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Conceptual design of control system for component sorting

Oleksandr Postrygan
ATS Automation Tooling Systems Inc., 730 Fountain Street North, Building #2, Cambridge, Ontario, Canada,
oleksandr.postrygan@gmail.com

Keywords: conveyor, controlling, simulation, sorting.

Abstract: This article deals with the conceptual design of the control system for a line intended for sorting products. It is an automated workplace with sensor differentiation of products and subsequent separation. The preliminary arrangement of the workplace and the placement of sensors and actuators is proposed. Control networks for the control system in the form of block diagrams are also proposed.

1 Introduction

The article deals with a case study of an automated production line for sorting and transporting products in crates to their final destination. This is a model situation created for educational purposes. The creation of such models is a suitable tool for training technicians and operators of production lines [1-5].

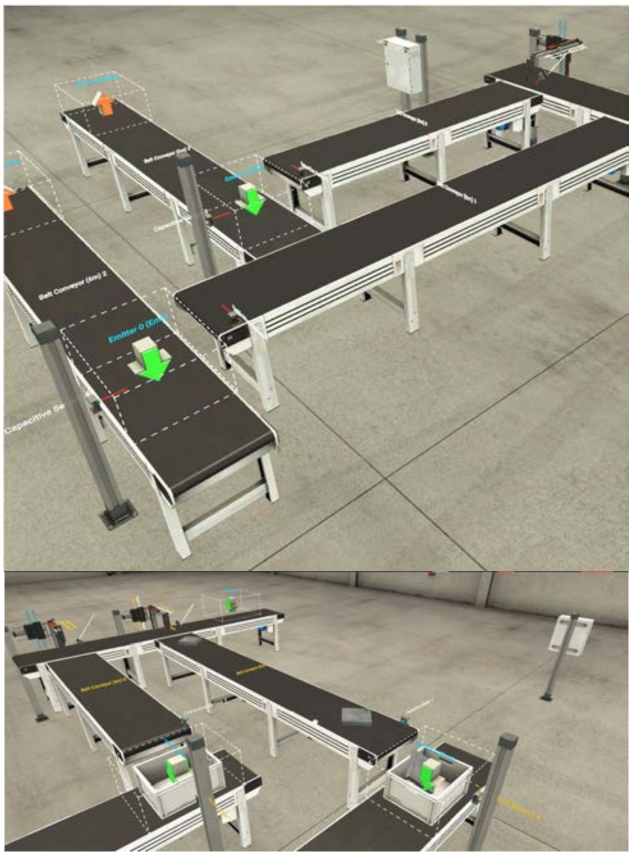

Figure 1 Sorting line concept with conveyors

The concept of this production line (Figure 1) consists of five connected conveyors. The first conveyor contains a sorting station with two linear actuators for moving the product to the next conveyor (Figure 2). The sorting and movement of the linear sorting linear actuators is automatically controlled according to the information from the sensors for detecting the material of the product, and accordingly the products are moved to the next appropriate conveyor (Figure 2).

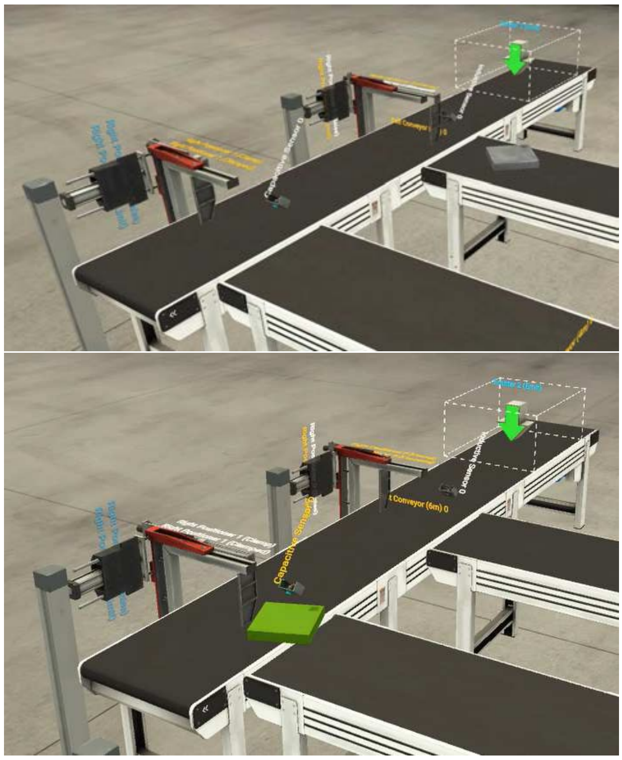

Figure 2 Sorting of products

The system includes, from the sorting conveyor, two paths of transport conveyors for the transport of sorted products. The products are then transported to the end of the conveyor where they are moved by gravity into the crate, which is placed on another conveyor located lower by the height of the crate (Figure 1). The sensor detects the gradual collection of products into the crate, and after counting the desired number of products, the crate with the products is set in motion by means of a conveyor and transported to the destination zone. From these conveyors, the parts crates are then taken to the next part of the production process.

For the purposes of the design of the control system and the program, a logistic scheme with the placement of sensors and actuators was designed (Figure 4).

The next part of the article describes the design of the control program for the PLC system, which will be the control system for this proposed sorting system (Figure 3).

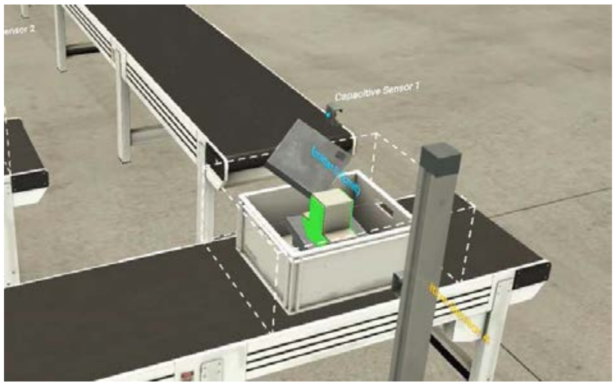

Figure 3 Storing products in a transport box

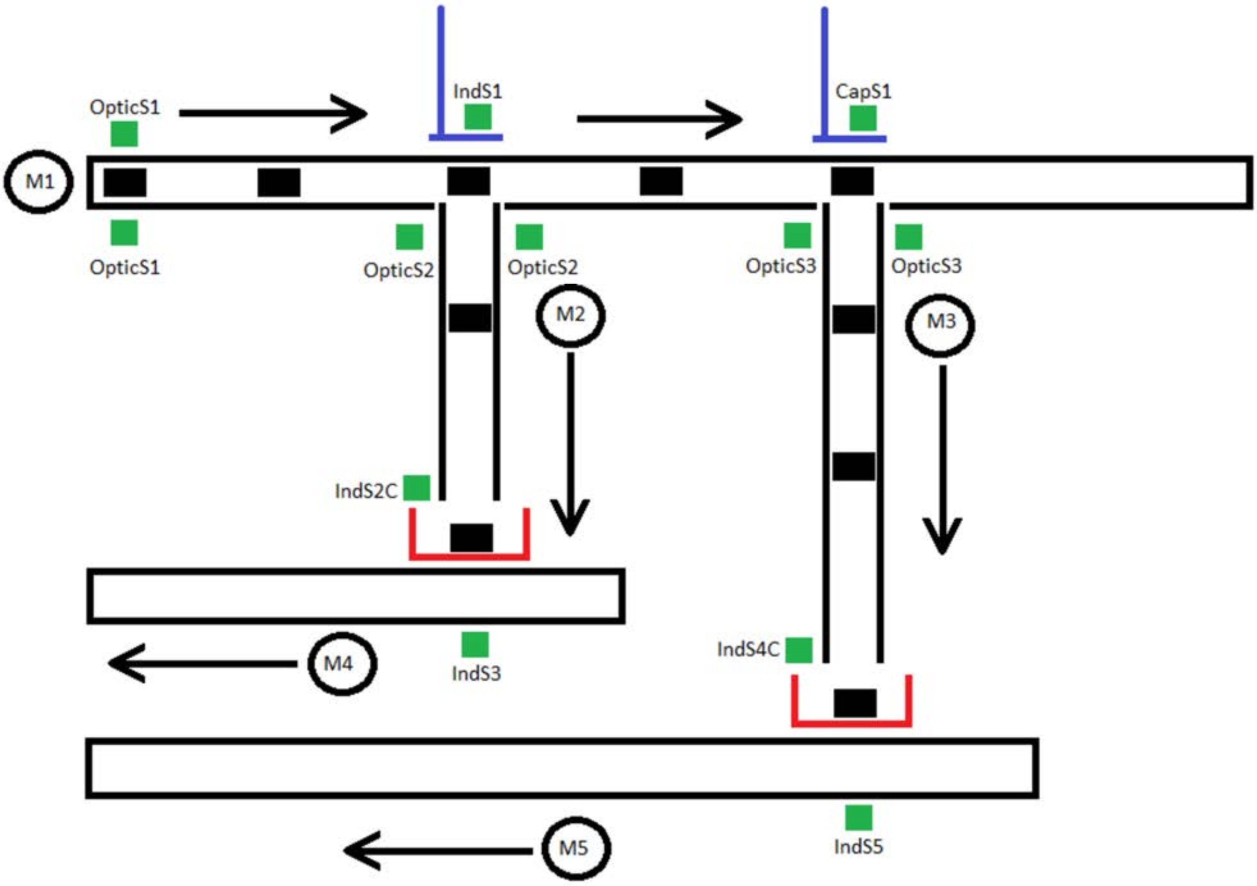

Figure 4 Schematic of the placement of sensors and actuators

2 Control program proposal

All programs for the PLC system are designed in FBD (Function Block Diagram) language. The control program for the motor M1 is designed in Figure 5 and is solved using a flip-flop SR block. The control program for the first sorting arm (Figure 6) is solved using the timer block and is connected to the corresponding sensor of the product IndS1. The control program for motor M2 (Figure 7) is compiled using a timer block and is started using information from the Optics2 sensor. The control program for the sorting arm (Figure 8) is similarly solved using a timer block triggered by information from the CapS1 sensor. The control program for the M3 motor (Figure 9) is started by the timer block connected to the OpticS3 sensor.

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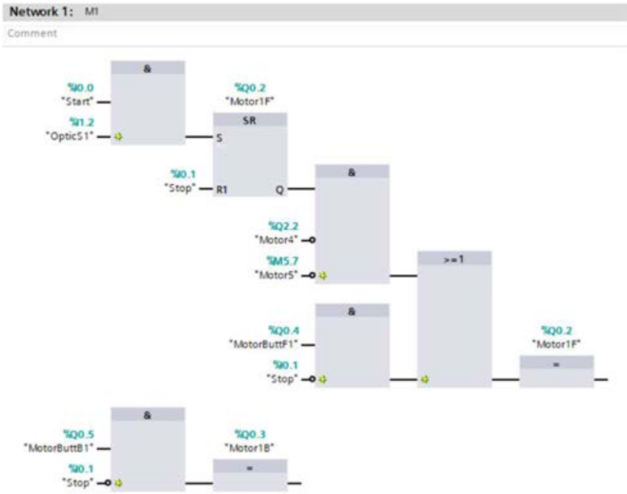

Figure 5 Control diagram for motor M1

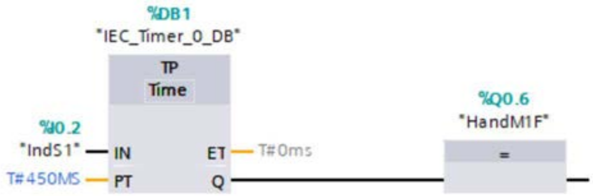

Figure 6 Control program for 1st sorting arm

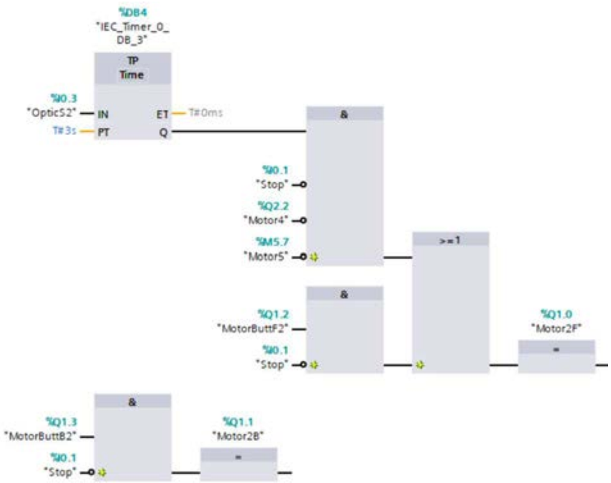

Figure 7 Control program for motor M2

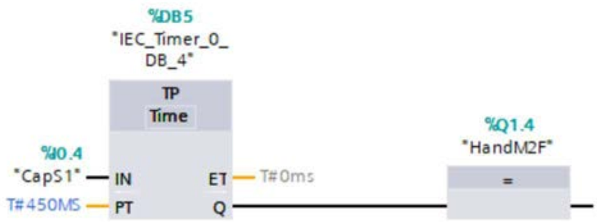

Figure 8 Control program for 2nd sorting arm

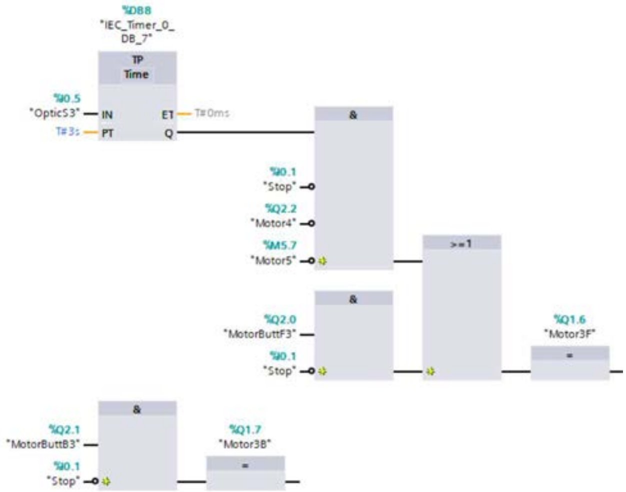

Figure 9 Control program for motor M3

The control program for motor M4 and motor M5 (Figure 10 and Figure 11) is solved using the counter block connected to sensors IndS3 and IndS5.

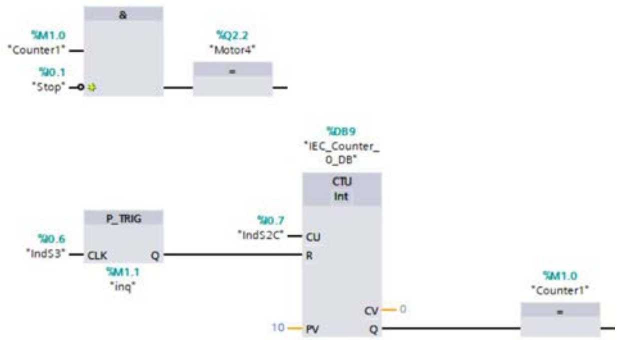

Figure 10 Control program for motor M4

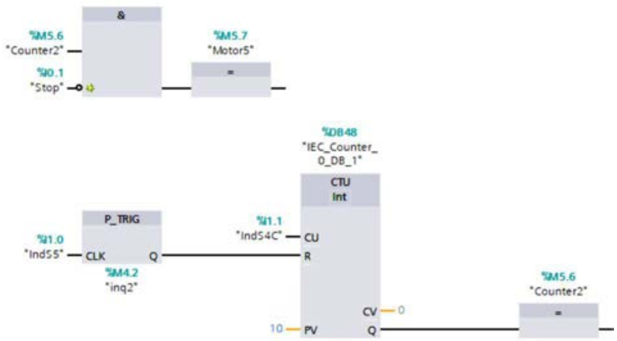

Figure 11 Control program for motor M5

The HMI (Human Machine Interface) interface (Figure 12) is designed for a 7” TFT color display. The movements of individual products are indicated using motion animation. The counting of individual products is displayed in a text window. The display also has buttons for starting and stopping the entire system, as well as buttons for manual control of the device. Product sensors are highlighted in color at the moment the product is detected on the conveyor.

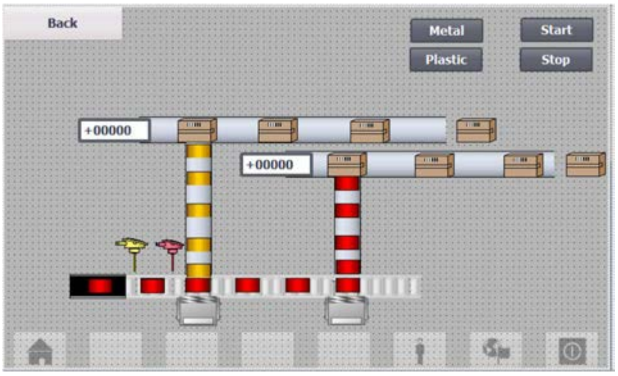

Figure 12 HMI design

3 Simulation

An essential part of the design of the control program and application for HMI is the simulation of the entire production process (Figure 13, Figure 14, Figure 15). This is a very important part because almost all the flaws and weaknesses of the design will be covered here. At the same time, the simulation will show the measures that need to be taken during the actual design of the mechanical and electrical parts.

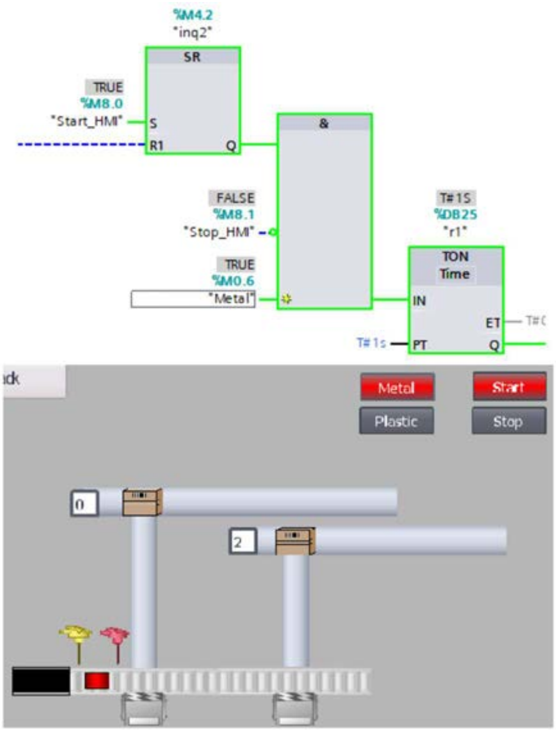

Figure 13 Simulation of metal part transport

In the simulation, it is indicated by color which parts are active with a logical value of 1 and which parts are with a logical value of 0. Along with the simulation of the block diagram, it is also possible to simulate an HMI application that is linked to the function of the FBD diagram.

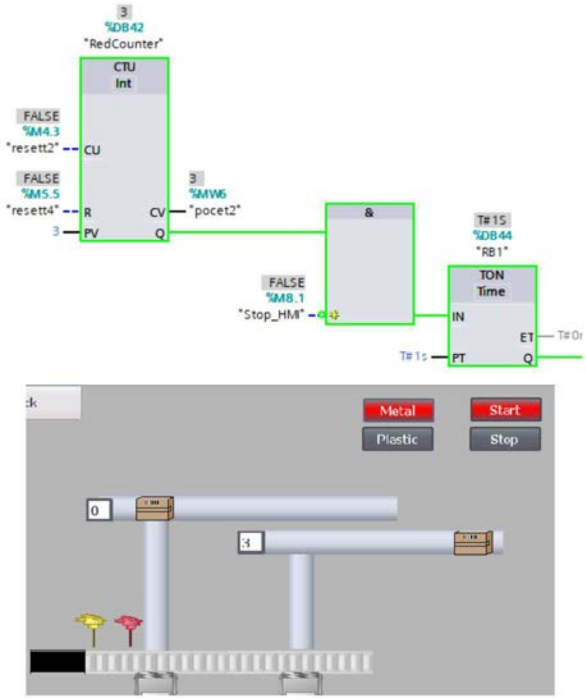

Figure 14 Simulation of box transport

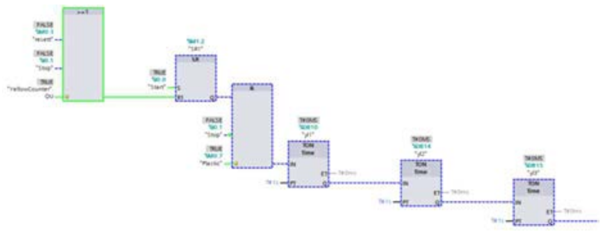

Figure 15 Simulation of transport abortion of part on conveyor

However, these simulation results are often incomprehensible to the customer, and it is more appropriate to add a visualization in a 3D environment to the simulations (Figure 16, Figure 17, Figure 18, Figure 19), where it is possible to see the movement of the products in real time and thus it is also possible to test the timing individual operations. In Figure 16 shows the arrangement of the sensors and in figure 17 the proposed arrangement of the sorting arms is shown. The collection of products into the box and the transport of the box with the product is shown in the simulations in Figure 18.

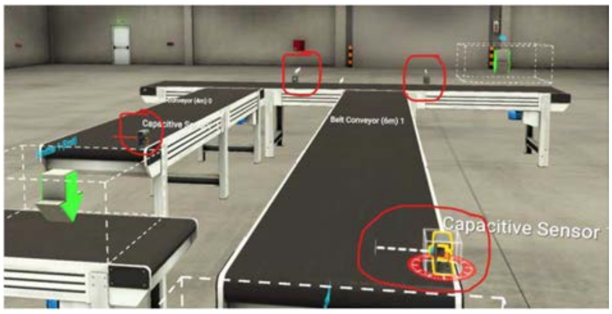

Figure 16 Placement of sensors in simulations

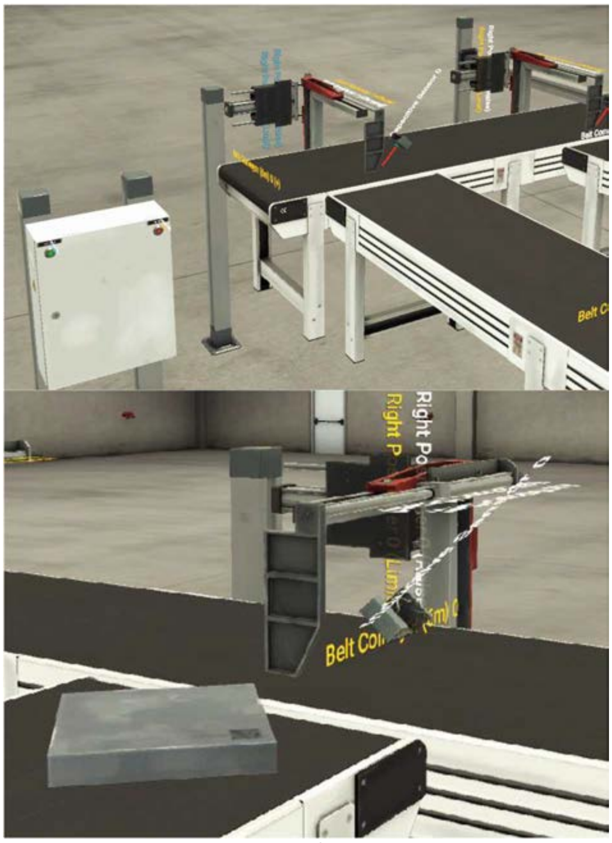

Figure 17 Creation of sorting arms

The overall view of the simulation is in Figure 19 and can be rotated and zoomed. The control panel of the device can also be part of the simulation model of the line.

The simulation confirmed the suitability of the chosen concept for an automated sorting line. The overall simulation provides a comprehensive idea of the spatial arrangement of the line and provides space for structural mechanical designs and electrical designs.

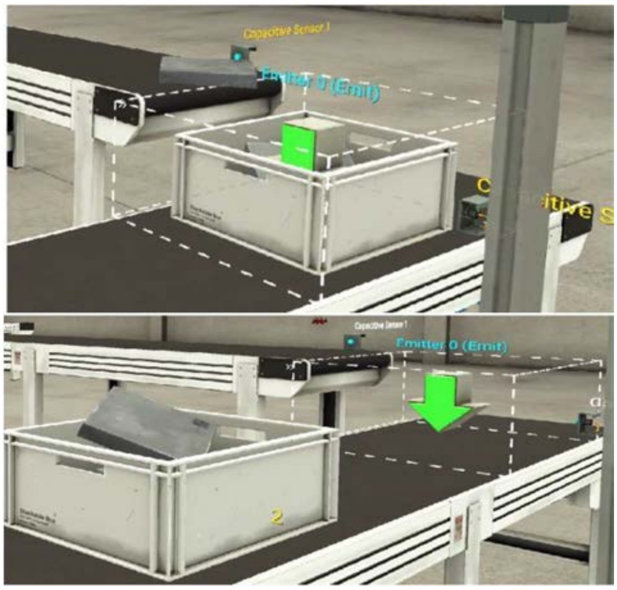

Figure 18 Box movement simulation

Figure 19 Simulation of the entire system

4 Conclusion

The article presents a methodology for designing a management concept for an automated sorting line. This concept was refined into a proposal for the arrangement of sensors and actuators, and control programs were created for individual actuators located in the device. An HMI panel with an application for process visualization and device control was also designed. Realized simulations showed the suitability of the designed concept and control programs.

Simulation proves to be a useful tool in the design of automated processes, where it offers the possibility of testing the device at an early stage of the design in order to complete the design of the device in detail and modify it from the point of view of safety and reliability, taking into account the energy point of view [6-14].

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Wheeled robot for rough terrain

Branislav Uljan
Technical University of Kosice, Faculty of Mechanical Engineering, Letna 9, Kosice, Slovak Republic, EU,
branislav.uljan@tuke.sk
Michal Kelemen
Technical University of Kosice, Faculty of Mechanical Engineering, Letna 9, Kosice, Slovak Republic, EU,
michal.kelemen@tuke.sk (corresponding author)

Keywords: robot, wheeled, rough terrain, pwm, sensor.
Abstract: The article deals with the design of a robot chassis intended for movement on uneven terrain. The chassis is composed of a front part with two parallel arranged wheels and two tiltable parts with serially placed wheels. This concept adapts to uneven ground surfaces.

1 Introduction

Wheeled chassis intended for movement in rugged terrain have rigid suspension chassis that only partially compensate for surface irregularities. The use of such types of chassis is often excluded, as they are able to overcome obstacles only up to one third of the wheel diameter. In order to overcome dimensionally larger obstacles, unnecessarily large wheels must be used, which unnecessarily increases the dimensions of the chassis and makes it impossible to apply the chassis in confined spaces. The use of unnecessarily large and heavy chassis also means increased energy requirements for the operation of such a chassis.

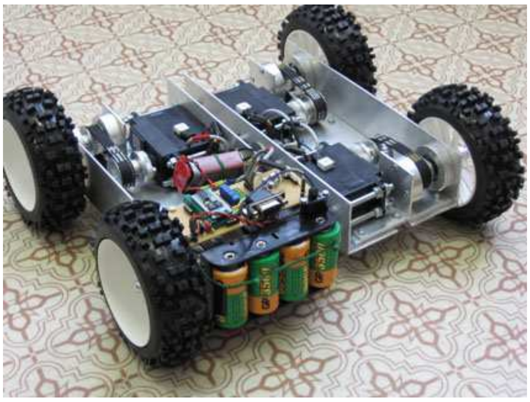

Figure 1 Wheeled robot with a longitudinally divided chassis

Previously designed mobile robots adapt well to uneven terrain, but in some cases the obstacle clearance is insufficient and the robots cannot develop sufficient traction to overcome uneven terrain (Figure 1, Figure 2).

The design of a wheeled robot with a longitudinally divided chassis (Figure 1) seems to be a good solution, but experiments have shown that this chassis concept is unsuitable for obstacles larger than the radius of the robot's wheel.

The robot with adjustable chassis height (Figure 2) already offers better characteristics when driving uneven terrain, but its stability when moving is worse, and the traction of this chassis is also insufficient for overcoming obstacles larger than the wheel radius.

A new suitable solution would be to design a chassis with six wheels with multiple joints for better adaptation to uneven terrain.

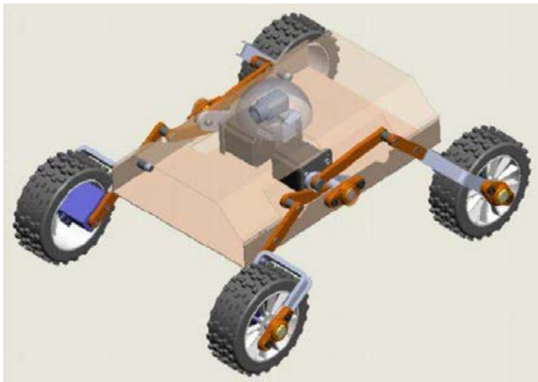

Figure 2 A robot with an adjustable chassis height

2 Control system design

This wheeled robot (Figure 3) is intended for movement on rugged terrain, while the designed arrangement allows overcoming obstacles with a height corresponding to the size of the chassis wheel diameter. With a regular four-wheel chassis, this height is only about a third to half the size of the wheel diameter.

This proposed robot concept (Figure 3) uses six driven wheels for its movement with separate motors for each wheel. Two pairs of wheels on both sides of the chassis are placed on the left and right swing arm, so that the wheels follow the terrain as best as possible during the movement of the chassis. This ensures that the wheels are in contact with the ground even on uneven terrain, thus ensuring maximum traction and the ability to overcome obstacles.

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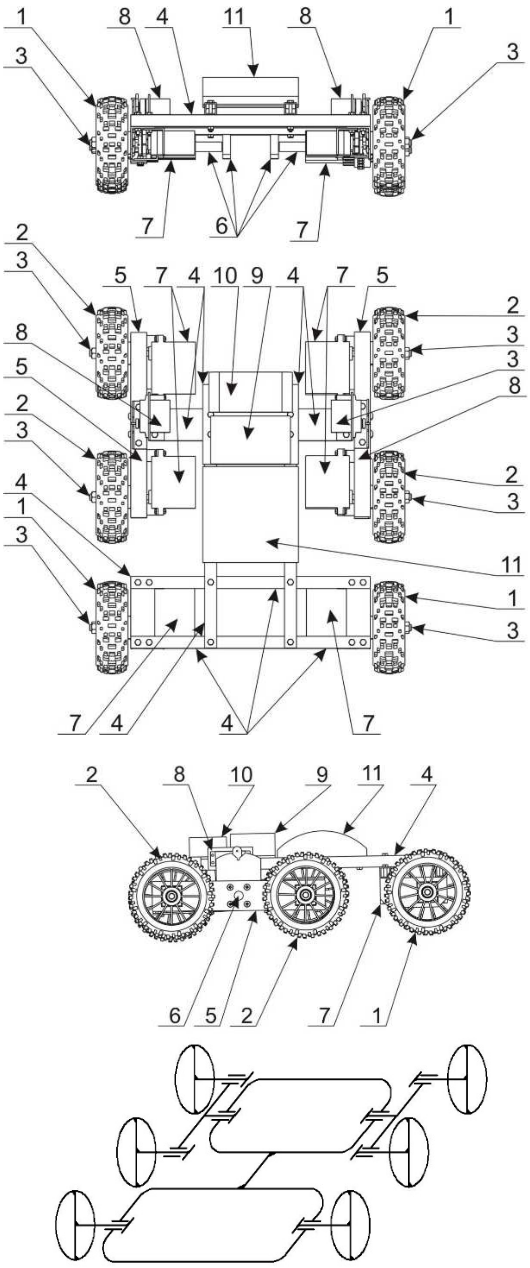

1 – Wheel stored in the frame; 2 – Wheel stored in swinging arm; 3 – Shaft with bearing and bearing housing
4 – Frame; 5 – Swing arm; 6 – Bearing mounting of swing arm; 7 – Engine with gearbox and clutch for wheel drive; 8 – Engine with lever mechanism for chassis reconfiguration; 9 – Module with electronics; 10 – Accumulators; 11 – Handling superstructure

Figure 3 Robot concept for rough terrain

The chassis of this robot (Figure 3) also has the ability to reconfigure from a six-wheeled chassis to a four-wheeled chassis. For this reconfiguration, an engine is placed to realize the reconfiguration of the chassis with a lever gear. Reconfiguration to a four-wheel chassis is more advantageous when moving on terrain without obstacles, and thus it is possible to turn off the motors of unused wheels and thus save energy in the accumulators, which makes it possible to increase the range of the chassis.

The essence of this robot consists in the fact that the chassis contains one pair of wheels on shafts with bearings and bearing housings firmly connected to the chassis frame and two pairs of wheels on the sides of the chassis, whose bearings with bearing housings are fixed on swinging arms.

The advantage of this robot lies in the fact that this arrangement makes the chassis adaptable to uneven terrain and thus achieves a better contact of the wheels with the terrain, which ensures better traction of the chassis and drivability of the terrain.

In addition, this chassis can be reconfigured if necessary, i.e. changed from a six-wheeled to a four-wheeled one.

The designed robot (Figure 3) contains six wheels (1), (2) and a frame (4) with swinging arms (5). In the front part, the frame (4) has wheels (1) on both sides attached to the shafts and stored in bearings with bearing housings (3). In the rear part of the frame (4), in the bearing housings (6), swinging arms (5) are placed on both sides, on which are placed two wheels (2) fixed on the shafts in bearings and bearing housings (3). The rotation of all wheels is ensured by a separate motor with a gearbox and clutch (7) for each wheel (1), (2) separately. Swinging arms (5) with wheels (2) rotate freely in the bearing housing (6) according to terrain irregularities. The swinging arms (5) can also be tilted using a motor with a lever mechanism for reconfiguration (8). By tilting the swinging arms (5), it is possible to reconfigure the chassis from a six-wheeled to a four-wheeled one, in which it can move on flat terrain without obstacles in a more energy-efficient mode. In the case of uneven terrain, it is possible to reconfigure the chassis to a six-wheeled one using the engine with a lever mechanism (8), which better copies the uneven terrain and thus achieves better traction. The module with electronics (9), accumulators (10) and handling superstructure (11) are located in the upper part of the frame (4).

3 Simulation of crossing an obstacle the size of a wheel

With a suitable distribution of weight on all wheels, a chassis with this concept should be able to overcome obstacles with a height corresponding to the size of the wheel diameter, such as a curb. With a regular four-wheel chassis, this height is only about a third to half the size of the wheel diameter.

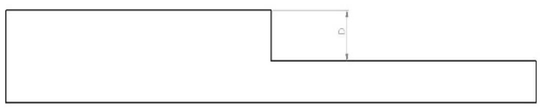

Figure 4 The shape and size of the obstacle

For these purposes, a simple chassis model with such a concept was built in the simulation program based on the kinematic diagram and simulated when passing such an obstacle.

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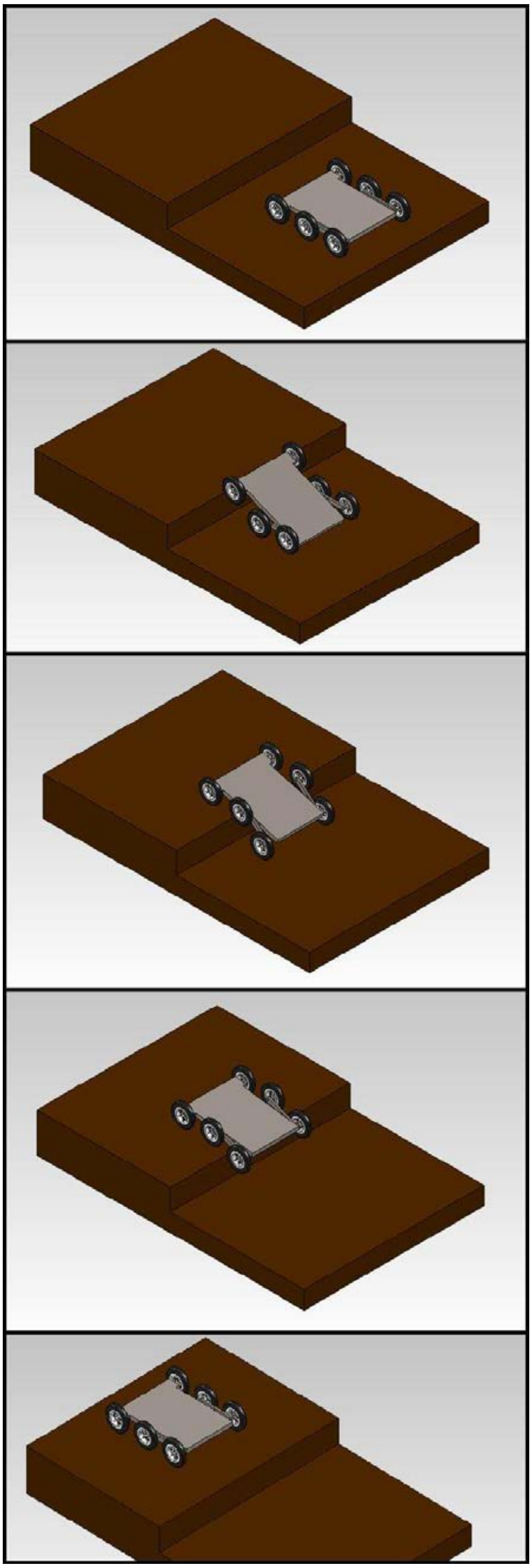

Figure 5 Phases of the robot crossing an obstacle

The chassis of the robot overcomes the obstacle in such a way that each axle overcomes it individually.

4 Design of robot chassis drives

An approximate calculation (1) was used for the design of the robot chassis drives:

$$F_{app} = m \cdot g \cdot (\mu \cdot \cos\alpha + \sin\alpha + \frac{a}{g} \cdot \vartheta) \qquad (1)$$

Where:

- m is the weight of the robot, we assume a total weight of 6kg with a load capacity of 2kg
- g - gravitational constant
- μ - traction coefficient of friction
- α - the maximum slope of the terrain, considered is 30°
- a - chassis acceleration
- R - wheel radius, resulting from the selected wheels
- υ - coefficient of rotational resistance
- J_c - total moment of inertia of all parts needed for later calculation
- k_b - safety coefficient

It is possible to determine the approximate movement speed of the robot for the selected drive (2):

$$v = \left(1 - \frac{M1}{M}\right) \cdot n \cdot \pi \cdot 2 \cdot R \qquad (2)$$

5 Chassis reconfiguration mechanism

When moving the chassis, it may be advantageous to raise the wheels of the middle axle so that they do not contact the ground. This is how we get a four-wheel chassis with a rigid frame. We can prevent free rotation of the arms, slightly raise the action superstructure, turn off the motors of these wheels and thus save energy.

When designing the mechanism, an effort was made to minimize the consumption of the motor used for reconfiguration when the axle is raised. There was also an effort to ensure that the arm could tilt freely as it is in the original concept of the chassis, and only in the case of lift, this rotation was blocked (Figure 6).

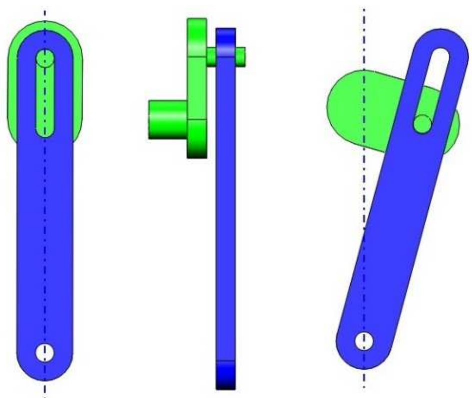

Figure 6 Reconfiguration lever mechanism

The mechanism is based on two levers. One of them (green) is driven by a motor. This lever has two positions. Turning it also turns the second lever (blue). In this second position, when the moment is applied to the second lever, the force of the drive motor is not needed, since the force transmitted to the first lever passes through the axis of its rotation and thus acts only as a radial force (Figure 7, Figure 8).

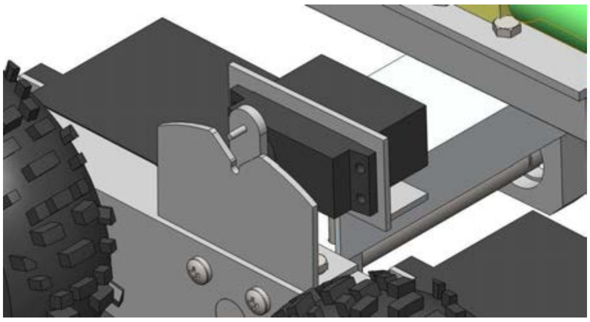

Figure 7 Construction of the reconfiguration mechanism

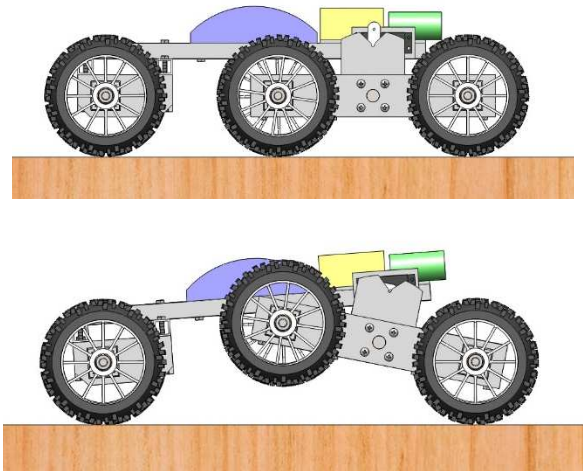

Figure 8 Reconfiguration of the robot chassis

The designed wheel bearing shaft was dimensioned and checked using the Finite Element Method. Stresses are reduced according to the Mises theory of strength (Figure 9, Figure 10).

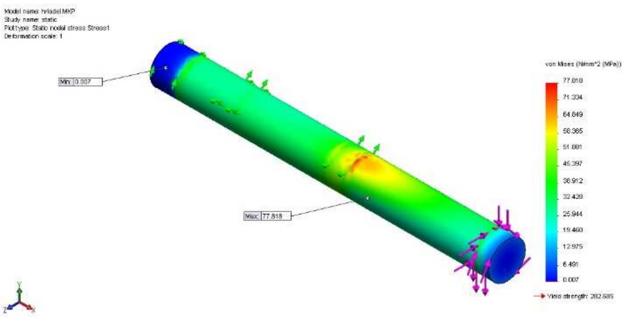

Figure 9 Calculated stresses on the shaft

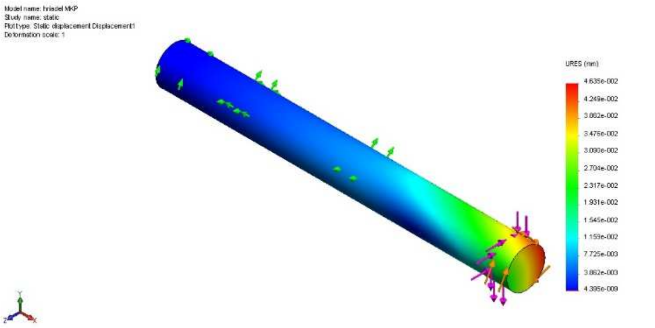

Figure 10 Calculated deformations on the shaft

The frame (Figure 11) is composed of aluminium alloy profiles. The wheel shafts as well as the swing arm shaft are made of steel. The material of the bearing houses is an aluminium alloy. The wheels are fixed on the shaft with a nut. The control of stresses and deformations is in Figure 12.

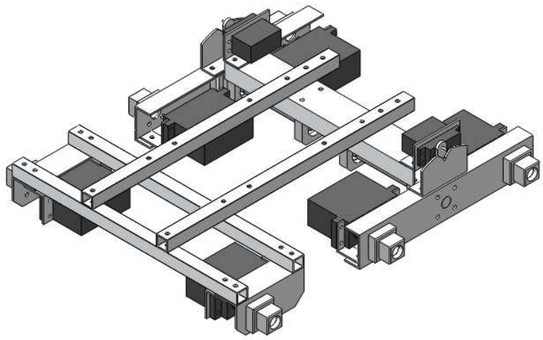

Figure 11 The designed chassis frame of the robot

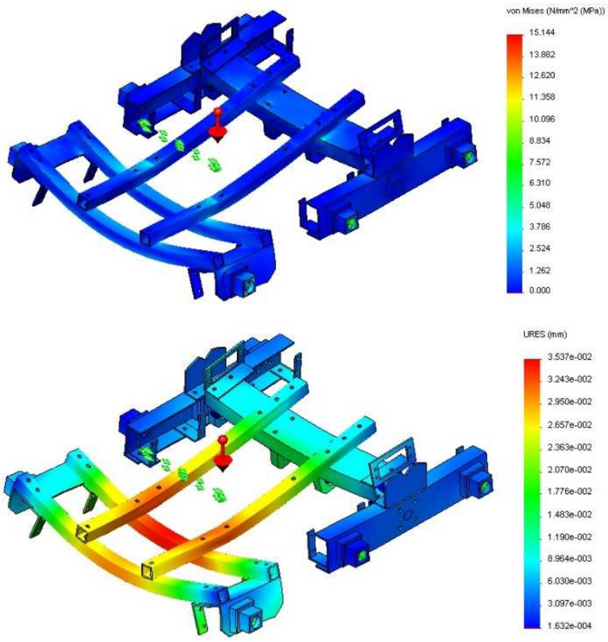

Figure 12 Stresses and deformations of the robot chassis frame

The designed swinging arm was loaded with the estimated force during the simulations and the stresses and strains were determined (Figure 13).

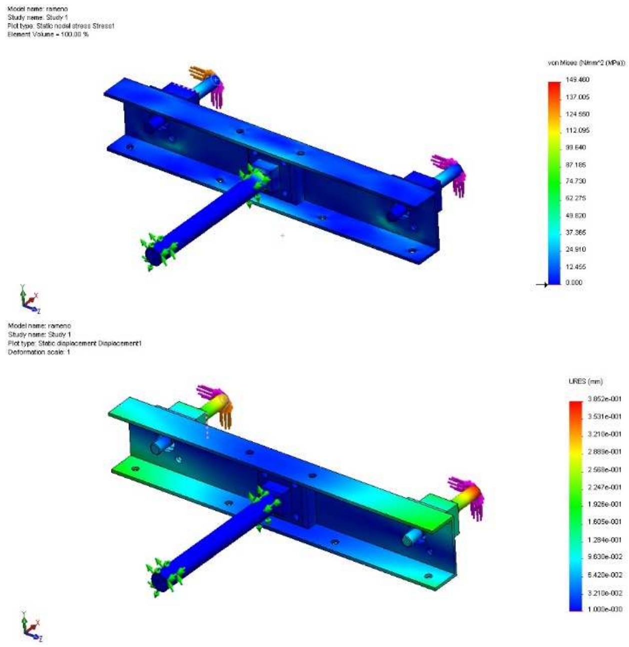

Figure 12 Stresses and deformations of the swinging arm

The realized prototype of the mobile robot was experimentally verified both indoors and outdoors on obstacles exceeding the size of the wheel, and the robot overcame all test obstacles.

Figure 13 Mobile robot prototype

6 Conclusion

The article discussed the design of a mobile robotic chassis that better overcomes locomotion over uneven terrain and is able to overcome obstacles even higher than the size of the wheels, even without increasing the height of the robot chassis and increasing the height of the center of gravity. The proposed solution is even redundant and reconfigurable because it contains an additional degree of freedom in the chassis for modification of the chassis or improvement of maneuverability when overcoming obstacles.

A similar approach to improving the properties of products can also be applied in other areas where innovation and the addition of new functions to existing products is needed.

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