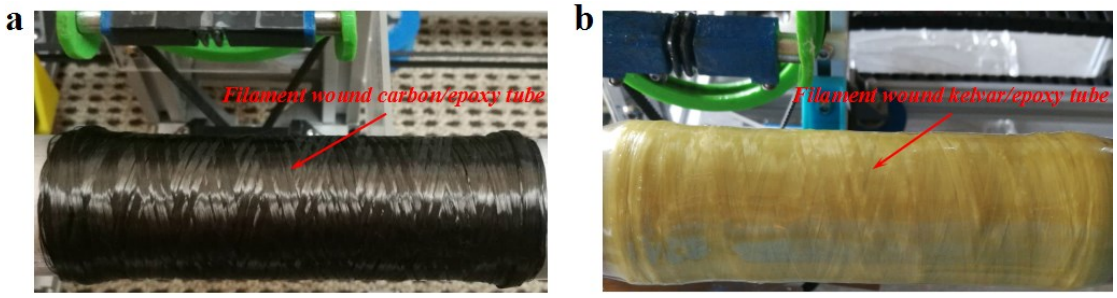

Figure 15. Machine winding results using IWinder software: (a) dry winding; (b) wet winding

In order to verify this 3-axis filament winding machine can produce a good winding angle, filament winding angle precision measurement is performed to evaluate winding angle quality. Figure 16 presents filament winding angle precision measurement methods, which are used to dry winding condition and final condition filament wound composite tubes. Dry winding specimen is measured using angle protector, and digital microscope is select to measure final condition tube. Based on 30 measurable angle values of 45° and 75° winding angles, this machine can acquire ±0.5° winding angle deviation, which is defined as a good accuracy winding angle accordingly. It also directly confirms machine capability and wireless control system performance, which indicates that it is accepted and sufficient mobile software to apply to filament winding technique.

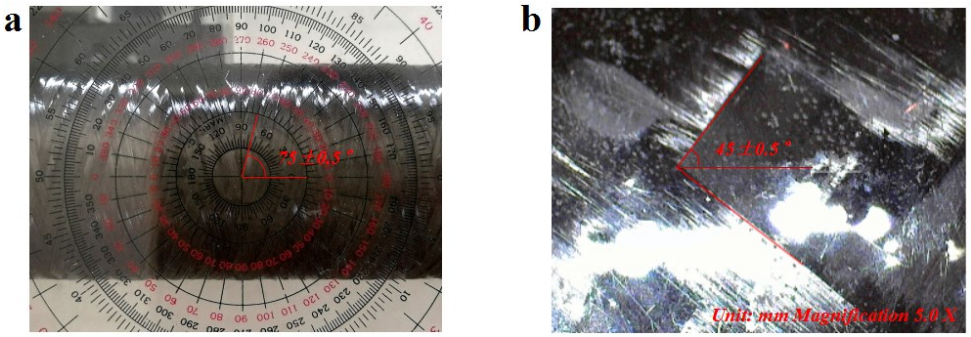

Figure 16. Filament winding angle precision measurement methods: (a) angle protector in dry winding condition; (b) digital microscope in final condition

5. Conclusion

The 3-axis filament winding machine is fabricated and developed to produce filament wound products using wireless technology. The mobile software is designed to control machine 3 numerical controlled movements, which is developed based on the MIT App Inventor platform. The mobile software can successfully control the machine to produce filament wound tubes from minimum 20° to maximum 90° winding angle, thickness, and length. It is expected that dry and wet winding experimental results are aimed to demonstrate software operability and feasibility. Filament wound composite tubes with limited winding angle scope can be produced using carbon and kevlar fibres, which can qualify machine and software capabilities. However, there are limitations to control distance, tension force control and winding angles. Meanwhile, the main contribution is that the wireless control system is

customized in winding machine control system accordingly. The wireless technology can be capable of advancing filament winding technique development and prospect.

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