A Knowledge Engineering Approach To Fault Detection In Production Systems

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A KNOWLEDGE ENGINEERING APPROACH TO FAULT DETECTION IN PRODUCTION SYSTEMS

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ABSTRACT

This paper presents a scheme for fault detection (FD) in production systems from default to faulty machine conditions and processing through packaging operations. The FD scheme is predicated on integrated control mechanisms combining soft and hardwares. The software applications include the principles of knowledge engineering utilized in the knowledge extraction and storage processes of default physical conditions of all systemic components susceptible to wear, tear or performance deterioration over time, a bottom-top fault tree diagnostic approach for the establishment of cause and effect diagram, production rules and boolean logic for the establishment of conditional statements and components classification respectively. The hardware includes a Siemen Programmable logic controller (PLC) unit, control switches, audio detecting devices, electric motor, conveyor belt, light dimmers and gear chains amongst others. The validation process was carried out in two separate experiments; firstly with a corked bottle and following with an uncorked bottle. The bottles were transported on a conveyor belt mechanism. The handling of an uncorked bottle resulted in a systemic error which triggered the audio-visual devices resulting in the immediate stoppage of the handling process. However, in the case of a corked bottle, the handling process went through successfully without any error prompting.

Keywords: *fault detection, knowledge engineering, automatic, production systems, conveyor system*

1.0 INTRODUCTION

With rapid innovations, rising complexity and interconnectedness, dependency as well as the asynchronous interactions among the subunits of production systems and manufacturing processes, research in the field of precision diagnosis or exact component fault detection technique has heightened in the past few decades. The origin of faults in systems is more often than not an impromptu act. Early detection of faults during production can lead to the avoidance of abnormal progression and reduced productivity. Literature has established in recent times that some petrochemical industries incur losses estimated at 20 billion dollars per annum due to faulty production systems Venkatasubramanian (2003a). Fault detection could be defined as the problem of detecting changes in the parameters of a static or dynamic system Venkatasubramanian (2003b). “In modern manufacturing systems, various sensors are equipped to collect data for monitoring, controlling and improving process performance” Lada et al. (2002). In their paper, Li and Jeng (2010) proposed a systematic approach to detect, isolate and identify multiple sensor faults for multivariate dynamic systems. Yüksel and Sezgin, (2010) applied their diagnostic theory to robot manipulators using soft computing techniques, as an integrator of Neural Network (NN) and Fuzzy Logic (FL). In their paper, Cork et al. (2005) presented a review of techniques that can be used to track the system health onboard an Unmanned Air Vehicle (UAV). Their research primarily focuses on real-time, onboard implementations for generating accurate estimations of aircraft health for fault accommodation and mission management.

Littlewood et al. (2000) carried out a review of literature containing many studies of the efficacy of fault finding techniques with the aid of a developed software. In their paper, Cusidó et al. (2010) proposed a signal processing method, which combines wavelet and power spectral density techniques giving the power detail density as a fault factor. The method shows good theoretical and experimental results. Merzouki (2010), proposed a fault diagnosis approach christened Fault detection and isolation (FDI) of a class of networked control systems (NCS). This was applied for to a telerobotics system. A template monitoring model which describes event observations and demonstrates a method for automatically generating template from timed automata specifications was proposed by Holloway et al. (1997). Fu et al. (2010), developed a dynamic principal component analysis (DPCA) method which was employed for system identification and model reduction. Shi-Chang et al. (2006), used multiple heterogeneous on-board sensors, networked and deployed in large numbers in a complex Multistage Manufacturing System (MMS). The Distributed Sensor System (DSS) provides unprecedented opportunities for fault detection and isolation. A method of fault detection and classification in semiconductor manufacturing was provided by Seob and Keun (2007). In the method, delicate variations of actual data of parameters for which normal values of a manufacturing condition change according to time are detected very precisely and sensitively. In their paper, Kao et al. (2009) presented an analytical fault detection and diagnosis (FDD) scheme using model-based and signal-based methodology with wavelet analysis on signals obtained from sensors and sensor networks. Fingerprint analysis and signal-based FDD were also presented with an experimental framework.

Patton et al. (2000), used soft computing (SC) methods to enhance the quantitative model-based approach for residual generation in FDI. Their paper discussed several methods of combining quantitative and qualitative system information and their practical value for fault diagnosis of real process systems. Ruusunen and Paavola (2004) proposed a monitoring approach which integrates a model-based method and systematically collected expert knowledge and data. A review paper which summarizes the recent researches and developments performed in condition monitoring of the induction machine with the purpose of rotor faults detection was presented by Mehrjou et al (2011). A brief status on condition monitoring and fault diagnosis in wind energy conversion systems, was presented by Amirat et al. (2009). Toliyat et al. (2011), presented state-of-the-art non-invasive methods that can be utilized for running machines without interfering with or interrupting their processes. They further explained how digital signal processors makes it possible to seamlessly integrate the task of condition monitoring and fault diagnosis with machine control algorithms. Catarino et al. (2004), presented a system which was developed with the purpose of performing the analysis in real time of the knitting process, supplying the parameters of major concern for production and furthermore, allowing the detection, identification and location of faults. Patton et al (2008) proposed a diagnostic model to automatically detect and identify faults in manufacturing processes by using a wavelet-based method. The idea behind the method was to use an image processing system that performs the following phases: image capturing, image pre-processing, determination of region of interest, object segmentation, computations of object features and decision-making. Catarino et al (2002) developed a system for knitting process monitoring and fault detection on weft circular knitting machines.

This paper has proposed a fault detection concept that is predicated on the principles of knowledge engineering. A simple conveyor belt system for materials handling as shown in Figure 1 was used to convey single units of capped and uncapped bottles at different instances. While the capped bottles are classified as non-defective, the uncapped bottles are classified as defective materials. The system is meant to detect a defective material at a point during the handling process and respond by activating an audio-visual output system which is simultaneously accompanied with a shutdown of the system.

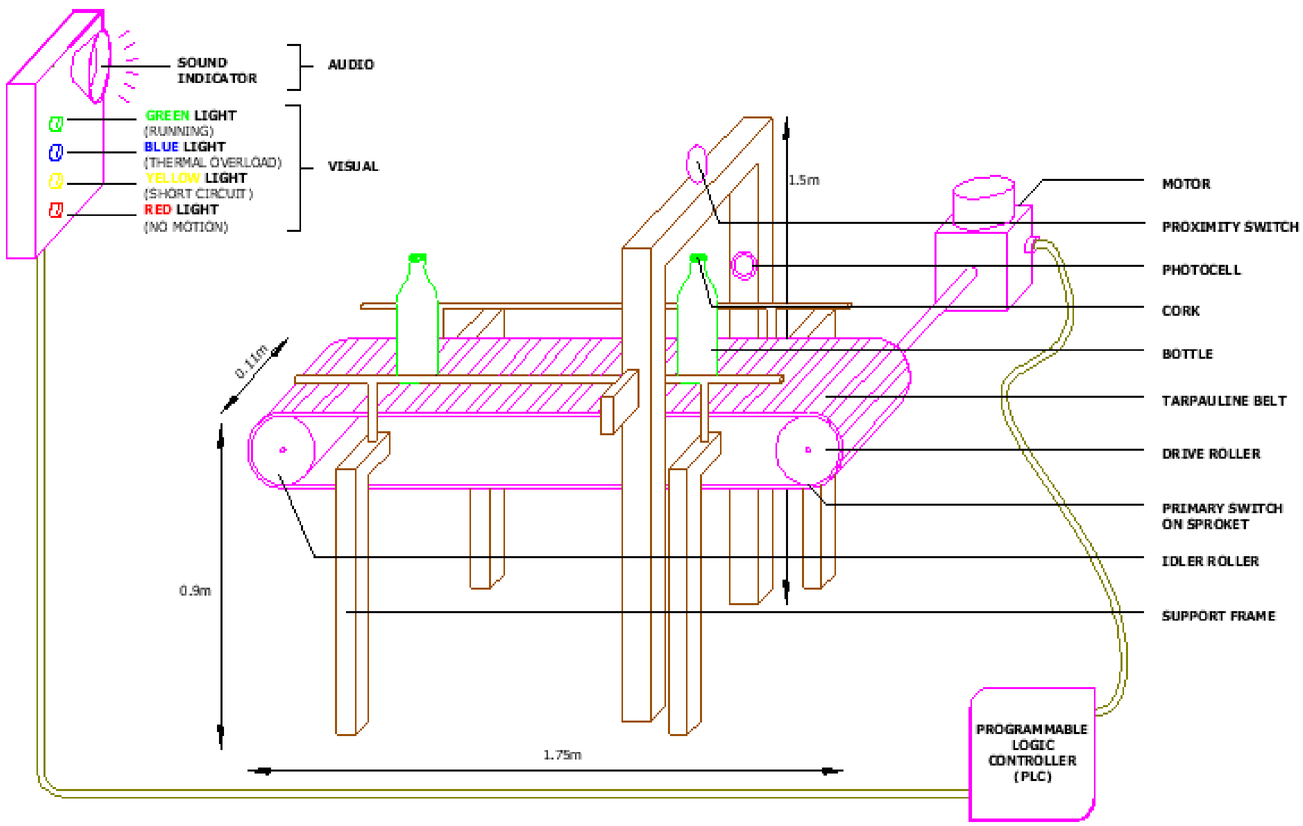


Figure 1. A sketch of the prototype conveyor system

2.0 MATERIALS, COMPONENTS AND TECHNIQUES

This section presents basic a brief on the materials, components and techniques used in this paper:

2.0.1 Fault Tree Analysis

A fault tree diagram follows a top-down structure and represents a graphical model of the pathways within a system. The pathways interconnect contributory events and conditions using standard logic symbols (AND, OR, etc.). Fault tree diagrams consist of gates and events connected with lines. The AND and OR gates are the two most commonly used gates in a fault tree. While the AND gates are used to denote the occurrence of two events (or more) at the same time, the OR gates on the other hand are used to denote a situation where either one or more events can occur. The triggering of these events usually resort to an output which could be interpreted to be systems failure or correctness.

2.0.2 Production Rules

This is one of the most popular and widely used knowledge representation technique. Production systems apply rules in representing and reasoning with knowledge. They started out in an attempt to model human related problems by providing solving techniques which capture the role of short term memory as seen also in expert systems. They are now the most common form of knowledge representation in expert systems. A production rule system is also typically used to provide some form of artificial intelligence, which consists primarily of a set of rules about a behavior. Production consists of two parts:"IF" statement and the "THEN" statement also. If a production's precondition matches the current state of the world, the action is said to be triggered. Rule-based systems normally use a working memory that initially contains the input data for a particular run and an inference engine to find applicable rules and apply them. The rule interpreter or inference engine must provide a mechanism for prioritizing production when more than one is triggered.

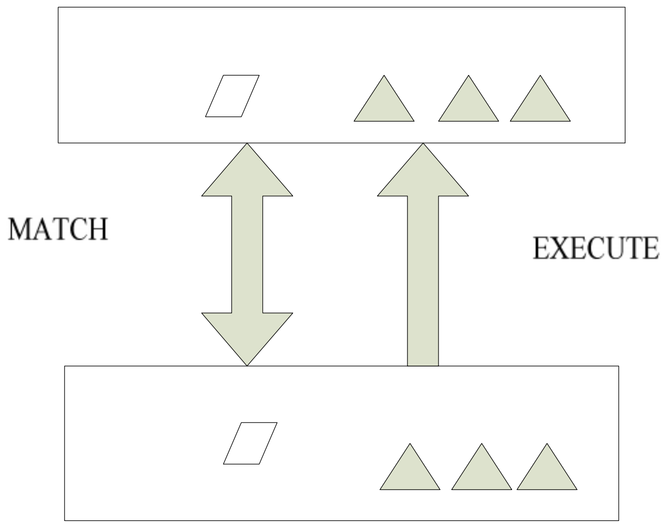


Figure 2. The production rule interpreter cycles through match-execute sequence

2.0.3 Boolean Logic

This tool defines the rules for expressing and simplifying problems into binary logic statements of 0 and 1.The following logical connectitudes depicts various operations that can be carried out in Boolean logic. Logical disjunction is an operation on two logical values, typically the values of two propositions, that produces a value of false if and only if both of its operands are false. The truth table for **p OR q** is as follows:

2.0.4 Audio Detecting Devices

The Audio based device is a sound producing system which triggers when there is a system failure .In this project a siren system built into the controller unit is triggered to create an alarm or sound signal. The built prototype was fitted with light indicators that come on when a fault occurs in the system. The system has also been fitted with an audio system that also comes on simultaneously whenever a fault occurs.

2.0.5 Visual/Sensory Devices

The sensory system functions by collecting optical data. The sensory system is capable of detecting a faulty condition as: uncorked bottle being conveyed along the conveyor belt. Two colored indicators red and green are attached to these devices. When system failure occurs the red light indicator is activated while the green light comes up when the system is in a normal working condition.

2.0.6 The Programmable Logic Controller

A programmable logic controller (PLC) or programmable controller is a digital computer used for automation of electromechanical processes. Unlike the general-purpose computer, a PLC is designed with multiple inputs and output arrangement, extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. Programs to control machine operation are typically stored in battery-backed or non-volatile memory. A PLC is an example of a real time system since output results must be produced in response to input conditions within a bounded time, otherwise unintended operation will result. PLCs are programmed using ladder logic or statement list.

2.0.7 Electric Motor

An electric motor uses electrical energy to produce mechanical energy. Electric motors are found in household appliances such as fans, refrigerators, washing machines, pool pumps, floor vacuums, clothes dryers, hair dryers, forced air home furnaces, computers requiring cooling, many DVR recorders, attic fans, range hoods, bathroom fans, boot dryers, pellet stoves, many electric heaters, heat guns, and fan-forced ovens. They are also found in many other devices such as computer equipment, in its disk drives, printers, and fans; and in some sound and video playing and recording equipment as DVD/CD players and recorders, tape players and recorders, and record players. Electric motors are also found in several kinds of toys such as some kinds of vehicles, fans, cool water mist fans, blow torches, pencil sharpeners, fan-forced ovens, and robotic toys. In the current research, a 0.55kw motor was used.

2.0.8 Conveyor Belt

A belt conveyor consists of two or more pulleys, with a continuous loop of material - the conveyor belt - that rotates about them. The belt consists of one or more layers of material they can be made out of rubber. Many belts in general material handling have two layers. An under layer of material to provide linear strength and shape called a carcass and an over layer called the cover. The carcass is often a cotton or plastic web or mesh. The cover is made of rubber or plastic compounds. Covers can be made from more exotic materials for unusual applications such as silicone for heat or gum rubber when traction is essential.

2.0.9 Light Dimmers

Dimmers are devices used to vary the brightness of a light. By decreasing or increasing the RMS voltage and hence the mean power to the lamp it is possible to vary the intensity of the light output. Although variable-voltage devices are used for various purposes, the term dimmer is generally reserved for those intended to control lighting. Modern dimmers are built from silicon-controlled rectifiers (SCR) instead of potentiometers or variable resistors because they have higher efficiency. A variable resistor would dissipate power by heat (efficiency as low as 0.5). By switching on and off, theoretically a silicon-controlled rectifier dimmer does not heat up (efficiency close to 1.0).

2.0.10 Gear Chains

A **gear** is a component within a transmission device that transmits rotational force to another gear or device. A gear is different from a pulley in that a gear is a round wheel which has linkages ("teeth" or "cogs") that mesh with other gear teeth, allowing force to be fully transferred without slippage. Depending on their construction and arrangement, geared devices can transmit forces at different speeds, torques, or in a different direction, from the power source. The most common situation is for a gear to mesh with another gear, but a gear can mesh with any device having compatible teeth, such as linear moving racks.

2.0.11 Control Switches

Here, we have the circuit breakers, the contactors, thermal overloads switches with auxiliary.

The circuit breaker is an automatically-operated electrical switch designed to protect an electrical circuit from damage caused by overload or short circuit. Unlike a fuse which operates once and then has to be replaced, a circuit breaker can be reset (either manually or automatically) to resume normal operation. A contactor is an electro-magnetic switching device (a relay) used for remotely switching a power or control circuit. A contactor is activated by a control input which is a lower voltage / current than that which the contactor is switching. Contactors come in many forms with varying capacities and features. Unlike a circuit breaker a contactor is not intended to interrupt a short circuit current.

2.0.12 Thermal Overload

Thermal overload depicts a situation whereby there is an accumulation of heat due to the motor's operational mode .Consequently, this could lead to a trip or stoppage of the motor. For protection against overloading or overheating, a contactor with a thermal overload relay was introduced to our design.

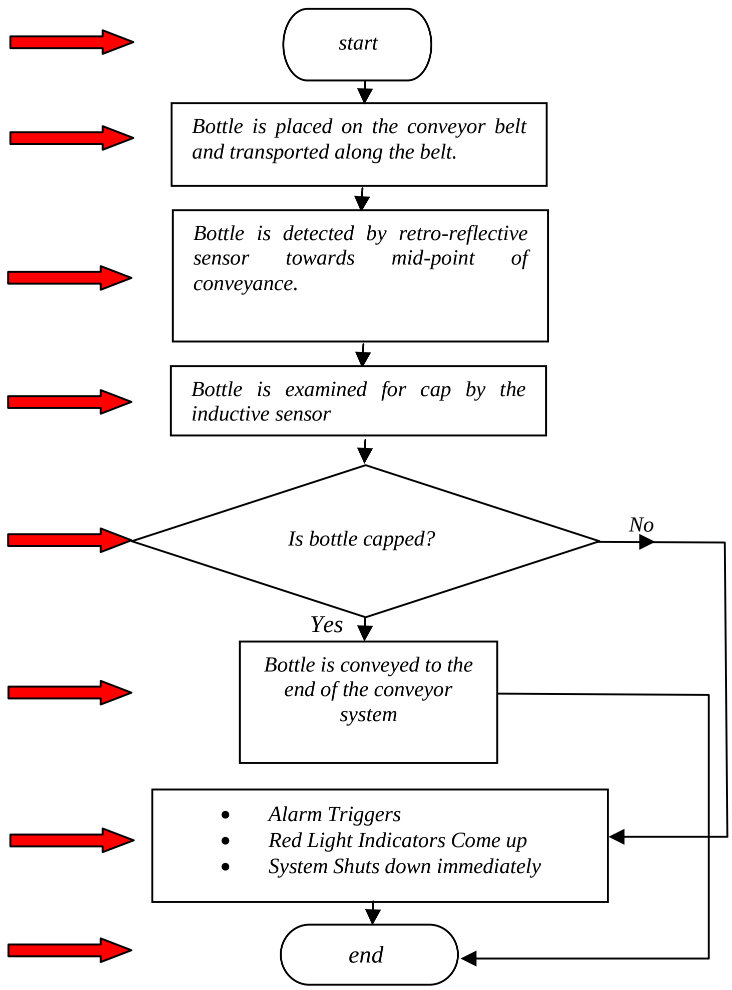
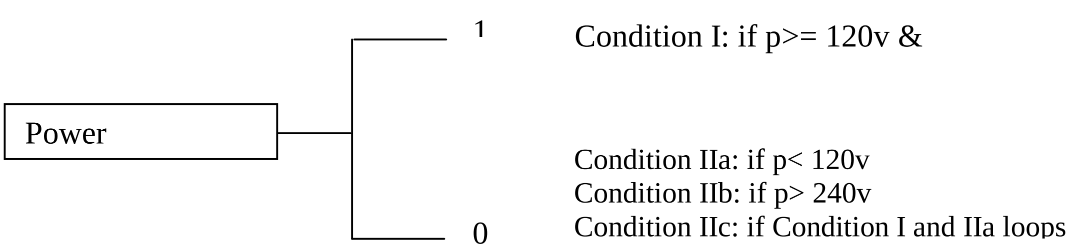


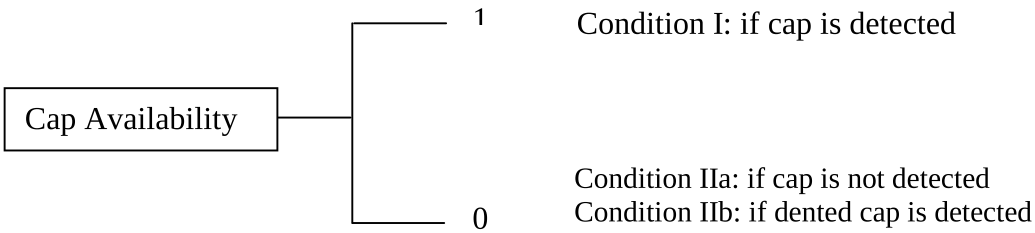
Figure 3: A flow chart showing the fault detection procedure.

3.0 KNOWLEDGE ENGINEERING CONDITION MONITORING MODEL

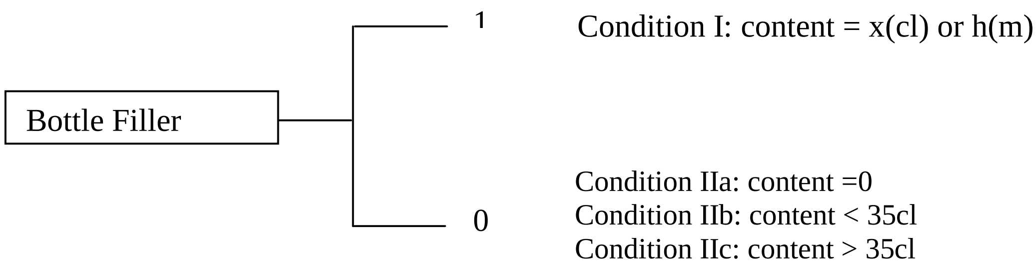
The condition monitoring model for some selected components prone to deterioration over time in the production system is as presented below:



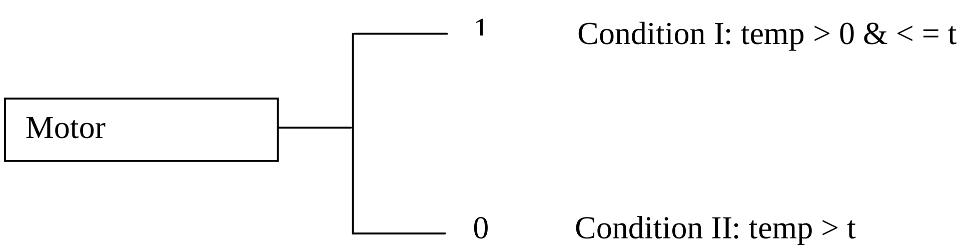
Condition 1 ; {Power available} {Indicator _Green _Light}
Condition IIa ; {Power_not available} {Indicator_ Red_Light}
Condition IIb ; {Surge} {Indicator _Red_Light}
Condition IIc ; {Partial Contact} {Indicator _Red_Light}



Condition 1 ; {Cap available} {Indicator _Green _Light}
Condition IIa ; {Cap_not available} {Indicator_ Red_Light}
Condition IIa ; {Cap_detector_bad} {Indicator_ Red_Light}
Condition IIb ; {Cap_dented} {Indicator _Red_Light}



Condition 1 ; {Filler good_condtion} {Indicator _Green _Light}
Condition IIa ; {Filler not_functional} {Indicator_ Red_Light}
Condition IIb ; { Filler leaking} {Indicator _Red_Light}
Condition IIb ; { Filler Bad_level_indicator} {Indicator _Red_Light}
Condition IIc ; { Filler over_gauge} {Indicator _Red_Light}
Condition IIc ; { Filler Bad_level_indicator} {Indicator _Red_Light}
where,
x = desired content volume and h = height of bottle filled



Condition 1 ; {Motor good_condtion} {Indicator _Green _Light}
Condition IIa ; {Motor bad-condition} {Indicator_ Red_Light}
where,
t = upper permissible temp. range

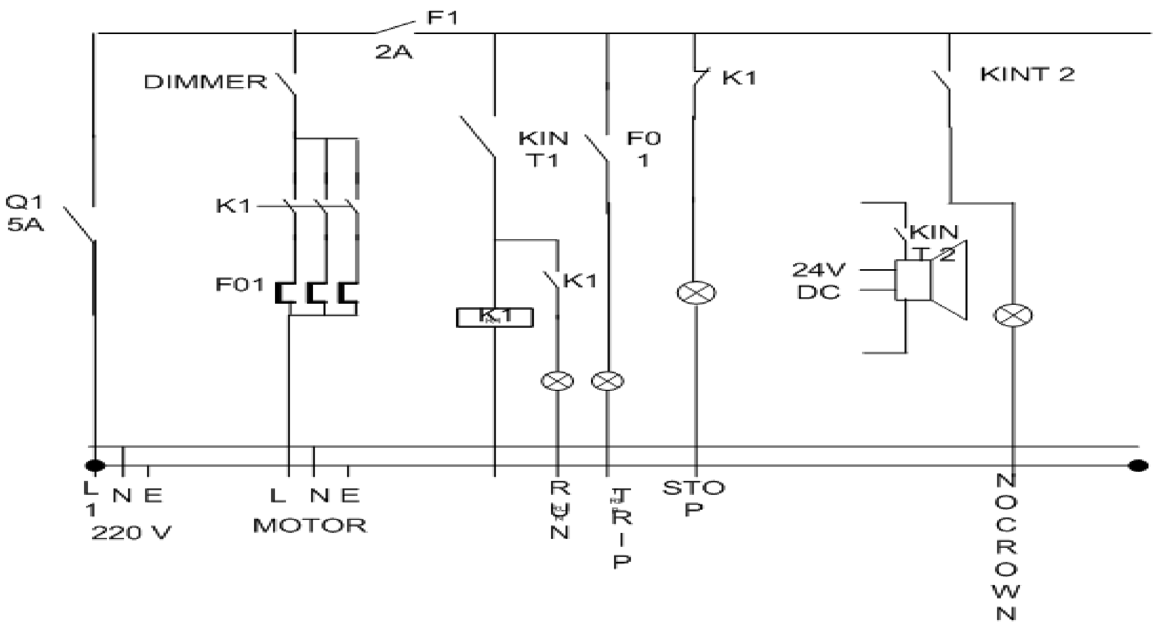


Figure 4: Basic Electrical Circuit for the system.

Figure 4 shows an electric life feed supply to Q1 the mains. The mains with an amperage of 5amps is looped into F1 a 2A Circuit Breaker, a circuit breaker with an amperage of 2amps and a light dimmer whose function in this circuit is primarily to reduce the speed of the electric motor. The wiring is seen to proceed further into K1 contactor, thermal overload protection and to the control relays Kint1 and Kint2.

Following below is Figure 5 which shows the Siemens PLC interfaced with the electrical circuit. The Siemens PLC is operated using a 24 volts adaptor connected to its live and neutral terminals while its outputs are connected to a 220volts sources. Once all the connections are in place, the circuit breakers are switched on, the ON push button is depressed and the auxiliary contact of the contactor becomes active thereby causing power to flow to the electric motor. This results in the motion for the transportation of the bottles along the belt. The OFF button breaks contact thereby ending flow of electric current to the motor. The thermal overload protection helps to protect the motor from excessive or increased thermal energy. Figure 6 shows the side view of the control panel. The control panel contains push buttons and other peripherals for starting, stopping and overall actuation of the system. These components are better viewed in picture form in the following sections.

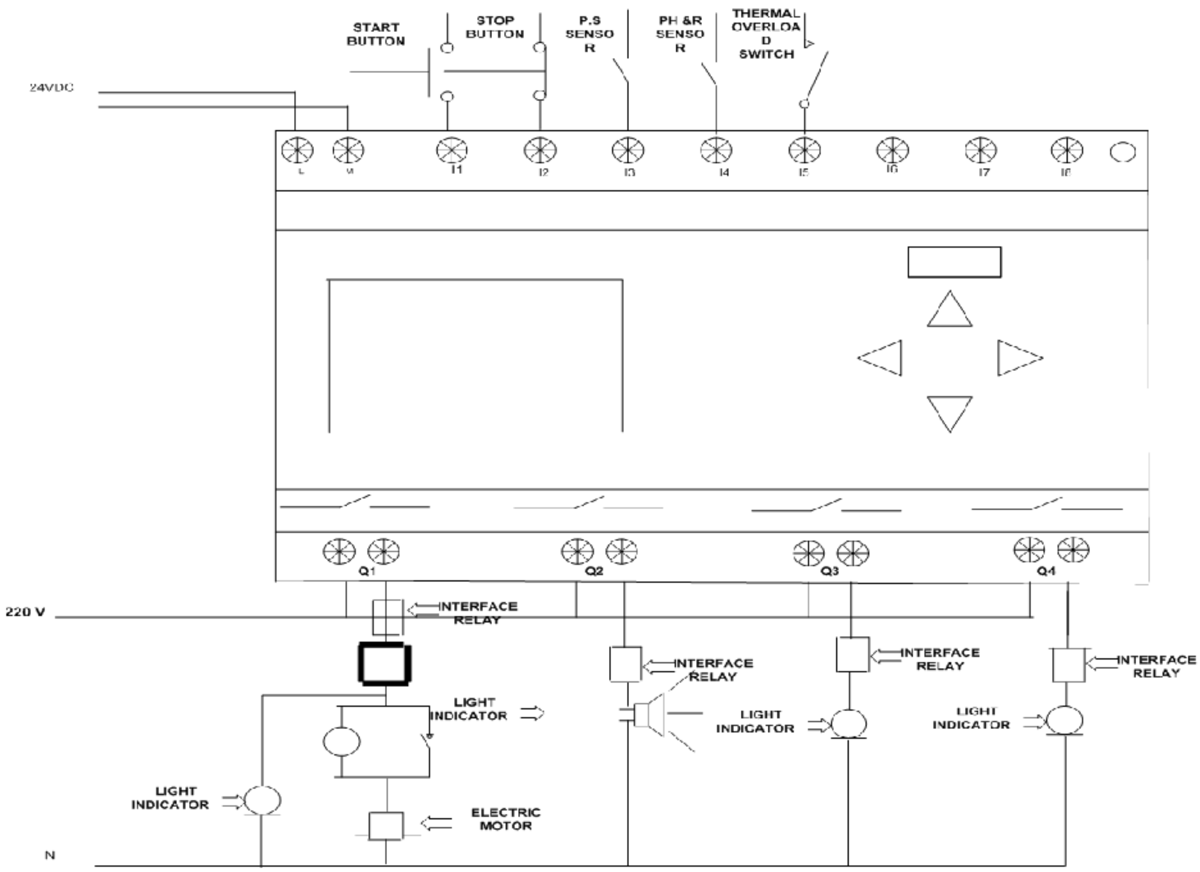


Figure 5. PLC interface with the electric circuit

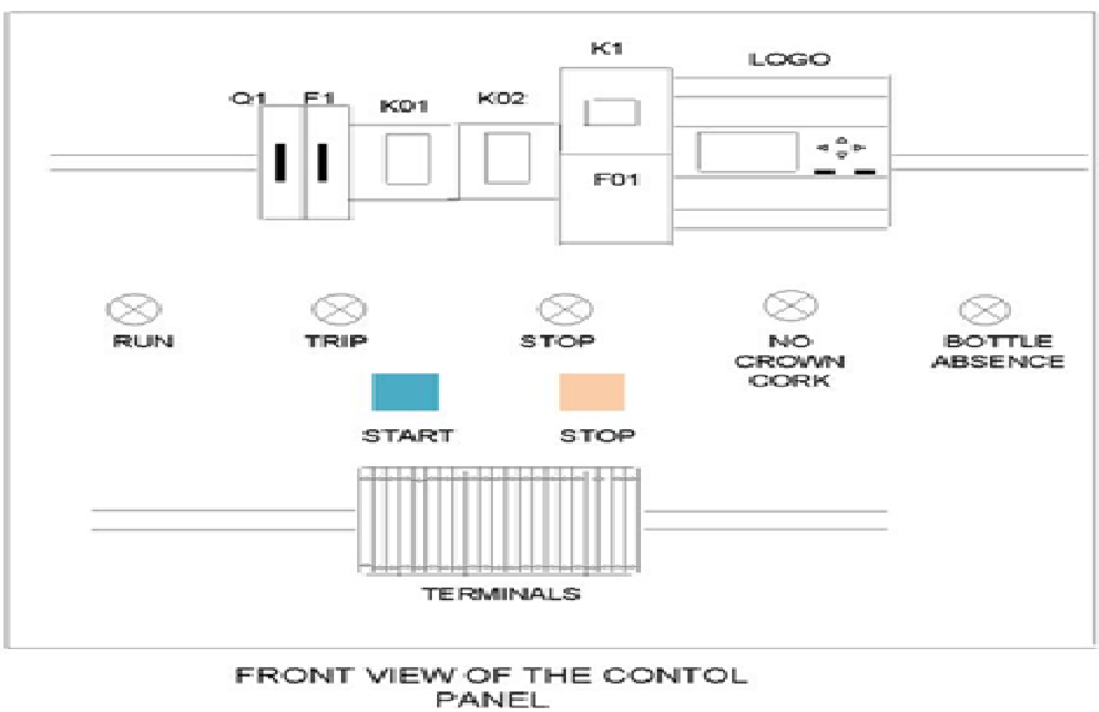


Figure 6. Diagram showing the gadget configuration of the control panel

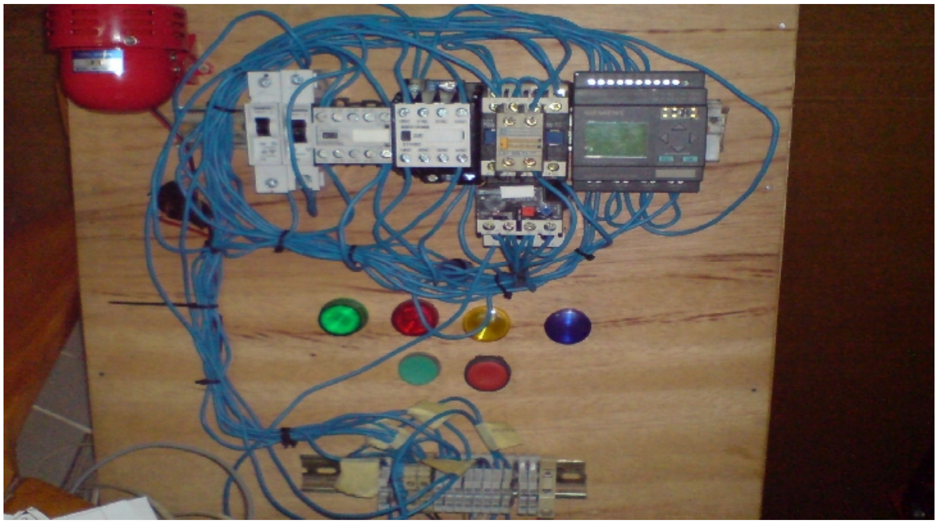


Figure 7. A picture of the electrical unit

4.0 RESULTS/DISCUSSIONS

This section presents the results obtained from experiments performed using the conveyor belt system for corked and uncorked bottles. The experiments were carried out distinctly for the two different classes of conveyed materials. A siemen PLC with eight inputs and four outputs was used to coordinate the operational sequence of other components and devices to facilitate the system's intelligence. Figure 8 shows the PLC initialized interface. Output 1(Q1) comes on because the model has been switched "ON" from the start button causing the motor to run.

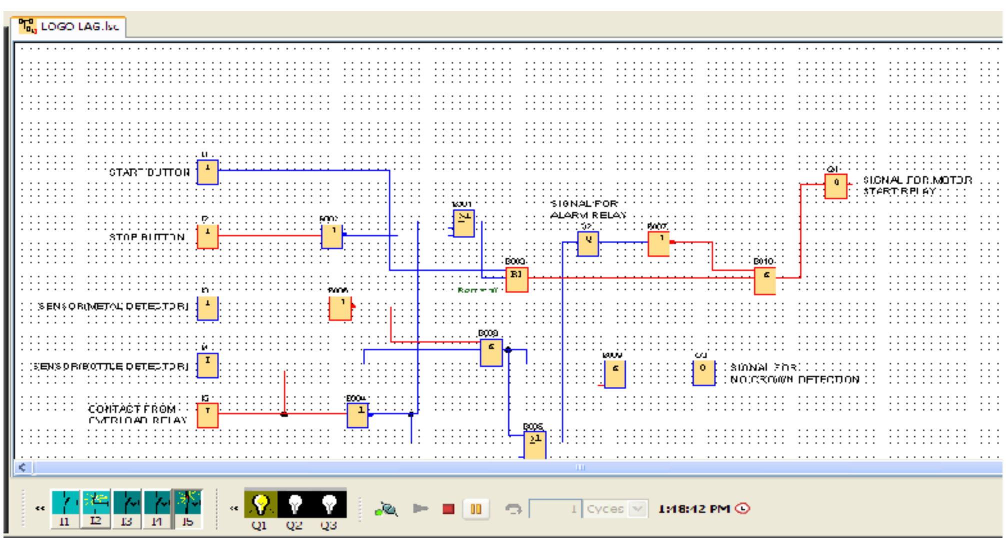


Figure 8. Plc software interface showing an initialized system.

Figure 9 is a PLC display of a system in good working condition. From the interface, it could be seen that both Inputs 3 and 4 nomenclatured (I3) and I4 respectively are closed meaning that both the crown cork and bottle have been sensed hence keeping the system running. Output 1 i.e. Q1 is seen to have remained ON which is an indication that the motor is working. Motor shuts down only when an abnormal scene arises.

Figure 10 shows a corked or capped bottle successfully conveyed from one end of the system to the other. This confirms the validity of Figure 9.

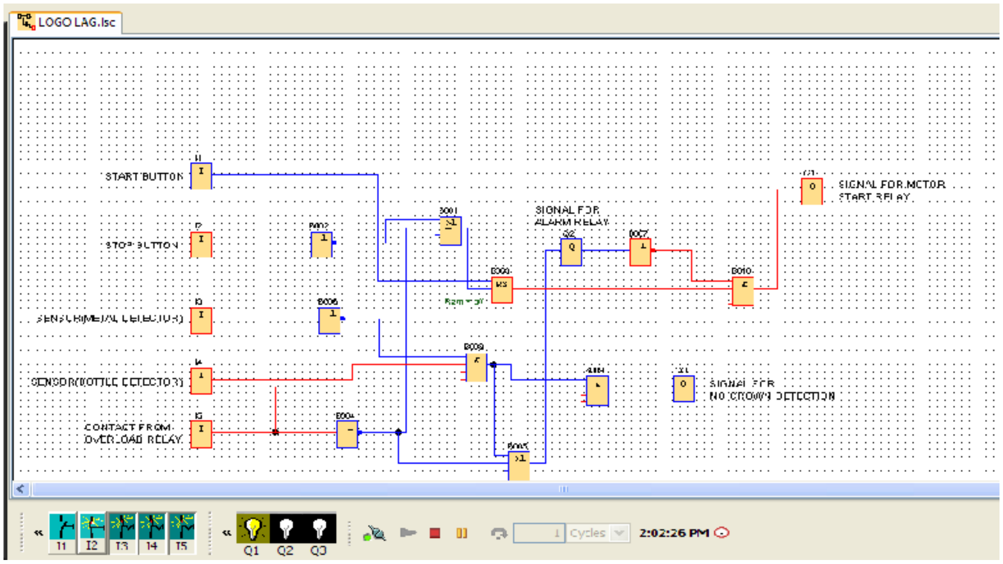


Figure 9. Plc software interface for a bottle with cap.

Figure 10. Experiment showing a successfully conveyed capped bottle

Figure 11 is a display of a defective system as depicted by the PLC. It is obvious that Q2 (signal for alarm relay) and Q3 (signal for no cap detection) are already triggered on indicating that no crown cork detected however, a bottle is present. No signal is seen from input 3 but a signal comes from input 4 only hence triggering the alarm Q2 and indicator light Q3 for defective system. The system simultaneously triggers off. Figure 12 is a further confirmation of the representations in Figure 11. The bottle is seen trapped underneath the detecting station along the conveyor belt.

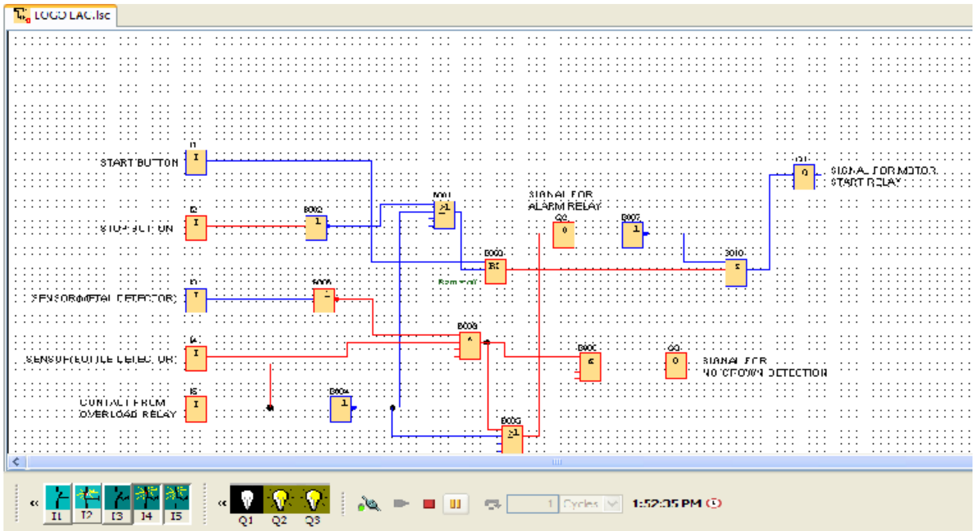


Figure 11. Plc software interface for a bottle without cap.

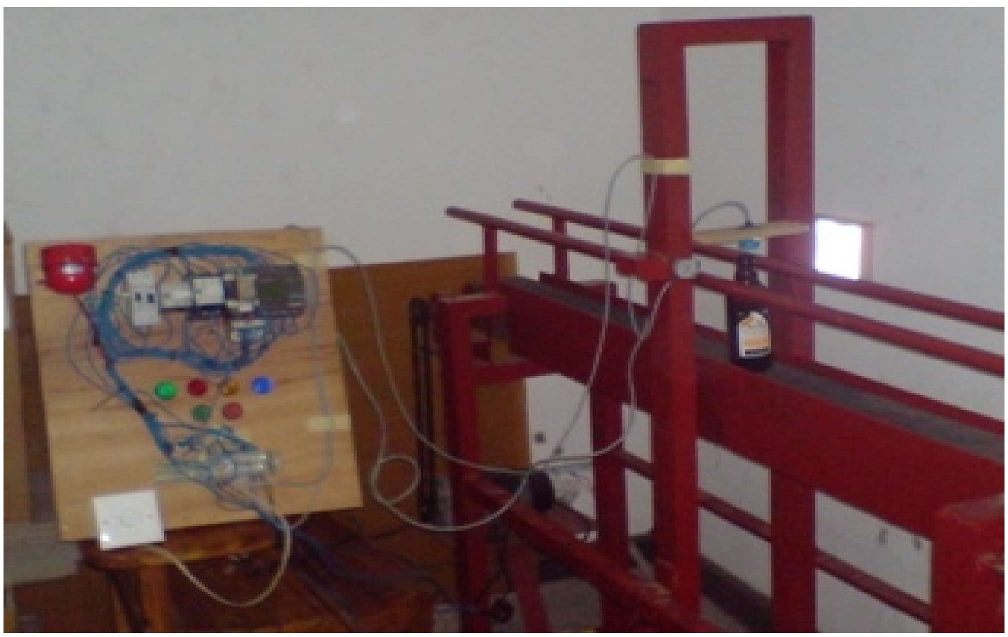


Figure 12. Experiment showing a trapped uncapped bottle

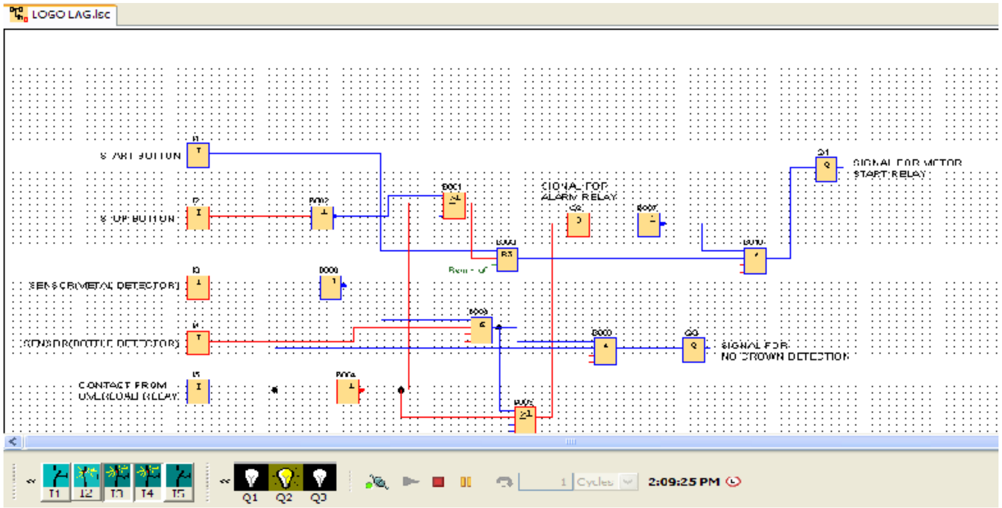


Figure 13. Plc software interface for detecting thermal overload.

Also presented is the thermal condition of the motor. The PLC interface herein as presented in Figure 13 represents thermal overload of the PLC. Q2 the alarm signal is prompted to come on hence shuting down the system. Thermal overload on the motor is a condition which subjects the motor to excessive heat hence leading to its damage.

4.0 CONCLUSION

This paper has proposed a fault detection concept that is predicated on the principles of knowledge engineering. A simple conveyor belt system for materials handling was used to convey separately, units of capped and uncapped bottles. While the capped bottles are classified as non-defective, the uncapped bottles are classified as defective materials. The system is meant to detect a defective bottle (uncapped) at a point during the handling process and respond by activating an audio-visual output which is simultaneously accompanied with a shutdown of the system. The outcome of our results has shown the degree of effectiveness of the proposed concept. Nevertheless, the entire concept as earlier depicted of the knowledge engineering process is not fully implemented in this research. On going research on a similar production system would integrate the principles of digital image processing and fault tree diagnostic approach for the establishment of cause and effect diagram among others.

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