Team B-ARM Outline

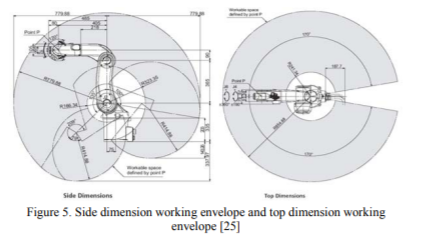
Tyler Han, Nathan Spicer-Davis, Brendan Cutick, Rohith Chintala, Elizabeth Myers, Cynthia Sheng, Eric Oh, William Rende, Aidan Sandman-Long, Kenji Tsukamoto, Nick Webb, Erik Zavorin

I pledge on my honor that I have not given or received any unauthorized assistance on this assignment/examination.

**Chapter 1: Introduction**

* Introduce the problem and explain why it is important?
  + The problem: how can one print on broken/uneven materials to repair them. The main problem which our project aims to look into is satellite servicing and space station repair. This project is an inspiration and extension of the Ranger satellite servicing robot [5] and the results published by research looking into 3D printing in space [1]. Currently, astronauts must EVA out of the ISS in order to repair damages caused by space debris on satellites or even the ISS itself [3]. If it is possible to automate this process and remove the human factor, astronauts may not have to EVA as often (and thus reduce the risk of injury) and repairs may become more complex and precise.
  + The extended problem for the project would be anywhere in which it would be dangerous or harmful to the mission for a human to make a repair on some structure. (e.g. submarine, abandoned buildings/unstable buildings, unstable vehicles, etc.) There are many places in which this technology may be applied.
* In general, what has been done to try to solve it in the past?
  + Fairly recently, there have been applied means of 3D printing more unconventional materials (eg. metals, artificial organ tissue, etc.) [4]. However, they have not been utilized in the way that we intend to research (on-the-spot printing that is not limited to the confines of a printing bed).
* What are the broad weaknesses in the prior research or gaps in the overall literature on this topic that you can fill?
  + The main weakness in existing 3D printing solutions is that it is bound to the bed of a printing device, meaning it cannot print directly onto most objects. The team has observed a potential gap in research on 3D printing on uneven surfaces or in real environments. This gap of research will likely be the target of our project.
* What research questions guide the study?
  + How can we use on-site 3D printing to repair structures? How can we integrate 3D printing with robotics?
  + How does 3D printing in a hard vacuum affect the print?
  + What challenges does a 3D printer end-effector face?
  + What materials have been sought after for repair-focused 3D prints?
  + What can a group of students at our level contribute to the gap in research in this area?
  + What innovations can be applied such that the 3D printer is environmentally dynamic?
  + How small can the 3D printer be made?
  + Can the materials be manipulated such that it will leave the site undamaged? How will that affect the 3D print material?

**Chapter 2: Literature Review**

* Specifically, what prior research approaches and designs have been used to address this question?
  + Multiple robotic arms used to create a larger structure due to the capacity of material in a single arm [20].
  + Using 3D scanners to scan material and then make a two-part mold to create replicas [6].
  + Robotic arm control using external cameras to analyse the arms surroundings [7].
* What established theories and methods are appropriate for your study?
  + General robotics theory and structure (this can be things such as trajectory calculations, working envelope, predetermined configurations for electronics design) [10]. Material testing methods for strength.
  + The team anticipates making use of the infrastructure advised by the Ranger [5] project on campus as its current research is similar to our anticipated research.
  + A team of researchers used frequency response function data to assess structural physical integrity and damage failure of structural materials. Their algorithm indicates the magnitude and location of damage however, the damage detection algorithm is not applicable for small-sized internal cracks or flaws [2].
  + An experiment was conducted to determine the effects of microgravity on additive manufacturing, and researchers found that modified versions of commercial 3D printers are able to 3D print in space. This could be applied to our project if we included 3D printed repairs in space [22].
* What measures, concepts, tools or materials have been tested or used in the past?
  + A mixture of concrete, water, and sand has been used as a material printed by a robotic arm [19].
  + Tip to tray distance, density of material and other relevant measurements of 3D printing in space [18].
  + Cold spray additive manufacturing has been researched and tested as an option for repair [8]. Other methods of additive manufacturing were also researched with respect to construction [9].
* What are the strengths and weaknesses of previous approaches?
  + As the team has not been able to find any research on printing in dynamic/non-stable environments, there is not much to conclude about strengths and weaknesses of previous approaches in this area.
  + In imaging, [2] describes a potential solution to automating the damage detection process as an alternative to manual processing
  + In the field of robotics, there have been extensive research into how the device should be built and for various purposes
    - Biological inspiration and degree-of-freedom research (DOF) are important factors when considering design [11] [16]. For our purposes, we must consider the necessary degrees of freedom should the decided design be a robotic arm. Compensating for the end-effector will be reliant upon the degrees of freedom and their structural integrity.
      * Robotic redundancy occurs when there are more degrees of freedom necessary to plan a certain path [17]. Research into eliminating redundancy should be looked into for this project. Fuzzy pid control [21] is an example of one approach to this problem.
    - Pathing and related algorithms for motion have extensive literature [12]
    - Vision systems (i.e. video) for path planning, adjustment, and calibration [13]. This will be vital in calculating the working envelope of our device. Moreso if the desired end effector is a 3D printer since it would be optimal to reach as much volume as possible. 
    - Kinematics and control systems for multiple robotic entities working simultaneously toward one task [14] [15]. A consideration for our purposes may be to ‘divide and conquer’ using multiple robotic arms to accomplish a repair. However, multiple entities under a single system will have to compensate for the new working envelope of these two devices.
* How do the previous approaches apply to your project?
  + The various approaches that were studied will lay the groundwork needed for the team to successfully plan and create a prototype.
  + Previous work in the field of robotics will allow us to develop an arm with 3-D printing capabilities.
* How will you use this information to answer your team’s guiding research questions?
  + Current theory and concepts can accelerate our research process, allowing us to use standards that have been predetermined to be optimal for certain configurations. It will also help guide us on which holes in the research we can fill with our experimentation.
  + What is cost-benefit analysis of the arm as opposed to replacements or manual repairs?

**Chapter 3: Methodology**

* If you are using the scientific method, what is your research hypothesis?
  + With respect to engineering design, the scientific method may be used briefly as the team experiments with materials and various structures. Questions such as the following may be asked:
    - What are the effects of 3D printed material on various surfaces (other than printing beds)?
    - What are the effects of attaching a 3D printer on the end effector of a robotic arm on the 3D print job.
  + As we progress through the design, we expect new research hypotheses but most likely not one that will encompass the research project as a whole
* If applicable, describe why the chosen design is the best for the project. (If your team is unsure whether or not to include this information, please ask the course instructors.)
  + As the research project focuses on engineering design, a suitable approach would be to divide the goal into smaller tasks and test components independently. This would require an experimental design approach, allowing real values to be obtained when analyzing components and how those components compare with alternatives.
* What type of data do you need to answer the research questions? It is important to know?
  + Experimental lab research will be used to develop better solutions to answer the research questions.
  + Assessments of design and prototyping (strength of material, number of moving parts, cost, etc.)
  + Further research into current literature will provide answers to the following questions. Where is this a problem? How often is the problem occuring there? How long does the problem take to fix?
* Where will you find these data (including a description of your sample, if applicable)?
  + From published journals, IEEE standards, project testing and talking with people in the field. They will be peer reviewed, as well as consult our librarian on exactly how we want to research and where we want to research.
* How will you collect these data? Walk the reader through your research process step by step. Include as many details as you can at this point. If you already have lab protocols, include them as appendices.
  + The team plans to collect data through research and testing components in engineering-related assessments (e.g. stress test, simulations- any type of testing that might discover and help compensate for a particular weakness)
  + Process: collect information and design potential prototypes, maybe end up focusing on a very specific aspect of the project (i.e. imaging, or inexpensive design for High precision 3d printer)
  + Measurement of difference in a control vs. repaired piece can hold.
* Explain, based on the state of current research, how the findings of your project will contribute to the academic field in which you are working.
  + There is potential for an implementation of this technology to be used in satellite servicing, architectural repairs, underground support, etc.
  + Successful research could also provide methods or at least some literature for printing on irregular surfaces that require mapping.
* What are your anticipated results? What do you hope to find?
  + We hope to complete at least a design of the prototype and perhaps fabrication. We hope to find that the concept is feasible and can be used in the real world.
  + The anticipated result of this project is a proof of concept prototype with enough data to prove the potential use of a 3D printing robotic arm for repairs.
* Why will the anticipated results be an important contribution to the research field (i.e., what gaps in knowledge will be filled or what problems will be addressed?)?
  + The prototype will contribute to (specified field) existing research by proving the possibility and necessity of a robotic arm to do complex repairs with 3D printing.

### Chapter 4: Supplemental Information.

* Will your team break-up into sub-teams? If so, how will you divide the work?
  + Yes, we will have a coding team and a mechanical design team. As our methodology gets more developed, these two sub-teams may break up into smaller groups with different tasks assigned to them
* What is your timeline for completion?
  + Complete all research on the project by the end of sophomore year and making small prototypes of different parts by the end of second-semester junior year. Then begin working on the full arm and have it completed by the end of senior year.
* What is your anticipated research budget?
  + The anticipated budget needed for this project will most likely exceed the $1800 dollars provided by the Gemstone honors program so fundraising and grants will be necessary.

### References

[1] N. Leach, “3D Printing in Space: 3D Printing in Space,” Archit. Design, vol. 84, no. 6, pp. 108–113, Nov. 2014.

[2] Z. Wang, R. M. Lin, and M. K. Lim, “Structural damage detection using measured FRF data,” Computer Methods in Applied Mechanics and Engineering, vol. 147, no. 1–2, pp. 187–197, Jul. 1997.

[3] E. L. Christiansen, K. Nagy, D. M. Lear, and T. G. Prior, “Space station MMOD shielding,” Acta Astronautica, vol. 65, no. 7–8, pp. 921–929, Oct. 2009.

[4] L. E. Murr, “Frontiers of 3D Printing/Additive Manufacturing: from Human Organs to Aircraft Fabrication†,” Journal of Materials Science & Technology, vol. 32, no. 10, pp. 987–995, Oct. 2016.

[5] S. Roderick, B. Roberts, E. Atkins, and D. Akin, “The Ranger robotic satellite servicer and its autonomous software-based safety system,” IEEE Intelligent Systems, vol. 19, no. 5, pp. 12–19, Sep. 2004.

[6] Q. Jiang, X. Feng, Y. Gong, L. Song, S. Ran, and J. Cui, “Reverse modelling of natural rock joints using 3D scanning and 3D printing,” Computers and Geotechnics, vol. 73, pp. 210–220, Mar. 2016.

[7] R. Szabó and A.-S. Gontean, “Full 3D Robotic Arm Control with Stereo Cameras Made in LabVIEW,” FedCSIS Position Papers, pp. 37–42, 2013.

[8] S. Yin et al., “Cold spray additive manufacturing and repair: Fundamentals and applications,” Additive Manufacturing, vol. 21, pp. 628–650, May 2018.

[9] D. Delgado Camacho et al., “Applications of additive manufacturing in the construction industry – A forward-looking review,” Automation in Construction, vol. 89, pp. 110–119, May 2018.

[10] V. Patidar and R. Tiwari, “Survey of robotic arm and parameters,” in *2016 International Conference on Computer Communication and Informatics (ICCCI)*, Coimbatore, India, 2016, pp. 1–6.

[11] V. Potkonjak, S. Tzafestas, D. Kostic, and G. Djordjevic, “Human-like behavior of robot arms: general considerations and the handwriting task—Part I: mathematical description of human-like motion: distributed positioning and virtual fatigue,” Robotics and Computer-Integrated Manufacturing, vol. 17, no. 4, pp. 305–315, Aug. 2001.

[12] H. Ueno and Y. Saito, “Model-based vision and intelligent task scheduling for autonomous human-type robot arm,” Robotics and autonomous systems, vol. 18, no. 1, pp. 195–206, 1996.

[13] W.-K. Song, H. Lee, and Z. Bien, “Kares: Intelligent wheelchair mounted robotic arm system using vision and force sensor,” Robotics and Autonomous Systems, vol. 28, no. 1, pp. 83–94, 1999.

[14] U. Frese, B. Baeuml, S. Haidacher, G. Schreiber, I. Schaefer, M. Haehnle, and G. Hirzinger, “Off-the-shelf vision for a robotic ball catcher,” in Intelligent Robots and Systems, 2001. Proceedings. 2001 IEEE/RSJ International Conference on, vol. 3. IEEE, 2001, pp. 1623– 1629.

[15] B. Bauml, O. Birbach, T. Wimb’’ock, U. Frese, A. Dietrich, and¨ G. Hirzinger, “Catching flying balls with a mobile humanoid: System overview and design considerations,” in Humanoid Robots (Humanoids), 2011 11th IEEE-RAS International Conference on. IEEE, 2011, pp. 513–520.

[16] A. Sharma and M. M. Noel, “Design of a low-cost five-finger anthropomorphic robotic arm with nine degrees of freedom,” Robotics and Computer-Integrated Manufacturing, vol. 28, no. 4, pp. 551–558, 2012.

[17] S.G. Tzafestas, A. Zagorianos, T. Pimenides “A solution to the velocity control of redundant robots,” Math Comput Simulation, 40 (5–6) (1996), pp. 565-576

[18] T. J. Prater *et al.*, “A Ground-Based Study on Extruder Standoff Distance for the 3D Printing in Zero Gravity Technology Demonstration Mission,” p. 94.

[19] C. Gosselin, R. Duballet, Ph. Roux, N. Gaudillière, J. Dirrenberger, and Ph. Morel, “Large-scale 3D printing of ultra-high performance concrete – a new processing route for architects and builders,” *Materials & Design*, vol. 100, pp. 102–109, Jun. 2016.

[20] X. Zhang *et al.*, “Large-scale 3D printing by a team of mobile robots,” *Automation in Construction*, vol. 95, pp. 98–106, Nov. 2018.

[21] H. Malki, D. Misir, D. Feigenspan, G. Chen et al., “Fuzzy pid control of a flexible-joint robot arm with uncertainties from time-varying loads,” Control Systems Technology, IEEE Transactions on, vol. 5, no. 3, pp. 371–378, 1997.

[22] M. P. Snyder, J. J. Dunn, and E. G. Gonzalez, “Effects of Microgravity on Extrusion based Additive Manufacturing,” *AIAA Space Conference and Exposition*, Sep. 2013.