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Research paper

Formal Modeling of Cyber-Physical System for Conveyor Sorter

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Abstract

Conveyor is usually used in materials handling in manufacturing. Conveyor able to transfer the product from one to another place. In order to use concept of Cyber Physical System (CPS), conveyor have to represent itself to user in cyber and physical. CPS is a communication between cyber and physical of product in real-time system which is user can control the conveyor by using cyber or manually. In this paper, we focused on three goals which are to design CPS model for manufacturing application, modelling the system by using concept Object-Oriented (OO) in any OO software and verification on model using model-checking method. This paper proposes conveyor system as the model for manufacturing. We represent the model as cyber conveyor according to physical conveyor and proposed the methodology how they communicate each other in real time.

Keywords: *cyber-physical system; formal method; industrial automation system; model checking; programmable logic controller.*

1. Introduction

Nowadays, by using Internet in short time we can interact with others and get the information from worldwide. From time to time, the technology of Internet has been rapidly developed in many kind of applications that useful to people used it. Throughout the years, control and system researchers have pioneered the development of advancement of effective system science and engineering tools or methods. For example, time and frequency domain method, state space analysis, system identification, optimization, and robust control. In advancement of Internet, that was exist a new technology paradigm called Cyber-Physical System (CPS). CPS is the combination of communication technology between ‘cyber’ and ‘physical’ in industrial area applications [1]. For now, CPS is spread widely the information and advantages of it.

With recent developments that have resulted in higher possibility of sensors, data acquisition systems, and computer networks, the nature’s completion of industry forces more factories to move forward in implementing high technologies. Cyber Physical System (CPS) is one of part in Industry 4.0 revolution. To make Industry 4.0 possible, CPS give the basic for creation of the Internet of Thing (IoT) combines with the internet of services [2]. CPS is interdisciplinary system which is to conduct the output of the system on widely distributed embedded computing systems by the combination of computation, communication and control technologies [3]. They are revolution and combination of the existing network systems and common embedded systems.

Uses of CPS include critical infrastructure control (electric power, water resources, gas and fuel distribution, transportation, etc.), process control and manufacturing, highly dependable medical devices and systems, traffic control and safety, advanced automotive systems, energy conservation and environmental control. The design and verification of cyber physical systems requires a good understanding of formal mathematical methods that are found in both computer science and the common engineering disciplines. These formal methods are used to model, verify, and design complex embedded systems in which the interaction of computational and physical processes must be approached in a complete way [4]. Formal methods are a field of software and engineering concerned with through mathematical specification, design, and verification of systems [5-7]. Verification is defined as the confirmation by examination and arrangement of target confirm that the specified requirements have been full filled, whereas validation is defined as demonstrating that the specific requirements for a specific intended use are full filled [8-9]. This paper introduces the concepts of model checking and process of verification and validation by model checking works in cyber physical system approach.

In this paper, we discuss the use of formal methods of model-checking, a technique for verifying if a finite-state system satisfies a property specified in temporal logic and approach it into cyber-physical system concept [10]. Model-checking is work on how to check algorithmically of system whether a design correctly implements a specification. In the next section, we review the concept of formalism method and techniques of model-checking.

2. Cyber physical System

Cyber Physical System (CPS) are real-time computation system that are unified with the physical field capabilities that can interact through artificial intelligence technologies [11-13]. The competency to collaborate with, and grow the abilities of the physical world through calculation, correspondence, and control is a key empowering enabler for future innovation improvements. Possibility and research challenges join the plan and advancement of next generation space vehicles and planes, completely self-sufficient urban driving, hybrid gas-electric vehicles, and artificial that allows to give signal to control physical targets.

Since system level constancy properties include both cyber and physical perspectives, verification of worldwide behaviors of must assess the heterogeneity of models. On the off-chance that differing models are joined just toward the finish of a development process, rising failures are probably going to be hard to both follow back to fault and to fix. Treating disciplines independently inside the design procedure along these lines can possibly moderate development. In the advancement of CPS are to be designed monetarily, the plan procedure must be community oriented and multi-disciplinary, while additionally allowing the affirmation raising exercises of simulation, testing and verification process [14].
CPS is still in growing development among engineers and researchers. Professional and institutional barrier have resulted in narrowly defined, subject specific research and instruction venues in academia for the skill and engineering disciplines. Enquiry is partitioned into isolated sub disciplines such as sensors, communications and networking, control theory, mathematics, computer science and software engineering. For example, systems are analyzed and design depends on variety of formal method and techniques. Normally, a specific formalism represents to either the digital or the physical procedure well, but not both of them. Through differential equations are utilized for displaying physical rules, structures, for example, Petri nets and automata are used to represent behavior of discrete and control flows. In facts, this approach in concepts and formalisms may get to help component-based approach to CPS development. It represents a difficult issue for confirming the general accuracy and safety of designs at the system level, target of physical and behavioral connections [13].

2.1. Framework of CPS

From Figure 1, in [18] proposed the CPS framework in terms of domain, facets and aspects. Domain is intended that this concept can be applied to CPS application such as manufacturing, transportation, energy, healthcare and etc. Facets are the view on CPS including the process in the application system. They contain precise activities and outputs for addressing concerns. Aspects are powerful groupings of cross-cutting concerns. Concerns are interests in a system relevant to one or more stakeholders such as functional, business, trustworthiness, timing, data, boundaries, computability and life-cycle.

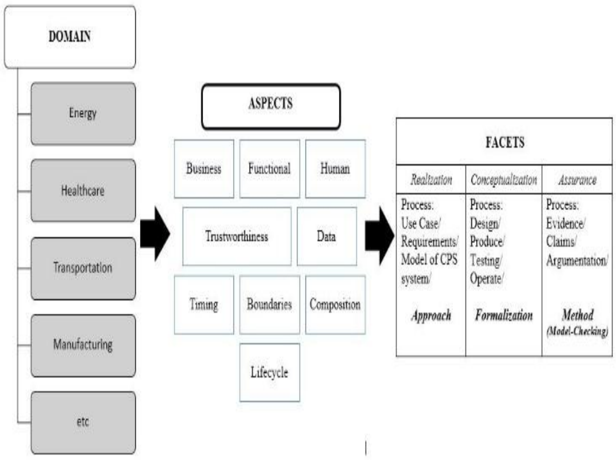

Fig. 1: CPS framework, domain, aspects and facets [18]

In facets part, it consists of conceptualization and realization activities which is represents the system in application plant that will be used. This also represent the properties or requirements of the system. Below conceptualization activities, we have to illustrate the system in use case to model the CPS system. Then, construct the concept in realization activities which is reform the system in formal language or formal method. Then, assurance the system by using verification (such as model-checking). The formal method and verification information have been discussed in next subtopics.

2.2. Formal method of CPS

According to Figure 2, formalization of the informal specification consists of three tasks which are formalization of specific properties, formal modelling of the uncontrolled process, and direct formal modelling of the control algorithm. In this case study, second task which is formal modelling of the uncontrolled process related to conveyor system modelling. This process is resulting in a process model that is needed in model based approaches. This model for discrete or hybrid that depending on the properties to check.
In previous work [20], control strategies for CPS were exhibited. In this paper a practical method for modeling and verification of CPS systems process using simulation and formal methods is proposed. This examination depends on the utilization of an orderly procedure that utilization mathematical reasoning to confirm that outline particulars incorporate certain design requirements to enhance reliability analysis. This includes the use of simulation as well as formal methods to enhance the validation and verification in allowing the detection of defects and errors during the design and operation of such systems. This approach has just been effectively utilized for the exact examination of an assortment of complex frameworks before [20]. While simulation method is embedded in this work, we mean to give formal analysis in future work. Because of the achievement of the Internet and embedded systems in automobiles, planes, and other security critical systems, we are probably to become even more consider on the best possible working of computing devices in the future. Indeed, the pace of progress will probably accelerate in coming years. Because of this quick development in innovation, it will turn out even more important to develop methods that increase our confidence in the correctness of such systems.

2.3. Model Checking

Model checking is an auto-technique of verifying the finite state concurrent systems. Based on simulation, testing and deductive seasoning, this technique gives numeral of advantages from it uses. As the result, this technique has been used successfully to verify the complex designs system and communication protocol [21]. The prime objection in this technique is to deal with the state space explosion problem. This problem occurs in systems with many components that can interact with each other that have data structures that can assume many different values [15-17].

3. PLC model of Conveyor Sorter

The conveyor sorter with PLC trainer in Figure 3 is an ideal training system makes it possible to get know and compare different type of sensor use in systems. The sorting station sorts work pieces onto three slides. Work pieces placed on the start of the conveyor are detected by an IR sensor. Sensors upstream of the stopper detect the work piece features (metal, white and black). In this conveyor, it consists of input and output component which are:

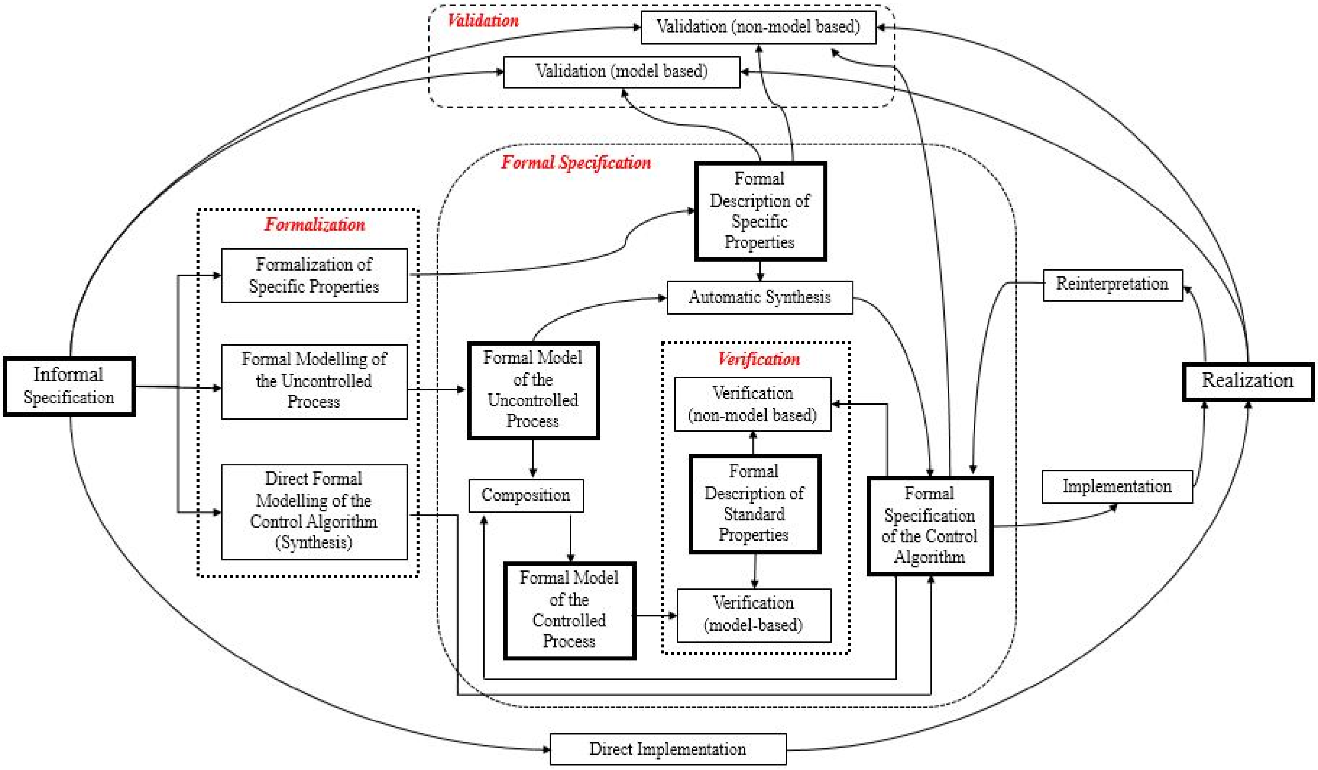

Fig. 2: Details process with formal specification and method [19]

Table 1: Input and output component

Input		Output
Start Button	C3 sensor (S10)	Actuator 1 (C1)
Stop Button	Capacitive sensor (S1)	Actuator 2 (C2)
C1 sensor (S8)	Fiber Optic (S2)	Actuator 3 (C3)
C2 sensor (S9)	Inductive sensor (S3)	Motor

3.1. Model operation of conveyor sorter

First, user have to turn ON the Start Button at the control panel. Testing for checking the cylinder and motor are starting before the conveyor run. When the conveyor is ready, put the material one by one on the conveyor belt. For all sample, when material was detecting by S10 and C3 retract to allow material go through the next part. Starting with black sample, S1 will detect the sample and give instruction to C2 to extend. Then, when white sample, S2 will detect the sample and C1 extend. Meanwhile nothing will happen to any cylinder when S3 detect an aluminium sample. The below flowchart gives the details about the operation of the conveyor sorter.

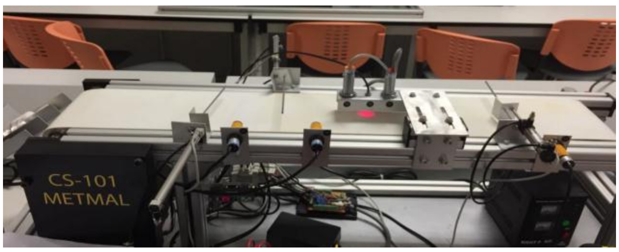

Fig. 3: Conveyor sorter plant

Table 2 shows the presume of the pre-post condition for this case study. Pre-condition is a statement or set of statements that outlines a condition that should be true, or conditions that should be true, when the operation is called. The operation is not guaranteed to perform as it should unless the pre-conditions have been met. Meanwhile, post condition is a statement or statements describing the condition that will be true when the operation has completed its task. If the operation is correct and the pre-condition(s) met, then the post-condition is guaranteed to be true.

In this case study, in pre-condition involve S1 and S2 which is sensor for detect black and white sample respectively. The input consists of cylinder which are C1 and C2. For simple explanation, when S1 detect the black sample, C2 will extend to push while when S2 detect the white sample, C1 will extend to push it. Otherwise, nothing happens to any cylinder when S3 detect the aluminium sample.

Table 2: Model pre-post condition

Pre		Input		Post	
S1	S2	C1	C2	S1(K+1)	S2(K+1)
1	0	0	1	0	1
0	1	1	0	1	0
1	0	1	0	0	0
0	0	0	0	1	0

3.2. Ladder Diagram

Figure 5 is some part in ladder diagram that use in this case study. Rung 4 is consists operation between sensor and its cylinder by follow the type of material (black/white/aluminium).

4. Methodology

In this approach, we focusing in formal modelling and cyber part to represent the conveyor sorter. Firstly, we created the virtual conveyor sorter by using Tecnomatix Software. Figure 6 is the illustration of the simulation that divided into three function which are by material (aluminium, white and black). Next we focused on the modelling of plant. In this work, we formed the modelling by applying the Object-Oriented Petri Net (PN) for formalize the model.

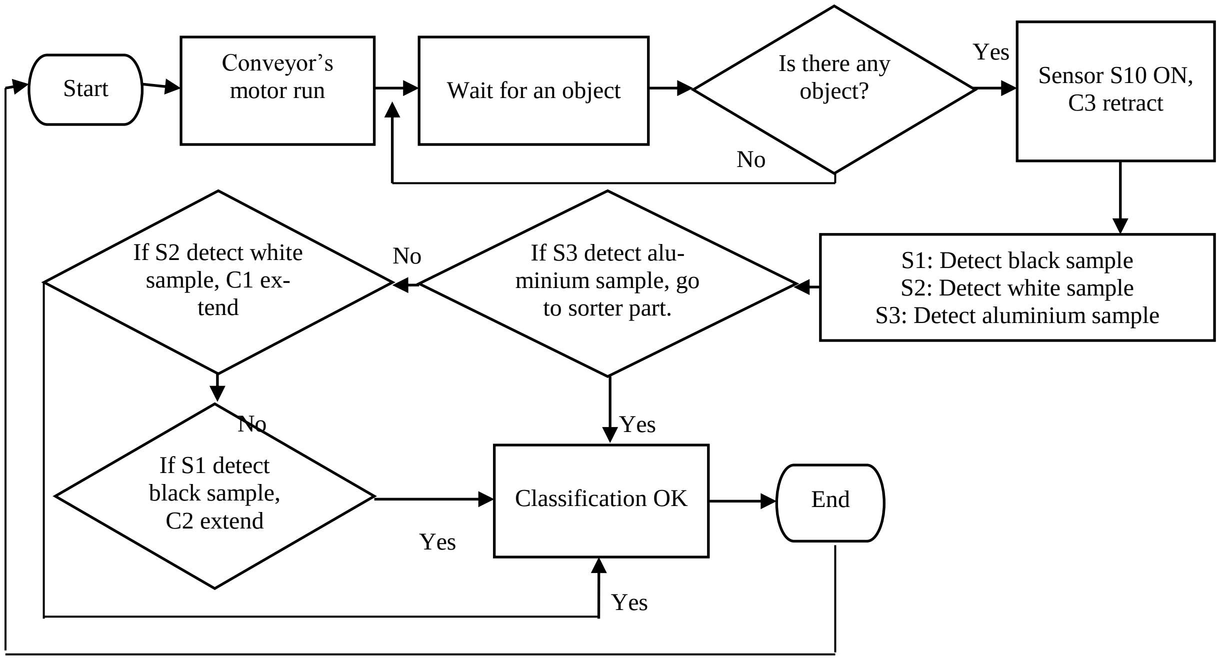

Fig. 4: Flowchart of conveyor sorter

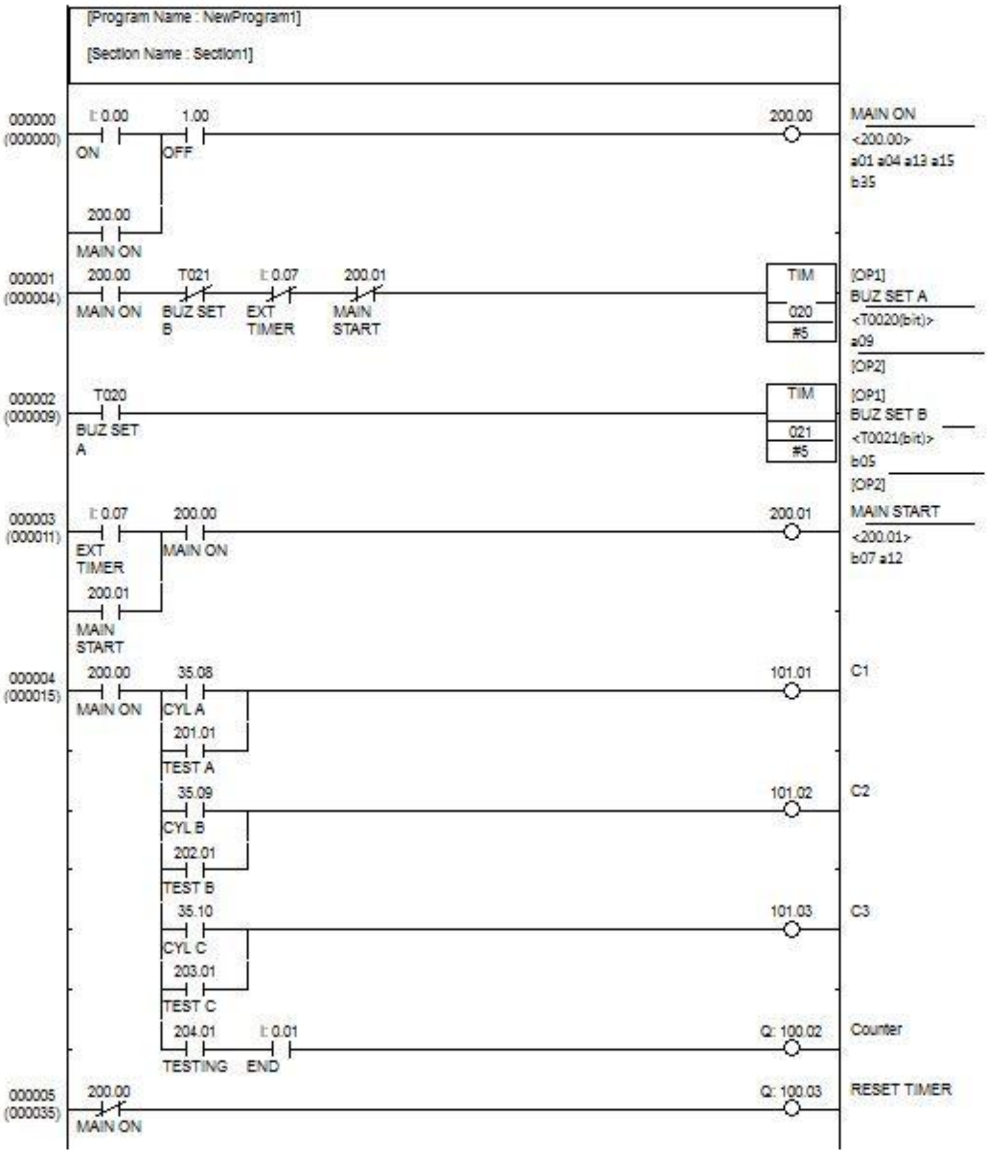

Fig. 5: A part of ladder diagram for conveyor sorter system

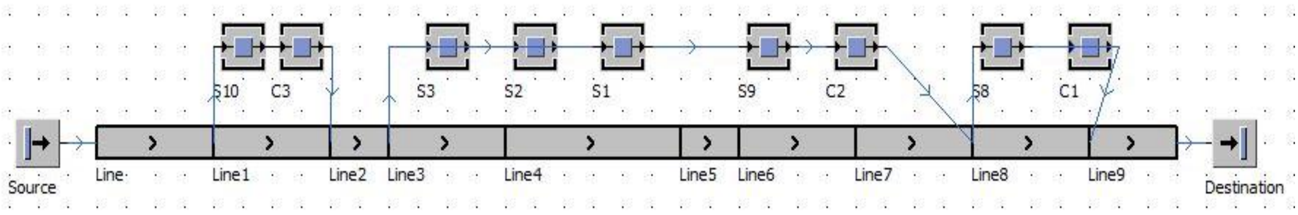

Fig. 6: Virtual plant of conveyor sorter (cyber part)

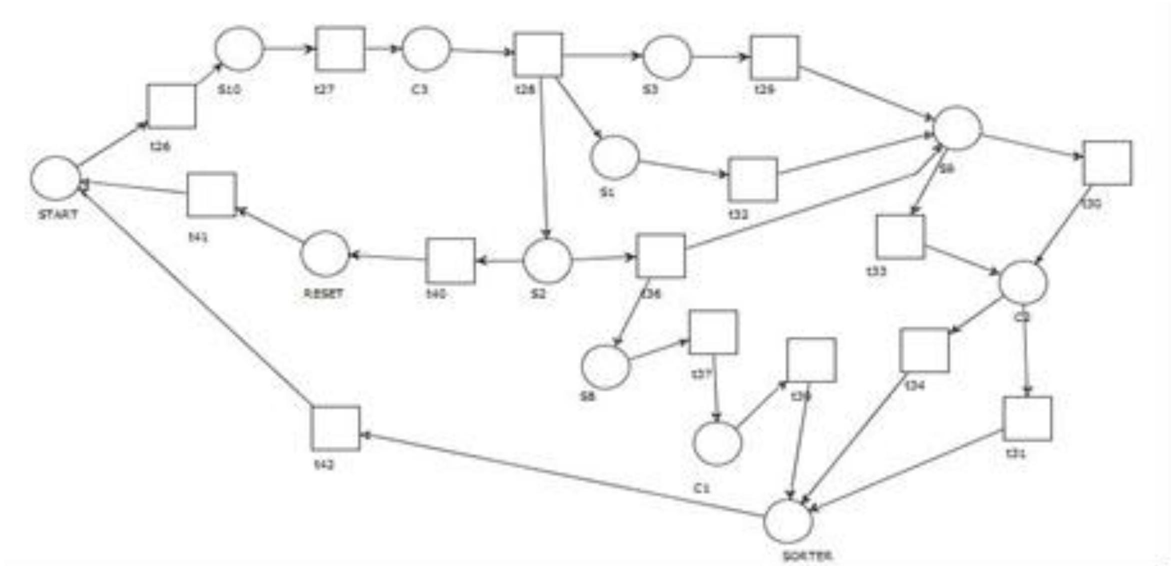

Fig. 7: Formal model of conveyor sorter using Petri Net

The following table is details instruction of conveyor sorter:

Table 3: List of instruction of conveyor sorter

Label	Instruction	Label	Instruction
T26	Conveyor upload material	T33	Give sign to C2 extend
T27	Gives instruction to C3	T36	Detect white material, give sign to C1
T28	Makes decisions part	T37	Give sign to C1 extend
T29	Detect aluminium material, will not give sign to any cylinder	T40	Counter ON
T31	No reaction to C2	T41	Reset to zero
T32	Detect black material, give sign to C2	T42	End

5. Conclusion

This paper focused on three goals which are to design CPS model for manufacturing application, modelling the system by using concept Object-Oriented (OO) in OO software and virtual simulation of conveyor sorter. We also proposed conveyor system as the model for manufacturing and represent the model as cyber conveyor according to physical conveyor and proposed the methodology of cyber part and formal method application in conveyor sorter.

Our next tasks are to conduct verification of the designed CPS model with certain predetermined specifications and investigate the effectiveness of our strategy to validate the CPS model for further application in reconfigurable logic control.

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