Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 1, 2021, Pages. 3463 - 3469

Received 15 December 2020; Accepted 05 January 2021.

Additive Manufacturing of Physical Sensors for Biomedical Applications: A State of the Art Review and Future Research Prospective

Ranvijay Kumar

Department of Mechanical Engineering, Chandigarh University, Mohali-140413, Punjab, India

Email:ranvijayk12@gmail.com

Abstract

The biomedical sensors are the electronic devices which converts the biomedical signals into electrical signals for measurement of biomedical activities. The additive manufacturing is one of the proved technologies for the manufacturing of functional as well as nonfunctional prototypes. The additive manufacturing processes in form of various technologies have been reported for the preparation of sensing structures. The among the different biomedical sensors such as; physical sensors, chemical sensors, bio-potential sensors and bio-analytic sensors, the additive manufacturing of physical sensors have been widely reported by previous studies. The physical sensor includes sensors includes sensors such as; geometric, mechanical, thermal, hydraulic, electric and optical sensors. The present study is a state of the art review for the preparation of physical sensors by additive manufacturing processes. This study highlights the overview of previous studies and direction for future studies for manufacturing of physical sensors by additive manufacturing approach.

Keywords:3D printing, physical sensors, mechanical sensors, thermal sensors, optical sensors, biomedical sensors

INTRODUCTION

Sensors are the essential part essential part for biomedical field which counts the activities in form of output as electrical signals. The additive manufacturing is one of the most applicable technologies for the manufacturing of sensors. The additive manufacturing is best known for manufacturing of customized and design flexible sensors for the range of biomedical applications[1], [2]. The previous studies have been reported for the number of studies which have shown the promising manufacturing of functional sensors by using additive manufacturing technologies. [3]have been reported the additive manufacturing process for the manufacturing[4]–[6] of deformable hydrogel bases strain sensor. The bio-analytic sensors are also among the biomedical sensors which may be also manufactured by using additive manufacturing techniques. The study has been reported for the additive manufacturing of electrochemical systems [7]. [8]have been highlighted the preparation of polyvinylidenedifluoride-Zinc oxie (PVDF-ZnO) based feedstock filaments of fused filament based sensors for the manufacturing of the sensors in biomedical applications. The study performed by [9]has been supported by the shape memory investigations for possible

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 1, 2021, Pages. 3463 - 3469

Received 15 December 2020; Accepted 05 January 2021.

biomedical applications. In the satellite qualification structural applications, the role of the multi-materials additive manufacturing is important. The study have been reported for the manufacturing of embedded sensors[10] in satellite applications [11]. The study has been reported for the volume-invariant ionic liquid microbands based additive manufacturing process for the possible application in biomedical field [12]. The manufacturing of lab-on chip devices has been reported by using the additive manufacturing process for the biomedical applications [13]. In the proceeding of functional prototypes manufacturing the manufacturing of the stretchable and wearable devices in form of sensors component have been also reported (Abshirini et al., 2019). [14]have been also reported the additive manufacturing of the capacitive sensors for biomedical applications. The bio-inspired 3D printing is advancement in the additive manufacturing for the biomedical applications. [15]have been reported the additive manufacturing process for self-sensing capability. The numerous role of the piezoelectric materials have been reported for the manufacturing of sensors in biomedical applications. [7]have been reported the additive manufacturing of the piezoelectric materials for ultrasonic sensing. [16]have been proposed the additive manufacturing of stretchable tactile sensors. Similarly the additive manufacturing of sensors in biomedical applications have been reported for the various application such as; micro-fluidic pressure sensors [17]), wire and mesh capacitive sensors; low cost electronic sensors; stretchable sensors using self-healing materials, battery less pressure sensors and stain induced biomedical sensors.

It is evident from the literature that additive manufacturing is an important manufacturing process for the preparations of the sensors in biomedical applications. The previous studies have been reported for the manufacturing[4]–[6], [18] of the biomedical sensors for the different measurements. The present study is a state of the art review for the preparation of physical sensors by additive manufacturing processes. This study highlights the overview of previous studies and direction for future studies for manufacturing of physical sensors by additive manufacturing approach.

Biomedical sensors

The biomedical sensors are broadly classified as the physical sensors, chemical sensors, bio-potential sensors and bio-analytic sensors (see Fig. 1). The sensing by the biomedical sensors may be in form of fluid pressure, temperature, motion, capacitive measurement, blood pressure, blood flux, magnetic and electric fields. Similarly the high end biosensors can be used for sensing of the protein, enzymes, vitamins, DNA, RNA, dopamine, microbial concentration as well the antigens[15]Now a days, the additive manufacturing processes have been widely used for all types of materials such as; polymers, metals, oxides, ceramics, polymer matrix composites, metal matrix composites, alloys etc. with customized design and flexibility so that this techniques is most acceptable for the preparations of the biomedical sensors.

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 1, 2021, Pages. 3463 - 3469

Received 15 December 2020; Accepted 05 January 2021.

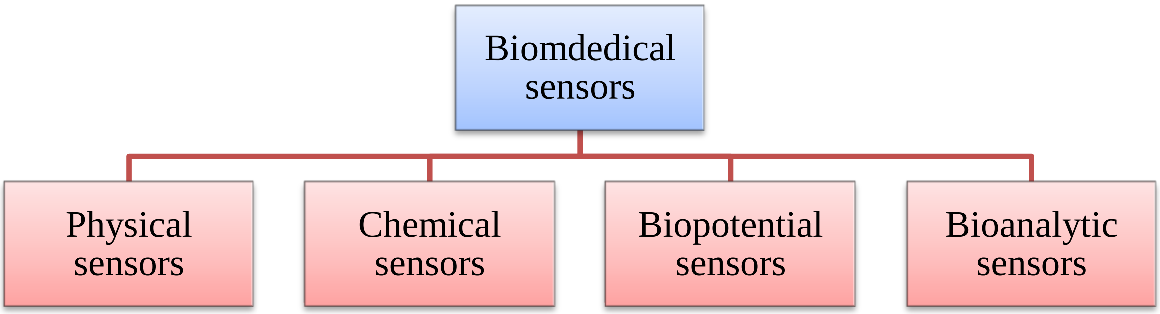

Fig. 1 Classification of biomedical sensors(Zhou et al. 2015)

Additive manufacturing of physical sensors

Fig. 2 shows the classification of the physical sensors. The geometric, mechanical, optical, thermal, hydraulic and electric sensors are some of the physical sensor which can be used in biomedical applications. The additive manufacturing has been grated as one of the promising techniques for the manufacturing of physical sensors. The study has been suggested the preparation of the stain sensors [19]stretchable tactile sensors [3]piezoelectric transducer [20], embedded optical element etc. by using the additive manufacturing techniques. The physical sensors can be prepared by using the different combination of materials such as; polymer-metal composites, metal-oxide composites, polymer-oxides composites, polymer-ceramic composites, polymer-metal-ceramic-oxide composites etc. The materials configuration can be customized with varying the proportions for preparation of physical sensors in biomedical applications.

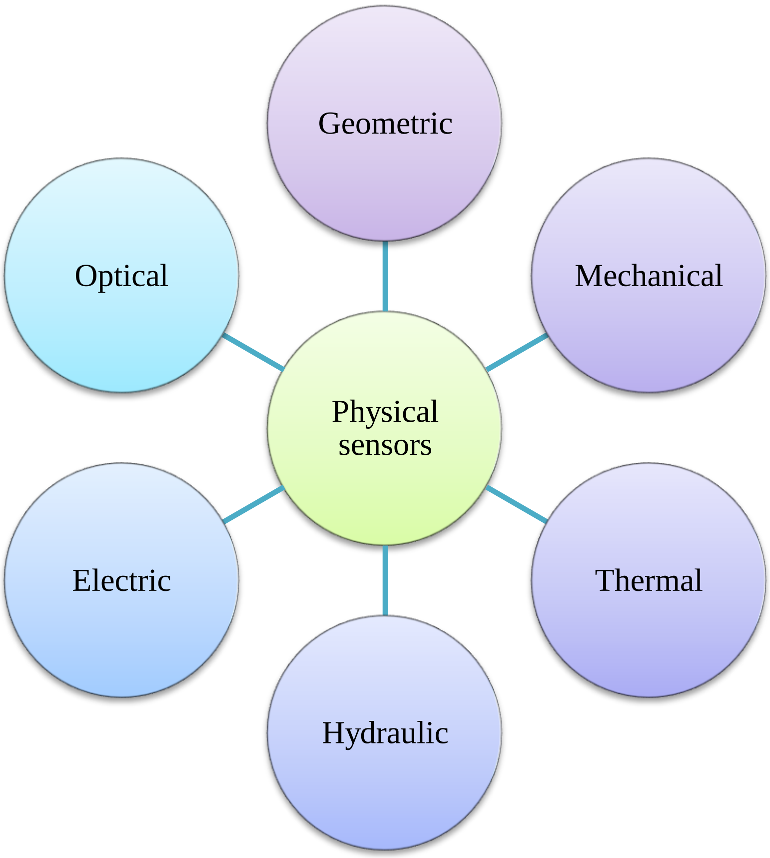

Fig. 2 Classification of physical sensors (Zhou et al. 2015)

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 1, 2021, Pages. 3463 - 3469

Received 15 December 2020; Accepted 05 January 2021.

Future prospective for additive manufacturing of sensors in biomedical applications

To meet the previous studies and to know the future aspects of additive manufacturing for preparation of physical sensors in biomedical applications the 'webofscience' database has been used for analysis on VOSviewer software package. The keyword '3D printing of biomedical sensor' has been put on www.webofknowledge.com and a total of 107 results in form of research papers have been retrieved. The minimum number of occurrences of each term has been set to 7 and a total of 12381 terms found. Under minimum occurrences of each term 7, a total of 64 terms have been met the threshold of the study and these terms have been taken for network analysis (see Fig. 3). The previous studies have been reported for the manufacturing of the sensors with additive manufacturing with investigations of performances, composites, force, sensors, detection, hudrogels, shape, cell, organ and fabrication for possible applications in soft robotics, biomedical devices, wearable electronics, biomedical applications, electronics, actuators, drug delivery and tissue engineering etc.

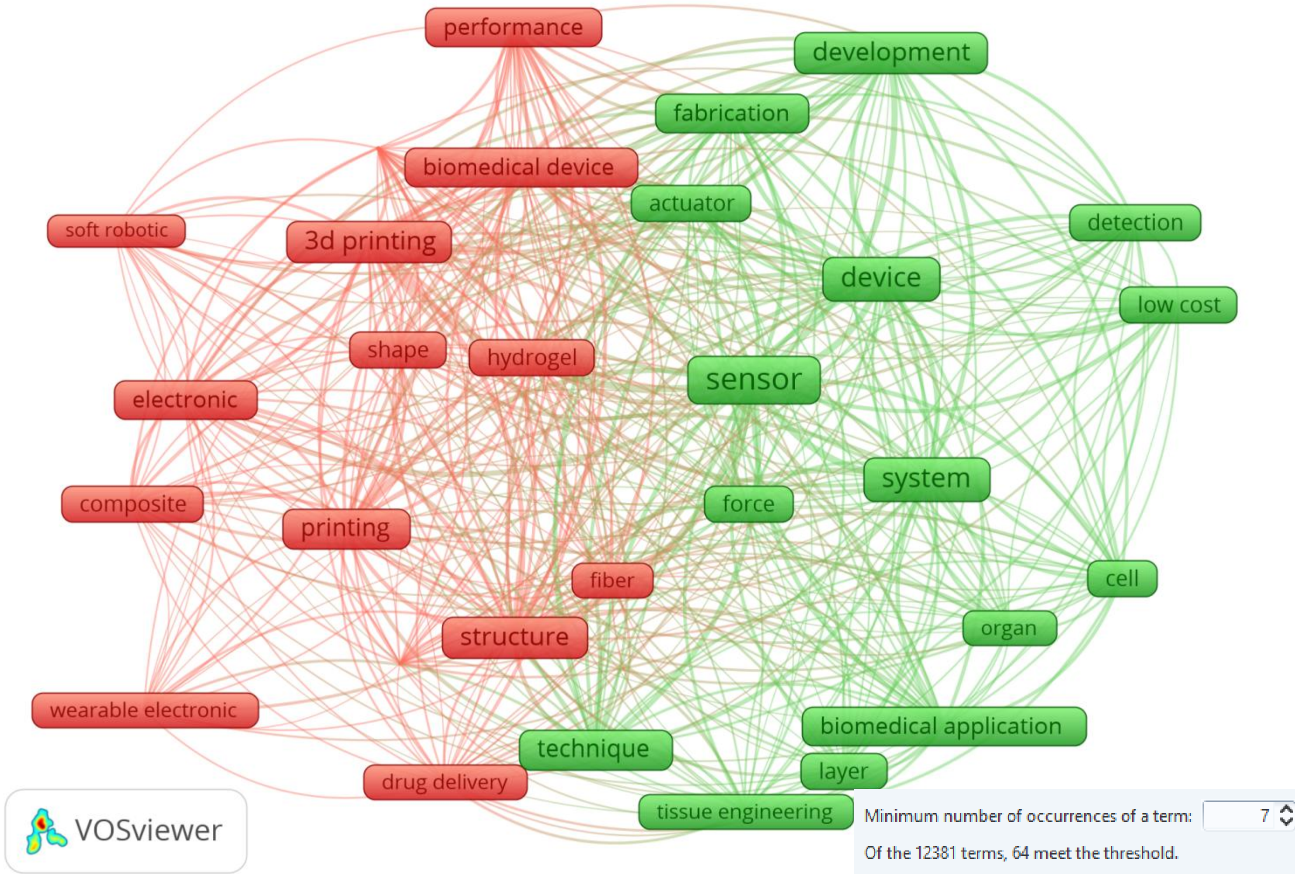

Fig. 3 Bibliographic map based text data VOSviewer analysis for 3D printing of biomedical sensors (database source: www.webofknowledge.com)

Fig. 4 shows the bibliographic network analysis for studies related to additive manufacturing in biomedical applications. To meet the future aspect of studies, the analysis has been conducted.

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 1, 2021, Pages. 3463 - 3469

Received 15 December 2020; Accepted 05 January 2021.

As per Fig. 4, there are number of studies may be conducted for the additive manufacturing of the physical sensors for biomedical applications. The investigations made be conducted for the additive manufacturing of the force based sensors, full working sensing devices, actuators, detection of physical activities, cell and organ sensors in biomedical and tissue engineering applications etc.

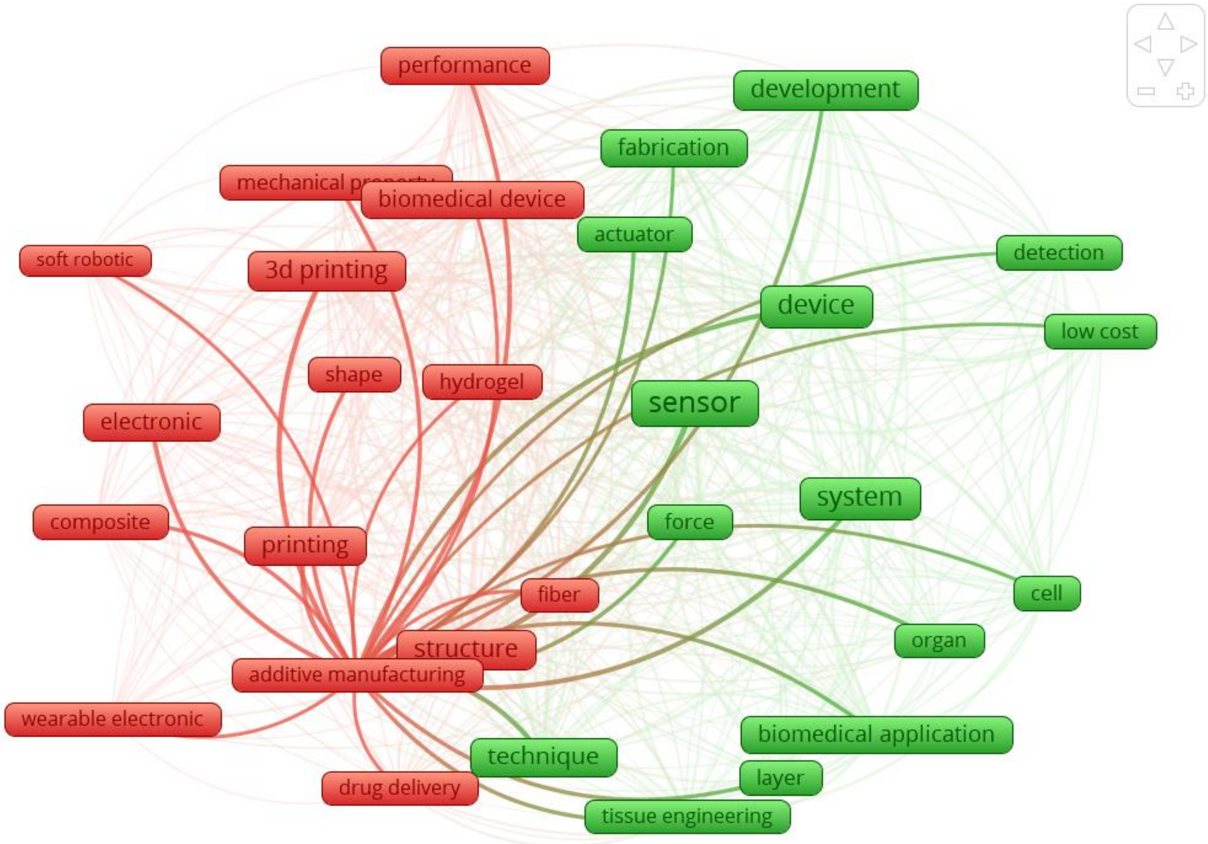

Fig. 4 Bibliographic network analysis for studies related to additive manufacturing in biomedical applications

CONCLUSIONS

The additive manufacturing has been considered as one of the most essential technologies in the manufacturing of the physical sensors in biomedical applications. The previous studies have been reported for the manufacturing of the sensors with additive manufacturing with investigations of performances, composites, force, sensors, detection, hudrogels, shape, cell, organ and fabrication for possible applications in soft robotics, biomedical devices, wearable electronics, biomedical applications, electronics, actuators, drug delivery and tissue engineering etc. The investigations may be conducted for the additive manufacturing of the force based sensors, full working sensing devices, actuators, detection of physical activities, cell and organ sensors in biomedical and tissue engineering applications etc. Also, the studies may be conducted in future for the bio-manufacturing of biosensors such as; the protein, enzymes, vitamins, DNA, RNA, dopamine, microbial concentration as well the antigens.

Received 15 December 2020; Accepted 05 January 2021.

Acknowledgement
The authors are highly thankful to University Center for Research and Development, Chandigarh University, for technical assistance.

REFERENCES

[1] L. Tabard *et al.*, "Robocasting of highly porous ceramics scaffolds with hierarchized porosity," *Addit. Manuf.*, vol. 38, 2021.
[2] V. K. Tiwary, N. J. Ravi, P. Arunkumar, S. Shivakumar, A. S. Deshpande, and V. R. Malik, "Investigations on friction stir joining of 3D printed parts to overcome bed size limitation and enhance joint quality for unmanned aircraft systems," *Proc. Inst. Mech. Eng. Part C J. Mech. Eng. Sci.*, vol. 234, no. 24, pp. 4857–4871, 2020.
[3] U. Golcha, A. S. Praveen, and D. L. Belgin Paul, "Direct ink writing of ceramics for bio medical applications - A Review," in *IOP Conference Series: Materials Science and Engineering*, 2020, vol. 912, no. 3.
[4] P. Gairola, S. P. Gairola, V. Kumar, K. Singh, and S. K. Dhawan, "Barium ferrite and graphite integrated with polyaniline as effective shield against electromagnetic interference," *Synth. Met.*, vol. 221, pp. 326–331, 2016.
[5] Lalita, A. P. Singh, and R. K. Sharma, "Synthesis and characterization of graft copolymers of chitosan with NIPAM and binary monomers for removal of Cr(VI), Cu(II) and Fe(II) metal ions from aqueous solutions," *Int. J. Biol. Macromol.*, vol. 99, pp. 409–426, 2017.
[6] K. M. Batoo *et al.*, "Structural, morphological and electrical properties of Cd2+doped MgFe2-xO4 ferrite nanoparticles," *J. Alloys Compd.*, vol. 726, pp. 179–186, 2017.
[7] K. Kumar, D. Zindani, and J. P. Davim, *Rapid prototyping, rapid tooling and reverse engineering: From biological models to 3d bioprinters*. De Gruyter, 2020.
[8] S. Kumar, R. Singh, M. Singh, T. P. Singh, and A. Batish, "Multi material 3D printing of PLA-PA6/TiO2 polymeric matrix: Flexural, wear and morphological properties," *J. Thermoplast. Compos. Mater.*, 2020.
[9] A. Kumar *et al.*, "Investigating the influence of WEDM process parameters in machining of hybrid aluminum composites," *Adv. Compos. Lett.*, vol. 29, p. 2633366X2096313, Jan. 2020.
[10] N. Mittal, U. Singh, and B. S. Sohi, "A novel energy efficient stable clustering approach for wireless sensor networks," *Wirel. Pers. Commun.*, vol. 95, no. 3, pp. 2947–2971, 2017.
[11] I. V Panayotov, V. Orti, F. Cuisinier, and J. Yachouh, "Polyetheretherketone (PEEK) for medical applications," *J. Mater. Sci. Mater. Med.*, vol. 27, no. 7, 2016.
[12] D. Zheren *et al.*, "3D micro-concrete hybrid structures fabricated by femtosecond laser two-photon polymerization for biomedical and photonic applications," in *Proceedings of the IEEE International Conference on Industrial Technology*, 2016, vol. 2016–May, pp. 1108–1114.
[13] S. Agarwala and W. Y. Yeong, "3D printed electronic tracks for bio-integrated free-form devices," in *Proceedings of the International Conference on Progress in Additive Manufacturing*, 2016, vol. Part F129095, pp. 313–317.

Received 15 December 2020; Accepted 05 January 2021.

[14] J. S. Chohan *et al.*, “Taguchi S/N and TOPSIS Based Optimization of Fused Deposition Modelling and Vapor Finishing Process for Manufacturing of ABS Plastic Parts,” *Materials (Basel).*, vol. 13, no. 22, p. 5176, Nov. 2020.

[15] R. D. T. Rico, J. A. J. Méndez, A. Prats-Galino, and S. F. P. González, “Taking advantage of 3D technology in health sciences: 3D PDF,” in *ACM International Conference Proceeding Series*, 2019, pp. 321–325.

[16] L. Yu, L. Tse, and K. Barton, “Airflow assisted electrohydrodynamic jet printing: An advanced micro-additive manufacturing technique,” in *ASME 2015 International Manufacturing Science and Engineering Conference, MSEC 2015*, 2015, vol. 1.

[17] A. P. Rajan, A. V Mulay, and B. B. Ahuja, *An automated acupressure glove for stress and pain relief using 3D printing*. Springer Singapore, 2016.

[18] S. Kumar, M. Kumar, and A. Handa, “Combating hot corrosion of boiler tubes - A study,” *Eng. Fail. Anal.*, vol. 94, pp. 379–395, Dec. 2018.

[19] B. K. Nagesha, V. Dhinakaran, M. Varsha Shree, K. P. Manoj Kumar, and T. Jagadeesha, “A review on weldability of additive manufactured titanium alloys,” in *Materials Today: Proceedings*, 2019, vol. 33, pp. 2964–2969.

[20] L. Jonušauskas, D. Gailevičius, S. Rekštyte, T. Baldacchini, S. Juodkazis, and M. Malinauskas, “Mesoscale laser 3D printing,” *Opt. Express*, vol. 27, no. 11, pp. 15205–15221, 2019.