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Enhanced Agility for Assembly Tasks via Self-Sufficient Mobile Working Stations

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Abstract

This paper introduces the standardized design and the use of self-sufficient Mobile Working Stations (MWS) for meeting upcoming requirements in providing agility for wide range assembly tasks. It describes how the physical equipment of an assembly line can be prepared for being fit for processing highly customized or even fairly new products outside the existing production portfolio in a very short time. Herein all relevant mechanical, informational and safety related aspects for a new setup have to be obtained. This includes a maximum in functionality and universality of the single MWS and the environment of the factory as a whole as well as the use of a Real Time Locating System (RTLS) for providing the always up to date positions of the MWS or other moveable elements in such an agile factory. The paper closes with an outlook to related ongoing research topics.

Keywords: agility; assembly; self-sufficient working stations; smart factory; real time locating system

1. Introduction

Hard automation concepts for production lines - typically made for series production - cannot meet increasing demands in customization and lot-size-one-productions any longer. Only an always feasible and rapid adaption of production facilities will lead to an adequate response for actual and future markets [1-3].

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Accordingly there has to be found a solution for being capable to do quick new setups and consumer oriented alignments of existing and new production facilities in order to fulfill the steadily changing requests of the market. Such kind of readiness also provides an important contribution for getting the time-to-market down [4-6]. Overall it would be an extremely valuable part for the execution of living agility in the shopfloor.

In general and unfortunately the actual situation in production halls still is not really ready for this. The typical designs of production lines are not made for this because the bases for their plannings have always been a more or less contained product portfolio and thus their physical executions naturally end up in a more or less single purpose arrangement of facilities. Together with all the connections to the building - e.g. the mechanical fixings, the strings of the energy supply, the compressed air supply and the wired information supply - has created an even more rigid networked and inflexible body which cannot easily be disrupted for meeting agile requirements. This means that such frame conditions of the past of course cannot cope with being ready for the production of a rather new product in an acceptable short time.

That is why at the “smartfactory@tugraz” - the research and learning factory at Graz University of Technology - there has been created a concept with so-called Mobile Working Stations (MWS). These MWS can be understood as pieces of a puzzle or modules for doing a quick and easy new setup of a production line [7]. The principal idea of such a concept is not completely new [8, 9], nevertheless the approach introduced in the following compared with existing solutions has got new characteristics and higher functionalities which primarily are the

- use of MWS in also any rotary position and the
- fully self-sufficiency of an MWS.

These new features allow an enhanced modularity and provide a maximum of new alignments and functions as a whole. This for instance allows material flows not remaining in straight lines but also multi-directional and it offers a maximum of compatibility (see Fig. 1).

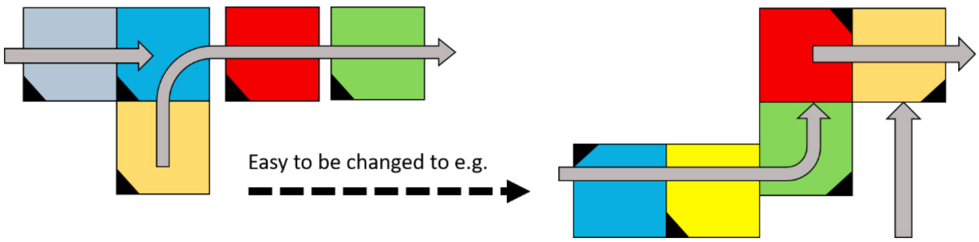


Fig. 1. Principal idea and enhanced functionality of MWS, ready for displacement via translation and rotation at will.
Source: Own representation.

2. The design of MWS

The necessary adaptiveness of assembly units has already been accepted since a while. It is also recognized that an agile infrastructure needs to abandon from fixed assignments of products to assembly facilities [10] which all reminds of series or mass production. What still and widely is lacking is the description of not only conceptual but feasible technical solutions. And this should be introduced and explained via the following executions.

Kern et al. e.g. follow the principal distinction between a “product based approach” and a “process based approach” [11]. The first approach finds its focus on the fulfillment of a certain defined value adding process for a selection of products whereas the second follows the coverage of the same technology for the whole product range. Both have their limits because they are still oriented on the existing product portfolio and this definitely stands in contradiction with the original idea of agility.

So one basic innovation of the MWS presented here is not only the exchangeability of certain modules of a production line, but also the provision of a high adaptiveness regarding the inner(!) set ups of MWS. So with this approach one can follow both aspects of Kern et al. as well as being open for really new products. In the further descriptions and for this research for the specific inner setups of the MWS the notation “skill” will be used. “Skills” are the consciously done abstractions for a specified set of functions of an MWS in order to get utilized in the most universal way for new arrangements in the newly desired value adding chain (also compare chapter 3.1.).

As for the basics of MWS it is quite obvious that moveable modules cannot exceed a certain limit of weight and dimension. That is why this concept can only and reasonably be applied for assembly tasks of and for small and medium sized parts. Tool machines, ovens, big presses and the like must remain as immovable parts of a - quite frequently only temporarily - redesign. Nevertheless if only selected sections of the value chain can follow the MWS-concept the desired agility at the shopfloor can already be increased significantly.

2.1. Standardized main dimensions

The core body of any MWS - still without any specific functional build up - is a framework made of light weight profiles with rollers and pedestals as well as a light weight plate on top of the framework. The selected standard plate with 700 mm x 700 mm settles the basic horizontal dimensions of any MWS. Whatever the specific build up on top of an MWS consists of, the horizontal dimensions must not deviate from this predefined 700 mm or a multiple of it in order to comply with the defined grid dimensions of any future alignment of production modules, respectively MWS. The consciously defined squared dimension of the MWS allows the highest possible use for any reconfiguration because it also opens the possibility to work with more than only one preferred orientation of the MWS.

The top plate is one with T-grooves for enabling an easy mounting of various machinery and devices what in this case finally leads to a defined working height of 810 mm. The plate has also got individual through holes for getting the wiring of the build ups down to the various control and support units placed underneath the plate.

2.2. Self-sufficiency of the MWS

The creation of moveable modules for setting up more or less individual production lines has already been done by well-known automation suppliers (e.g. FESTO: Modular Production System - MPS® [12]) and these systems can be purchased ready for use. The innovative approach regarding the desired realignment and the very USP of the MWS introduced here is their autarky which avoids a lot of work when doing reconfigurations.

The MWS described here e.g. are fully equipped and independent in concerns of power supply (electricity, compressed air), logic control and external information. All components needed for this are mounted underneath the base plate of the MWS and build a highly compact design (see Fig. 2).

a b

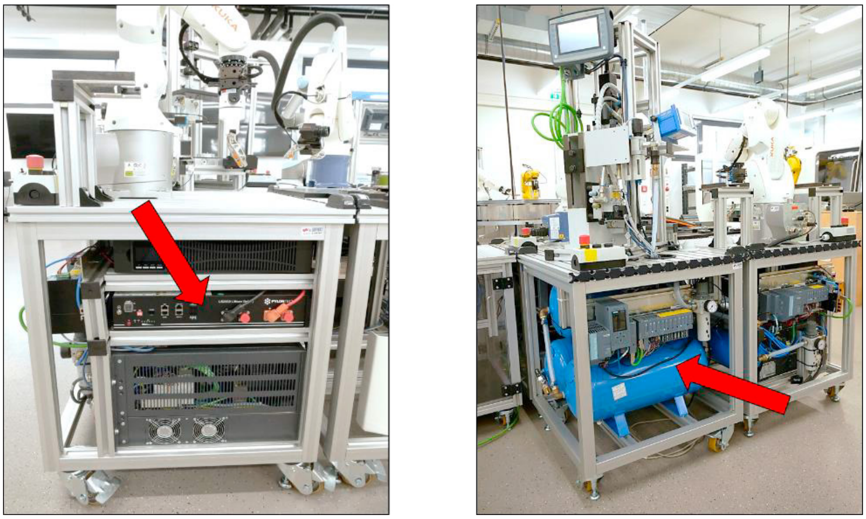


Fig. 2. Execution of self-sufficiency at MWS, (a) accumulator, (b) tank for compressed air.
Source: Own representation.

The independency of electricity is solved via the use of accumulators, the compressed air is provided by own prefilled tanks. The logic units (controllers, CPUs, etc.) are all externally fed with information and data via WLAN. This all effects that there is no need for getting wired connections to the MWS usually coming from the walls, the ground or the ceiling. In case of doing a redesign - now with MWS - one can find following advantages:

- Close to zero wiring work (before and after reconfiguration).
- Free orientation of MWS for best material flow.
- All side barrier free access for Automated Guided Vehicles (AGVs) and similar.

These preconditions in terms of design enable the most of the principle "Reconfigure and Produce" with the benefit that only a minimum of finishing work after rearrangement of the MWS has to be done.

2.3. All side accessibility

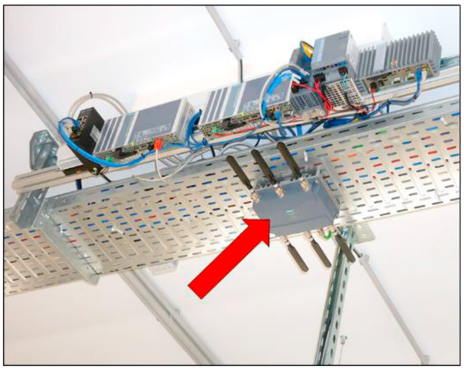
Offered modules of similar concepts - compare e.g. SmartFactoryKL (Technologie-Initiative SmartFactory KL e. V., 2020 [13]) or the MPS® of Festo (Festo 2020) [12] - generally can be applied only in a preferred orientation. This is due to once and permanently defined loading fronts and interfaces and this again because of its internal conveyor belt systems. The introduced concept with MWS here is designed for providing an accessibility from mostly all sides. The squared shape of the MWS and the targeted intra-logistics without rigid and volume taking conveyors hereby helps a lot.

A consequence of being precisely and tightly connected to any other MWS side by side at working height it is not allowed to have any installation protrude outside the overall prism with its 700 x 700 mm basic area. When following these rules this concept opens up many options for getting new combinations of MWS (see Fig.1).

2.4. Informational architecture

As already indicated this concept does not foresee cables for the information transfer either. That is why the information supply is completely done via WLAN. All MWS are equipped with WLAN modules and always stand in the sound reach of a router (see Fig. 3a, red arrow) which is mounted at the ceiling of the factory and is tethered with the factory network.

a



b

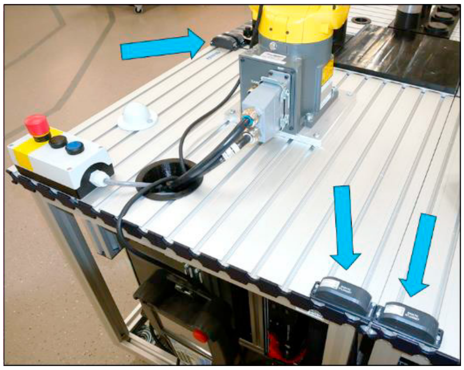


Fig. 3. WLAN Router (red arrow) and RTLS Equipment (blue arrows). Source: Own representation.

All assembly tasks are triggered by a Manufacturing Execution System (MES) which addresses the internally called "the brain". This unit is not more than a simple Industrial Personal Computer (IPC) which controls the control units on board of the MWS (in this case via the product SIMATIC by Siemens) which again coordinate all the sensors and actuators on the MWS related applications. All the defined end signals of any assembly task are all transferred back to the MES via the same wireless architecture in order to trigger the subsequent actions of the work plan.

For localisation purposes of the MWS a Real Time Locating Systems (RTLS) is installed. This system consists of a pair of active transponders (battery inside) mounted at each MWS (see Fig. 3b, blue arrows) and nine gateways (see Fig. 3, left side, blue arrow) for the coverage of the whole shopfloor. The RTLS again is a Siemens product [14] which is based on the Ultra-Wide-Band (UWB) technology. For the actual research it is 20 MWS which are integrated in the current RTLS environment.

3. Agility at work

Agility is the high readiness to manufacture a similar or even new product with rather the same and already existing facilities or the chance to go only into little adaptions of the same. But acting agile has also got the command to mind a couple of aspects before going into such a new situation.

3.1. Checking the feasibility

Before the reconfiguration of an assembly line is going to be executed a feasibility check has to be done and/or the potential deficits have to be determined. Thus there has to be looked up a well maintained data base, which contains the most important and critical information about all available facilities - in best case already agile modules like MWS - in order to find out if there is any knock out criterion at a very early stage.

As for this a couple of approaches can be found in literature in order how to match requirements and capabilities of the available facilities [15] [16]. But the capability taxonomies provided by these authors mostly offer only theoretical models and cannot deliver the important syntax for getting the balance of requirements and capabilities as an output from an automatized process, such as e.g. the simple computerized statement that a certain assembly job can be executed at the shopfloor or not.

This fact also belongs to the current subjects of research at the smartfactory@tugraz. So its team has started to work with the notation "skills" for describing the relevant capabilities of an MWS. For assembly tasks this exemplarily could be "Handling", "Pressing", "Joining", "Screwing", Glueing", "Laser Marking" "Measuring", and the like. Knowing these basic skills in combination with its decisive quantifications (see Table 1 and Table 2) a new configuration of MWS can be lined up in a first and rather easy step. The method for checking the match of requirements and capabilities unfortunately still is a highly manual and analogue one. The target is to develop a program assisted process for getting a much more quick and easy value for the match achievable. It should be clear that a really agile organization is not bound to a get match level of 100 % or even close to. Some rest in the range of 15 % or even higher can and must be managed by additional innovative measures. Real entrepreneurs act proactively and courageous, they only need quick and reliable indications if it can work.

Table 1. Quantification of skills at the example of the MWS for handling

"MWS Handling"	
Standardized Table:	700 x 700 x 810 mm
Interface for Mountings	T-Shape-grooves
Handling Device (HD):	Industrial Robot, Kuka KR3
Reach of HD, max	541 mm
Weight max of HD	3 kg
Gripper 1, opening width	25 mm
Gripper 2, opening width	40 mm
Power Supply	Accumulator, output 24 V DC
Material inbound via	Slots, exchangeable
Material outbound via	Slots, exchangeable
Camera on board	Yes
HMI on board	No
Safety Devices	Emergency Stop, Physical fence & light curtains

Table 2. Quantification of skills at the example of the MWS for screwing

"MWS Screwing"	
Standardized Table:	1400 x 700 x 810 mm
Interface for Mountings	T-Shape-Grooves
Screwing Device (SD)	Weber screwer SEV-C, guided by UR 5
Reach of SD	Max. 850 mm (= Reach of UR5)
Screw Sorter ready for	M3 x 8 mm
Power Supply	Accumulator, output 24 V DC
HMI on board	No
Safety Devices	Emergency Stop, HRC applications (robot and screwer)

3.2. Execution of the physical MWS rearrangement

As soon as the feasibility has been proved positively each single MWS needed for the new assembly line can be rearranged according to an optimum of material flow or other relevant goals. At this stage of development the realignment of MWS still has to be done manually (see also 4.1.). Latest here the self-sufficiency of the MWS turns out to be highly advantageous because the wiring work is close to zero and the movements are rather easy because of the rollers mounted at the support construction of the MWS.

Fig. 4. Example for a specific set up with various MWS

3.3. New calibration of interacting MWS

The "Reconfigure and Produce"- promise worked quite well if there would be required only a sequence of MWS internal (!) operations. Out of the command to set up a new line all the MWS logically more or less have to interact within this new arrangement by forwarding material, collaborating with aggregates of other MWS or finding the exact positions at the corresponding MWS when e.g. the robot of one MWS grasps an assembly part from the MWS nearby.

Especially for meeting the last mentioned requirements one cannot expect that a positioning with an accuracy of fractions of a millimeter - what is necessary quite often - can be achieved automatically after a rearrangement. That is why after having finished the physical rearrangement the points of aim for important and precision bound handling and positioning movements of robots and/or logistic devices have to be newly adjusted and calibrated. Also this has to be evaluated as a still disadvantageous aspect. Therefore the ongoing research activities at the smartfactory@tugraz are focusing on intelligent and automated solutions which should be able to cover this task without human bound activities (see also Chapter 4).

3.4. Redoing the safety precautions

The realignment of the MWS and its connected facilities also disrupt former safety arrangements which have to be adapted according to the new situation. Hereby it cannot be assumed that the former safety toolset is able to fulfill all the new requirements for an again safe work. For being well prepared for this demand, it is recommended to have a sound basic equipment for safety installations on stock. Also this seemingly minor issue shows that a high reactiveness needs a certain form of overcapacities not only in form of direct machinery.

In avoidance of major surprises of any kind - not only in safety issues - it is also a good advice to work with the method of virtual commissioning as a part of the planning activities [17, 18]. Via this method a maximum of unforeseeable effects can be detected and fixed early enough.

4. Ongoing research

Having already mentioned a couple of open desires in the whole system for making agility a living and feasible thing the following topics are going to become subjects of further research.

4.1. Autonomous rearrangement overnight

The idea of a realignment of MWS and similar moveable facilities is going to be continued by the goal to have this done automatically, ideally overnight. This should save manpower and time, knowing that this approach definitely is not one out of the “Plug and Play” tool set. For achieving this one again needs highly special HW (automated shuttles with a flat design and a compact and powerful lifting device, see e.g. Fig. 5) as well as mighty SW which also considers the planning results of the new layout and controls the mode and the sequence of the replacements. Also here the RTLS has got an important role in order to check the actual positions dynamically and to check the results after verification.

a b

Fig. 5. Examples of AGVs with lifting robots. (a) GoPal from robotize; (b) MiR500 from Mobile Industrial Robotics.
Sources: robotize 2020 [19], Mobile Industrial Robotics, 2020 [20].

4.2. Enhancement of accuracy in localisation

One might expect that such RTLS allow to address the point of aims rather precisely in the range of only a few centimeters if not millimeters. But actually this Ultra-Wide-Band (UWB)-based system - the best in class for area localisation and high stability [21] - so far can provide repeat accuracies not better than 25 - 30 cm which is also a result of first tests in the smartfactory@tugraz and also corresponds with the data sheet of the supplier. The mentioned values are sufficient for typical outdoor or rough indoor requirements but not for environments with a high grade of automation and robot assisted systems as executed in the smartfactory@tugraz.

Therefore the accuracy of the localisation task (via RTLS and/or combined systems) is going to be investigated and improved as well. The current work is based on the UWB technology but there are also works on alternative and innovative triangulation approaches. This all is going to be done in cooperation with Siemens AG Austria and research institutes like the Institute of Technical Informatics at Graz University of Technology as well as the shuttle supplier Incubed IT.

Finally one has to respect that desired accuracies of only fractures of centimeters or millimeters cannot be obtained via - even enhanced - RTLS concepts. It is quite clear that the so-called “last mile” for a higher accuracy can only be fixed via superposed vision control systems and the provision of high performant processing units for computing the high volumes of data.

4.3. The AGV has to do the last mile

The AGVs have got an important role within the agile concept. Once they connect the world of MWS with the immovable world of heavy machines and second they are the ones which can do this very last mile best. They will be trained not only to be silly executors for obviously hard to be determined local targets but the AGVs have to become active finders. For achieving this the smartfactory@tugraz has got the best preconditions because in the meantime it has got a 5G-campus solution installed and activated [22].

With these fortunate environment it should work that a 5G tethered camera mounted on the AGV transmits high frequency vision data to a high performing stationary CPU. The processed data output - this is e.g. commands of correction for the steering unit of an AGV or the supervision of a whole fleet of AGVs - is sent back to the AGV with lowest latency. All these high cycled data exchange should allow to achieve much higher precision than with actually available localisation systems possible and only 5G enables the necessary speed and bandwidths.

4.4. Finding dynamic targets

The rough position of any target - e.g. an MWS - can and should always be localized via the RTLS, only the last mile must be done via vision based assistance. When working with agile reconfigurations - as described in chapter 3 - the positions of MWS and alike do not remain static as a reliable basic map for the AGVs. The more the dynamic reality at the shopfloor is always faster than any dedicated planning in the production engineering depart-ment. Here again the RTLS will provide the real time information for the AGVs where all the objects are currently located independently if they have moved in the last two seconds or not.

In the smartfactory@tugraz first tests according this topic have already shown rather promising results [23]. The AGV definitely found a recently displaced MWS via processing the RTLS data provided for the control unit of the AGV. As a next step the bearable load of dynamic changes (= number of transponders to be read and the rate and extent of changes) is going to be investigated. Overall the self-sufficiency of this subsystem of agility is supposed to achieve a sound maturity rather soon.

4.5. Considerations on the return on investment

The equipment and installations for such an agile concept described are not really low cost. That is why there will be separated considerations on the Return on Investment (ROI) of such high tech solutions because they will only be accepted if substantial profits can be made via this way of serving the markets with adopted or new products demanded very quickly. These investigations should also lead to a proposal that tells in which steps such solutions should be implemented (roadmaps), beginning with the major question: Under which circumstances does it make sense to do it at all - and if yes - in which scope?

5. Conclusion

The use of MWS is a promising way in order to facilitate a really agile shopfloor. For this purpose the MWS must follow certain rules concerning the design and the selection of technical build ups. For taking the most of the advantages the equipment must be high end because the foreseen self-sufficiency of the MWS definitely is costly (accumulators, localisation equipment, etc.). The concept itself is coherent though being aware that there are many hurdles to take as soon as a fully automated reconfiguration is intended. So the topic around agility and MWS offers many ongoing research activities. The enhancement of the localisation accuracy, the work with dynamic targets and - last but not least - the economic evaluation of such an agile approach is only a short selection of the future work at the smartfactory@tugraz.

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