Description of the technology

Your task is to develop the control software for an automated retrieval system inside an automated warehouse. The system forwards totes (boxes) from storage bays to the output conveyor using a rail-guided cart (see Figure 1).

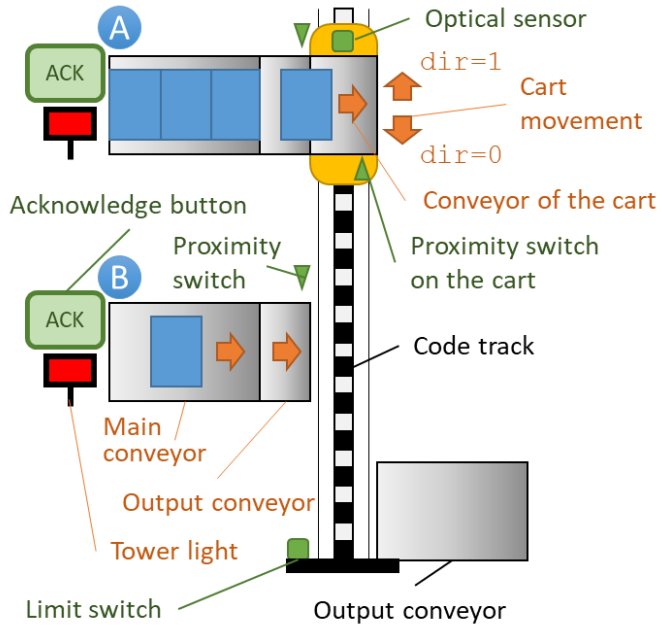

Figure 1 - Automated retrieval system

Storage bays are equipped with two conveyors, which can be driven individually. Totes are stored on the main conveyor, which – when turned on – transfer them to the output conveyor, which forwards the first tote onto the cart. A proximity switch is installed next to the output conveyor, which provides an active signal if a tote has reached the end of the output conveyor. Storage bays are also equipped with a tower light to notify the operator if the main conveyor is empty, and a pushbutton, which is used to acknowledge the refill of the storage bay.

The cart is moved along the track by a motor with direction set by a PLC output. A code track with black and white stripes is installed next to the track and is observed by an optical sensor on the cart. By counting the rising edges of its signal, the position of the cart can be determined (see incremental encoders).

The cart is also equipped with a roller conveyor and a proximity switch next to it.

Totes shall be transported to the output conveyor of the system (note that it is different from the output conveyor of a storage bay), which is located at the end of the track and is running constantly. At the position of the cart corresponding to the output conveyor (i.e. at the end of the track), a limit switch is installed, which is active if the cart is at the end of track.

Specification

Storage bays shall be operated the same way. When the system is turned on, output conveyors of the storage bay is empty. Then both conveyors (both the main and the output conveyor) shall be turned off and kept running until a tote arrives at the proximity switch of the bay. When the signal of the proximity switch changes to active, both conveyors shall be stopped immediately.

When a tote shall be transferred from the storage bay and the cart has arrived, the output conveyor of the station shall be turned on (the main conveyor shall be kept off). As soon as the tote on the output conveyor leaves the proximity switch (i.e. its signal changes to inactive), the main conveyor shall be turned on and the two conveyors shall be kept running until an other tote reaches the proximity switch.

If no tote arrives at the proximity switch within 3 seconds after turning the main conveyor on, the storage bay is considered empty. Then both conveyors shall be switched off and the operator shall be notified by turning the tower light on. The operator acknowledges the refill of the storage bay by pressing the ACK button (this pushbutton needs to be protected against weighing down, i.e. you shall use the edge and not the level of its signal). After the acknowledgment the tower light shall be switched off and both conveyors shall be started and kept running until a tote reaches the proximity switch.

The position of the cart is unknown when the system is initialized, so it shall moved to the limit switch by turning the motor on and setting the direction output to 0. When the limit switch is reached, the motor shall be immediately turned off. If the retrieval of a tote is requested, the cart shall be moved to the corresponding storage bay by turning the motor on and setting the direction output to 1. Position of the cart can be determined by counting the rising edges of the optical sensor. The counter shall be reset every time the cart reaches the limit switch next to the output conveyor (reference position).

As the cart reaches a storage bay, the roller conveyor on it shall be turned on (output conveyor of the storage bay shall be turned on at the same time). When the signal of the proximity switch on the cart becomes active, the roller conveyor shall be turned off and the cart shall be moved to the output conveyor of the system by turning the motor on and setting the direction output to 0 (there is no need to count the edges of the optical sensor, the cart shall move until the limit switch turns active).

When the cart reaches the end of the track, it shall be turned off and the roller conveyor on the cart shall be turned on. The conveyor shall be switched off 1 second after the signal of the cart's proximity switch becomes inactive. The cart shall be kept at the limit switch until a new retrieval operation is requested.

The control system communicates with the Warehouse Management System (WMS) using 3 digital and 1 numeric channel. The WMS requests the retrieval of a tote by a rising edge on the request input of the PLC (`%IX0.7`). The SKU (identifier of the product stored in the totes) is available as an 8-bit unsigned integer at the input channel `%IB1` of the PLC. Note that this value might vary during the operation, so the SKU shall be considered valid only when a rising edge of the request input is detected.

The control system sends to signals towards the WMS. If the cart is at the limit position (at the output conveyor of the system) and has no tote on it (i.e. the conveyor of the cart is off), the ready output (`%QX0.6`) shall be active. The WMS sends a new request only while the ready output is active, i.e. rising edge of the input `%IX0.7` can occur only if the value of output `%QX0.6` is 1.

Upon a request for retrieval, the control system can decide whether it can be fulfilled or not. It the SKU does not correspond to either of the storage bays or the corresponding bay is empty, the output corresponding to an invalid request (`%QX0.7`) shall be active until the next request (rising edge of `%IX0.7`). Otherwise, the output `%QX0.7` shall be set to 0 and the cart shall be started towards the corresponding storage bay. Parameters of the storage bays are given in Table 1.

Table 1 - Parameters of the storage bays

Station	Position (increment)	SKUs stored
A	158	2, 3, 4, 5, 6, 7
B	78	39, 40, 41, 42, 43, 44, 45

Simulation environment

The project archive `automatedRetrieval.projectarchive`, which you can download from the web site of the course, includes the device driver and library required for the simulation of the process, as well as a template project with a visualization screen of the system. The file can be opened by the File > Project Archive > Extract menu command. The dialog displayed after opening allows selecting the directory to extract the archive and choosing which components to install (see Figure 2). You shall keep all the checkboxes checked for correct operation.

After clicking the Extract button, the archive is processed, device drivers and libraries are installed to CODESYS and finally the template project is opened.

Extracting the archive is necessary only when opening the project archive for the first time. After that the project (a file with extension `.project`) can be directly opened from the folder to where it has been extracted (as set in the dialog).

PLC inputs and outputs connected to the simulated process are given by Tables 2 and 3, while the visualization screen is shown by Figure 3.

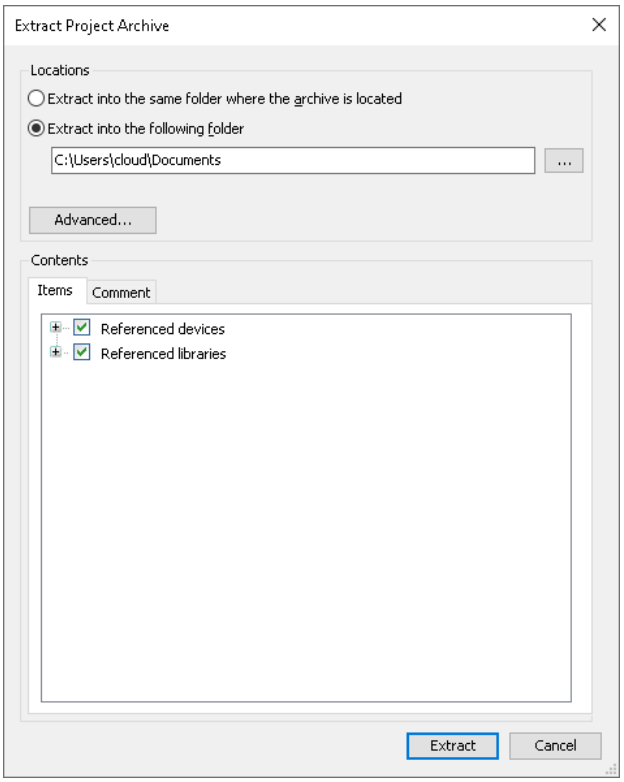

Figure 2 - Extract Project Archive dialog

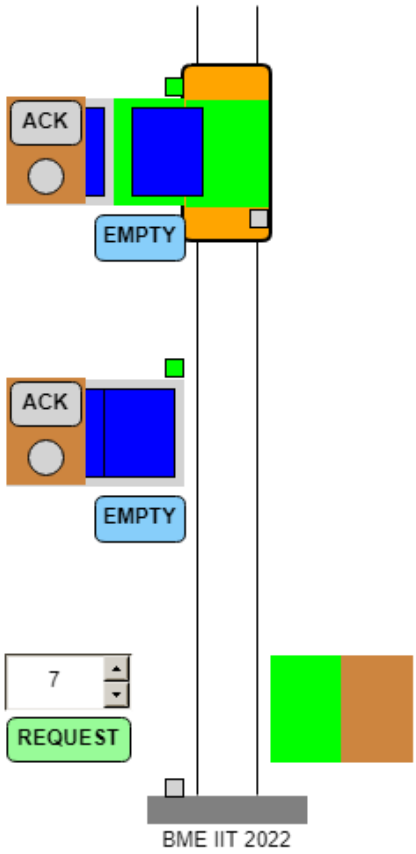

Figure 3 - HMI screen

The visualization shows running conveyors in green. Proximity switches of the storage bays, which are represented by small boxes above the output conveyors, also change their color to green if their signal is active. The circles at the storage bays, which represent the tower lights, turn red when activated. The ACK pushbutton acts as a switch (i.e. it changes its state when clicked), so protection against weighing down can be tested.

Clicking the EMPTY button below a storage bay removes all but the first tote from the corresponding station, hence it can be emptied fast. Totes are repositioned on the main conveyor when the ACK button is pressed.

Position of the cart changes according to the PLC outputs, the conveyor and the proximity switch are displayed in green when active, similarly to the storage bays and the box corresponding to the limit switch, located near the track at the bottom. As the signal of the optical sensor on the cart changes with a frequency higher than the refresh rate of the HMI, its state is not represented.

The SKU requested by the WMS can be set in the input field at the bottom both by typing or using the spin buttons. Level of the request input can be set by the REQUEST pushbutton, which also acts as a switch. As the WMS can only request a new item when the system is ready, the signal can be changed active only if the ready output (`%QX0.6`) is active.

If the control output of the control system corresponding to the fact that the request can not be fulfilled, the background of the numeric input changes to red.

The simulation is stopped and a HALT signal is displayed in the following cases:

- a tote is forwarded from a storage bay while the cart is not at the correct position
- a tote is forwarded from the cart while it is not at the output station of the system
- the cart moves to the same direction after reaching the end of the track

Certain elements of the project are password protected. You are not required to modify those elements.

Table 2 - PLC inputs

Address	Description
%IX0.0	Proximity switch of storage bay „A” (1: tote at the end of output conveyor)
%IX0.1	Acknowledgment button of storage bay „A”
%IX0.2	Proximity switch of storage bay „B” (1: tote at the end of output conveyor)
%IX0.3	Acknowledgment button of storage bay „B”
%IX0.4	Optical sensor on the cart (position can be determined by counting its rising edges)
%IX0.5	Limit switch at the output conveyor of the system
%IX0.6	Proximity switch on the cart
%IX0.7	Request form WMS
%IB1	SKU requested (USINT)

Table 3 - PLC outputs

Address	Description
%QX0.0	Main conveyor of storage bay „A” (0: off, 1: on)
%QX0.1	Output conveyor of storage bay „A” (0: off, 1: on)
%QX0.2	Tower light of storage bay „A” (0: off, 1: on)
%QX0.3	Main conveyor of storage bay „B” (0: off, 1: on)
%QX0.4	Output conveyor of storage bay „B” (0: off, 1: on)
%QX0.5	Tower light of storage bay „B” (0: off, 1: on)
%QX0.6	Ready signal to the WMS (1: the system is ready to accept a request)
%QX0.7	Request can not be fulfilled signal to the WMS (1: request can not be fulfilled)
%QX1.0	Cart motor on/off (0: off, 1: on)
%QX1.1	Cart motor direction (0: towards the output conveyor of the system)
%QX1.2	Roller conveyor on the cart (0: off, 1: on)

Assignment

Develop a program using **structured text (ST)** language which controls the automated retrieval system according to the specification.

Requirements

- You shall use the CODESYS 3.5.18.20 environment and the template project provided for the assignment (automatedRetrieval.project).
- You are allowed to use structured text (ST) programming language solely.
- You shall define a freewheeling task with priority value higher than 0 to schedule the execution of the program.
- You are free to declare any local variables and function block instances.

Submission

CODESYS project of the solution (one single file with the extension `.project`) shall be submitted at the web page of the course (https://edu2.cloud.bme.hu/BMEVIIIAC03). By uploading the project, you state that you have solved the assignment individually, without use of illegal assistance. No other documents beside the project shall be submitted.

Solutions are checked within 72 hours of submission and you will be informed about the result by email. Incorrect solutions might be corrected any time before the deadline. The assignment is accepted if the solution uploaded to the web site is correct at the moment of the deadline.

Projects which can not be compiled are not accepted and can not be corrected during the study period.

Deadline: 4 December 2022. 14:00:00

Tips

- You shall define a function block type for the control of the storage bays. Add an input which can be used to request the forward of a tote from the output conveyor to the cart and an output which reports whether the storage bay is empty.
- Control of the cart can be implemented in the main program (however it is recommended to use a function block).
- You shall implement state machine-based control. Review the desired operation, draw its state diagram, establish the output mapping and implement the control algorithm!
- Don't limit the number of state variables used – if you need an auxiliary variable (e.g. an input variable) beside a state variable to set the value of an output, you shall decompose the given state to multiple states.
- Appropriate use of a `CASE` structure helps a lot when selecting the storage bay corresponding to a given SKU.
- You shall count the rising edges of the optical sensor only when moving towards the storage bays – when returning to the output conveyor of the system, the cart shall simply move until it reaches the limit switch.
- The task is simple - do not overcomplicate the solution!
- Don't forget to define a task for scheduling your program!
- Don't forget to start the softPLC before download! The softPLC is stopped after two hours, so if a download error occurs, you might need to start it again.
- Check your solution by simulating all possible scenarios (right and wrong SKUs, empty storage bays etc.)!