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Micro and desktop factories for micro/meso-scale manufacturing applications and future visions

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Abstract—Micro and desktop factories are small-size production systems suitable for the manufacture of small products with micro and/or macro size features. The development originates in Japan, where small machines were developed in order to save resources when producing small products. In the late 1990's, the research spread around the world, and since then multiple miniaturized production systems have been developed. However, the level of commercialization and industrial adoption is still relatively low and the breakthrough remains unseen. This paper discusses the potential application areas of micro- and desktop factory solutions. The research has been carried out as a mixed-method research combining extensive literature survey and 18 semi-structured interviews in Europe. The interviewees are both from academia and industry, including equipment and component providers, as well as users and potential users.

I. INTRODUCTION

Today's industrial production is rather different than a couple of decades ago. Products are becoming smaller, more complex and production systems have to cope with changing requirements due to the short product lifecycles, fluctuating demand and product customization. Consequently, new production paradigms for more flexible production have been introduced, including Lean manufacturing, flexible manufacturing and reconfigurable manufacturing. In addition, the sustainable manufacturing paradigm has raised ecologic and social aspects of production on the table. Companies have to think more and more about their ecological footprint in terms of energy consumption, use of recourses and recycling, as well as well-being of their workers, among others.

New production technologies have been developed to meet the flexibility and ecological requirements of modern production. Miniaturization of production equipment has been suggested as one solution for more eco-friendly production. The term microfactory originates from the research conducted in the 1990's in Japan, where smaller machines were developed in order to produce micro parts and machines. Energy saving and economizing were some of the primary goals of this development [46]. In the late 1990's, the research spread around the world, and multiple miniaturized production systems were introduced. In addition, new topics, such as modularity [13], virtual models [50] and cleanrooms [55] were integrated into the microfactory research.

Within the discipline, the terminology alternates considerably. In this paper, micro and desktop production systems refer to micro and desktop factories (e.g. [4][16][28][49]) and modular microfactory platforms (e.g. [13][14][55]), as well as miniaturized production equipment in general, including e.g. desktop-size machining units (e.g. [35][45][47]), robotic cells (e.g. [31][34][8]) and rapid prototyping units. Despite of large amount of research cited above, the level of commercialization and adoption of microfactory solutions remains still relative low. The discipline lacks of empirical cases and industrial practice on microfactory-related business. However, few commercial desktop factories have been developed (e.g. [20][24][39]). Small-size machining units exist (e.g. [22][36][56]) and desktop-size stand-alone automation units have been developed for different purposes (e.g. [6][2][23]). In addition, desktop-size rapid prototyping units are appearing on the market (e.g. [11] [44] [58]).

The aim of this paper is to examine how micro and desktop factories are used in the industry today, and especially to envisage what would be their potential application areas in the future. The research was carried out as a mixed-method research, and it has an inductive approach. Besides the literature, 18 semi-structured interviews were conducted in Finland, Germany, Switzerland and France, in the autumn 2011. The interviewees were both from academia and industry, including equipment and component providers, as well as users and potential users of micro and desktop factory solutions.

The interviews involved cases in which the industrial products have arisen from the academic microfactory research. These included, e.g. an academic spin-off, Percibio Robotics, which further developed and commercialized an academic micromanipulation system [18], and Asyril, which commercialized a miniaturized delta robot, Pocket Delta [2][9]. µFemos [7] and microFLEX [20] represent cases where products have been developed based on direct funding and cooperation between the industry and academics. MAG Lean desktop cell (currently further developed JOT Intelligent Desktop Automation Platform) is a good example on how research can encourage product development in industry [39]. The interviews were conducted also among users and potential users of microfactory solutions. These included for example Nokia, which uses desktop automation cells in their cell phone production [37][57], and Biohit, producing liquid handling products, diagnostic tests and analysis systems, which would like to use desktop factories for certain stand-alone processes [21]. The interviews were conducted, in addition to the literature survey, in order to get a more realistic view of the current and potential application areas of microfactories.

The paper is organized as follows. In section II the TUT-microfactory concept and its various applications are introduced. Section III discusses the application areas of micro- and desktop factories speculated in the literature. In section IV the current industrial practices are highlighted and finally the conclusions are drawn in section V.

II. Introduction to TUT-Microfactory concept and its Applications

Tampere University of Technology (TUT) has a strong background on microfactory research since 1999. In this section the TUT-microfactory concept and some of its applications are shortly introduced.

A. TUT-Microfactory concept

The TUT-Microfactory© is a modular construction kit type concept with easy and rapid reconfigurability for different manufacturing processes of hand held size or smaller products. The system structure is designed with an idea that a base module can work as an independent unit including all needed auxiliary systems. The base module includes a clean room class work space, a control cabinet and the equipment needed by the clean room. Since the production module does not need a separate control cabinet the factory can be aggregated fast and easily on a desktop table or other flat surface. This and small size of the modules enable extreme mobility of the production capacity. The outer dimensions of one module are 300 x 200 x 220 mm and the inside workspace is 180 x 180 x 180 mm. [15][16]

The production module can be tailored to certain processes by placing process modules on top of the base module. In addition to the top side, both sides and the front side can be left open when adjacent cells compose one integrated work space. Feeders and other devices can be placed in the opening on the front side. All interfaces in the TUT-Microfactory concept have been designed to be as simple as possible. The base modules can be locked next to each other side by side, front by side, or front by front allowing nearly unlimited number of factory topologies, ranging from a simple line type to a freely branching one. The physical interface between two base modules includes two hybrid connectors for electrics/electronics, an interlocking system and connectors for pressurized air and vacuum. [15][16]

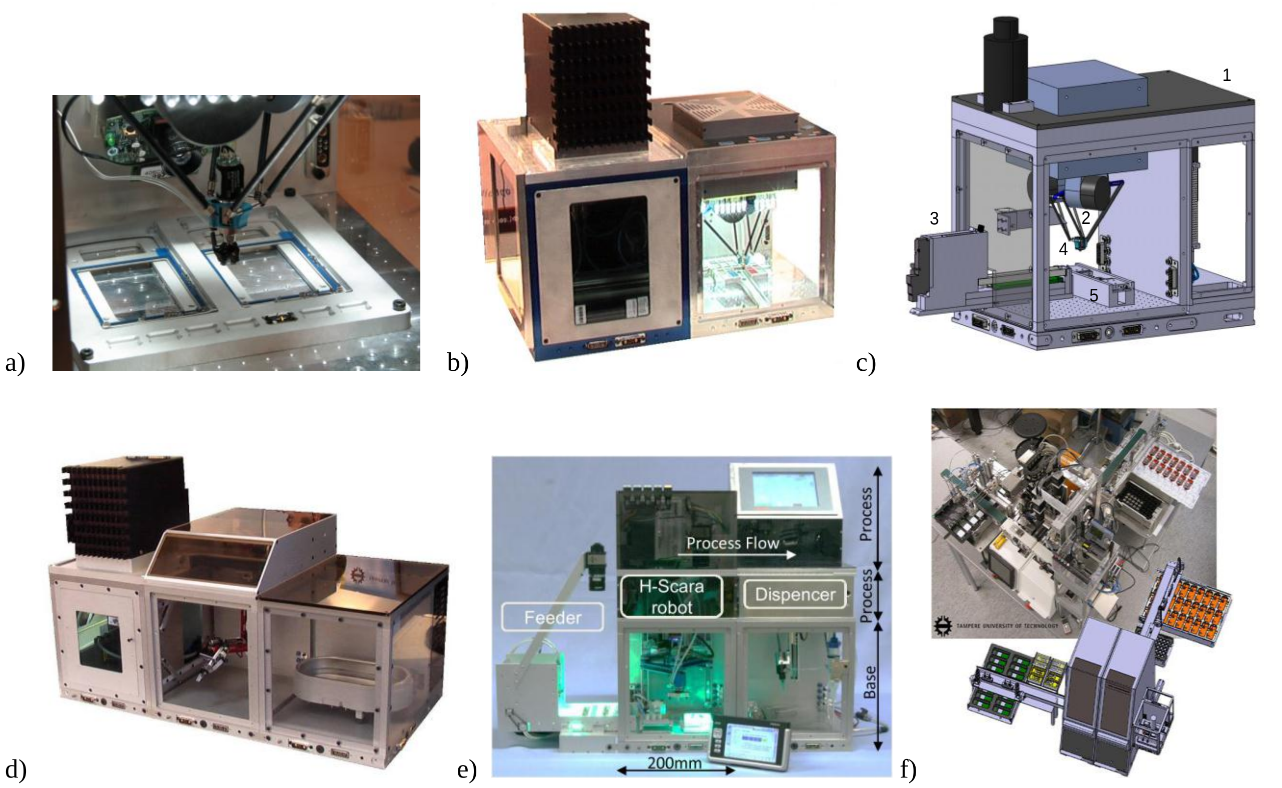

Figure 1. TUT-Microfactory applications: a) a loudspeaker assembly, b) laser marking, c) spring assembly, d) manufacturing of medical implant, e) gas sensor assembly, f) cell phone assembly.

B. Applications of TUT-Microfactory concept

Several demonstrations, some of those shown in Figure 1, have been realized with the TUT-Microfactory concept during the past and ongoing research projects. One of the first case processes was assembly of a cell phone loudspeaker in 2005 (Fig. 1a). The assembly operation was a pick and place operation of the loudspeaker from a jig to the cell phone cover. The component size was 10.9 x 7.4 x 2 mm and weight less than 1 gram. As a manipulator a PocketDelta robot from Asyril [2] was used. [14]

The laser marking microfactory (Fig. 1b) was built as a demo for the Laser 2007 fair in Germany. The case products were personalized aluminum business cards with sizes of 4x9mm and 9x20mm. The case was a good introduction to the point-of-need manufacturing. The visitors could personalize their own business cards and get them manufactured right away. [16]

As a part of the Desk project in 2008, the first industrial demonstration was conducted. The case process was a small spring placement in a MEMS sensor component (Fig. 1c). The small size (D 0.7 mm, L 2.54 mm) and a complex shape made the spring extremely difficult to handle. The factory was built using only one TUT-Microfactory module. Besides the base module (1), a PocketDelta robot (2) was used as a manipulator, and the springs were fed by a machine vision based flexible feeding system, the Wisematic Minifeeder™ (3). The vacuum gripper (4) had a fiber optic sensor to detect the spring in the gripper. In addition, a small lead frame stepper (5) was designed to move the base components. The stepper uses pneumatic actuators and an optical sensor to detect the position of the lead frame. [16]

The first process chain level three-cell demonstration was a manufacturing process of a medical implant, a laser-machined silicon rubber ear tube (D 3mm, L 5mm) (Fig. 1d). The manufacturing process consisted of machining and cleaning. Three base modules and two process modules were used in the demonstration. The first module included a 20W laser lathe with a scanner and an on-line inspection system. The on-line inspection system was used for measuring the dimensions of the tube. The second module included a 5 DOF articulated joint robot, which reached adjacent cells as well. It was used to load the lathe and move the implants to washing. The final module included an ultrasonic washing system. [15]

The gas sensor assembly was a good introduction to different joining processes (Fig. 1e). The case product was a gas sensor (L 78mm, D 12mm), including two identical plastic frame parts, a detector in a metal package and an exciter. There were three phases in the assembly process. First, the detector was placed in the plastic frame in right orientation. Second, the exciter was placed in a correct position and angle. Third, another plastic frame was glued on top of the other. The final microfactory assembly system consisted of two TUT-microfactory modules and a machine vision based flexible feeder for the frame parts. The first microfactory module was responsible for part handling and assembly operations. A new TUT H-Scara robot was used for the manipulation. Besides the robot, the cell included a vacuum gripper, two standard 2-inch trays for component feeding, a turning unit and cameras. The second microfactory module provided the gluing process. It consisted of a low cost cartesian TUT Linear Motor robot, a dispensing valve, an assembly jig for the base frame, a controller and an HMI unit. [52]

In the Mz-DTF project (2009-2010) the factory level integration of microfactory modules was considered and implemented. As a demonstration, a complete mobile phone assembly line was built out of commercial components and the TUT-Microfactory modules. The assembly process consisted of pick-and-place manipulation and screwing. The TUT-Microfactory module was used as a flexible screwing cell and larger desktop prototypes from industrial partners were used for the pick-and-place operations. The implementation was successful, but also some challenges came up. Even though, handheld-size products fit perfectly into the TUT-Microfactory, the subcontractors in the electronic industry still tend to use rather large trays. Compact feeding systems, e.g. tape-and-reel, bowl and machine vision based flexible feeding, need to be further developed and accepted as an industry standard.

III. Application Areas of micro- and Desktop Factories

In this section, the broad range of potential applications for micro- and desktop factory solutions, speculated in the literature, are discussed. In section A these application areas are categorized based on the supply chain. In section B the different levels of microfactory automation are described.

A. Applications categorized based on the supply chain

This section draws a vision about the possible application areas where microfactories could be used in the future. Both the microfactories' role in different supply chains and the potential industries and applications will be covered. The use of microfactories is categorized into three principal scenarios: I) miniaturization of production equipment in a traditional production and supply chain, II) relocating production further into the downstream and III) production on the spot. Figure 2 shows the above mentioned three scenarios and listed several different application areas for micro and desktop equipment that are speculated in the literature.

1) Miniaturization of production equipment in traditional production and supply chain – Scenario I

The first scenario takes place in a traditional production chain. In this scenario the traditional large-scale production machines are replaced and/or supplemented with the micro and desktop production systems, and the production process remains the same. In general, micro and desktop factories could be applied to all products and processes, which fit into the reduced working space. However, it does not mean that the miniaturization would necessarily be feasible. Usually there already exists large-scale machinery for any given process. A desktop machine or a factory is bought instead if it is better for the application or if it can cut costs. However, the miniaturized system is likely to be more expensive or a compromise in some way. Therefore, the investment requires other motivation.

By definition, micro and desktop factories are small and they can save space. Thus, they are expected to cut costs of facilities, e.g. rents or capital costs, as well as costs of energy, material, heating, air conditioning, illumination, waste and recycling. What seems to be quite important in many cases is that they enable more production capacity in existing factory buildings. Similarly, local cleanrooms can cut cleanroom investments and maintenance costs. Finally, micro factories are expected to be more flexible, having shorter set up times. The flexibility reflects to capital costs as less stock of products and semi-finished products is needed. The cost reduction factors of micro factories have been discussed in the literature (e.g. [31][32][33]). Furthermore, some product characteristics might be enabled when shifting from large-scale equipment to smaller ones, e.g. small-size machinery and grippers might be gentler for fragile products compared to the traditional equipment.

Kawahara et al. [26] argue that micro and desktop factories could be used as micro chemical plants. Applications include e.g. drug fabrication, micro cultivation and chemical reaction of dangerous materials. Multiple benefits relate to the small reaction space. The reaction starts and ends quickly. Thus, risky exothermic reaction can be safely achieved. In addition, truly homogeneous chemical reaction becomes possible as the concentration differences decrease. [26] However, micro factories are not suitable for large volumes. For example, instead of pharmaceutics industry, micro cultivation and micro reactors might suite better for laboratory environments [21].

Component and micro part manufacturing was one of the original applications for micro factories. The benefits relate mostly to floor space reduction and relating costs. The small components are made of multiple materials: metal (e.g. jewellery, gears and watches), glass (e.g. microscopes, laboratory instruments and contact lenses), plastic (e.g. hearing aids and implants), ceramics (e.g. dental products and moulds), biodegradables (e.g. implants) and silicon (semiconductors, e.g. sensors). Potential miniaturized processes include e.g. injection moulding (e.g. [41][42]), machining and additive manufacturing, including 3D printing and lithography. In addition, components can be fabricated in a cleanroom or under a special condition (e.g. [26][29][55]).

I. Traditional supply chain					II. Relocating production further into the downstream			III. On the spot manufacturing	
A. Processing Industry		B. Piece Goods Industry							
Primary reasons to invest on miniature production systems + Increasing profitability: cost savings - Cost of facilities (rents or capital costs, heating, air conditioning, illumination, etc.) - Clean room investment and maintenance costs - Costs of flexibility, quality or manual assembly - Cost of energy - Cost of material - Cost of waste and recycling - Capital costs (set ut time, cycle times, etc.) + Enabling products characteristics (e.g. fragile products)					**Primary reasons to invest on miniature production systems** + Increasing profitability: cost savings and add-on sales - Capital costs (stock of products and semi-finished products) - Add-on sales - Product customization - Fast delivery + Enabling product characteristics (perishable products and groceries)			**Primary reasons to invest on miniature production systems** + Enabling production and the whole business	
1. Raw material production	2. Material production	3. Component manufacturing	4. Assembly	5. Finishing and inspection	6. Transportation, onthe fly/way	7. Storage and wholesaling	8. Retailing	9. Production in the place of ordering	10. New applications
									
What? - Testing and analyses on the spot - Oil-field investigation **Why?** - Portable test equipment	**What?** - Medical - Chemistry - Low-volume process industry products **Processes** - Chemical reactions of dangerous materials - Micro cultivator - Drug fabrication and encapsulation	**What?** - Metal - E.g. jewellery and watches - Glass - E.g. micro-optics - Plastic - E.g. hearing aids - Ceramics - E.g. dental - Biodegradables - E.g. implants - Silicon - Semiconductors **Processes** - Injection moulding - Machining - Additive manufacturing - 3D printing - Lithography **How?** - Fabrication in a cleanroom or under special conditions - Combining to 3D printing	**What?** - Portable devices - Precision mechanics, e.g. - Watches - Micro-motors - Gears - Micro-optics - Jewellery - Life science - Medical/dental - Semiconductors - Sensors - MEMS products **Processes** - Pick and place - Screwing - Dispensing - Laser processes - Ultrasonic welding - Heat treatment - Palletizing **How?** - AAM (Difficult manual operations) - Parallel / 3D production layout - Cleanroom assembly	**What?** - Small products or components, e.g. - CE marking - Optical control of assembly - Sterilization of medical implants **Processes** - Marking - Scratching/laser - Coating - Paint/UV-printing - Washing - Cleaning - Sterilization - Optical control - Packing - Processes under special condition	**What?** - Small products having long time of delivery and stabile demand - Pershable products - e.g. grocery **Why?** - To shorten delivery - To protect the perishable products	**What?** - Small products having modular design and intermediate level of personalization **Why?** - Dynamic supply chain and delivery - Wholesale level mass customization	**What?** - Small highly personalized products, e.g. - Contact lenses - Watches - Jewellery - Cosmetics - Small sports equipment - Craft shops - Medical **How to personalize?** - Coating - Paint/UV-printing - E.g. laptops - Marking - Scratching/laser - E.g. iPods - Final assembly - E.g. eye glasses - Final design - E.g. custom-fit sports equipment - Drug dosage and encapsulation	**What?** - Exchange parts - Spare parts - Medical products - Small products having critical time of delivery **Why?** - No space for factory - No time to deliver - Impossible logistics **Where?** - Urban factory - Remoteness - Space - Oceans and air - Researchers' special conditions - Battlefield - The third world **Medical products** - Custom implants - Battlefield - Dental - Third world - Drug fabrication - Dosage and encapsulation - Sterilization	**What?** - New applications for automation and industrial machinery **Why?** - The process is the product(education) - Impossible sub-contracting (laboratory) **Where?** - Prototyping - In a office (desing, engineering or architecture) - Education - At school - At Fablabs - Laboratory automation - Processes inside of industrial and laboratory equipment - Craft shops - At home - Consumers - Communities

Figure 2. Application scenarios for microfactory systems [43].

Assembly operations are other promising applications for micro factories. Suitable small-size products include e.g. portable electronic devices [24][40], precision mechanics (e.g. watches, micro-motors and planetary gearheads) [54][25][10], micro-optics, life science products (e.g. test kits) and other small medical products, dental products, semiconductors, sensors and measuring devices as well as other MEMS products [1]. Suitable miniaturized assembly processes include e.g. pick and place, screwing, dispensing, ultrasonic welding [24][40] as well as palletizing [3].

Finally, micro and desktop factories could be used for finishing, inspection or packing. Potential applications could be e.g. CE marking, visual control of assembly or sterilization of small medical implants. Other miniaturized processes include e.g. marking, laser carving, painting, UV-printing [52], ultrasonic washing [15], cleaning and sterilization. Sankyo Seiki made the first commercial equipment for cleaning of micro-parts [38]. In addition, a micro factory with a cleanroom enables processes under special conditions. Again, the only restriction is that the small products and components have to fit into the working space.

2) Relocating production downstream - Scenario II

The second scenario relates to relocating production further into the downstream in the supply chain. Because of the small size, micro factories could be used for e.g. production on the way, or for personalization at the wholesaling and/or retailing level. A small and mobile production system could be integrated e.g. into a car, truck, train, ship or aeroplane. The process could shorten delivery and enable production of perishable products on the way. [26] The shorter delivery could gain add-on sales. In addition, capital costs are expected to decrease, as delivery is faster and stocks of finished products decrease. Suitable products would be small and perishable products having a long time of delivery and a stabile demand.

The second option to relocate production further into the downstream is to place some production phases at the wholesaling and/or retailing level. At wholesaling level, the model would suite well for personalization of small products having modular design and an intermediate level of personalization. At retail level, micro factories could be used to personalize small and highly personalized products e.g. contact lenses, watches, jewellery, cosmetics, small sport equipment, pharmaceutics and other medical products. Potential processes include coating and UV-printing (e.g. electronics), marking (e.g. jewellery), final assembly (e.g. optics), machining (e.g. custom-fit sport equipment) and sorting (e.g. drug dosage and encapsulation). The advantage relate mostly to add-on sales. Customers might choose the product because it is more personalized. In addition, decentralized production hubs are expected to increase dynamics of the supply chain, adapting more easily to a fluctuating demand and decreasing costs of logistics. Goldsmiths, opticians, and orthotics are examples of current businesses, relating to retail level personalization.

However, a lot of uncertainty relates to the advantages of bringing the production further into the downstream. Production during transportation is speculated to shorten delivery times. However, since the duration of actual transportation (especially air cargo) is usually short compared to the actual delivery time, this might not be the case. It is also speculated that the costs of logistics and capital tied to stocks would decrease with mobile factories. On the other hand, production equipment requires space in the transportation vehicle and therefore transportation capacity decreases.

In addition, the impact of personalization on the costs of logistics depends highly on the processes. If the personalization happens during the assembly process, the components have to be transported to many locations instead of one factory. As a result, the costs of logistics might even increase. Therefore, subtractive manufacturing, coating and marking are more potential processes compared to assembly. Finally, the number of personalizing retailers includes a compromise as well. Multiple retailers can serve many customers but it increases costs. Companies might choose to personalize only in large flagship stores for marketing purposes, and centralize the service for other customers.

3) Production on the spot – Scenario III

The last scenario, on the spot manufacturing, relates to the speculated ‘ubiquitous manufacturing’ [48], ‘point-of-need manufacturing’ and ‘decentralized manufacturing’. As micro factories are small, they could be used to produce products on the spot in various locations. There are three principal reasons for manufacturing on the spot: no space for a traditional factory (e.g. urban fabrication in a city center), no time to order and deliver (e.g. battlefield) or impossible logistics (e.g. isolated places such as oceans or space). Production on the spot with micro factories would be ideal for small products having critical time of delivery, e.g. exchange parts [26], spare parts [48] and medical products or personalized implants [15], dental applications [56], drug fabrication, dosage and encapsulation, as well as sterilization. Battlefield [27], trouble spots, the third world as well as researchers' special conditions are examples of situations where logistics can be problematic.

The US Army has two good examples of point of need processes: Mobile Parts Hospital (MPH) and the Mobile Army Surgical Hospital (MASH). The MPH is a portable replacement part factory, which includes machinery and three machinists. In 2009, US Army had three MPHs in Iraq, Kuwait, and in Afghanistan. Since 2003, more than 100,000 critical parts have been produced at the points of need. The machinists make CAD drawings based on a broken part, drawings and verbal descriptions. When the CAD drawings are approved, a new part is fabricated in a few days. The point of need fabrication can provide huge cost savings. For example, the MPH made a rotor brake seal for an Apache helicopter. Instead of shipping the rotor back to the States, the helicopter could be used within days, and $393,000 was saved. [5] On the other hand the MASHs are container hospitals, which are used for lifesaving surgical care [27].

Besides replacing ordering, on the spot manufacturing includes other applications as well. The most potential applications are prototyping, e.g. in engineering, design, or architecture offices, or even personal fabrication at home or communities [51]. In addition, small automation could be used in laboratories [6], and for processes inside of industrial and laboratory equipment [12]. The small size is a benefit because non-manufacturing facilities are usually not built for heavy and large-scale machinery. In laboratories, logistics might be a problem. Samples cannot always be transported elsewhere. The processes need to be conducted on the spot, either manually or by machines which fit into the space. Also educational purposes represent a very promising application area for micro factories.

B. Scalability of automation with microfactory systems

In general, the levels of automation of the production systems can be categorized into manual, semi-automatic and fully automatic systems. In case of small products, several different strategies can be taken. Regardless of the scenario, micro and desktop factories can be used at different levels of automation, ranging from helping human operators to fully automatic lines.

Two main development directions for micro and desktop factories are envisioned. The first vision is to use small size equipment to aid human operators by performing tasks that require great accuracy or speed, are dangerous or very simple and repetitive and therefore boring for human operators (Fig. 3a & b). In these cases, the desktop size cells can be tele-operated (e.g. manipulation of small parts with very high accuracy), or they can be standalone units performing either a single operation (e.g. screwing) or a few process steps (e.g. picking and gluing a component with high accuracy), while the human operator performs more complex operations.

Within these cases the automation level can differ. For example in the Fig 2a the operator feeds the products and components to the desktop cell, which conducts the given process. Another option is to produce batches, as in the Fig. 3b. Here different feeding systems (e.g. trays) are used to feed multiple products and/or components to the desktop cell, which then produces the products or sub-assemblies in batches. These both approaches are in use in Nokia [37][57].

The second main development direction is fully automatic production lines consisting of small size production cells and integrated transporting system transporting the products or parts from one cell to another (Fig. 3c). This is very similar to the traditional production lines, the main difference being the size of the equipment.

In the future, one option is to combine manual assembly to low-level and high-level automation in a robot assisted cell type manufacturing (see Fig. 3d). In this vision, a robot and human operator would share the working space, which contains also one or more desktop size machines. The robot could aid the operator by performing simple and repetitive tasks (e.g. loading/unloading trays or machines) while the operator performs tasks requiring e.g. dexterous manipulation of flexible or delicate parts. The desktop cells, i.e. the high-level automation, would provide quality improvements to manual assembly.

IV. Current Practice in the Industry

The current use of micro factories relates mainly to the scenario I, discussed in the previous section. According to the interviews, micro factories are used in the industry mainly as stand-alone tools for component manufacturing and assembly processes. In many cases, flexibility requirements are too high for fully automatic desktop lines, as noted by Nokia [34]. Current industries adapting micro factories include e.g. watchmaking, telecom, medical and semiconductors. Processes include e.g. high precision pick and place, screwing, dispensing, palletizing and marking, as well as laser and plasma treatment. The miniature machining systems suite for versatile materials and applications, for

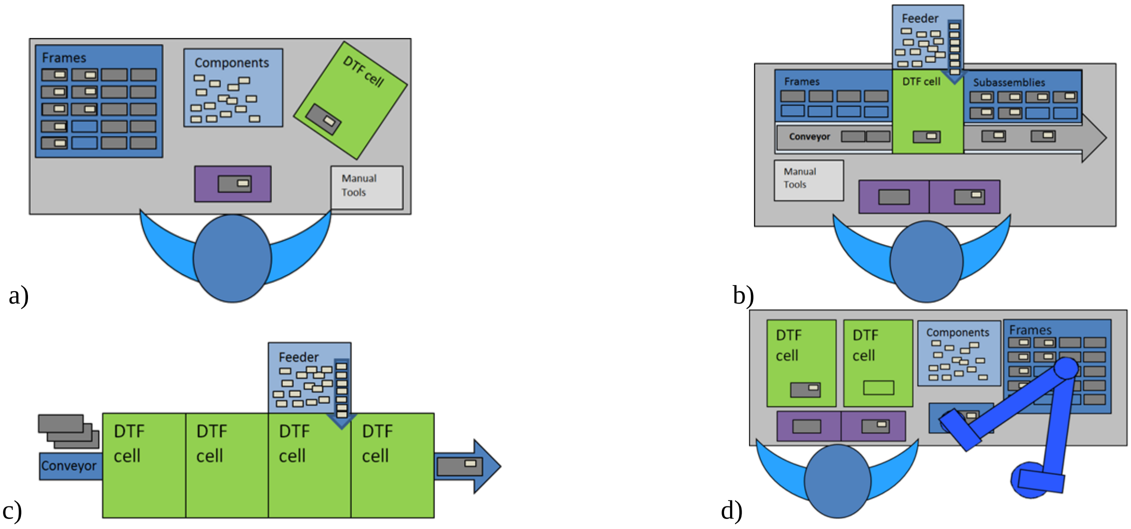

Figure 3. Desktop automation assisted assembly scenarios where one operation is automated a) one piece at the time, b) a small batch at the time using trays and feeders, c) fully automatic production line consisting of desktop size modules, d) robot and human sharing the same workspace in desktop production [43].

example metal (e.g. micro mechanics, jewellery and watches), glass (e.g. micro-optics), plastic (e.g. hearing aids), ceramics (dental applications) and biodegradables (implants).

MAG Lean and JOT IDeA desktop cells are used mostly in the electronic and life science industries as well as within component manufacturers (e.g. in the automotive industry). Processes include e.g. screw insertion, precision assembly, plasma treatments, dispensing, marking and cleanroom processes. In addition some special processes and assembly are combined into one cell. [19] At Nokia, the desktop cells are used currently as tools for repetitive assembly steps, or for processes which cannot be conducted by humans. The processes include screwing, gluing and precision assembly.

The watchmaking industry is the largest industry for all the products of Asyril. In addition, the medical and semiconductor industry have some applications. Applications include e.g. pick and place, feeding, palletizing and other standard applications. The customers prefer individual machines instead of lines. In addition, CPA integrates Asyril’s products for special applications, e.g. systems with multiple manufacturing steps or gluing. [9] The watchmaking industry is also important for Percibio Robotics. The applications include e.g. placing small stones in the encore of the motion and placing axis for gears in as small holes. [18]

Health care, medical, bio- and laboratory applications were cited as potential future applications by many of the interviewed companies. For instance, at Biohit, desktop cells could be used for machining of injection moulded components during the assembly. Secondly, desktop automation could be used for flexible co-operation between humans and machines, eliminating repetitive working phases. Finally, some other assembly phases, e.g. final liquid testing and packing, could have potential applications. [21]

On-the-spot medical applications were also brought up by the interviewees. Instead of having all the different variations of an implant, a hospital could buy bulk implants and specific machine to personalize them. Especially specific operations e.g. face and scull surgery, would benefit from the personalized implants, if the amount of surgeries could be decreased or they would shorten the time of dangerous operations. In case of average fracture, the surgeon has enough time to modify the implants. Metallic implants might be the first applications. The processes of biodegradable implants are still under development. [17]

However, there are some issues with the medical field. Medical industry is highly regulated and can thus be challenging for traditional automation providers. It is vital to understand the industry and the application area. For example, local cleanrooms interest companies in the bio industry. However, practical issues, relating e.g. to their maintenance, have raised questions. They require development and standardization. For instance, traditional cleanroom standards are still applied for local cleanrooms. A specific ISO standard is currently under development [30]. In addition, desktop factories might have more potential in research and laboratory use than in medical mass production. Pharmacy and micro cultivation require too high volumes. [21]

V. Conclusion and Discussion

In this paper, current and future applications of micro and desktop production systems were discussed. The literature speculates with a broad range of different applications and associated advantages, and similar aspects were also brought up during the interviews. As micro and desktop factories are not suitable for high volume production, in the future, especially the “on the spot” manufacturing of customized products, such as medical implants, and non-manufacturing applications, like educational and laboratory use, as well as prototyping, are promising.

As discussed in the introduction, industrial microfactory solutions have already been developed based on the microfactory research. However, introduction of new production technology and especially their adoption in real industrial contexts takes time. Companies and engineers prefer not to use these new production technologies, before there are more examples showing their benefits. To bring micro factories faster into the industry, more cooperation is needed between academics and the industry. More precisely, academics should continue on searching the limit of downscaling and simultaneously informing the industry and the new engineers about the technology. A large scale production demonstration is needed, to show and understand the potential. The equipment providers are already modifying and commercializing the concepts. In addition, the users of automation should inform the academics about which miniaturized applications and processes are needed. More attention should be directed towards industrial and business aspects. As noted, the academics and the industry have slightly different viewpoint to the miniaturization. More research about the feasible applications in various industries and their real benefits for the companies should be conducted. Case applications and demonstrations should be selected respectively.

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