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A control system for a *poundo* yam flour processing plant

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The use of control systems reduces the need for human involvement in food processing plants, reduces stress in the production process, and makes production more efficient and cleaner. A control system was designed for a *poundo* yam processing plant using the estimated time required by each machine in the plant and the sequence of operation. A flow chart was developed to analyse and study the timing and motion of individual machines and to control the operation of the machines. The C++ programming language was used to programme the programmable logic controller. A circuit was developed to control the electric motors, electric heaters and fans in the processing plant. Evaluation of the developed control system shows that it reduces the time spent per batch production from 7 hours to 5 hours 19 minutes (24.05% time reduction) and increases the efficiency of the plant from 73.4% to 84.90%. Human involvement was reduced by 75% (from 8 steps to just 2).

Keywords: Post-harvest, automation, pounding, logic controller, parboiling, peeling and slicing

JEL classification: O30, O31, O55

Introduction

Post-harvest food losses are caused by limited food preservation capacity and poor food preservation techniques. This gives rise to food and nutritional insecurity in developing countries. To prevent post-harvest losses, food processing operations have to be mechanised. Nigeria, as the largest producer of yam in Africa, has not fully utilised yam production due to inadequate post-harvest preservation techniques available for yam. Also to improve traditional food processing techniques, manual methods of processing have to give way to automation so as to improve hygiene and speed of production. More importantly, a country which cannot feed her citizens using local technologies that can be adapted from her own raw materials cannot achieve meaningful industrial progress. Pounded yam is a staple food, commonly prepared for lunch or dinner, which is consumed by almost every tribe in West Africa (Ayodeji and Abioye 2011). Traditionally, pounded yam is made by physically pounding boiled yam in mortars with pestles by one or more persons, depending on the quantity. This method is time consuming, tedious, unhygienic and requires considerable labour, which eventually adds to the cost of preparation and has discouraged a majority of people from preparing and hence, consuming the food. These limitations together with some other environmental and hygienic factors gave rise to the need for a less strenuous and cheaper method of making pounded yam.

Recently, *poundo*-yam flour has become an emerging alternative to pounding boiled yam as it can easily be turned into pounded yam by merely dissolving a measured mass of the flour in a quantified volume of boiled water and carefully stirring the mixture until the desired consistency is reached, making the process easier, more efficient and less time-consuming (Otunola and Ogunbiyi 2005). *Poundo* yam flour preparation involves six process stages, viz. washing, peeling and slicing, parboiling, drying, grinding and sieving (Babajide et al. 2007). The *poundo* yam flour processing plant is a mechanically improved method of converting the raw yam tubers into a powder form. The processed yam in powdered form can be packed in bags and sealed cans which are either preserved for sale or exported to other parts of the globe. The advantages of the new method and other information are well reported in the works of Otunola and Ogunbiyi, (2005), Babajide et al. (2007) and Ajibosin et al. (2005).

However, these efforts to develop a highly efficient plant for the production of *poundo* yam flour from raw yam have short-comings in terms of being time wasting, unhygienic and not cost effective, which results from lack of integration and automation of the machines used in the processing plant. Consequently, a control system is required to be developed for the processing plant by estimating individual and total time required by the machines in the plant. The control system is focused on an analysis of time (duration) used by the machines and the movement of the yam from one machine to another in the plant (Ogata 1990). Since the yam moves from one machine to another and spends different times in each machine, the whole system has to be controlled automatically for optimal performance.

Control systems are employed in manufacturing systems for the achievement of effective, efficient, and fast processes, so as to achieve a high production rate. This will also help to minimise or eliminate stress induced errors, due to human involvement in the system (Leigh 1985). The aim of this work is to develop a control system for a *poundo* yam flour processing plant already developed as shown in Figure 1 (Ayodeji et al. 2012) and evaluate the performance of the developed control system.

Literature review

In the past, humans were the main means of controlling a system but control engineering has evolved over time. More recently electricity has been used for control and early electrical control was based on relays (Bennett 1994). These relays allow power to be switched on and off without a mechanical switch. It is common to use relays for simple logical control decisions. The development of low-cost computers has brought the most recent revolution, the programmable logic controller (PLC). The advent of the PLC began in the1970s, and has become the most common choice for manufacturing controls (Franklin and Powell 1986, D'Souza 1988, IDC Technologies 2012). PLCs have been gaining popularity on the factory floor and will probably remain predominant for some time to come. This is because of the advantages they offer as they are cost effective for controlling complex systems, are flexible and can quickly and easily be reapplied to control other systems, their computational abilities allow more sophisticated control, troubleshooting aids make programming easier and reduce downtime and reliable components make them likely to operate for years before failure (Nise 2000).

In manufacturing systems, automation comes into play when it is required to operate equipment and machinery with the help of sophisticated systems and information techniques. Conventional manufacturing systems face the problem of slow response to production challenges. The initial design of a manufacturing system uses mechanised machinery, where human operators are employed to use their knowledge and muscular capabilities to operate the machines. However, global economic activities requires machines that uses automation tools such as sensors, transducers, signalling devices, automated switches, and various types of logic controllers in other to respond quickly or adapt to operational and functional tasks required from the system (Bennett 1994). Automation can be applied in different areas, such as manufacturing, businesses, and services. In earlier manufacturing and business/services operations, telephone operators were employed to attend to customers. These activities have been replaced with automated telephones, switchboards and answering

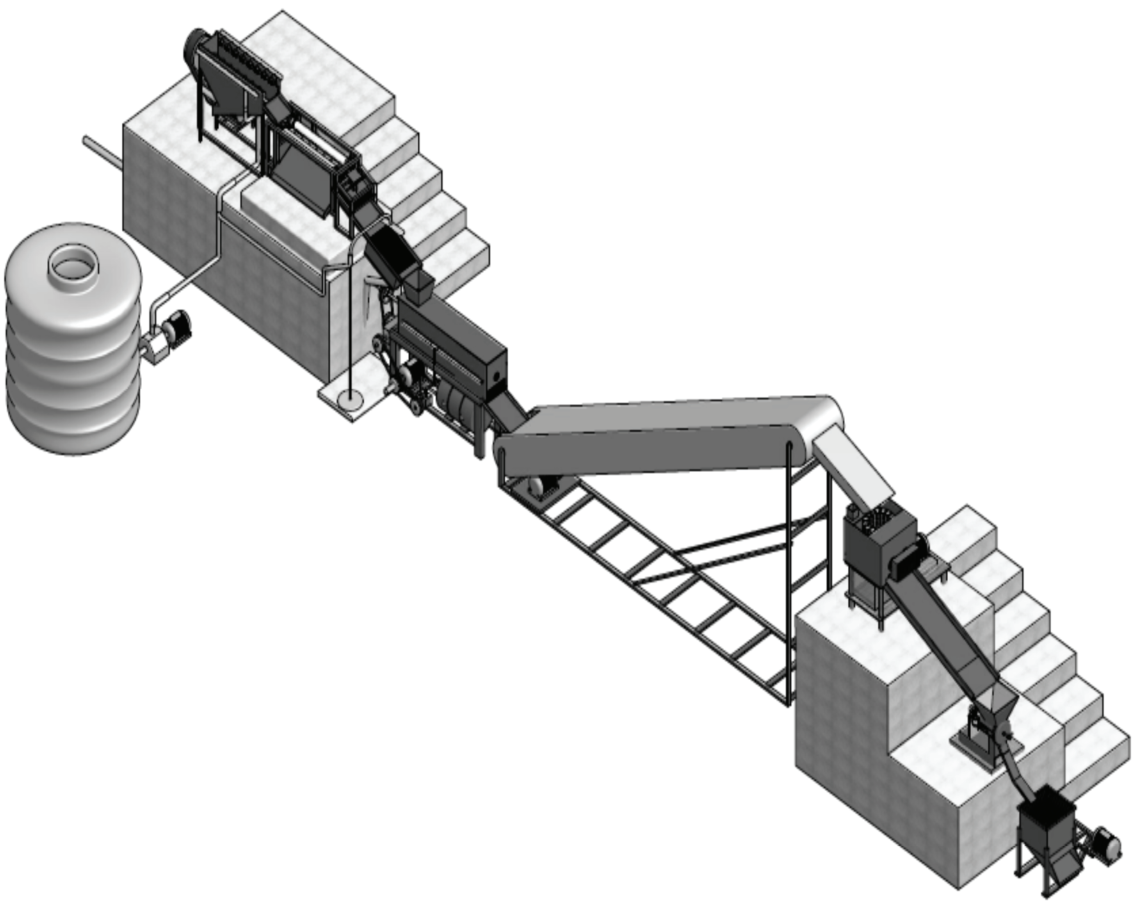

Figure 1: Poundo yam flour processing plant

machines, which have incorporated programs that can provide solutions to questions in some cases. Moreover, the earlier use of slow medical techniques for diagnosing medical issues, such as radiography, human genes, sera cells, and tissues, have been replaced with automated and sophisticated equipment in order to reduce the time to achieve medical results. In the banking industry automated teller machines have reduced the cash transactions services, in order to increase security in respect of money theft. In essence, increases in the global economy in the 20th and 21st centuries are the result of application of automated systems in different fields of manufacturing and business activities where human operators cannot function effectively.

Manufacturing tasks involving hard physical activities in hazardous environments has posed great health risks on workers in the system, over the years. This has increased the accident/mortality rate of workers in the past. The application of automated systems in recent manufacturing systems has reduced accident rates. More and more autonomous activities carried out by human operators in industries have been replaced by automatic systems in the form of robots. This has also helped increase product quality, particularly in the area of material handling and assembly.

However, the emerging trend of automated systems has posed some challenges in some areas in the world. One of the challenges is the increased rate of unemployment. It is claimed that the use of automation systems have replaced human operators, and as such rendered people jobless. Secondly the technical knowledge required to develop and maintain these systems is practically not available globally, and as such the initial cost of installation, maintenance, and expertise is high. In particular, security threats and vulnerability have been a major drawback of these systems in industries owing to their restricted level of intelligence. In addition the cost of development of this automated equipment in a small-scale business, starting from research to accomplishment exceeds the long-term acquired profit due to usage. In essence a huge amount of capital is required for initial set up of this equipment, despite the fact that there is a division in the cost of production, which is usually done in batches (Bolton 2011). In order to combat the effect of these disadvantages, the purpose of manufacturing has shifted beyond the issues of production, cost, and time, and has expanded into increases in the quality of products and manufacturing processes (Kalani 1989, Bolton 2011).

Considering the case of automobile manufacturing systems, initial installation of engines had an error of about 1–1.5% due to manual installation of pistons into engines, which has been reduced to 0.00001% with the use of automated systems (Nise 2000). However, consideration should be taken not only of their cost effectiveness, but also the hazardous outcomes of these systems for the environment. These effects can be summarised as energy usage and the release of hazardous substances into the environment in the form of chemicals, oils, exhaust gases and metals (Ibrahim 2002). Application of automation to food processing industries where the hygiene of the product is paramount, has in no small measure improved the quality of the products. Development of control systems for the *poundo* yam flour processing plant will optimise the plant and produce quality *poundo* yam flour with high integrity at a faster rate, increasing the profitability, reducing post-harvest loss experienced in yam production and make the nutritious pounded yam available for all its lovers everywhere around the globe.

Methodology

A flow chart for the movement of the yam from one stage to the other, the time it spends in each stage and the time a particular machine should start working was developed and coded using the C++ programming language, which forms the design of the control panel. A programmable logic controller PLC (PIC 16F877), was suited to control the electric motors of the machines in the processing plant, following the sequence of operation. The operational sequence is loaded as a chip which is downloaded on the PLC to control the machines. The completion times and heating temperatures were used as a means of controlling the sequence in conjunction with sensors.

The electric motors in the processing plant are controlled using relays, controlled by optical controllers which receive control signals from the PLC. Figure 2 shows the flow chart used in the design of the control system and Figure 3 shows the circuit diagram for the control system. The PIC16F877 is a popular PIC microcontroller used in many commercial, industrial and hobby applications. This is an 18-pin device which can operate at up to 20MHz clock speed. It offers 8192 × 14 flash program memory, 368 × 8 bytes of RAM data memory, 256 × 8 bytes of EEPROM nonvolatile data memory, two 8-bit and one 16-bit timer with pre-scaler, watchdog timer, 33 bi-directional (Input/Output) I/O pins, external and internal interrupt sources, and a large current sink and source capability. Figure 4 shows the pin configuration of the PIC16F877. I/O ports are accessed as in the PIC16F84 where each port has a direction register (TRIS) which determines the mode of the I/O pins. One of the nice features of the PIC16F877 is that it contains a multiplexed eight-channel A/D converter with 10-bit resolution. The controller was programmed using the C++ programming language. The code generated is included in Appendix A

Results and discussion

The total time required by the processing plant per batch of production is a summation of the time required by individual machines and time required to get the product from one machine to another. The total time estimated to produce 12.25 kg of *poundo* yam flour from 25 tubers of raw yam (50.25 kg) is 315 minutes (5 hours 15 minutes) at maximum drying temperature of 50 °C, which is a 15.22% time reduction

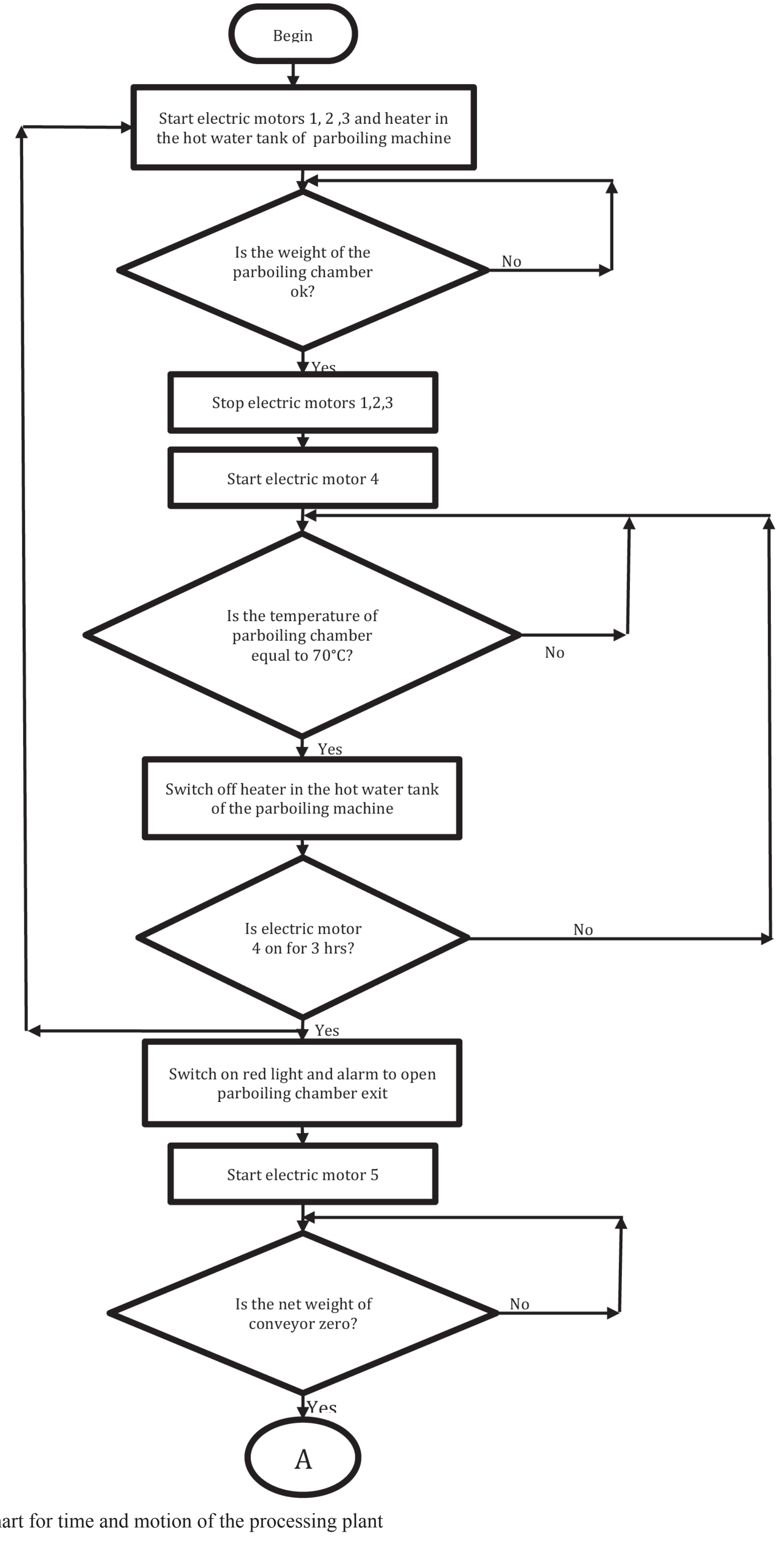

Figure 2a: Flow chart for time and motion of the processing plant

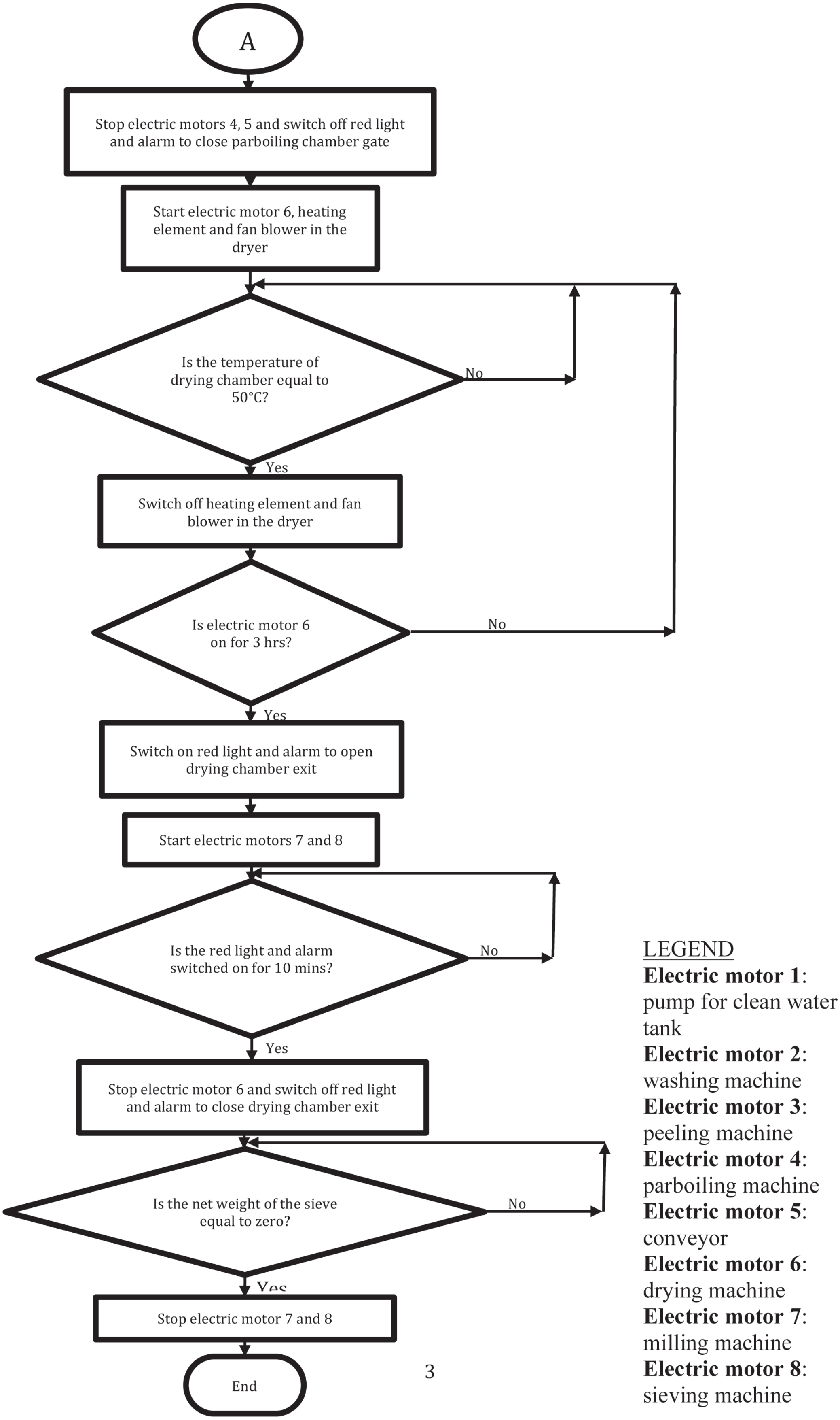
A
Stop electric motors 4, 5 and switch off red light and alarm to close parboiling chamber gate
Start electric motor 6, heating element and fan blower in the dryer
Is the temperature of drying chamber equal to 50°C?
No
Yes
Switch off heating element and fan blower in the dryer
Is electric motor 6 on for 3 hrs?
No
Yes
Switch on red light and alarm to open drying chamber exit
Start electric motors 7 and 8
Is the red light and alarm switched on for 10 mins?
No
Yes
Stop electric motor 6 and switch off red light and alarm to close drying chamber exit
Is the net weight of the sieve equal to zero?
No
Yes
Stop electric motor 7 and 8
End
3
LEGEND
Electric motor 1: pump for clean water tank
Electric motor 2: washing machine
Electric motor 3: peeling machine
Electric motor 4: parboiling machine
Electric motor 5: conveyor
Electric motor 6: drying machine
Electric motor 7: milling machine
Electric motor 8: sieving machine

Figure 2b

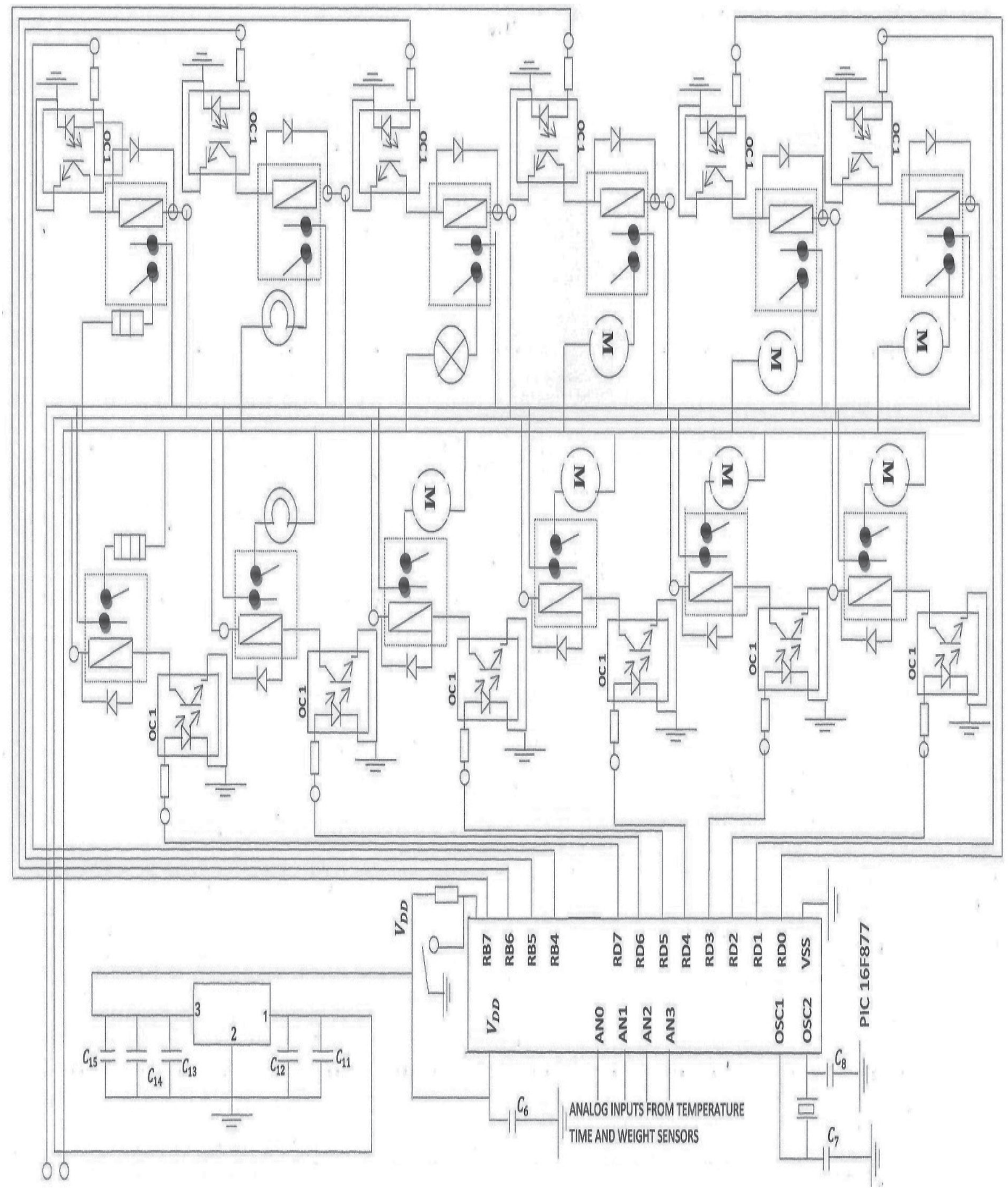

Figure 3: Circuit diagram for the control system of the processing plant

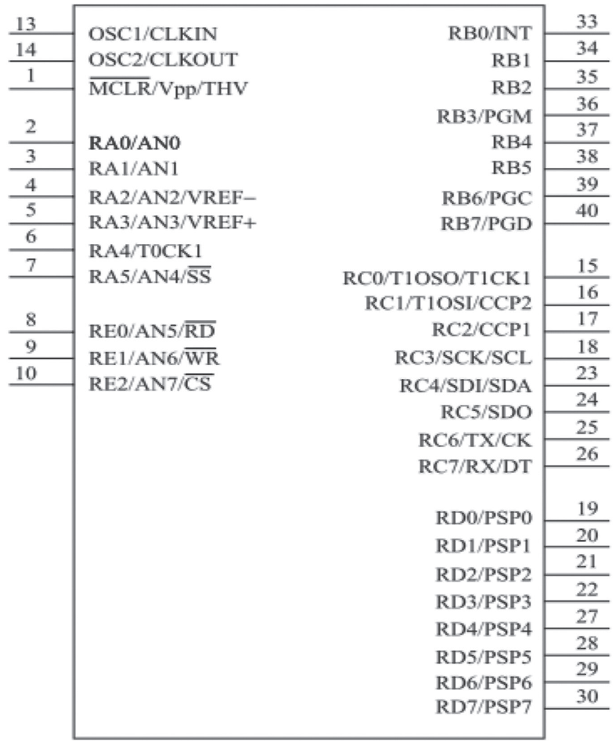

Figure 4: PIC 16F 877 pin configuration

when compared with 371.59 minutes (6 hours 12 minutes) taken to produce the same quantity of *poundo* yam when the machines are controlled manually.

Average time required per batch production of each machine in the plant was determined after three different trials and the results are presented in Table 1. The efficiency of the processing plant with the developed control system was determined to be 84.90% compared to 73.4% when the machines are controlled manually, which is a 15.67% improvement in the efficiency, and human involvement was reduced by 75% (from 8 to just 2 steps) in the entire processing plant.

Electric motors 1, 2 and 3, which control the clean water pump, the washing machine and the peeling and slicing machine, respectively, start at the same time. The switching off of these motors depends on the weight of the sliced yam in the parboiling machine. The electric heater used in the parboiling machine is started alongside with electric motors 1, 2, 3 so that the water in the hot water tank of the parboiling machine is already at 50 °C (being the parboiling temperature) as the yam gets to the parboiling machine. Electric motor 4 (parboiling machine) is switched off after 1 hour 35 minutes (this being the time required for the parboiling to take place) by the PLC and electric motors 5, and 6 (conveyor and drying machine, respectively) are switched on. Electric motor 6 stays on for three hours and electric motor 5 is switched off as soon as the load sensor on the conveyor indicates a zero value. Electric motor 6 and a fan in the drying machines stop when the load in the conveyor reads zero and electric motors 7 and 8 (milling and sieving machines respectively) are switched on 10 minutes before electric motor 6 is switched off. Electric motors 7 and 8 stop simultaneously when the load in them reads zero.

Conclusions

A control system for effective utilisation of *poundo* yam flour processing plant that is comprised of 7 different machines (washing, peeling and slicing, parboiling, conveyor, drying, milling and sieving) with 8 electric motors has been developed with an efficiency of 84.90%, which is a 15.67% improvement over the manual control of the machines in the plant and a time reduction of 56.55 minutes (15.23%). The time estimated for manual control of the plant is 6 hours 12 minutes. Time and motion study of the entire plant helped to develop a flow chart which was used to code the PLC that controls the whole system. The plant produced 12.25 kg from 25 tubers of yam (50.25 kg) of *poundo* yam flour within 5 hours 15 minutes with the developed control system. Human involvement is reduced by 75% with the 8 steps required for manual control reduced to just 2 steps with the developed control system. This is a significant improvement to the quality and the rate at which pound yam flour is produced. Currently, a business plan for commercialisation of the processing plant is being developed. Further work will involve incorporating packaging machines to optimise the processing plant.

Table 1: Time required by individual machines in the plant.

Machines	Average weight of the yam before (kg)	Average weight of the yam after (kg)	Rate of the machine	Average time taken with control system (min.)	Average time taken without control system (min.)
Washing	50.25	48.00	31 sec./yam	12.92	21.92
Peeling & slicing	48.00	45.75	9 sec./yam	3.75	12.83
Parboiling	45.75	46.65	0.00056 m^3/min.	77	85.62
Conveyor	46.65	46.65	0.53 kg/s	1.52	8.72
Drying	46.65	12.30	0.16 kg/min.	216	227.32
Milling	12.30	12.28	0.062 kg/s	3.31	9.54
Sieving	12.28	12.25	0.38kg/s	0.54	5.64
Total time taken from washing to sieving				315.04	371.59

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Appendix A

```
# include<16f877>
# USE DELAY (CLK = 4000000)
Void main ()
{
while (input (pin-B7))
{
output-high (pin-RD0); /* to start motors 1, 2, 3*/
output-high (pin-RD1); /* to start heater 1*/
if (input (pin-AN0)) /* pin B1 is set when the weight in
per-boiler chamberis ok */
{
output-low (pin-RD0); /* to stop motors 1, 2, 3*/
output-high (pin-RD2); /* to start motors 4 */
}
if (input (pin-AN1)) /* for temperature detection */
{
output-low (pin-RD1);
if (input (pin-clkin)) /* i.e. up to 3 hrs running motor 4*/
{
output-high (pin-clkout);
output-high (pin-RD3);     /* to switch on red light to
open per-boiler exit*/
output-high (pin-RD4);     /* to start motor 5*/
}
if (input (pin-AN2)) /* to check for zero sufficient weight
on conveyor*/
{
output-low (pin-RD2);
output-low (pin-RD4);
output-low (pin-RD3);
}
Output-high (pin-RD5); /* to start motors 6 */
Output-high (pin-RD6); /* to start heater 2 and blower*/
if (input (pin-AN3))
output-low (pin-RD7);
output-low (pin-clkout);
if input (pin-clkin)) /* for 3 hrs running motor 6*/
{
Output-high (pin-clkout);
Output-high (pin-RB5); /* to switch on green light to open
dryer gate*/
Output-high (pin-RB6); /* to start motors 7, 8 */
}
Output-low (pin-clkout);
if (input (pin-clkin)) /* for 10 mins green light on */
{
Output-high (pin-clkout);
Output-low (pin-RD5);
Output- low (pin-RB5);
}
if (input (pin-RB4)) /* net weight on sieve = 0 */
output-low (pin-RB5);
}
}
```