

Construction of Various Materials Using Stationary or Mobile Systems Ranging from Polymers and Concrete to Metals and Ceramics Using Advanced Sintering: A Review

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Abstract

This research provides a review of the current state of the art of mobile additive manufacturing. It reviews the current capabilities of mobile manufacturing units. This includes aerial and ground-based vehicles i.e. it describes the challenges of mobile manufacturing ranging from path planning, localization, to communication between various units. It also describes the role of Artificial intelligence in flexible and smart manufacturing. Additive manufacturing has revolutionized the manufacturing industry in terms of material wastage and quicker manufacturing. Also, it is portable due to its ability to produce a wide range of parts without big machines and tools. It also discusses the challenges of mobile manufacturing of various materials including materials which require sintering. It discusses the alternatives of conventional sintering which could save time, energy and could be deployed in a flexible manner; hence, increasing the range of materials manufactured in hard-to-reach environments.

Keywords: Mobile additive manufacturing, Sintering, Metals, Swarm manufacturing

Introduction

A review on mobile manufacturing units have comprehensively outlined the current state of the art of these systems ranging from ground based to aerial systems. It also discusses the concept and significance of swarm manufacturing.

Among the seven additive manufacturing techniques (Rastegarpanah et al., 2024), only material extrusion has so far been implemented in mobile systems. This is primarily due to its low weight and simple design, which facilitate integration into mobile systems. Furthermore, it has only been implemented for the fabrication of materials that do not require sintering, since sintering demands heavy equipment and extensive shielding. However, factory-in-a-box setup is available currently which extrudes, debinds and sinters in a container (Tao et al., 2024). The idea of discussing sintering options in comparison to traditional ones is the possibility of incorporating them in mobile systems both aerial and ground, to take the current mobile manufacturing a step further through the manufacturing of sinter able materials using mobile setups.

Moreover, it discusses the current challenges of ground based and aerial systems in terms of localization, path planning, material delivery and the coordination of multi-robot systems. It also presents Artificial intelligence as a possible solution to these problems.

Methods

This section provides a review of the current state of mobile vehicles in terms of ground-based, aerial, solo or collaborative systems. It also provides a review of advanced sintering technologies which could be integrated with mobile systems to manufacture materials like metals, ceramics which require sintering. Lastly, it provides a short review on the importance of machine learning in additive manufacturing i.e. how could it be used to make it better.

Mobile Manufacturing Ground-based Solo Systems

Various ground-based systems have been developed which deposits and builds concrete while moving (Tiryaki et al., 2018; Sustarevas et al., 2018). Both of them discuss about path planning and localization of the nozzle during printing. Both of them use structured lab environments and sensors to achieve the purpose. Koala 3d prints PLA while climbing using additive manufacturing. The machine combines a climbing robot with a 3d printer (Kayser et al., 2018). Table 1 below summarizes the technologies.

Table 1: Ground-based solo systems

Name	Technique	Material	Coordination with other robots
Printing-while-moving: a new paradigm for large-scale robotic 3D Printing (Tiryaki et al., 2018)	Ground	Concrete	No
A mobile agile printer robot for on-site construction (Sustarevas et al., 2018)	Ground	Building material	No
Koala 3D (Kayser et al., 2018)	Ground	PLA plastic	No

Ground-based swarm systems

Fiberbots work in collaboration and each constructs a composite tube by winding fiber and resin around it. The robots can climb the composite tube, extend it and can build structures upto tens of times larger than themselves from raw and homogeneous materials (V'elez et al., 2020).

Mobile systems are used to print additively by depositing material used for construction purposes (Sustarevas et al., 2019). Similar mobile systems are used to print plastic filaments using fused deposition modelling approach (Marques et al., 2017). A group of researchers have developed multiple mobile robots to construct a large single piece concrete structure (Zhang et al., 2018). Table 2 below summarizes the technologies.

Table 2: Ground-based swarm systems

Name	Technique	Material	Coordination with other robots
Fiberbots (V'elez et al., 2020)	Ground	Fiberglass composite	Yes
YouWasps (Sustarevas et al., 2019)	Ground	Construction material	Yes
3D printer for cooperative 3d printing (Marques et al., 2017)	Ground	PLA	Yes
Large scale 3d printing by a team of mobile robots (Zhang et al., 2018)	Ground	Concrete	Yes

Solo Aerial Systems

Much research has been done in aerial drones for 3d printing. Jacob et al. (2024) have developed a drone for 3d printing in multidirection during flight. They have used polyurethane foam as the extrusion material (Jacob et al., 2024). A hexacopter which detects cracks in road during flight then gets down and repairs it by 3d printing asphalt over it (Doychinov et al., 2019). Nettekoven and Topco (2021) have developed a drone which prints a single layer of PLA while in flight (Nettekoven & Topco, 2021). However, there are significant improvements required as ground contact is present which is necessary to remove in order to print more layers. Table 3 below summarizes the technologies.

Table 3: Solo Aerial systems

Name	Technique	Material	Coordination with other robots
Multi-Directional Aerial 3D Printer (Jacob et al., 2024)	Aerial	Expanding foam	No
Infrastructure Robotics Research (Doychinov et al., 2019)	Aerial	Asphalt	No
A 3D Printing Hexacopter (Nettekoven & Topco, 2021)	Aerial	PLA	No

Swarm Aerial Vehicles

A group of researchers have developed multiple mobile robots to construct a large single piece concrete structure (Zhang et al., 2022). Ghaziani M., has developed a gimbal for precise printing of PLA from the quadcopter. He has also simulated the concept of swarm UAVs in his thesis (Ghaziani, 2023). He has made significant improvement in printing PLA as compared to Nettekoven's work (Nettekoven & Topco, 2021). However, Ghaziani's results are not tested on the actual drone but only on the test bed and in simulations. Table 4 below summarizes the technologies.

Table 4: Swarm Aerial Systems

Name	Technique	Material	Coordination with other robots
Aerial additive manufacturing with multiple autonomous robots (Zhang et al., 2022)	Aerial	cementitious-polymeric composite mixtures	Yes
Fused filament fabrication via multi quadcopter collaboration (Ghaziani, 2023)	Aerial	PLA	Yes

Advanced Sintering

As opposed to conventional sintering, various other sintering technologies like microwave, laser diode and IR sintering have been shown to be effective. These techniques are effective as well as less heavy than the conventional sintering apparatus.

This study describes advantages of microwave sintering over conventional sintering; microwave sintering requires much less energy in less time and better mechanical and physical properties are achieved (Oghbaei & Mirzaee, 2010). Another study has concluded that an IR/red diode laser with a wavelength of 808 nm and a laser power ratio of 1.0 is feasible for sintering 3D printlets (Lekurwale et al., 2022). Students from Aerospace engineering at the California State University presented their proposal to deal with lunar dust during landing. Their design features a rover equipped with a microwave sintering apparatus that would traverse the lunar surface, heating and fusing the top layer of regolith to form a solid path for landers. This method is energy-efficient and sustainable, relying on solar power and utilizing materials readily available on the Moon (Tao et al., 2024). This is still a proposal and needs to be developed. If it develops, it will be a breakthrough as it will be so much easier for humans to land on Moon. The idea of discussing here is the incorporation of microwave sintering apparatus in a rover.

A patent describes a machine which debinds and sinters filament extruded metal or ceramic parts. The debinding heater is a low intensity laser or an infrared lamp. Preferably, the low intensity laser is a 1W, continuous wave diode laser for debinding, with a wavelength of ~850 nm. the sintering heater is a CO₂ Laser or a Nd:YAG Laser, a microwave heater or an induction heater (EP 4 137 254 A1, European Patent application, 2023/08, 21192364.4). This could lead to a key contribution to the flexible manufacturing as it has consolidated the material extrusion process in a single machine as opposed to previous practices.

Vilchez et al. (2023) have designed a novel induction heater for sintering powdered extruded material (Vilchez et al., 2023). All of the techniques discussed above are lighter and compact which makes them suitable for integration with mobile manufacturing devices. However, shielding remains an important aspect to take care of during the process.

Role of Machine Learning in Additive Manufacturing

Since Mobile AM does not have guided rails, printing without them especially in air is tricky due to vibrations and air quality, hence, Machine learning can help in adjusting nozzle based on prior trajectories and image data. Also, it can help in optimizing process parameters for printing.

A study has performed a review on deep learning across seven major AM categories - binderjetting, directed energy deposition, material extrusion, material jetting, powder bed fusion, sheet lamination, and vat photo polymerization (Islam et al., 2024). Another study has performed a review on how machine learning can help improve additive manufacturing by identifying defects, quality assurance and process efficiency

(Inayathullah & Buddala, 2025). It also describes whether supervised, unsupervised, semi-supervised or reinforcement learning to be applied based on the AM data available. These techniques can help in making accuracies real time during printing. Another study has developed a GUI for optimizing process parameters of extrusion based 3d printing which can speed up the time to manufacture with less material waste and more cost efficiency (Rahmani et al., 2022).

Discussion

This above review has outlined the state of the art of ground and aerial mobile manufacturing. The ground based techniques reviewed focus on path planning and feedback control. On the other hand, aerial vehicles facilitate manufacturing in dynamic environments but raise new challenges of flight path planning, vehicle stability and localization. Collaboration of unmanned aerial vehicles or ground vehicles is also being investigated to build a more robust system. However, these systems still lack robustness in terms of localization, communication and material delivery. Algorithms of machine learning like regenerative and deep learning could be used to produce a more reliable network of mobile robots especially for accuracy from aerial devices as achieving sub millimeter accuracy with the drone in flight during printing is a challenge and an area of further research.

The above review discusses alternative options like laser diode, microwave and induction heaters which may be employed in a mobile setup due to their compactness. This will revolutionize what materials could be printed. Still, the advanced methods need more work before they are able to being deployed in a mobile setup.

Conclusion

The above review tells about the current research in mobile manufacturing machines. Most of the ground and aerial work has been done to extrude cement or polyurethane foam. Ground based mobile systems have so far manufactured plastic, concrete, clay, fiber composites and polyurethane foam. And most of them work in coordination with other robots to flexibly manufacture. Future research could focus on more efficient systems in terms of path planning, coordination, obstacle avoidance and more varied materials using different AM techniques. Since the systems rely on laboratory conditions for localization especially the aerial ones, hence, future work could address integrating various sensors like vision, LiDAR for multirobot localization in dynamic environments. Machine learning could be integrated further to allow robots to detect and correct defects in real time. Besides, standards for mobile AM machines are not built yet in terms of optimal size, energy efficiency and precision. This is a crucial step in accelerating development in mobile manufacturing as it would unite researchers at one point which would serve as a building block towards novelty in this area.

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alone are responsible for the content of the paper.

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