Project Trifecta

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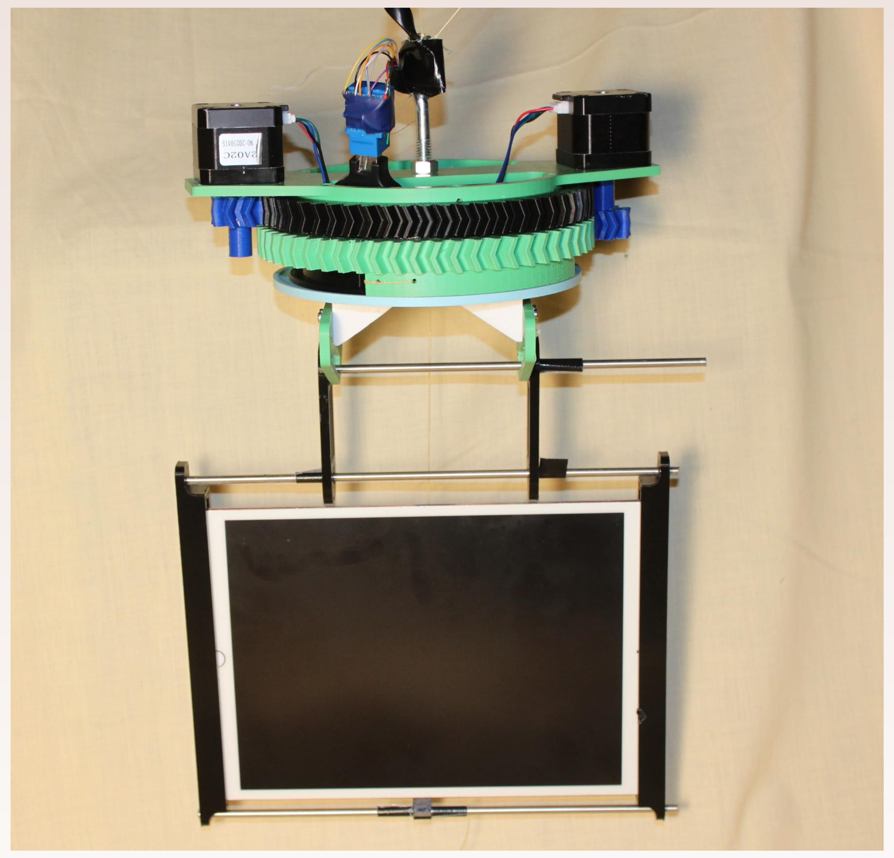

Introduction

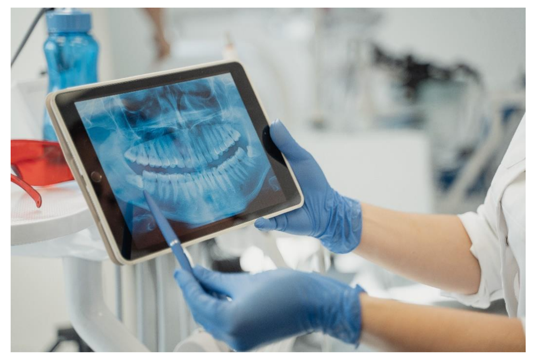

Figure 1: Dentist viewing x-ray scans.

Professionals in dynamic workplaces such as surgeons (Fig.1), chefs, mechanics (Fig.2), and assembly line workers often need both hands free to do their jobs but must frequently view information on displays.

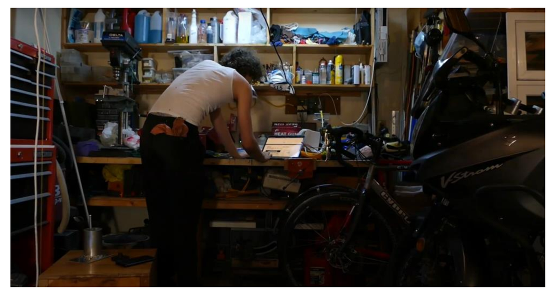

Figure 2: A Mechanic working.

Our users require:

- Hands-free operation
- Reliability
- Safe Operation
- Ease of Use
- Scalability

Early Designs

From the outset, our project has been inspired by products like the Skycam [3] (Fig.3).

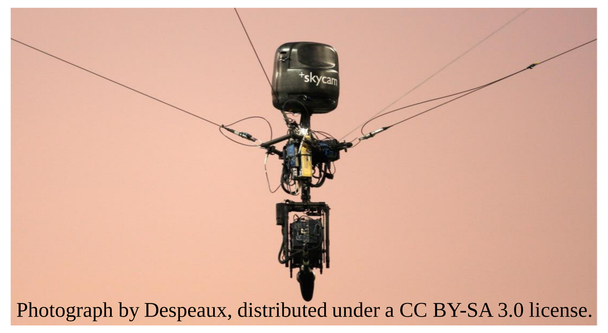

Figure 3: Skycam camera system.

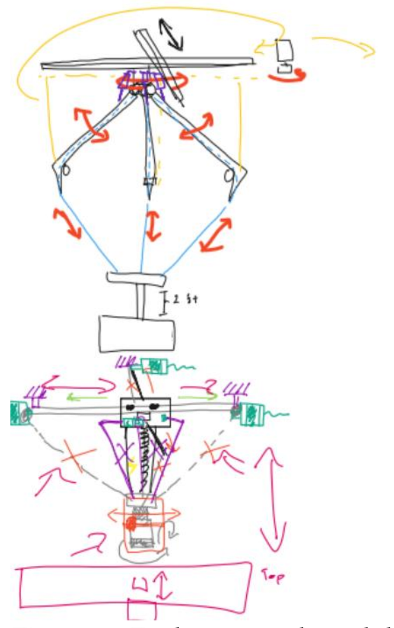

Figure 4: Early gantry-based design. (Above)

We used the C-Sketch method during our initial brainstorming.
Some early designs involved:

- Four cables instead of three
- Rail-based movement (Fig.4)
- Heavy pan-tilt counterweights
- Separate horizontal and vertical movement cables
- Pneumatic actuators

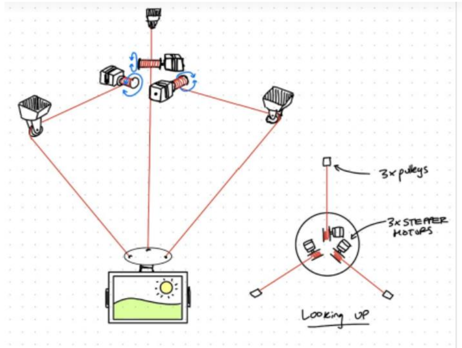

Figure 5: Three-pulley cable design (Right)

Production and Development

Afterwards, we developed criteria and ranked ideas to finalize a design. The group chose to use cables (Fig.5); this reduced bulk and were less obstructive than rails. Additionally, the group was inspired by an existing differential pan tilt system and created a fully custom design to fit the group's purposes.

A bill of materials was created (Fig.6). As many parts as possible were sourced from group members' personal supplies, only a few components needed to be purchased. A scale model was built at the IGEN shop for testing code, and a full scale model was constructed in a group member's garage. Group members met a few times a week at the garage to assemble the full scale prototype.

The pan tilt system went through one major iteration and proved to need the most continued development out of all physical components. The code was also subject to continued development as it was integrated it with the physical prototype.

Item	Quantity	Total Price
Nema23 Stepper Motor	3	$60.00
Nema17 Stepper Motor	2	$10.00
TB660 Stepper Motor Drivers	3	$15.00
A4988 Stepper Motor Drivers	2	$2.00
12V Buck Converter	1	$10.00
350W 36V Switching Power Supply	1	$40.00
Arduino Mega	1	$10.00
10 Channel Coiled Wire	1	$15.00
Powerbar	1	$10.00
Male/female ethernet jacks	2	$5.00
Kevlar string 200ft	1	$15.00
Pulleys	3	$10.00
Total		**$202.00**

Figure 6: Bill of materials.

Physical Design

The design consists of three primary stepper motors handling the motion system (Fig.7). These large motors each are connected to a motor driver and power supply. These are placed on the ground, below pulleys mounted to the ceiling.

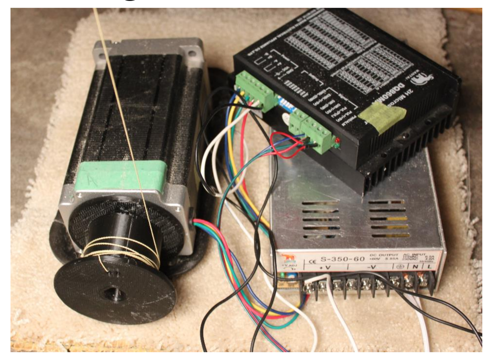

Figure 7: Stepper motor, driver, and PSU

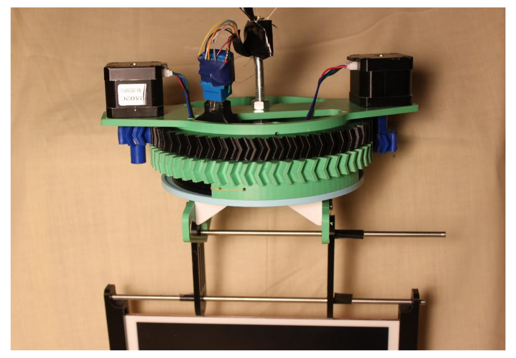

Figure 8: Pan Tilt mechanism

Kevlar cable is wrapped around a custom spool on the end of each motor and fed through a pulley above. The cables are routed to meet at a central platform. This platform includes two additional stepper motors, which transfer rotation to two gears rotating about the mounting point of the cables (Fig.8). Rotating the top and bottom gear together rotates the display, while rotating the bottom gear on its own adjusts the tilt angle. The pan/tilt stepper motors are wired through an ethernet cable to motor drivers at the system's base (Fig.10). The display is mounted on a sliding hinge supported by steel rods (Fig.9).

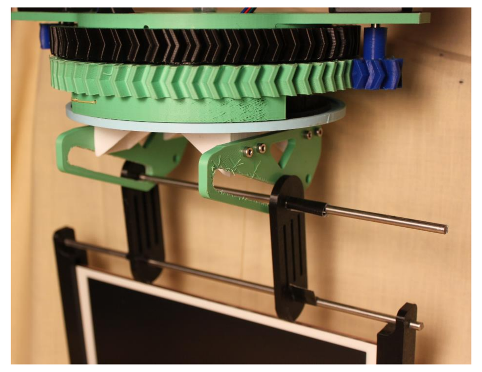

Figure 9: Display hinge

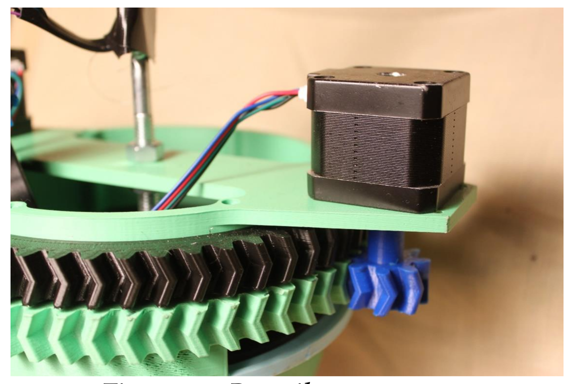

Figure 10: Pan tilt stepper motor

Each motor driver is wired to an Arduino Mega, where commands are fed from a computer (Fig.11).

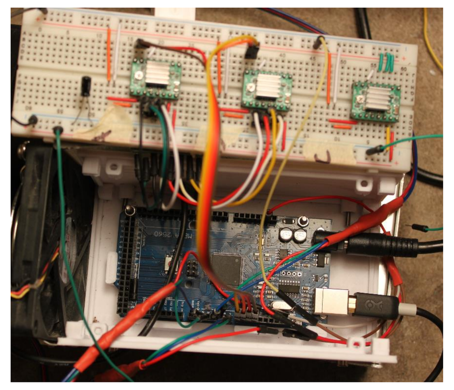

Figure 11: Stepper drivers and Arduino

Software Design

Although remote control systems were outside the scope of our project, the underlying framework was designed to make future developments in this area seamless. The block diagram below illustrates how inputs from a serial monitor or future remote-control systems are processed and turned into motion (Fig.12).

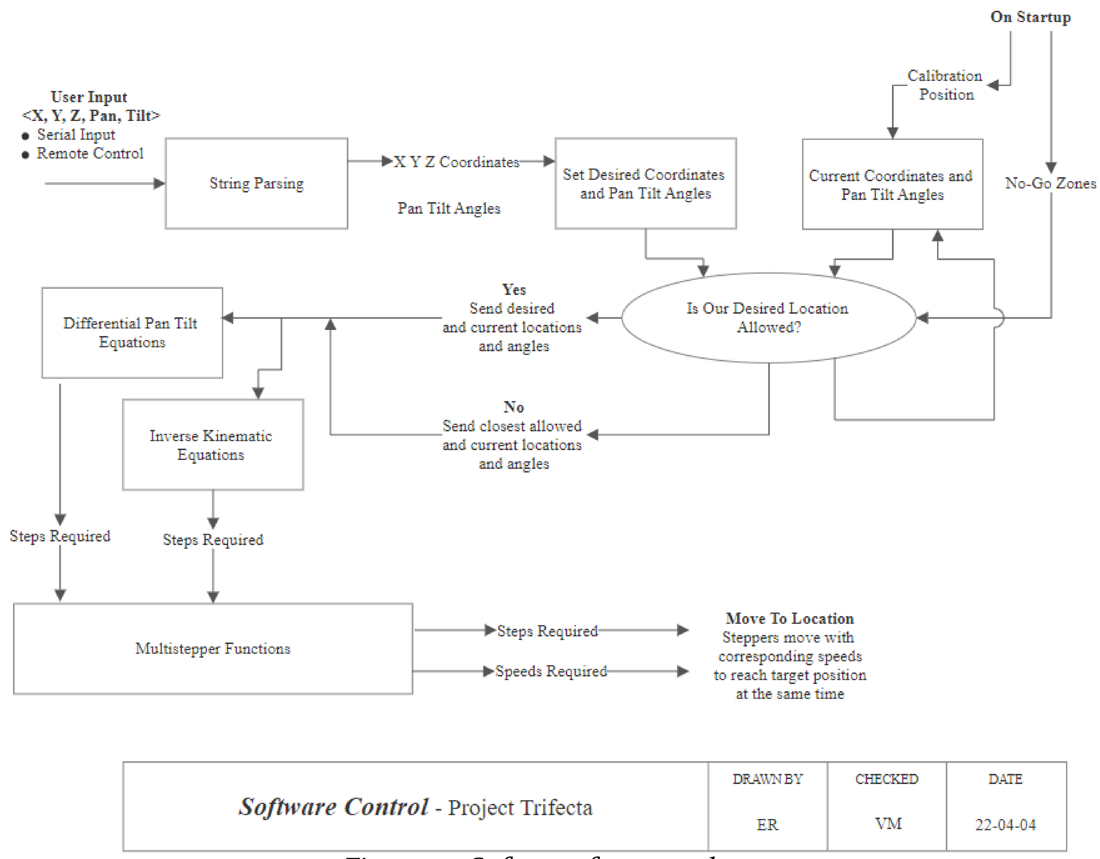

Figure 12: Software framework

Inverse kinematic equations (Fig.13) are used to calculate our systems desired path vector and subsequently calculate the change in cable length required for each XYZ stepper motor (Fig.14).

$$A = \sqrt{(\frac{x_{room}}{2} - x)^2 + (y_{room} - y)^2 + (z_{room} - z)^2}$$

$$B = \sqrt{(x)^2 + (y)^2 + (z_{room} - z)^2}$$

$$C = \sqrt{(\frac{x_{room}}{2} - x)^2 + (y)^2 + (z_{room} - z)^2}$$

Figure 13: Pulley position vector length

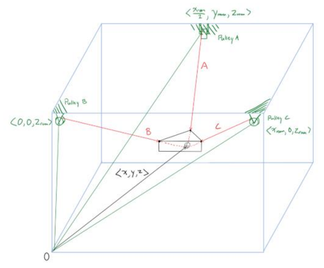

Figure 14: Vector kinematic model

The differential pan-tilt equations translate desired yaw and pitch angles into required steps. To pan the system, both small steppers must be stepped equally in opposite directions. To tilt the system, The upper stepper must be stepped independently.

Testing and Validation

To ensure our design met all our requirements, we evaluated our design in terms of our specified criteria, both quantitatively and qualitatively.

Consumer Cost and Reliability:
Our total cost of materials was **$202**, less than many competing products on the market. Our cables, motors, and pulleys are very sturdy, and our 3d-printable pan-tilt is very easy to maintain, keeping upkeep costs low.

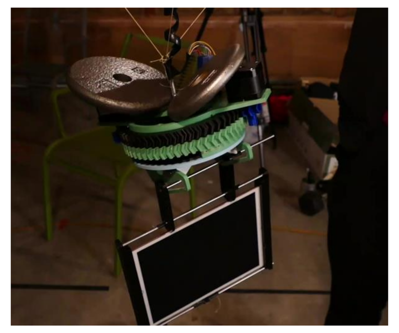

Figure 15: Load capacity demonstration

Figure 16: Motion speed test

Safety:
Our payload weight of 1.5 kg is lower than our specified max weight of 2 kg. Each of our cables can support a weight of 45 kg, so they will not snap (Fig.15). User specified "No-Go Zones" prevent dangerous collisions.

Positioning and Scalability:
Our system comfortably exceeds our speed requirements, moving 75 inches in 11 seconds (Fig.16). Our designs scale is only limited by cable length and greater cable obstruction functional area. The positional accuracy is incredibly high, our motors rarely skip steps.

Ease of Use:
Lower speeds and a single point mounting were chosen to increase stability and decrease oscillations. The system's sound intensity peaks at around 50 dB, approximately the level of normal conversation.

Future Development

We fully met our main goals and are now looking forward on how the scope of the project could be expanded. Potential developments include:

- Reducing oscillations at the platform with active vibration dampening.
  To reduce XY oscillations and improve stability, bell cranks attached to custom dampeners can be added to the end effector platform.
- Hands-free remote control, voice commands, custom position setting
  Our system has been designed with future remote control in mind. Users should be able to control the monitor hands-free.

References

[1] S. Kawamura, W. Choe, S. Tanaka and S. Pandian, "Development of an ultrahigh speed robot falcon using wire drive system", *Proc. IEEE Int. Conf. Robot. Autom.*, pp. 215-220.

[2] A. Riechel, P. Bosscher, H. Lipkin and I. Ebert Uphoff, "Concept paper: Cable-driven robots for use in hazardous environments", *Proc. 10th Int. Top. Meeting Robot. Remote Syst. Hazardous Environ.*, pp. 310-316, Mar. 2004.

[3] "SkyCam.", 2007.

[4] "CableCam.", 2007.

[5] Albus, J., Bostelman, R. (1993), The NIST robocrane. J. Robotic Syst., 10: 709-724. https://doi.org/10.1002/rob.4620100509

[6] K. Maeda, S. Tadokoro, T. Takamori, M. Hiller and R. Verhoeven, "On design of a redundant wire-driven parallel robot warp manipulator", *Proc. Int. Conf. Robot. Autom.*, pp. 895-900, May 1999

[7] T. Harmon, R. Ambrose, R. Gilbert, J. Fisher, M. Stealey and W. Kaiser, "High-resolution river hydraulic and water quality characterization using rapidly deployable networked infomechanical systems (NIMS RD)", *Environ. Eng. Sci.*, vol.

[8] T. Ludvigsen, *Hangprinter*. [Online]. Available: https://hangprinter.org/.

[9] R. G. Roberts, T. Graham and T. Lippit, "On the inverse kinematics statics and fault tolerance of cable-suspended robots", *J. Robot. Syst.*, vol. 15, no. 10, pp. 581-597, 1998.

[10] S. Fang, D. Franitza, M. Torlo, F. Bekes and M. Hiller, "Motion control of a tendon-based parallel manipulator using optimal tension distribution", *IEEE/ASME Trans. Mechatron.*, vol. 9, no. 3, pp. 561-568, Sep. 2004.

[11] C. Liu, G.-H. Cao, and Y.-Y. Qu, "Workspace Analysis of Delta robot based on forward kinematics solution," *2019 3rd International Conference on Robotics and Automation Sciences (ICRAS)*, 2019.

[12] I.-H. Li, H.-H. Chiang, and L.-W. Lee, "Development of a linear delta robot with three horizontal-axial pneumatic actuators for 3-dof trajectory tracking," *Applied Sciences*, vol. 10, no. 10, p. 3526, 2020.