PAPER NAME

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AUTHOR

Rudi Kurniawan Arief

WORD COUNT

6317 Words

CHARACTER COUNT

33254 Characters

PAGE COUNT

12 Pages

FILE SIZE

463.4KB

SUBMISSION DATE

Apr 2, 2023 11:28 PM GMT+7

REPORT DATE

Apr 2, 2023 11:28 PM GMT+7

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International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-4, February 2019

Hardware Improvement of FDM 3D Printer: Issue of Bed Leveling Failures

Rudi Kurniawan Arief, Erry Yulian T. Adesta, Irfan Hilmy

Abstract*: Rapid Prototyping is one of many technologies that trigger the Industrial Revolution 4.0. The open source system that applied to 3D printer system make the research development grow rapidly. Most favorable research topics are in the area of extrusion head, material and functional modification. But the difficulties in leveling the heated bed has created worst user experiment and cause some catastrophic failures to be happens. This paper reviewed the research conducted around improvement of the FDM printer's hardware. The cause of most occur failures in FDM printing also discussed. To overcome the disturbing failure caused by the lack of levelness of the heated bed, a pine trees liked pin system is introduced.

Key words: FDM, 3D Printer, Bed Leveling, Heated Bed, Printing Failures.

1. INTRODUCTION

Rapid Prototyping (RP) process is a relatively new technology in manufacturing that becoming a branch of Additive Manufacturing (AM) process [1][2]. Contrast to traditionally Subtractive Manufacturing (SM) process that remove materials to form a new shape, this technology create a part from none to become a shape, so there are no material wasted [3][4]. With this additive-ability, manufacturing of complex, difficult and almost impossible shape can be process [5].

The first development of RP technology already started in the early 1980's for creating of models and prototype parts only. In late 2000's, the technology of RP is developed significantly. The invention of various machines, techniques and materials has brought this technology growing so high to become a today's hot topic technology. Currently, at least eight systems of rapid manufacturing are available, from the most expensive and complex one to the simple and affordable such as Fused Deposition Modeling (FDM). This technology is one of many that trigger the industrial revolution 4.0 and soon will reach its golden era.

Since its was born in 1980's RP already plays important role to developed various fully functional products in vast range of application. 3D printer as the representative of RP family line up have many types with various different system and materials. [6]. Three types of materials are use as production material for this technology; solid, liquid and powder form that today can be found in the wide range of colors and specifications. Those are used to produce different character of part and machine.

In 2010, the American Society for Testing and Materials (ASTM) thru group "ASTM F42-Additive Manufacturing" has categorized the 3D printing by seven categories as Directed Energy Deposition, Binder Jetting, Vat Photo-polymerisation, Material Extrusion, Material Jetting, Sheet Lamination, Powder Bed Fusion [2].

II. FUSED DEPOSITION 3D PRINTER

A. Review of FDM 3D Printer

The most common RP machine for home and educational use is the Fused Deposition Modeling (FDM) machine that invented by Scot Crump, the co-founder of FDM manufacturer called Stratasys Inc. in 1989 [7][6] [8]. The first desktop FDM 3D printers were invented the team of Professor Adrian Bowyer at the University of Bath, and recognized as open sourced Replicating Rapid Prototyper (RepRap) initiative. This project resulting an open design, self-reproducible 3D printer that available to download online for other users [9] [10]. Nowadays FDM has become widespread machine that sold everywhere and built by everyone. Arduino platform commonly used for control system to perform simple manufacturing operation [11]. Despite of its common use to build the action figures and toys, FDM also started to be used in fashion industry, medical industry as well as technical parts. This show how wide is the using of this cheap and simple machine.

FDM is a RP machine that using Cartesian system for movements. The main components of this machine are moving along the axis of x, y and z or some are using the mixing of translation and rotational movements vary depends of the movements type [8]. However, the system or movement type used, mostly all of FDM 3D printers consist of main part as below:

1. Printer Head : Heater device to liquify thermoplastic material or filament and distributed through a nozzle.
2. Arms : Moving component to held and move printer head to desired position.
3. Heated Bed : Flat area to distribute the extruded filament that become a form of product / part. This component usually fixed, move along z axis only or y axis only.
4. Control system : Open source CNC router system to control every movement and setting of the whole machine.
5. Frame : Supporting structure to place all of the components.

Manuscript published on 28 February 2019.
*Correspondence Author(s)
Rudi Kurniawan Arief, Phd Student, Department of Materials & Manufacture Engineering, International Islamic University Malaysia, Gombak, Malaysia.
Erry Yulian T. Adesta, Professor, Department of Materials & Manufacture Engineering, International Islamic University Malaysia, Gombak, Malaysia.
Irfan Hilmy, Assistant Professor, Department of Materials & Manufacture Engineering, International Islamic University Malaysia, Gombak, Malaysia.

6. Stepped Motor: Electric motor to move all moving part that connected with rubber belt.

7. Spooler : Filament container that will feed to printer head.

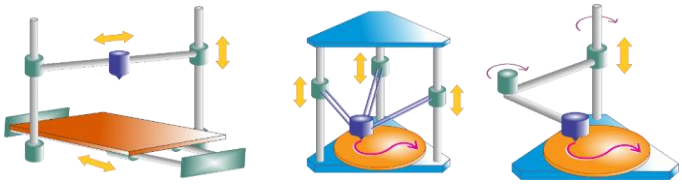
FDM printer distributes the melted material by the arm and bed that will move along the x, y and z axis. Commonly, this type of printer employed the arm for x and y movements while bed moves in z direction, or the bed moves in y axis direction. The movements are controlled by open source CNC based routing program using Arduino platform. Processing software is required to covert 3D design to machine language or G code. The size of FDM 3D printers is decreased day by day for mobility purposes so it can be use and stored properly only in the working table and become a desktop 3D printer [12].

B. Classification of FDM 3D Printer

The FDM 3D printers are classified by the movement system of its head and bed as follow:

1. Cartesian Method: Most available 3D printer is using Cartesian method. The movement of the extrusion head and heated bed is linear along the x, y and z axis. In some type, extrusion head is moving in x and y axis while heated bed is moving upward in the z axis. Another type of Cartesian allowed the heated bed to move horizontally in the y axis while the extrusion head move along the x and z axis [8]. This is the simple but accurate method in which best for rectangular shaped products. This method is easy and cheap to manufacture and operated.

2. Delta Method: This method is the most recent hot topic. Movements of delta printer are based on parallel coordinate system by free trajectories generated by articulated axes. It has 3 moving arms where the extrusion head attached and a static bed [8]. This printer works better to produce circular shapes. The printer that using this method has bigger flexibility, higher speed, higher working space and high stability [13]. 3. SCARA Method: This is a simplify method of the Selective Compliance Assembly Robot Arm (SCARA). This printer has 3 degree of freedom and driven by 3 stepped motors with a static bed and 2 moving arms (shoulder and elbow) that connected together and attached to a vertically moved bracket. According to Figure 1 SCARA type robotic system has three degrees of freedom and it is actuated by three servo motors to do one vertical and two horizontal motions [14]. This method is more complicated than other methods. Most of SCARA printer still in development phase and no commercial printer available so far.



a) b) c)

Figure 1. a) Cartesian Method, b) Delta Method, c) SCARA Method.

C. Advantages of FDM 3D Printer

Despite its simple and cheap advantages, there are more advantages that makes this technology lovable, not only for toy maker but also for the research means. FDM machine is reliable and cost friendly for small scale production and produce replacement spare parts [15]. FDM is very user friendly, even a fashion designer can use it creatively [16]. Complex geometry that difficult to manufacture by machinery process can be produced with FDM technology [17]. Nowadays, more microfluidic researches use FDM machine in their laboratory. [18]. RP technology begins to brings significant impact in small production [3].

III. DEVELOPMENTS IN FDM 3D PRINTER

A. Research in FDM 3D Printer

Many researches have been conducted around the world in developing the FDM 3D printing topics. Development of material, system and also hardware has been rapidly grown during these past view years. This paper identify some research works that related to FDM 3D printer. Related research was searching thru internet browsing that has been published by the Scopus, IEEE explore, Core.ac.uk, Google Scholar and Research Gate's website from 2011. Searching activities found more than 3000 publications with keywords; 3D printer, 3D printing, FDM, 3D printer improvement, 3D printer development. The searched items then filtered to 205 related to FDM 3D printer topic. The results of the literature search activities then filtered to choose the topic related to hardware development with 39 papers was found. Development and improvement of Head system and frame function were the most discussed topics. Here the developments of hardware related discussed with the most research conducted in development of extrusion head. Second most discussed topic related to modification and enhancement of FDM printer function or new function development based on the FDM method (see Table.1).

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Table 1. Research Article Related To Hardware Improvements of FDM Printers

No.	Author	Year	Title	Improvement Topic					Research Focus
				Bed	Feeder	Frame	Function	Head	
1	Boriano Heras, Enrique Blaya Haro, Fernando de Agustín del Burgo, José M. Islán Marcos, Manuel D'Amato, Roberto [19]	2018	Filament Advance Detection Sensor for Fused Deposition Modelling 3D Printers		√				Development of system to detect extrusion failures in FDM 3D printers by sensing that the filament is moving forward properly or not.
2	Stopka, M Kohár, R Weis, P Šteininger, J [20]	2018	Concept of modular 3D printer construction			√			Design a 3D printer's construction that the dimensions can be change according to the actual need.
3	Daniel, Alvarez Christian, Vasquez [21]	2018	Improvements to control system of a multi-extruder 3D printer using a Controller Duet card					√	Multiple extrusion head of 3D printer with rotation system.
4	Oo, Htin Lin Ye, Kyaw Zaw Linn, Ye Htet [22]	2018	Modeling and Controlling of Temperature in 3D Printer (FDM)					√	Design of temperature control to stabilized heat of the extruder head
5	Teliskova, Monika Torek, Jozef Cmorej, Tomas Kocisko, Marek Petrus, Jaroslav [10]	2017	Adjustments of RepRap Type Printer Workbench	√					Part adhesivity using various bed's material
6	Patil, Ashish Patil, Bhushan Potwade, Rahul Shinde, Akshay Shinde, Rakesh [23]	2017	Design and Development of FDM Based Portable 3D Printer			√			Briefcase liked design concept of portable 3D printer which can be carry anywhere.
7	Quatrano, A. De Simone, M. C. Rivera, Z. B. Guida, D. [11]	2017	Development and Implementation of a Control System for a Retrofitted CNC Machine by Using Arduino			√			Making of new 3D printer by converting the obsolete machine in order to reduce the amount of electronic and industrial wastes.

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8	Zeleny, Petr Ruzicka, Vojtech [24]	2017	The design of the 3D printer for use in gastronomy				√		Modification of RepRap FDM 3D Printer for Chocolate Food Printing by modifying the extrusion head. Syringe extrussion method was using to replace the Filament extrusion head.
9	Deshmukh, Suhas P. Shewale, Mahesh S. Suryawanshi, Vishal Manwani, Akhil Singh, Vishal Kumar Vhora, Rushabh Velapure, Mihir [7]	2017	Design and Development of XYZ Scanner for 3D Printing				√		Modification of 3D printer structure to use for a 3D scanner.
10	Xie, Yi Tan, Yuegang Ma, Guofeng Zhang, Jun Zhang, Fan [25]	2017	Design and Implementation of Chocolate 3D Printer				√		Design of food printer with FDM method. The machine build from scratch with syringe extruder moving in X&Y axis and the bed move along the Z azis
11	Alimanova, Madina Zholdygarayev, Aslanbek Tursynbekova, Aiym Kozhamzharova, Dinara [26]	2017	Overview of Low Cost Self Made 3D food printer				√		Development of low cost 3D printer to print chocolate material.
12	Acosta, Everardo [27]	2017	Laser Printhead Concept Design For A 3d Moving Platform				√		Modification of FDM 3D printer head that can be interchangeable with any machinery's head types.
13	Chen, Xiaolong Liu, Xinhua Childs, Peter Brandon, Nigel Wu, Billy [28]	2017	A Low Cost Desktop Electrochemical Metal 3D Printer				√		Modify desktop 3D printer for electrochemical process with syringe head.
14	Han, Shanling Xiao, Yu Qi, Tao Li, Zhiyong Zeng, Qingliang [29]	2017	Design and Analysis of Fused Deposition Modeling 3D Printer Nozzle for Color Mixing					√	Development of two channels nozzle for color mixing filaments

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15	Koc, Emre [30]	2017	Investigation Of Heat Sink Geometry Effect On Cooling Performance For FDM 3d Printer Liquefier					√	Investigated the cooling performance of the different heat sink types on the FDM 3D printers by using CFD analysis.
16	Maria, Luigi Piperi, Erald [31]	2017	Extruder Head Thermal Analysis For An Open-Source 3D Printer					√	Evaluation of the extruder head for an open-source 3D printer thermal effects based on the finite element analysis (FEA) by using SolidWorks software, and based on the thermographic analysis by using thermal camera for image capturing.
17	Kun, Krisztián [4]	2016	Reconstruction and development of a 3D printer using FDM technology			√			Create a structure, where the extrusion head unit does the X-Y movement at the same time, and to be able to print support material.
18	Kumar Singh, Abhishek Chauhan, Sriram [2]	2016	Technique to Enhance FDM 3D Metal Printing				√		Conceptual design of FDM metal printing
19	Oberhauser, Joseph Q. [32]	2016	Design, Construction, Control, and Analysis of Linear Delta Robot			√			Design and construction of a new 3D printer with linear Delta Robot method.

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20	Ogulmus, Ahmet Cakan, Abdullah Tınkır, Mustafa [14]	2016	Modeling And Position Control Of Scara Type 3D Printer			√			Modeling design of 3D printer using Scara method three degrees of freedom and it is actuated by three servo motors to do one vertical and two horizontal motions. Feeding system for 3d printing is placed to back of robot and it is extended at the end of the robotic arm
21	Sovaila, Florin Sovaila, Claudia Baroiu, Nicusor [13]	2016	Universal Delta 3d Printer			√			Making of new Delta 3D printer with components manufactured by other 3D printer.
22	Surange, Vinod G Gharat, Punit V [17]	2016	3D Printing Process Using Fused Deposition Modelling (FDM)			√			Making low cost cartesian 3D printer with price 15% lower than market.
23	Hoy, Brandon [33]	2016	Design and Implementation of a Three-Dimensional Printer Using a Cylindrical Printing Process			√			Making of Rotary 3D printer using a layered polar printing style, improving printing speeds compared to the standard Cartesian printing process.
24	Lin, Kuang Hao Shen, Che Ying Du, Jin Lin Wang, Guo Yi Chen, Hou Ming Tseng, Jan Dong [34]	2016	A Design of Constant Temperature Control System in 3D Printer					√	Design of temperature control to stabilized heat of the extruder head that affected by evironment temperature.
25	Hsieh, Cheng Tiao [35]	2016	Development of an Integrated System of 3D Printer and Laser Carving				√		Combined 3D printer's head and Laser engraving by modify Prusa i3 platform

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26	Pérez-Mesa, R. Travieso-Rodriguez, J. A. Corbella, X. Busqué, R. Gomez-Gras, G. [9]	2016	Finite Element Analysis Of The Thermal Behavior Of A Reprap 3D Printer Liquefier					√	Performance the analysis of a RepRap 3D printer Extruder by studying its thermal behavior. Focusing on the influence of the airflow generated by a fan coupled to the extruder during the printing process.
27	Wang, Guanyun Yao, Lining Wang, Wen Ou, Jifei Cheng, Chin-Yi Ishii, Hiroshi [36]	2016	X-Print: A Modularized Liquid Printer for Smart Materials Deposition					√	Build and customize FDM printer a liquid-based smart material printing platform with off-the shelf or easy to machined parts
28	Pilch, Zbigniew Domin, Jaroslaw Szlapa, Andrzej [37]	2015	The impact of vibration of the 3D printer table on the quality of print	√					Analyze the impact of mechanical vibrations on print quality. This research measures mechanical vibrations in the plane perpendicular to the surface of the table by using laser measurement techniques.
29	Gao, Wei Zhang, Yunbo Nazzetta, Diogo C. Ramani, Karthik Cipra, Raymond J. [38]	2015	RevoMaker: Enabling Multi-directional and Functionally-embedded 3D printing using a Rotational Cuboidal Platform			√			Modification of standard FDM printer with revolving cubodial method to reduce support and material waste

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30	Ali, Md Hazrat Mir-Nasiri, Nazim Ko, Wai Lun [39]	2015	Multi-nozzle extrusion system for 3D printer and its control mechanism					√	This paper presented a improvement of extruder head with 5 active head. This invention enable printing of 5 simultaneous different color without stopping the process for filament exchange.
31	Rupanagudi, Sudhir Rao Bhat, Varsha G. Savarni, K. R.Vaishnav Ram Bharadwaj, Sumukha Prasuna, Vaddi Naga Padma [40]	2015	A novel automatic low cost cutting machine-cum-3D printer using an image processing based control				√		Function improvement of the FDM 3D printer for cutting machine with image processing based control to be able to performed two process.
32	Ayodele, Babapelumi Ebun [41]	2015	Modeling Of Fdm 3d Printing For Improved Performance					√	Optimizing nozzle diameter and layer thickness to obtain best printing pattern for multi-head FDM printer.
33	Kallevik, Grutle [42]	2015	Designing a 5-axis 3D printer			√			Improvement of FDM printer by adding 2 more axes (Pentarod or 5 axis) over 3 existing axis.
34	Peli, Ricardo Sempértegui, Ana Morocho, Derlin Loza, David Alulema, Darwin Proaño, Mariela [43]	2015	Study, Design and Construction of a 3D printer implemented through a Delta Robot			√			Modify and built FDM printer delta method. Analyzed printing result for several shapes.
35	Wu, H.-X. Yu, Z.-H. Zhang, H Yang, Z.-S. Wang, Y [44]	2014	Method for monitoring of FDM 3D printer failure based on acoustic emission					√	Development of monitoring of filament breakage and extruder blockage based on Acoustic Emmision in FDM printer.

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36	Hudson, Scott E [45]	2014	Printing Teddy Bears: A Technique for 3D Printing of Soft Interactive Objects				√		Printing with cartesian method of FDM printer by using knitting head to knit a wool material to form a soft products.
37	BARTOŠ, Radko [46]	2014	Design Of Heated Print Bed For Fdm 3d Printer With F.E.M	√					Development of the heating system of FDM printer's bed using power resistor. Power resistors spread along the bed surface with specific arrangement to obtain better and even heat spreads.
38	David W. Eld [47]	2014	Ultra Affordable Rapid Prototyping : Creation And Setup Of An Experimental Fabrication Machine				√		Development of Print and Mill machine using FDM printer platform.
39	Dvoracek, Jan [48]	2011	A Distribution of Temperature Field in the FDM Printhead					√	Development and analyze of extruder head system with different length. The extruder developed to have filament feeder directly mounted to head system.

B. Hardware Improvements of FDM 3D Printer

Since this research is focusing in hardware improvements, the literature search's result of hardware improvements then classified into 5 categories (Fig. 2). The scientific articles about hardware improvements are explained in the table.1. Most of research regarding hardware improvements is focusing in extrusion head development by 39 articles, less research touch about improvement of heated bed in which has become one of most failure factor in FDM process. During 2011 to mid of 2018, 39 papers discussed about developments of the hardware of FDM 3D printer but no related papers found during 2012 to 2013 and 2017 is the highest with 12 papers found.

Research topic about the improvements of the extrusion head system is the most conducting toward the years. Head improvements is always a good topic to explore because of the development of material keep on growing. Failures related to material and extrusion process still become an issue that could be solved by the development of the extrusion head. The open sourced concept and simple mechanism of FDM printer allowed researchers to developed the system function wider. 11 researches have been conducted related to function modification and developments, from the gastronomy function to double function of additive and subtractive process, marks 2017 as the highest researches published. Development of FDM frame and its physical structures start to grow in 2015 and keep on exist till 2018. Frame's development topic discussed about the simplify the dimension, collapsible and expandable concept and printing axis addition. Development of heated bed remain very slow despite this component leave high complains from users. This paper will introduce the importance of developments of the heated bed system and the proposed development method.

C. Cause of Failures in FDM

Many cases of failure happened all around, especially for a new user. The failures are time consuming, waste of materials and could cause damage of the printer. Failures often happens because of inappropriate printing orientation, shrinkage miscalculate, inadequate structure, bed misalignment, lack of bed levelness, etc. [6] [49].

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Product failures commonly caused by Human error and Machine failure. Human error usually happened by the lack of maintenance activities, design faulty and inadequate setting of programs and those all could lead to both Machine and product failures [5][50]. But scientific research still rarely discussed about the failures in FDM 3D printer. Literature search only found 3 scientific literatures discussed this topic, the searching then continued to the 3D printing related web sites.

List of refferance article to analyzed cause of failure in FDM process:

1. Jaksic, N. I. (2015). What to do when 3D printers go wrong: Laboratory Experiences. In 122nd ASEE Annual Conference & Exposition (p. 26.1730.1-26.1730.11). Seattle. [49]
2. Krisna Kumar Shanmugham Chetiyar and S. S. Galla Venkata Sri, "Measurement of Surface Defects in 3D Printed Models", Dissertation, (2016). [51]
3. Gunaydin, Kadir & S. Türkmen, Halit. "Common FDM 3D Printing Defects", (2018), Unpublished Manuscript. Retrieved from https://www.researchgate.net/publication/326146283_Common_FDM_3D_Printing_Defects. [12]
4. All3dP.com 41 Common Problems: 2018 3D Printing Troubleshooting Guide.
5. Autodesk Redshift 5 Problems With 3D Printing And How To Fix Them.
6. Rigid.ink The Ultimate 3D Print Quality Troubleshooting Guide 2018: 44 Issues Explained - Gets Your Print Looking Perfect Not Pathetic.
7. Instructables.com 3d Printer Basics And Troubleshooting: FDM Printers.
8. Simplify3d.com Print Quality Troubleshooting Guide.

All of refferences above discussed about failure in FDM process and its cause. The cause of failure found in those articles classified into 10 classification. One classified cause of failure might be responsible for several problems. For example, article number 4th was explaining about 41 common problems found in FDM 3D printer, 9 of the problems was caused by heated bed leveling.

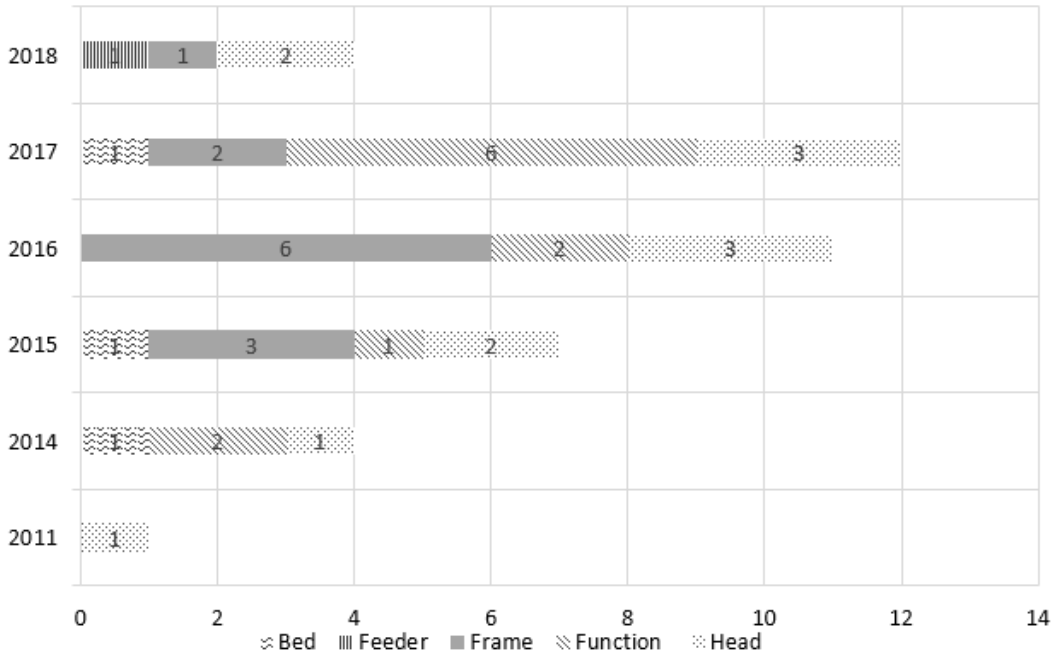

Figure 2. Hardware improvement's research topic in FDM printer

Tabel.2 Cause of Failures in FDM Process

No	Cause of problems	Number of Problems Found in references								Total problems	Percentage
		1	2	3	4	5	6	7	8		
1	Filament Roller	0	0	0	2	0	3	0	1	6	2,1%
2	**Bed leveling**	2	2	2	9	2	10	2	6	35	**12,2%**
3	**Extrusion Head**	2	2	2	18	2	23	2	11	62	**21,6%**
4	Material	0	1	1	8	1	9	0	6	26	9,1%

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5	**Application Setting**	0	1	0	12	2	24	3	21	63	**22,0%**
6	Filament Feeder	1	1	1	4	0	9	2	7	25	8,7%
7	Bed Adhesion	0	3	0	3	0	2	1	0	9	3,1%
8	Support Design	0	1	0	6	0	0	2	0	9	3,1%
9	Product Design	1	1	1	5	2	7	4	5	26	9,1%
10	Frame & accessories related	1	2	3	6	1	8	0	5	26	9,1%
										287	100%

Tabel.3 Heated Bed Problems Discussed in 3D Printing Forum

No	Forums	Keywords	Search	Related Topic	Percentage
1	https://www.reddit.com/r/FixMyPrint/	Heated bed problems	47	18	38%
2	https://www.3dhubs.com/talk/search?q=uneven%20bed	Uneven bed	75	23	31%
3	https://www.3dprintingforum.org/search?r=9471655&p=12	Bed problems	166	34	20%
Total			**288**	**75**	**26%**

Reviewing the discussion forum of 3D in the internet also conducted to justify the findings in table. 2 using "heated bed problems, uneven bed, bed problems" keywords. The data gathered from Reddit.com, 3dhubs.com and 3dprintingforum.org resulting of 288 problems found related to bed's problem in FDM 3d printer.

12,2% of failure cause is caused by lack of bed leveling (table. 2). In table. 3 shown 26% of total failures that affected by the bed's problems are caused by the lack of bed leveling. Based to all of data gathered, seems that leveling of heated bed problems still a big obstacle for the 3D printer owner, especially for the RepRap's 3D printer owner.

IV. NEW LEVELING TOOL INNOVATION

Various leveling tools are available in the market, from the hi-tech automatic leveler to the simple with water level tool. But for a RepRap machine those tools are not provided and some printer manufacturer not even introduce those tools that brought difficulties especially for a new user. current available leveling tools some complaints keep on arise. This research will try to fill up the empty space by focusing to find a simple and low cost system to level the heated bed that suitable the low cost RepRap FDM 3D printer.

A novel leveling tool will be proposed for in this research and analyzed in further process research process. The tool will be designed to be simple and cheap enough for low cost RepRap FDM 3D printer. The new tool will replace threaded bolts system (Figure 3.) that need another supporting tools in adjusting the leveling. The proposed tools will be pine trees liked pin to assure ease of installation and quick leveling (Figure 4.). The new tolls require force to push the bed down that can be done by using hands or with the extruder head to make sure the rings will be move to the same level.

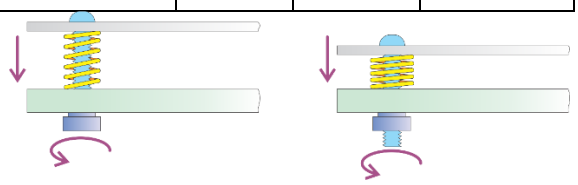

Figure 3. Current leveling system using screwed bolt

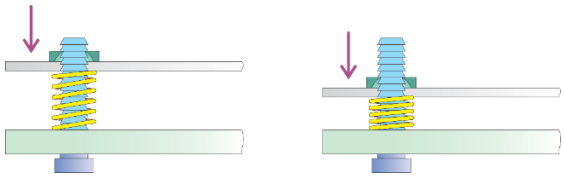

Figure 4. Proposed leveling system using pin

V.CONCLUSION

Research conducting in FDM 3D printer topic keep on growing recently. The introducing of open sourced 3D printer supports the growth in this research area. Most widely topic in improvement of printer's hardware is around the extrusion head. Another most disturbing cause of failure is the levelness of the heated bed, but very less research published to overcome this problem. This paper proposed a new leveling tool system to level the bed easily with affordable cost. The feasibility of the proposed tool will be analyzed in further research process.

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