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A MULTI-CHANNEL SYSTEM FOR DETECTING METAL CONNECTORS IN WASTE WOOD-BASED MATERIALS

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ABSTRACT

Metal connectors in waste wood-based materials should be removed before reused. A multi-channel metal connector detecting system is presented, detecting the metal connectors in waste wood-based materials. It include three parts: a high precision sensor for detecting metal connectors in waste wood-based materials, a multi-channel data logging and processing system based on microcontroller unit, and a model for positioning the metal connectors in waste wood-based materials. The high precision sensor has a magnet and, Holzer element and a differential amplifier and peak detector circuit. The multi-channel data logging and processing system has a micro-controller unit, an 8-channel AD converter and some auxiliary circuits. The model shows the relationship between the positions of metal connectors with the signals from 8 sensors. The experimental results show that the maximal detecting height is 2.0cm for the 0.8x11mm nail, as well as 4.8cm for the 3.5×30mm nail and the position error between the real positions of the nails and those get from the model is less than 1cm. The system can meet the practical needs of the reusing waste wood-based materials.

Keywords: *Waste Wood-based Materials; Metal Connector Detection; Positioning Model*

1. INTRODUCTION

Waste wood-based material includes waste wood, wood-based board and its products. Processing and utilizing waste wood-based material has an important significance for the conservation of wood resources and achieving the sustainable development of wood-based panels industry. It is estimated that China's annual waste wood and wood-based resources is about 85 million cubic meters, as three cubic meters of wood waste to produce one cubic meter of wood-based panel, which can produce 28.33 million cubic meters wood-based panels, equivalent to annual savings of 85 million cubic meters of timber, less deforestation of 1.172 million hectares. Recycling of waste wood-based materials, not only has played an important role in alleviating the shortage of raw materials of wood based panel industry, but also can change the traditional one-way timber consumption patterns and take the recycling economy development model to build a resource-saving and environment-friendly society [1-5]. The first for waste wood-based materials re-processing is to remove the impurities in it, including the connectors. Waste wood-based materials include a lot of metal connectors, especially the ferromagnetic metal parts, and these connectors not only exist on the surface of the wood material, but also in its internal, difficult to detect by the naked eye, thus it increases the difficulty for repartition and processing waste wood-based materials.

The metal connectors may damage the processing equipment, such as cutting tools. So how to quickly detect and locate these connectors becomes the first solved problem for comprehensive utilization of waste wood-based material [6].The methods for detection of metal connectors in waste wood-based material are that based on X-rays and the principle of electromagnetic induction. The method based on the X-ray can detect metal connectors in waste wood-based material very accurately and determine its position, but it has a high cost and needs professional security [6]. A single coil metal detectors can detect metal connectors, but because the detection coil is only one [7,8], can not position the metal connectors, so you need a lot of human to position the metal connectors, which increases a heavy cost for reusing the waste wood materials. The effect of the method based on the principle of electromagnetic induction depends on the performance of the detection coil, more parameters affecting the detection coil [7, 8]. [9] described a method based on the principle of electromagnetic induction to detect the connectors, but the stability of the detection sensor is poor, and it can only find out that whether there is a metal connector in waste wood-based materials.

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In order to accurately detect and locate the metal connectors in waste wood-based materials, this paper includes four parts, including the design of high-precision detection sensor, multi-channel data logging and processing system based on MCU (microcontroller unit), the positioning model for the metal connectors in waste wood-based materials and experimental results & analysis.

2. SENSOR FOR DETECTING METAL CONNECTOR

2.1 Principle Of Detecting Metal Connector

If there are no ferromagnetic objects near the magnet, its surrounding magnetic field strength does not change. While there are ferromagnetic objects near the magnet, the magnetic induction lines around the magnet will change, and then the magnetic induction B of a fixed point around the magnet will also change [7]. We can determine whether a metal connector exists in waste wood-based material by sensing the changes in the magnetic field around the magnets. According to this principle, the metal connector detecting sensor contains the detection probe, the Holzer element, differential amplifier and peak detecting circuit, as shown in Figure 1. Magnet can produce a fixed magnetic field, and a Holzer element is used to detect the changes of a fixed point in the magnetic field of the magnet, the differential amplifier and the peak detecting circuit can amplify the weak output signal of the Holzer element and detect the peak value of magnetic field changes. The output voltage range of the sensor for detecting the metal connector is 0-5V.

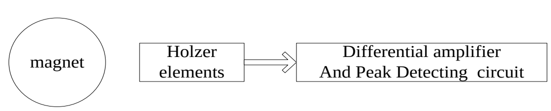

Figure1: The Block Diagram Of The Sensor For Detecting Metal Connector

2.2 Differential Amplifier And Peak Detector

In this study, a round magnet (diameter of 5.7cm, thickness 0.6cm) was used as detecting probe and the Holzer element (UGN3503) fixed in the center of the magnet as a probe to detecting the changes of the magnetic field. The UGN3503 has the sensitivity of 1.3mV / G, the static output voltage of 2.45V and operating voltage of 4.5-6V. When ferromagnetic objects are close to the detecting probe, the magnetic field around the detecting probe will be larger. The Hall element can accurately detect tiny changes of the magnetic induction. The Hall element output voltage of the Holzer element, which is in millivolt level, is very small. Taking the effect of noise into account, the differential amplifier was used to suppress noise and zero drift and provide a large enough amplification factor. The peak detector was used to detect the changes of the density of the magnetic field. The third amplifier was used to ensure that voltage output of the metal connection detection sensor is 0-5V. The schematic diagram of the differential amplifier and peak detector is shown in Figure 2.

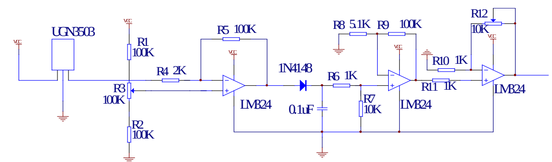

Figure 2: The Schematic Diagram Of The Differential Amplifier And Peak Detector

3. MULTI-CHANNEL DATA LOGGING AND PROCESSING SYSTEM BASED ON MCU

3.1 Hardware Of Multi-Channel Data Logging And Processing System

In order to accurately position the metal connectors in waste wood-based materials, this system should have the function of logging multi-channel sensors simultaneously and communicating with personal computer (PC). The STC89C52 microcontroller unit (MCU) is used as the main chip in this system, which is a low-power, low-cost, high-speed, highly reliable 8-bit microcontroller, and compatible with the MCS-51 instruction set, with internal Flash that can be rewritten 100,000 times or more. The analogy signals from sensors are digitized by an Analog-to-Digital converter (TLC1543, an 8-channel A/D converter with 10-Bit resolution) and processed in the microcontroller. A dual driver/receiver (MAX232) was used between microcontroller and PC [10]. The structure of the multi-channel system is shown in Figure 3.

The stability of the power subsystem is an important factor that affects the accuracy of the whole system, because the sensors and Analog-to-Digital converter all need a high- stability electrical power as reference voltage. The input of the power subsystem is direct current power with about +5V. A linear regulator (AMS1117-5.0, a low dropout three- terminal regulator with 1A output current capability) was used to keep electrical power in +5V with maxim tolerance of 2.0%. Some capacitors are used as filters with resistances. The schematic diagram of the power subsystem is shown in Figure 4.

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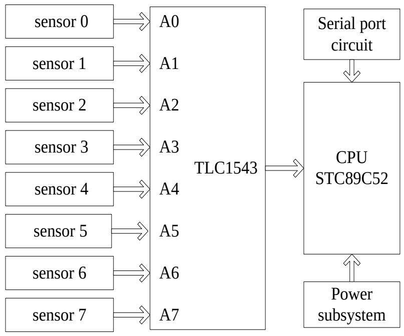

Figure3: The Block Diagram Of The Structure Of The Detecting System

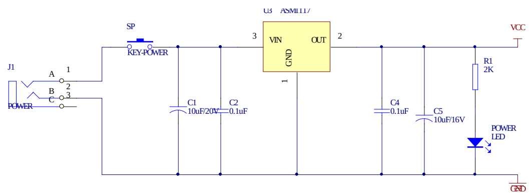

Fig.4 The Schematic Diagram Of The Power Subsystem

Some auxiliary circuits are indispensable for the smooth running the whole system, for example reset circuit and crystal oscillator circuit. The complete schematic of the multi-channel data logging and processing system is shown in Figure 5.

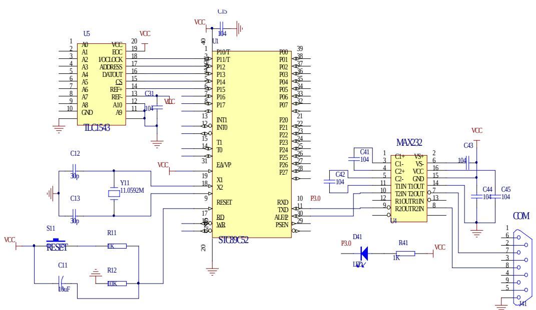

Figure 5: The Complete Schematic Diagram Of The Entire System

3.2 Software Of Multi-Channel Data Logging And Processing System

The software of multi-channel data logging and processing system includes the low-level software and up-level software. The low-level software running in the lower computer such as MCU or Programmable Logic Controller (PLC) is responsible for controlling the hardware and low-level data processing and transmitting. The up-level software running in the human-interface computer such as personal computer is responsible for up-level data processing and displaying its results.

3.2.1 low-level software

The low-level software running in the STC89C52 microcontroller includes 5 programming modules, system initialization, system calibration, data acquisition, the median filter, RS232 communication and so on. The program flow chart is shown in Figure. 6. System initialization mainly refers to the configuration of the microcontroller serial communication and other operating parameters. System calibration is collecting the reference value that is the output voltage values of each metal connection detection sensor when no metal connectors around the sensors. Median filter module is to eliminate the random noise in the data from all sensors. RS232 communication module cooperates with the serial communication software in PC to transmit the data between PC and microcontroller.

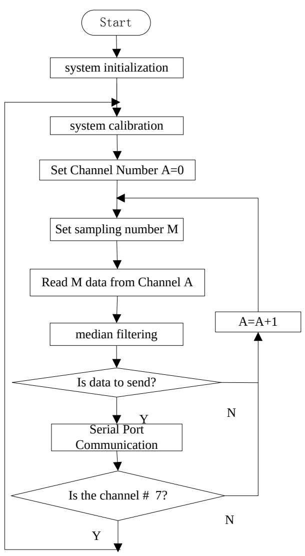

Figure 6: The Flow Chart Of Low-Level Software

3.2.1 up-level software in pc

The up-level software in PC can transmit data and commands between PC and microcontroller, also can further process the data from sensors and locate the metal connectors when there are some metal connectors in waste wood materials. It includes serial port initialization, locating metal connectors and displaying the results. Serial port initialization module sets the parameters of the RS232 communication (such as baud rate, communication mode, the size of sender/receiver buffer and so on) [11]. The module of locating metal connectors calculates the position of the metal connectors from the received data using the metal connector positioning model that will be detailed introduced in the next part of this paper. The program flow chart of the up-level software in PC is shown in Figure7.

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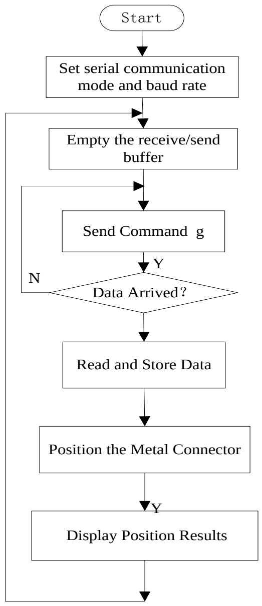

Figure 7: The Flow Chart Of Up-Level Software

4. POSITIONING MODEL OF METAL CONNECTOR

In this study, 8 detecting sensors are arranged in line, as shown in Fig.8. The sensor number of these 8 sensors is form 0 to 7. The diameter of the sensor (marked as d) is 5.7cm. The coordinate origin is at the left margin of the sensor 0. The s references to the distance from coordinate origin to the position of the metal connector. The former experimental results show that only one output of 8 sensors is changed when the metal connector is above the sensor and there are two changed outputs of 8 sensors when the metal connector is above two sensors. When there is only one changed output of 8 sensors, the positioning model is shown in formula 1. The sensor number is labeled as n.

$$s = \frac{d}{2} + d \times n \tag{1}$$

When there are two changed outputs of 8 sensors, the distance from the position of the metal connector to the center of the left sensor that have the changed output is labeled as a, as shown in Figure 8. The relationship between the two changed output ΔU and the distance a is shown as formula 2. The sensor number is labeled as n. ΔU_n is the change of the output from sensor n (n is from 0 to 7), and ΔU_{n+1} is the change of the output from sensor n+1. In this case the metal connector positioning model is shown in formula 3.

$$\frac{a}{d-a} = \frac{\Delta U_{n+1}}{\Delta U_n}$$
$$a = \frac{d\Delta U_{n+1}}{\Delta U_n + \Delta U_{n+1}} \tag{2}$$

$$s = \frac{d}{2} + d \times n + a \tag{3}$$

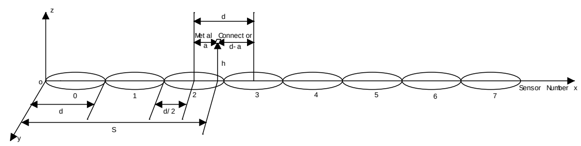

Figure 8: The Schematic Diagram Of The Installation Of Sensors

5. EXPERIMENTS AND RESULTS ANALYSIS

In this study, there are two types of experiments. One is test the ability of the sensors to acquire the changes of the magnetic field around them, the other is test the performance of the positioning metal connectors in waste wood-based materials.

In the first type experiments, 17 kinds of metal nails with different specifications were selected to be hung above a sensor separately. The maximal height (labeled as h) was record where the output of the sensor changed, as shown in Figure 8. The name, specification and the maximal height o of 17 kinds of nail were listed in Table 1.

Table.1 Experimental Data Of The Maximal Heights Of 17 Different Types Of Nails

Nail Name	Specification	Maximal Height（cm）
Round nail	0.8×11mm	2.0
Round nail	1.4×25mm	2.8
Hinge screws (nickel)	3.5×15mm	3.5
High strength double dry wall nail	3.5×25mm	4.4
High strength double dry wall nail	3.5×30mm	4.8
Galvanized screws	4.2×19mm	2.9
Galvanized screws	4.2×2.5mm	3.6
Cement nail	1.7×16mm	2.5
Cement nail	2.8x32mm	3.0
Flat cross drill tail screw	4.8×25mm	3.8
Salad head cross galvanized	4.8×16mm	3.6
Salad head cross galvanized	4.2×19mm	3.7
Salad head cross galvanized	4.2×25mm	3.8
Cross recessed high strength flat countersunk head tapping screws	5.0×10mm	4.0
Cross recessed high strength flat countersunk head tapping screws	5.0×16mm	4.2

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Cross recessed high strength flat countersunk head tapping screws	4.0×16mm	3.9
Round cross drill tail screw	4.2×19mm	4.3

From table 1, 0.8x11mm round nail is already a kind of smallest metal connectors used to fasten wood-based materials. From table 1, the maximal height for the sensor developed in this research is 2.0cm for the 0.8x11mm round nail. The bigger nails are the maximal height for the sensor developed in this research is larger. The first type experimental results show that the sensors developed in this study can detect the metal connector in waste wood materials up the depth of 2.0cm.

In the second type experiments, 10 pieces of waste wood-based materials, 6 from old furniture and 4 for frame of windows and doors, and 17 kinds of metal nails with different specifications that are same with those in the first type experiments, were used to test the performance of the positioning metal connectors in waste wood-based materials. Nails were implanted into the waste wood-based material at the depth less than the maximal heights that the sensor can detect them. The waste wood-based materials moved under the sensors, as shown in Figure 9. The detected distances of the metal connectors to the coordinate origin got by this system and the actual distances of the metal connectors to the coordinate origin got by straight scale were record. The metal connector positioning experimental data was listed in Table 2.

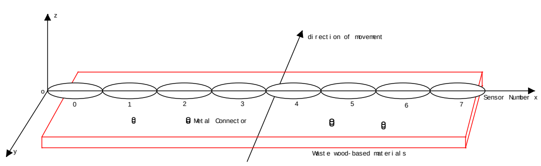

Figure 9. The Schematic Diagram Of The Positioning Experiments

Table.2 Experimental Data Of Metal Connector Positioning

Nail Name	Specifi-cations	S_0 (cm)	S_1 (cm)	ΔS * (cm)
Round nail	0.8×11mm	42.75	42.02	0.73
Round nail	1.4×25mm	37.05	37.92	0.87
Hinge screws (nickel)	3.5×15mm	17.05	17.89	0.84
High strength double dry wall nail	3.5×25mm	14.25	14.12	0.13
High strength double dry wall nail	3.5×30mm	8.55	8.62	0.70
Galvanized screws	4.2×9.5mm	37.05	38.00	0.95
Galvanized screws	4.2×19mm	10.06	11.60	1.54
Cement nail	1.7×16mm	20.84	22.00	1.16
Cement nail	2.8×32mm	17.10	16.38	0.72
Flat cross drill tail screw	4.8×25mm	32.33	34.02	1.69
Salad head cross galvanized	4.8×16mm	14.25	14.21	0.04
Salad head cross galvanized	4.2×19mm	12.39	11.46	0.93
Salad head cross galvanized	4.2×25mm	34.96	35.49	0.53
Cross recessed high strength flat countersunk head tapping screws	5.0×10mm	16.42	17.10	0.68
Cross recessed high strength flat countersunk head tapping screws	5.0×16mm	12.42	11.40	1.02
Cross recessed high strength flat countersunk head tapping screws	4.0×16mm	33.51	34.20	0.69
Round cross drill tail screw	4.2×19mm	5.53	5.70	0.17

* $\Delta S = |S_1 - S_0|$

From Table 2, it is known that the detected distance measured by the system developed in this study, from the position of the nail detected from the coordinate origin to the position of the metal connector in waste wood-based materials is basically same with the actual one that measured by the straight scale. The absolute value of the difference between the detected distance and the actual one is mostly less than 1cm that is accurate enough for reutilize the waste wood materials, because the position error of the metal connect is less than 5cm for the most Wood processing equipments in China.

6. CONCLUSIONS

From the design of the sensor for detecting the metal connector, the hardware and software of the multi-channel data logging and processing system, the metal connector positioning model and experimental data analysis, some conclusions are summarized as follows:

(1) The designed sensor can detect the metal connector which size is larger than 0.8mm even under the surface of the waste wood materials with the depth of 2.0cm. The bigger nails are the maximal detecting height of the sensor is larger. The performance of the sensor is better than that designed before.

(2) The Multi-channel data logging and processing system can simultaneously record,

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process and transmit the data for 8 sensors. The system can communicate with PC via the serial port.

(3) The metal connector positioning model shows the accurate relationship between the changes of the output from the sensor and the position of the metal connector in waste wood-based materials. The position error is less than 1 cm in this study, which can meet the need of the utilization of waste wood-based materials in China.

(4) The sensor and the system based on MCU are cheaper than that based on X-ray, because the price of the electrical component and MCU is very low. The multi-channel detecting system for metal connectors in waste wood-based materials has higher cost performance Ratio.

(5) The sensor based on the principal of electromagnetic induction can not detect the plastic and non-ferromagnetic metal connectors in waster wood materials that should be detected and removed, which is the further research in future.

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