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Test Bench Concept for Testing of Gripper Properties in a Robotic Palletizing Process

Jarosław PANASIUK*, Wojciech KACZMAREK, Michał SIWEK, Szymon BORYS

Military University of Technology,
Faculty of Mechatronics, Armament and Aerospace,
2 Sylwestra Kaliskiego Str., 00-908 Warsaw, Poland
**Corresponding author's e-mail address and ORCID*:
jaroslaw.panasiuk@wat.edu.pl; https://orcid.org/0000-0001-8480-1654

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Abstract. Palletizing and depalletizing processes require specialized equipment, such as grippers dedicated to the type and dimensions of the goods to be handled. The traditional approach used in the robotisation of palletizing workstations is therefore mainly based on the development of specialized grippers, whose design limits their use in other applications. The article presents a concept of a modular gripper system enabling palletization of goods in collective packaging, including cartons, shrink-wrap packs, and bags. The concept developed involves the construction of a gripper system based on common modules that provide for extensive parameterization of device operation. The authors also propose a test bench to test the properties of grippers in a robotic palletizing process.
Keywords: gripper, industrial robot, high speed camera, IMU, palletizing

1. INTRODUCTION

Palletizing is a process that can be used to fully prepare goods for storage and further distribution. It complements product logistics and ensures an efficient flow of products between the producer and the end customer[1]. Hence, palletizing and depalletizing processes are among the most common robotic processes found in virtually all industries [2]–[4]. These processes include palletizing products in a variety of packaging, including: boxes and cartons, trays and shrink wrap, crates, drums, cans, bags, and buckets. Designers of robotic palletizing workstations strive to create flexible workstations using industrial robots with dedicated attachments (grippers) [5]–[8]. It would seem that this approach offers an easy way to use this type of workstation for different applications. Unfortunately, most gripper design solutions available on the market are developed for specific products, so there is very little room for change of parameters.

The issue of robotic palletizing is widely known. Almost every robot manufacturer offers solutions dedicated to palletizing operations. However, the gripper design is centred around several groups of solutions resulting from the type of goods to be palletized. This is inextricably linked with the gripping method, with such options as force-fit, form-fit or combined, and the characteristics of the palletized goods. On construction, solutions are patented in global and national databases [9]–[12].

For goods packed in collective packaging (cartons, shrink-wrapped packs), it is common practice to use jaw grippers to grip the entire layer of goods from all four sides as long as there is no contact with fragile or sensitive goods. This solution is cheap, simple and effective.

Goods that are more susceptible to damage from gripper arm clamping require a device that allows the goods to be picked using form-fit gripping. This type includes the fork gripper, for instance.

Other examples of palletized goods include bulk goods in bag-type packaging. For this purpose, bag grippers are very often used, which, due to the method of picking (often from roller conveyors), the nature of the bag and the way it is filled with contents, require form-fit gripping.

The concept presented here involves the development of a gripper system comprising four devices that allow a relatively wide range of parameterization of operation. The assumption was made that there would be common modules in the individual devices of the system, on the mechanical (main mounting plate), pneumatic (control valves) and electronic (control system) levels. On the one hand, such a solution allows for partial hardware unification, which may facilitate repairs in case of mechanical problems and failures, and on the other hand, thanks to universal software, standardizes the robot-gripper communication. One important aspect for the construction and design of grippers is that tests must be carried out to evaluate the properties in a real workstation.

In section two, the authors discuss the design assumptions for a modular smart gripper system. The third section describes the conceptual design of the mechanical and software parts. In the fourth section, the authors present the concept of a gripper property test bench with a real industrial robot, a high-speed camera and MTi XSENS sensors. Section five contains the conclusions.

2. CONCEPTUAL DESIGN

The concept for the modular gripper system for the palletizing process was based on the requirements set by a client. These requirements applied to the following types of grippers:

- Roller Layer Gripper for handling full layers of Euro-pallet sized products.
- Compression Layer Gripper for handling full layers of Euro-pallet sized products.
- Bag Gripper for palletizing 20–50 kg bags.
- Fork Gripper for line palletizing.

2.1. Roller layer gripper for handling full layers of Euro-pallet sized products

As requested by the client, the gripper should pick up layers of products using a roller system and place them on pallets (in layers). In addition, the gripper should place paper/cardboard dividers on the pallet and be expandable to include a pallet gripper/handler.

Main gripper parameters:

- Supports 1200 mm × 800 mm pallet layers. The gripper should be scalable to handle layers of 1200 mm × 1000 mm, 1200 mm × 1200 mm and 1100 mm × 700 mm to 1300 mm × 900 mm.
- The gripper weight should not exceed 205 kg.
- The load capacity of the gripper should be capable of handling a layer of up to 100 kg.

2.2. Compression layer gripper for handling full layers of Euro-pallet sized products

The gripper should pick up and place a layer of products on the pallet by pressing on four sides with two sections. In addition, the gripper should place paper/cardboard dividers on the pallet and be expandable to include a pallet handler.

Main gripper parameters:

- Supports 1200 mm × 800 mm pallet layers. The gripper should be scalable to handle layers of 1200 mm × 1000 mm, 1200 mm × 1200 mm and 1100 mm × 700 mm to 1300 mm × 900 mm.
- The gripper weight should not exceed 130 kg.
- The load capacity of the gripper should be capable of handling a layer up to 180 kg.

2.3. Bag gripper for palletizing 20–50 kg bags

The gripper should pick up and place bags up to a total weight of 50 kg. In addition, the gripper should be able to form bags (using internal side compression force) and pick up and place paper/cardboard pallet dividers.

Main gripper parameters:

- Supports the following bag configurations: 1 × 20–25 kg, 2 × 20–25 kg, 1 × 50 kg.
- The gripper weight should not exceed 55 kg.
- The load capacity of the gripper should be capable of handling bags up to 50 kg.

2.4. Fork gripper for line palletizing

The gripper should be able to pick up products, including bags, and place them on a pallet. In addition, the gripper should be able to pick and place paper/cardboard dividers on the pallet.

Main gripper parameters:

- Supports cartons and bags up to 800 mm wide.
- The gripper weight should not exceed 55 kg.
- The load capacity of the gripper should be capable of handling products up to 60 kg.

3. MODULAR GRIPPER SYSTEM CONCEPT

Based on the client's requirements outlined in section 2, a structural solution for the gripper system was proposed. One of the main assumptions in the design work was to design common hardware and software modules of the gripper system for individual devices.

3.1. Roller layer gripper concept

Taking into account the maximum size of the load to be carried by the gripper and the assumption regarding the method of driving the rollers and the method of depositing the goods, we conceptually assumed a construction using a set of two independently driven rollers.

Figures 1 and 2 show the overall concept of the roller gripper with the main elements marked. The gripper is mounted to the robot flange at the mounting point (Fig.1-1). To pick up a product layer, the gripper control closes the two roller sections (Fig. 2-4) with chains (Fig. 2-2). The roller conveyor pushes the product layer into the gripper, while forming barriers and pneumatic pressure ensure correct positioning. At the drop-off point, the roller sections are open and the product is deposited in the storage area.

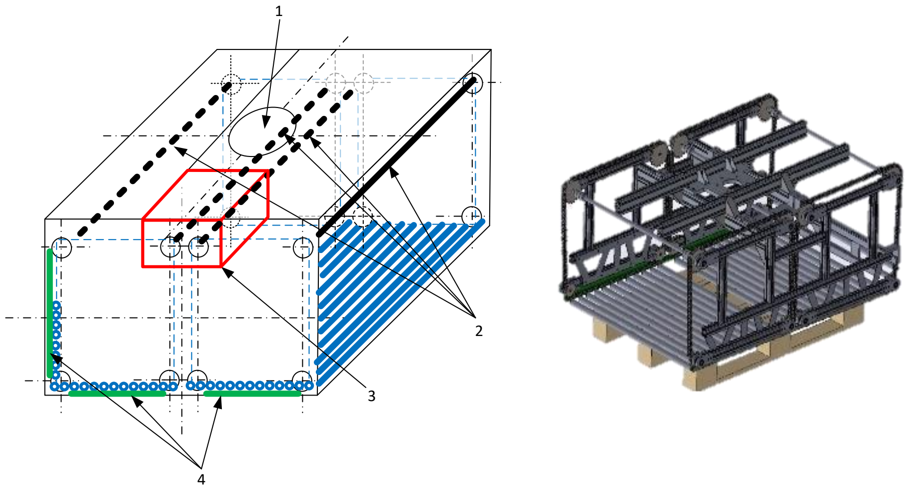

Fig. 1. Conceptual drawing of the roller gripper
1 – mounting location, 2 – axes coupling the roller ends, 3 – drive for independent chains, 4 – chain guides

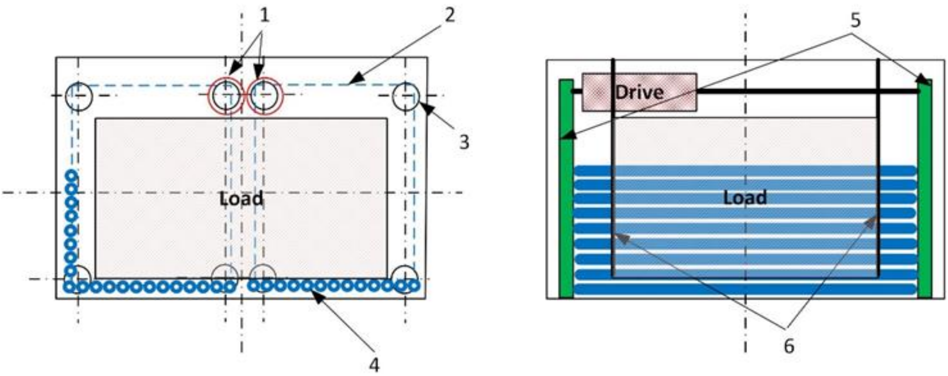

Fig. 2. Roller gripper working principle
1 – chain drive motors, 2 – drive chain, 3 – sprocket, 4 – rollers, 5 – chain guides, 6 – layer forming barriers

3.2. Compression layer gripper concept

Taking into account the maximum dimensions of the objects to be moved and their total weight, a structure based on two pneumatically controlled compression sections was assumed (Fig. 3).

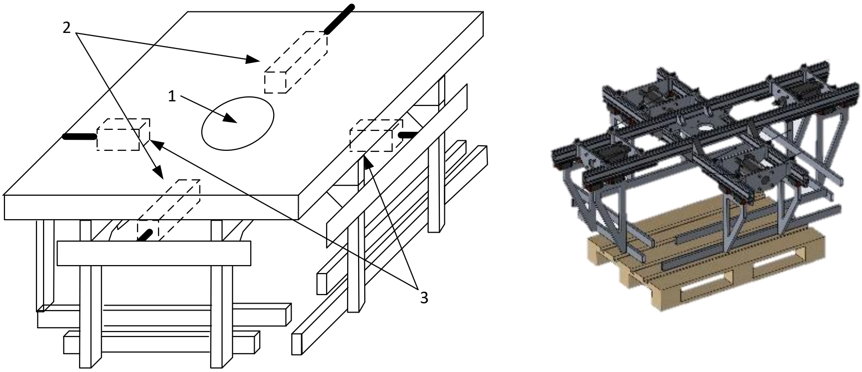

Fig. 3. Conceptual drawing of the compression gripper
1 – mounting location, 2 – section 1, 3 – section 2

The gripper must be able to handle product layers with dimensions of 1100–1300 mm × 700–900 mm. The proposed solution enables manual adjustment of the section spacing by up to 200 mm (Fig. 4).

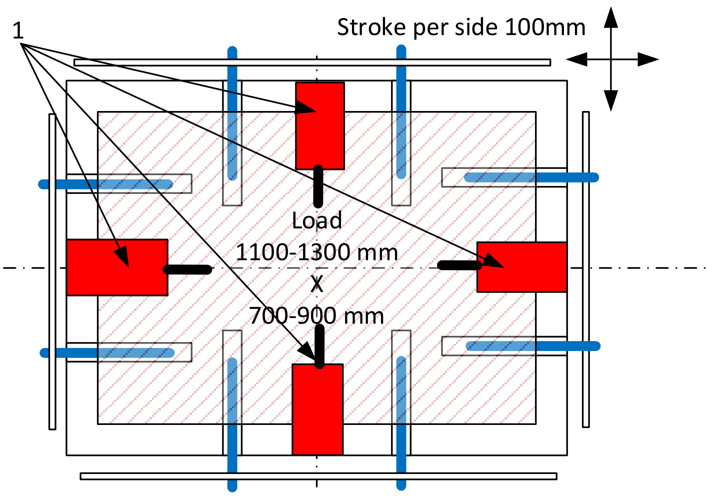

Fig. 4. Conceptual drawing of the jaw gripper
1 – pneumatic cylinders

Three variants of force transmission from the pneumatic actuator to the gripper jaws were considered (Fig. 5). The variant shown in Figure 5-a was chosen for its optimal gripper performance and compactness.

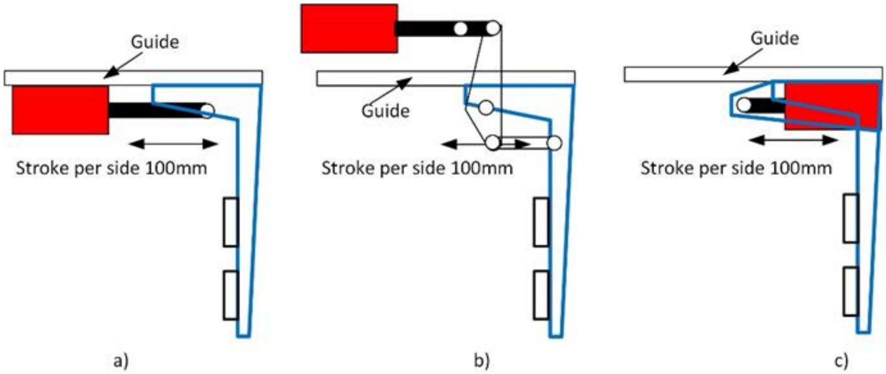

Fig. 5. Variants of force transmission from the actuator to the gripper jaws

3.3. Bag gripper concept

In developing the bag gripper concept, special attention was paid to the shape of the gripper jaw fingers and the method of assembly (Fig. 6). The proposed solution provides interchangeability of the main components with the fork gripper (base plate and jaws).

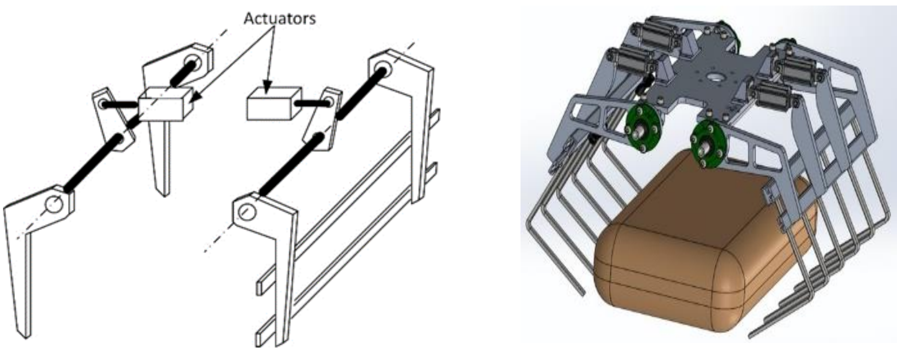

Fig. 6. Conceptual drawing of the bag gripper

The design allows for a smooth change in the spacing of the gripper jaw fingers and changing the number of fingers depending on the products to be handled, and the parameters of the roller conveyor delivering the products. The concept for mounting the fingers to the gripper jaws is shown in Figure 7.

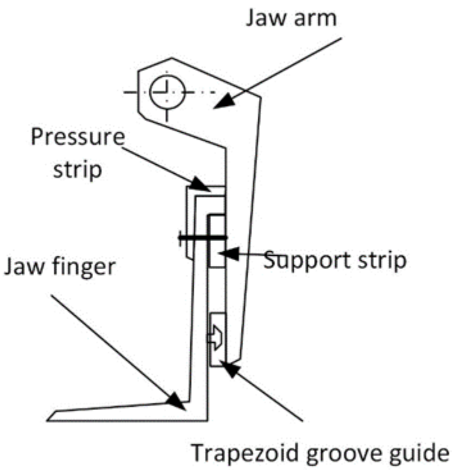

Fig. 7. Jaw assembly concept and finger shape

3.4. Fork gripper concept

The fork gripper concept proposes a modular design that shares a common base plate and jaw with the bag gripper (Fig. 8). The system is driven by a pneumatic actuator, which operates prismatically (Fig. 9) rather than rotationally as in the bag gripper concept (Fig. 6).

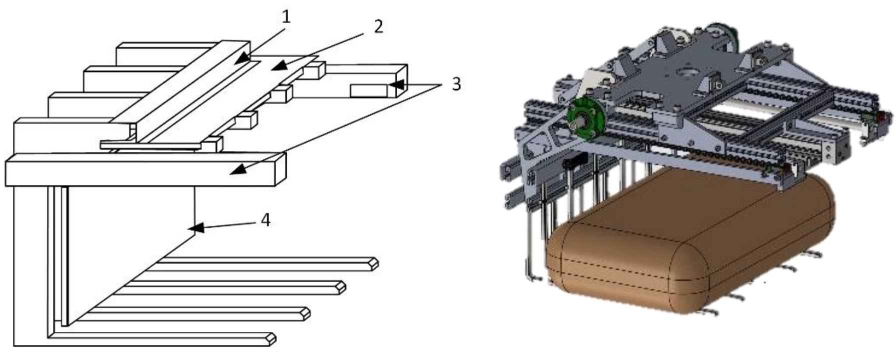

Fig. 8. Conceptual drawing of a rake gripper
1 – pressure strip, 2 – jaw finger connection plate, 3 – actuators with carriages,
4 – thrust/slide plate

The fork gripper uses one of the jaws of the bag gripper as a stationary jaw. The jaw drive cylinders have been replaced with tie rods, which immobilise the jaw giving it rigidity and eliminating the inertia and air compression in the cylinder caused by the bag load.

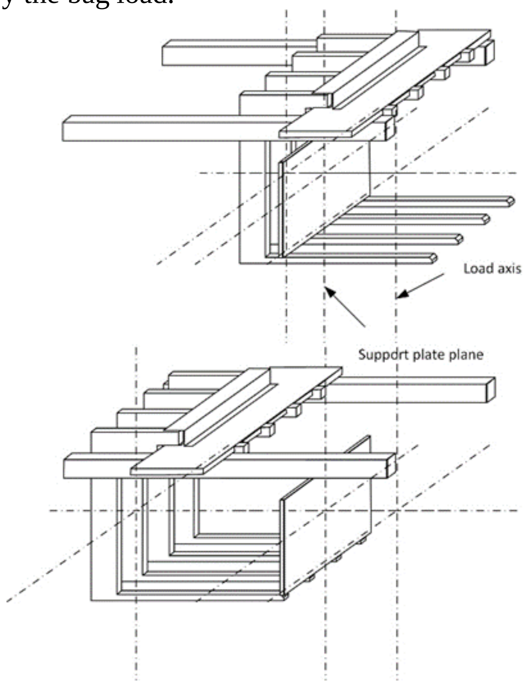

Fig. 9. Conceptual drawing of the fork gripper

3.5. Modular gripper control system concept

A universal control system for the Modular Smart Gripper System (MSGS) was proposed as part of the conceptual design. The main idea was to prepare a hardware platform that would enable control of all of the devices included in the MSGS. A Siemens S7-1200 PLC was selected as the hardware platform along with external I/O modules. The concept was to develop universal software for a set of four grippers. The controller's task will be to fully control and manage the functions of the grippers and handle potential errors. This will greatly simplify the role of integrators programming robots using the proposed gripper system.

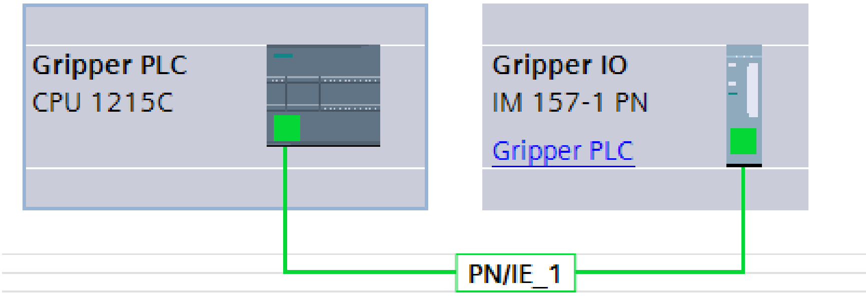

Fig. 10. View of the connection between the gripper controller
and the I/O modules.

Communication between individual elements of the workstation will be performed using Socket Messaging mechanisms which do not require additional hardware modules to operate.

4. GRIPPER TEST BENCH CONCEPT

The test bench concept is presented using a roller gripper constructed by the authors and mounted on a FANUC M-410iC/315 four-axis palletising robot (Fig. 11).

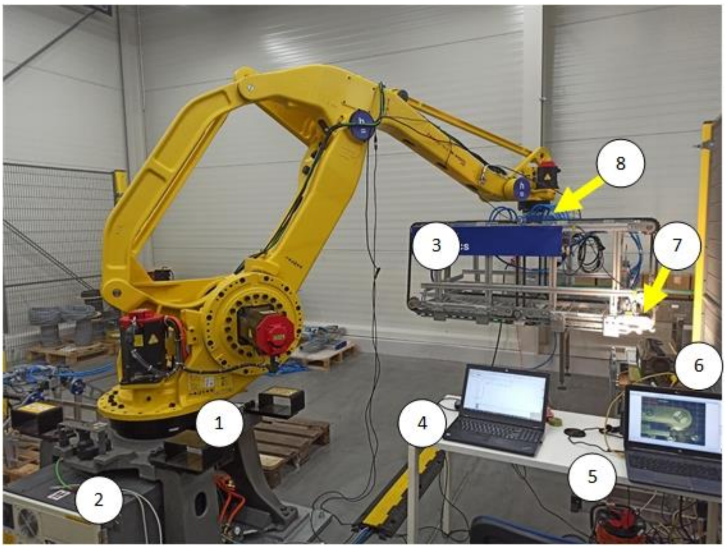

Fig. 11. View of the test bench
1 – M-410iC/315 robot, 2 – controller, 3 – gripper, 4 – computer with MT Manager software, 5 – computer with PCC software, 6 – PHANTOM V210 camera, 7 – MTi XSENS sensor, 8 – MTi XSENS sensor

The computer was connected to a PHANTOM V210 camera via Ethernet. The camera was configured using the PCC software. PCC also features video recording and vibration analysis of the gripper at the process point.

The following figure shows the location of the MTi XSENS sensors and the camera marker.

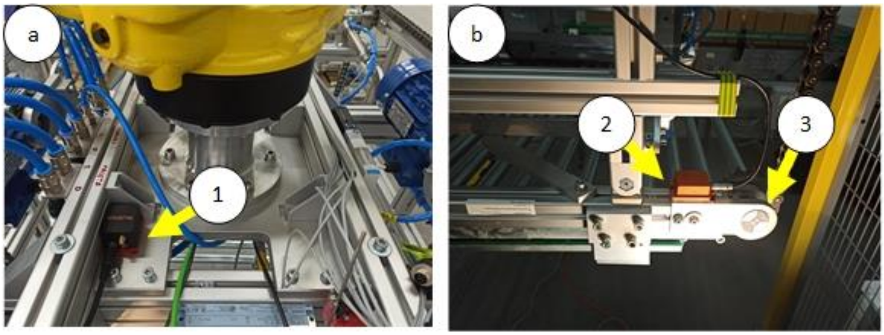

Fig. 12. Location of the MTi XSENS sensors
1 – MTi XSENS sensor on the robot flange, 2 – MTi XSENS sensor on the gripper, 3 – PHANTOM V210 camera marker

MT Manager was used to configure the sensors (Fig. 13). The software keeps track of the acceleration of the gripper. The main objective of the tests will be to check the impact of changing the parameters of the robot path (Tool Centre Point (TCP) speed, and acceleration and deceleration ramps) on the occurrence and magnitude of undesired phenomena.

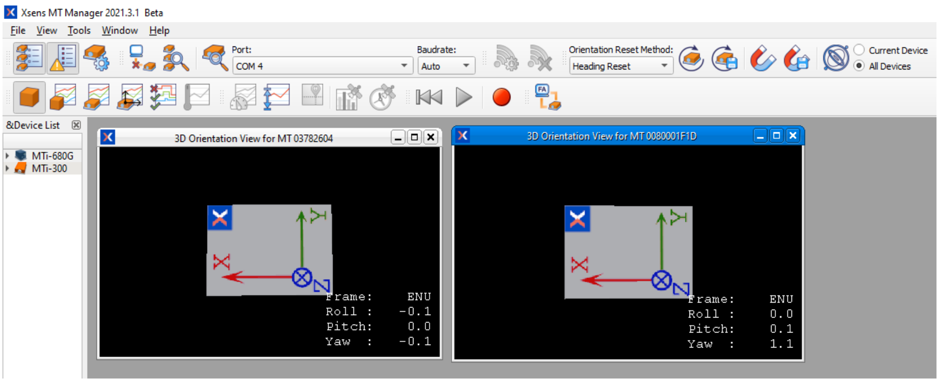

Fig. 13. MT Manager window

When designing the test bench, the authors focussed on developing a methodology that would enable tests to be carried out to analyse the parameters of the robotic palletising process.

Limitations related to the lifting capacity of the robot and the process carried out forced the development of a low-weight (197 kg) gripper with relatively large dimensions (1530 mm, 1075 mm, 775 mm).

The main objective of the methodology is to verify the design of the effector developed by the authors, and in particular its behaviour at process points where the gripper is subjected to the highest forces.

The concept involves recording videos with a PHANTOM V210 high-speed camera with a resolution of 800 × 600 pixels and at 2000 fps to enable analysis of the phenomena occurring at process points. The authors prepared test trajectories that reflect the robot's operation in an industrial setting.

The proposed trajectories take into account the working space and potential kinematic singularities of the manipulator. A TCP linear motion was proposed with start point P1 at coordinates x = -450 mm, y = 2500 mm, z = 75 mm and end point P2 at coordinates x = -450 mm, y = -500 mm, z = 75 mm. Point P2 is assumed to be the loading point of the gripper.

The motion instructions in the control program were as follows:
L P(1),R(51:SPEED) mm/s FINE ACC R(50);

where:

- L – robot motion interpolation type (linear interpolation),
- P(1) – robot trajectory point,
- R(51:SPEED) – register in which the speed is stored,
- FINE – method of reaching the point,
- ACC – acceleration parameter, whose value is stored in register 50.

Tests were assumed for the most common robot speeds (4000 mm/s, 3000 mm/s, 2000 mm/s 1000 mm/s), for different parameters of the acceleration function (ACC 25, ACC 50, ACC 75, ACC 100).

5. CONCLUSIONS

Recent articles from scientific journals prove that the search for versatile and flexible solutions that can be applied to robotic production lines is a worthwhile endeavour. It is difficult to create universal applications for such specialised devices as robotic effectors, including grippers, due to the high demands placed on production processes (e.g. accuracy, speed, repeatability, reliability). In palletising applications, the time taken to design and manufacture grippers, which are often unitary and structurally complex devices, is of considerable importance. The gripper system proposed by the authors offers modularity, which significantly reduces the time needed to adapt grippers to changing parameters of the production process and to exchange modules between grippers.

The proposed test bench and test methodology provide key information on the behaviour of the developed gripper design in process points at set motion parameters. Based on the results obtained, it is possible to optimise the robot's trajectory by parameterising the velocity and acceleration on selected path sections.

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Koncepcja stanowiska do badania własności chwytaków w zrobotyzowanym procesie paletyzacji

Jarosław PANASIUK, Wojciech KACZMAREK, Michał SIWEK
Szymon BORYS

*Wojskowa Akademia Techniczna,
ul. gen. Sylwestra Kaliskiego 2, 00-908 Warszawa*

Streszczenie. Procesy paletyzacji i depaletyzacji wymagają specjalistycznego osprzętu w postaci chwytaków dedykowanych do określonego typu i formatu towaru podlegającego paletyzacji. Tradycyjne podejście stosowane podczas robotyzacji stanowisk paletyzujących w głównej mierze opiera się więc na opracowaniu specjalistycznych chwytaków, których budowa ogranicza zastosowanie ich w innych aplikacjach. W artykule przedstawiono koncepcję modułowego systemu chwytaków umożliwiającego paletyzację towarów w opakowaniach zbiorczych w postaci kartonów oraz zgrzewek jak również opakowań workowych. Opracowana koncepcja zakłada budowę systemu chwytaków w oparciu o wspólne moduły, które pozwalają na szeroki zakres parametryzacji pracy urządzeń. Autorzy zaproponowali również stanowisko pomiarowe umożliwiające badanie własności chwytaków w zrobotyzowanym procesie paletyzacji.

Słowa kluczowe: chwytak, robot przemysłowy, kamera szybka, IMU, paletyzacja.