A Review Study of the 3-D Printing Techniques utilized in Developing Humanoid Robot

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Abstract
Research in the field of 3-D printing in humanoid robot is trending. Ranging from the designing of the structure of the robot, stability of the structure, material to be used, actuators, sensors, machine learning and artificial intelligence, machine vision, etc.In this review paper the role of 3-D printing in the Humanoid robots is discussed. Humanoid robot is a multidisciplinary platform combining electromechanical systems and artificial intelligence. Morphology in biped locomotion is a great challenge which is being worked by researchers. Varying from kid-size to adult size various research groups are working. Also a concept called soft skin for humanoid robots is being developed using 3-D printing with many-materials.Many robotic platforms don't give access to all research groups to use to proceed with that so that also becomes a great challenge.Humanoid robots are being used in various fields like domestic, medical, industries, etc. Reducing the number of actuators is also of a great significance.The concept of variable hyper-redundant robotic arm also came into existence using some materials.Humanoid robots are being developed for the interaction of them with the humans and the environment which should be safe.

I. Introduction
Humanoid robots evolution occur really fast. There is a lot of research going on the development of the robot with the human like structures. Many humanoid robots have been developed till date, namely, Poppy, Asimo, HRP-2, Kenshiro, Nao, Darwin Op, Nimbro Op, iCub, MU-L8 [1,2], Pepper [3], igus [4], HPR, WABIAN-RV, CALUMA, InMoov, imNEU[5], NimbRo-OP2, Honda Asimo, NASA Valkyrie, DLR TORO, Boston Dynamics, Petman, Atlas robots [8], NimbRo-OP2X, Toyota T-HR3 [9], Sweaty [10]. The evolution and development of 3D printing technology or in other words additive manufacturing is advancing at a very fast rate.

Fig. 1: From left to right: Honda Asimo, NimbRo-OP2X, Toyota THR3, Boston Dynamics Atlas, DLR-TORO.

The additive manufacturing technology was started from 1980s and from then has been used in rapid prototyping and then rapid tooling. It is used for the small batch production or developing a prototype of the project or product really soon[10]. Two legged humanoid robot i.e, for biped locomotion is gaining a hike. This is very complicated and a lot of research is going on to get the walking motion of the humanoid robot efficiently.Also a lot of work is going on the obstacle taken as stairs [6]. Materials like shape memory polymer are also being used in the requirement of varying stiffness of the robotic arm. To simplify the fabrication and easy usability this particular material is being used to manufacture the robotic arm using 3D printing. Here ABS and PLA materials are developed to print arm of the robot through 3D printing. When we use these materials we have to use the FDM additive manufacturing technology [7].

II. Humanoid Robots using 3D Printing
The robot 'Poppy' has been designed mainly focusing on the the aspects as follows- Morphology and biped locomotion (3D Printing usage), public and material human-robot relations, full-body compliance, robustness and safety, breakable, repairable, precision, stationary, movable outer the lab, simple and speedy to copy and affordable [1].

The MU-L8 humanoid robot has been designed to project human like body. The Marquette University (MU) Humanoid Engineering & Intelligent Robots (HEIR) Lab has developed MU-L8 for work in the creation of publicly intelligent robots [2].

Humanoid robots are being developed as service robots which dance, entertain, interact, educate, etc. Also for carrying and hugging these have to soft and safe for children as well adults and also for themselves. These are inspired by the biology. 3D was printed a flexible cut module, consisting of airtight hollow areas for the detection of air load. This element is used in moderate holding by a pressure responders regulator as shown in Fig.2 [3].

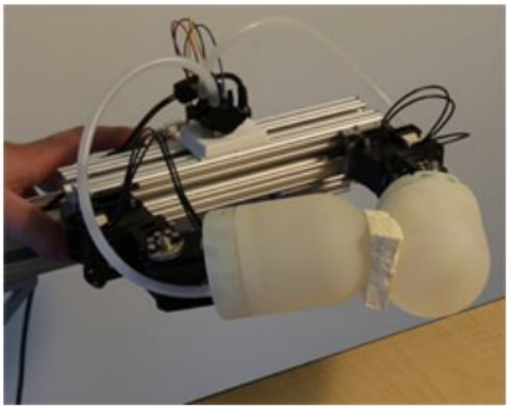


Fig. 2: 3D printed soft skin developed for safe interaction with children

The child's humanoid robot ' igus ' has been designed to be an open source benchmark platform which is reasonable, adaptable and simply adaptable. When released in open-source combination through this document, the 3D CAD files of this system are provided. The challenges such as perception of the environment of bipedal walking, object management and interaction between human and machine are examined. The parts of this are made using 3D printed and the material to be plastic [4]. The low cost humanoid robot 'imNEU', is developed considering the design similar to human and to mimic them. While designing the factors such lightweight of the robot, configuration which could be adjusted conveniently and the energy to be used efficiently have been considered. The former robot ' inMove ' is based on this robot. The whole body of the robot is impressed by the additive 3D technology [5]. The factor towards the motivation of researchers in the field of humanoid robots have been the desire to make a robot similar to human and make it behave like a human by using various technologies [8]. In order to address problems such as robot insecurity and complexity when dealing with real-life research groups, 3D printing makes things easier for a robot to develop [9].

III. Discussions and Results

Humanoid robot Poppy-a 84 cm high weighing 3.5 Kg has 25 joints with motors and many sensors. Also, 8 sensors of force under foot, two cameras having wide-angle and LCD screen of face and emotion detection and interaction with humans [1]. Comparison chart of various robots considering various parameters is shown in the Fig. 4.

	Size (cm)	Mass (kg)	Morphology simplifying walking Controller	Physical HRI Full-Compliance	Easily Reproducible	Easy to carry out	Open Source	Public Distribution	Cost (k$)
Darwin-Op	45	2.9		✓		✓	✓	✓	12
Neony	50	3.5		✓		✓			-
Nao	57	5.2				✓		✓	12
Acroban	65	5		✓		✓			9
BioBiped1	70	9.2	✓						-
Poppy	84	3.5	✓	✓	✓	✓	✓	✓	7.5
Nimbro-OP	95	6.6		✓		✓	✓	✓	22
semi-passive walker	100	~10	✓						-
Icub	104	22		✓			✓	✓	>350
Athlete Robot	125	10	✓						-
CB2	130	33		✓					-
HRP-2	154	58						✓	>400
Kenshiro	158	50	✓	✓					-

Fig. 4: Comparison of different robots on various parameters including Poppy

Fig. 3: Poppy Platform Overview

Lightweight and a suitable structure are crucial requirements for the robot. So the 3D designing and the selection of the material plays an important role as well.The properties of various materials which could be considered for the robot body material are as shown in the Table 1.

Table 1: Properties of some materials taken by poppy platform

Material	Mass Density $\rho\ (kg/m^3)$	Yield strength $\sigma\ (MPa)$	Young Modulus $E(GPa)$
Polyamide	930	49	1.65
Aluminum	2700	200	70
Steel	$7500 - 8000$	350	200
Titanium	4500	1200	114

The MU-L8 is of the size of a teen and the research work going on it focuses on the football skills of the robot so as to participate and perform well in the Robo Cup competition [2]. It is made up of ABS plastic, parts of which are printed by 3D printer. The use of the ABS material would use the FDM technology of 3D printing in other words additive manufacturing. Use of this material has provided them the easy and economically sound parts for the robot.

Fig. 5: Prototype of MU-L8

If airbag pressure exceeds or equals surrounding environmental pressures, the concept of the soft skin to protect children and their interaction with people will not change airbag shape unless external strength is applied. Here in Fig. 10, they are concurrently using two different materials, the area of the blue is rigid, and the area of the yellow is flexible. Solid works are used for the design and the part is imprinted with Vero White Plus (straight) and Tango Plus (flexible). The skin module is also connected to the silicone tube pressure sensor [3].

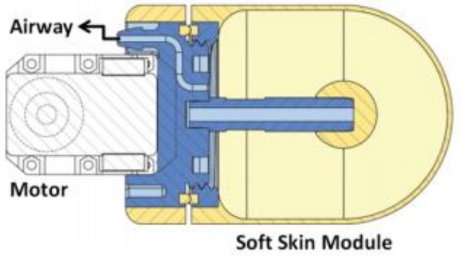


Fig. 6: Soft skin and motor cross-section

Fig. 7:3D printed soft skin

Another humanoid robot igus, which is an open source robotic platforms specifications have been given in the Table2.

Fig. 8:Humanoid Robot igus

Table 2: igus robot specifications

Type	Specification	Value
General	Height	90 cm
	Weight	6.6 kg
	Battery	4-cell LiPo (14.8 V, 3.8 Ah)
	Battery Life	15–30 min
	Material	Polyamide 12 (PA12)
PC	Product	Gigabyte Brix GB-BXi7-5500
	CPU	Intel i7-5500U (4 threads)
	Frequency	2.4–3.0 GHz
	RAM	4 GB DDR3
	Disk	120 GB SSD
	Network	Ethernet, Wi-Fi, Bluetooth
	Other	4 × USB 3.0, HDMI, MiniDP
CM730	Microcontroller	STM32F103RE (Cortex M3)
	Memory	512 KB Flash, 64 KB SRAM
	Frequency	72 MHz
	Other	3 × Buttons, 7 × Status LEDs
Actuators	Total	8 × MX-64, 12 × MX-106
	Head	2 × MX-64
	Each Arm	3 × MX-64
	Each Leg	6 × MX-106
Sensors	Encoders	4096 ticks/rev
	Gyroscope	3-axis (L3G4200D chip)
	Accelerometer	3-axis (LIS331DLH chip)
	Magnetometer	3-axis (HMC5883L chip)
	Camera	Logitech C905 (720p)
	Camera Lens	Wide-angle lens with 150° FOV

The "imNEU" humanoid, a dual wheel and a 3D-powered dual arm robot, is based on an open source platform called "inMoov". The upper body is made with 3D printer with the content PLA, biodegradable, without odour, on the humanoid roboter ' imNEU ' [5]. The list degree of freedom of the 'imNEU' robot is given in Table 3.

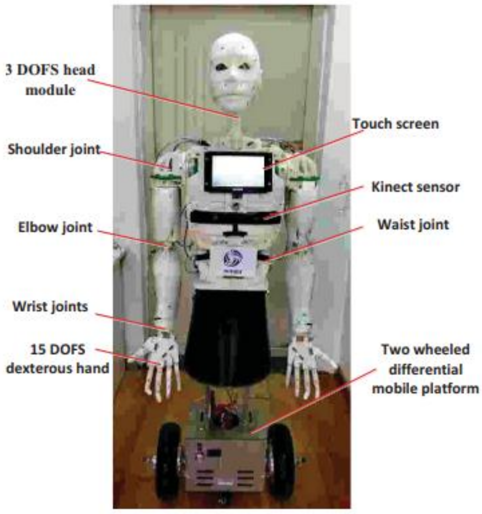


Fig. 10: 'imNEU' humanoid robot

Table 3: DOFs of 'imNEU'

Part	DoFs	Motors
Hand	15	5
Wrist	1	1
Elbow	1	1
Shoulder	3	3
Head	3	3
waist	1	2
Mobile Base	3	2 Hub Motors
Total	47	27

Another humanoid robot named 'NimbRo-OP2' is also bring upgraded from time to time. The specification of it is given in the Table 4. It is printed usind 3D entirely with the SLS technique on Polyamide 12. The 3D printing of the components have provided it vents in crucial points maintaining enough rigidity and supprt for torque [8]. The NimbRo-OP2X is the advanced version of the NimbRO-OP2. Its specifications are as shown in the Table 5.

Fig. 11: NimbRo-OP2 robot

Table 4: Nimbro-op2 robot specifications

Type	Specification	Value
General	Height & Weight	1345 mm, 17.5 kg
	Battery	4-cell LiPo (14.8 V, 6.6 Ah)
	Battery life	15–30 min
	Material	Polyamide 12 (PA12)
PC	Product	Intel NUC NUC7I7BNH
	CPU	Intel Core i7-7567U, 3.5–4.0 GHz
	Memory	4 GB DDR3 RAM, 120 GB SSD
	Network	Ethernet, Wi-Fi, Bluetooth
	Other	4 × USB 3.0, HDMI, Thunderbolt 3
CM730	Microcontroller	STM32F103RE (Cortex M3)
	Memory	512 KB Flash, 64 KB SRAM
	Other	3 × Buttons, 7 × Status LEDs
Actuators	Stall torque	10.0 Nm
	No load speed	55 rpm
	Total	34 × MX-106R
	Neck	2 × MX-106R
	Each arm	3 × MX-106R
	Each leg	13 × MX-106R
Sensors	Encoders	4096 ticks/rev
	Gyroscope	3-axis (L3G4200D chip)
	Accelerometer	3-axis (LIS331DLH chip)
	Camera	Logitech C905 (720p)
	Camera lens	Wide-angle lens with 150° FOV

Table 5: Nimbro-op2x specifications

Type	Specification	Value
General	Height & Weight	135 cm, 19 kg
	Battery	4-cell LiPo (14.8 V, 8.0 Ah)
	Battery life	20–40 min
	Material	Polyamide 12 (PA12)
PC	Mainboard	Z370 Chipset, Mini-ITX
	CPU	Intel Core i7-8700T, 2.7–4.0 GHz
	GPU	GTX 1050 Ti, 768 CUDA Cores
	Memory	4 GB DDR4 RAM, 120 GB SSD
	Network	Ethernet, Wi-Fi, Bluetooth
	Other	8 × USB 3.1, 2 × HDMI, DisplayPort
Actuators	Total	34 × Robotis XM-540-W270-R
	Stall torque	12.9 Nm
	No load speed	37 rpm
	Control mode	Torque, Velocity, Position, Multi-turn
Sensors	Encoders	12 bit/rev
	Joint torque	12 bit
	Gyroscope	3-axis (L3G4200D chip)
	Accelerometer	3-axis (LIS331DLH chip)
	Camera	Logitech C905 (720p)
	Camera lens	Wide-angle lens with 150° FOV

For the optimisation of its designe compared to its previos version, the material used in this is igus16 and SLS technology is used [9]. In the topology optimization concept which means the overall structure of the robot is being optimized i.e, some of the modules are joints complexities have been removed. As a case study the humanoid robot 'Sweaty' developed by University of Offenburg, its one module is taken and with the help of additive manufacturing or 3D printing the optimization is done. The module of the Sweaty robot which is selected as the case study was as shown in Fig.12, and The conventional and the 3D printed module of that module is as shown in the Fig. 13.

Fig. 12: Humanoid Robot Sweaty

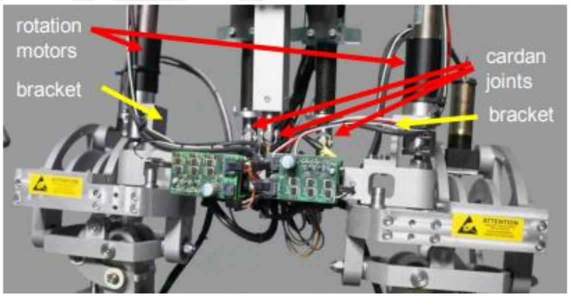
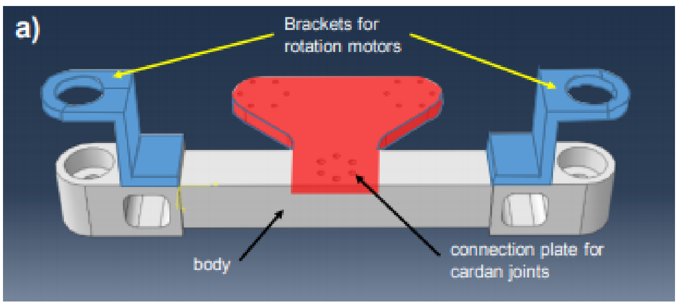


Fig.13 :Selected module of 'Sweaty'



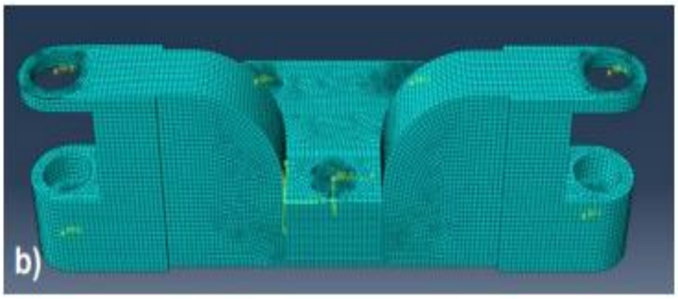


Fig.14: a) Conventional model b) 3D printed model

Conventionally the material used was AlZnMgCu1.5, comparing to that the module is conceptualised and analysed with respect to three other materials namely, AlMgSc, Ti6Al4V and Steel 1.2709 [10]. The comparison chart for the materials of all these materials i.e, the conventional one and the three variants used is as shown in the Table 6.

Table 6: Comparison chart for materials considered for topology optimization

Material	Yield stress [MPa]	Density [g/cm³]	Volume [cm³]	Weight [g]	Energy [mJ]	Costs [%]
AlZnMgCu1.5	450	2.78	217.0	99.2	4.3	100
AlMgSc	469	2.67	198.9	53.1	3.5	266
Ti6Al4V	945	4.45	185.1	82.3	2.3	398
Steel 1.2709	1000	8.04	208.6	167.7	1.4	305

IV. Conclusion

3D printing plays a very good role in the field of robotics. It is helping in the rapif prototyping and testing of the models or parts of the robot and in long term the entire structure of the humanoid robots are being printed using 3D printing technology of addtive manufacturing. It make the process of maiing a robot easy and fast. The techniques involved uptil now are two, those are-SLS and FDM. The materials used have been alloys of aluminium, steel and titanium, these use the SLS technique and are costly. The other option of materials preferred for the structure of the robot are ABS and PLA which are cheap and easily avaible and uses FDM technique for 3D printing . Depending on the requirement and budget of the robot, we can choose the specific material and technique as affordable and required.

V. Future Scope

Even though many of the papers review in the paper are open source, their still is scope for the upgradation of these platforms and they are working on to make these platforms to be available for the other research groups to wotk and bring advancement in the technology and overall development of the humanoid robots at a faster rate. The biped locomotion, wheel locomotion, usage of other sensors actuators, controllers, robot vision system, aritificial intelligence and many more things to be included in the humanoid robot for it to look like and behave as a human. The files of many of these open source robot platforms have been made available online with the release of these paper so that other interested researchers and research groups can make use of it and get the idean and knowledge of the development till date and could further contribute towards its improvement.

References

[1] MatthieuLapeyre, Pierre Rouanet and Pierre-Yves Oudeyer. The Poppy Humanoid Robot: Leg Design for Biped Locomotion. 2013 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) November 3-7, 2013.

[2] Adam B. Stroud, Matthew Morris, Kellen Carey, John C. Williams, Corey Randolph, Andrew B. Williams. MU-L8: The Design Architecture and 3D Printing of a Teen-Sized Humanoid Soccer Robot.In Proceedings of 8th Workshop on Humanoid Soccer Robots 13th IEEE-RAS International Conference on Humanoid Robots (Humanoids), Atlanta, GA, 2013.

[3] Joohyung Kim, Alexander Alspach, and Katsu Yamane. 3D Printed Soft Skin for Safe Human-Robot Interaction. 2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) Congress Center Hamburg Sept 28 - Oct 2, 2015.

[4] Philipp Allgeuer, Hafez Farazi, Michael Schreiber and Sven Behnke. Child-sized 3D Printed igus Humanoid Open Platform. 2015 IEEE-RAS 15th International Conference on Humanoid Robots (Humanoids) November 3-5,2015.

[5] Hongtai Cheng, Member, IEEE, Guangfei Ji, Student Member, IEEE. Design and Implementation of a Low Cost 3D Printed Humanoid Robotic Platform. The 6th Annual IEEE International Conference on Cyber Technology in Automation, Control and Intelligent Systems June 19-22, 2016.

[6] Ivan NikolovChavdarov. Walking Robot Realized Through 3D Printing. Submitted by Academician Ch. Roumenin on April 15, 2016.

[7] Yang Yang, Yonghua Chen, Yingtian Li and Michael Zhiqiang Chen. 3D printing of variable stiffness hyper-redundant robotic arm. 2016 IEEE International Conference on Robotics and Automation (ICRA) Stockholm, Sweden, May 16-21, 2016.

[8] GrzegorzFicht, Philipp Allgeuer, Hafez Farazi and Sven Behnke. NimbRo-OP2: Grown-up 3D Printed Open Humanoid Platform for Research. 2017 IEEE-RAS 17th International Conference on Humanoid Robotics (Humanoids) Birmingham, UK, November 15-17, 2017.

[9] GrzegorzFicht, Hafez Farazi, André Brandenburger, Diego Rodriguez, DmytroPavlichenko, Philipp Allgeuer, Mojtaba Hosseini, and Sven Behnke. NimbRo-OP2X: Adult-sized Open-source 3D Printed Humanoid Robot. 2018 IEEE-RAS 18th International Conference on Humanoid Robots (Humanoids) Beijing, China, November 6-9, 2018.

[10] Stefan Junk, Benjamin Klerch, Lutz Nasdala and Ulrich Hochberg. Topology optimization for additive manufacturing using a component of a humanoid robot. 28th CIRP Design Conference, May 2018.