ENGINEERING NOTEBOOK

LEAD AUTOBELAY DESIGN PROJECT

J. SCHWARK
2118091

Intro Ideas

16/07/2024

Ideas :

Stretch Detection

- Using a sensor to detect if the rope is stretched or not by scanning for specific fibres in rope. Stretch could indicate more than just pulling up slack.

Pros:
- Easy analysis system
- Rope design change
- Standard thread distance = distance tracking

Cons:
- Slow response times
- Degradation of rope
- Taking up slack?

Optical Pattern Recognition

- Similar to above, but using computer vision to detect patterns on the rope.

Pro's:
- Standard Pattern = distance tracking
- Rope design needed
- Easy to use acceleration and velocity too

Cons:
- Slow response time
- Degradation of patterns
- How would it know when to take up slack?
  ↳ double tug to signal?

Tension-based slack system

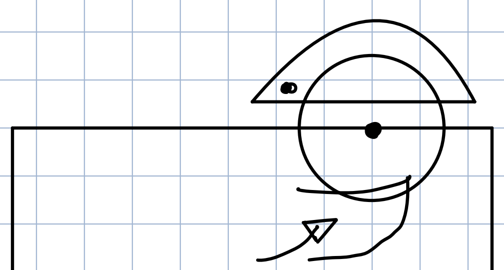
- Subsystem to monitor slack out of system. Could be :

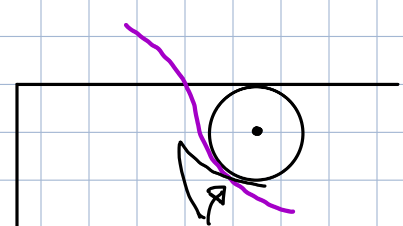
Start cue → retrieve slack → stop when tension reached → reset to normal mode.

↳ cue could also retrieve rope after completed climb. → reset to normal mode.

Table saw stopping mechanism

- This subsystem would take inspiration from traditional friction locks in modern belay devices and from the locking/detection method in circular & table saw finger detection mechanisms.





Notes on ProGrade System (Italy)

- Mode selection
- Partner check
  - ⇾ Pulls tension on your fig 8 knot ⇾ marker on rope.
- If you fall it soft catches you
- Waits ±30 seconds after fall to lower you.
  - ↳ this is your opportunity to keep climbing
- Have to "fall" at top to be let down.
- Touch screen prompts to start & retrieve rope after climb.

- Reviews said hard to read display from safety check / partner check distance.

Notes on Auroco system (2016) – "EPIC" device name. [Skylotec]

Electronic Partner for Individual Climbing

- Much smaller form
- 'Remote' on climbers arm
  - ↳ Stop & Go system with a motor/brake driven wheel
  - ↳ Button to pull up slack
  - ↳ Has a button for top rope mode too
- Falling: Device absorbs shock? Not much detal
  I think it just locks up on the rope.
- Mechanical Redundancy to back up electrical failure
- Fall detection on remote device.

- Targeted more @ industrial safety (pylon techs etc)
- Also NO LONGER AVAILABLE

SPECS

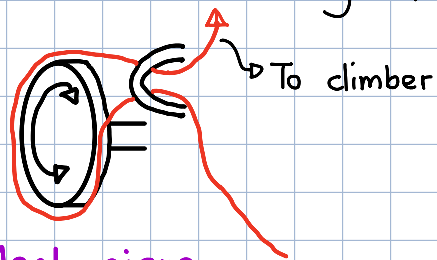
• Mult Redundancy
• 9kg
• $0{,}5\ m.s^{-1}$ (↓ speed)
• 200m max height
• ± 10 hour battery
• EN 341 Cert
  ↳ 125kg user
  ↳ fall factor 2
• 10,5mm static rope with shock absorber

22/07/2024

More Ideas:

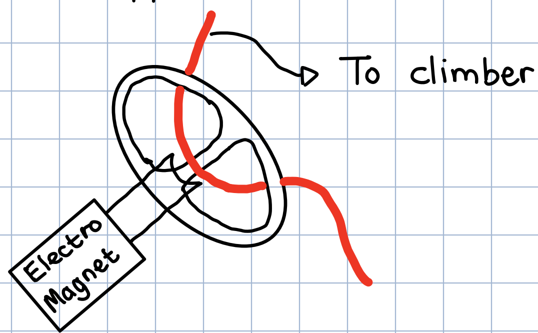
Wheel Monitoring

- This system would monitor the amount of rope passes it.
  This would allow monitoring of
  - place on the wall
  - slack paid out
  - RPM to detect speed of pull/fall.



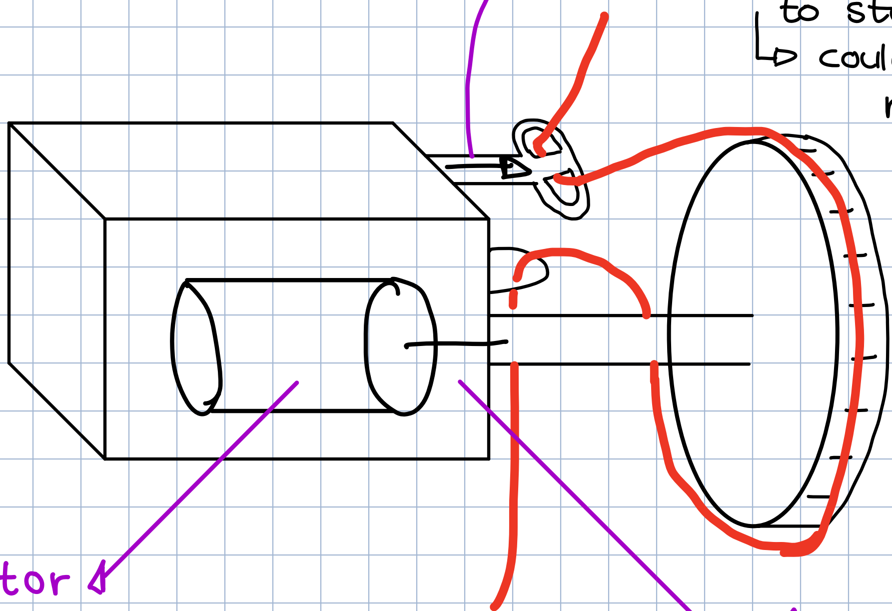
Locking Mechanism

- Inspired by traditional belay devices, however instead of the caribiner jamming the rope into the device due to momentum/force, an electro-magnet controlled piston would jam the rope around a metal ring.
  - Current supplied would control how hard a catch is.



System Design 1

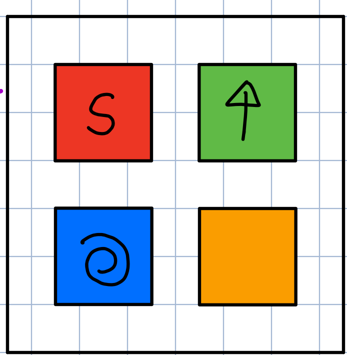
Fall Arrest System
- Electromagnet to jam rope to stop fall.
  - ↳ could be back-up to motor stopping.

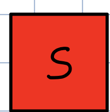


Motor
- Controls slack management

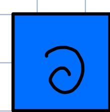
Measurement Sys (Rotary)
- Measures revolutions of wheel
- Measures direction of movement

Armband
- Worn by climber to "communicate" with auto-belay device.

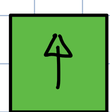




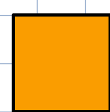
- This button would take up slack



- Respool the rope



- Ascend mode
  - pays out slack & keeps set tension



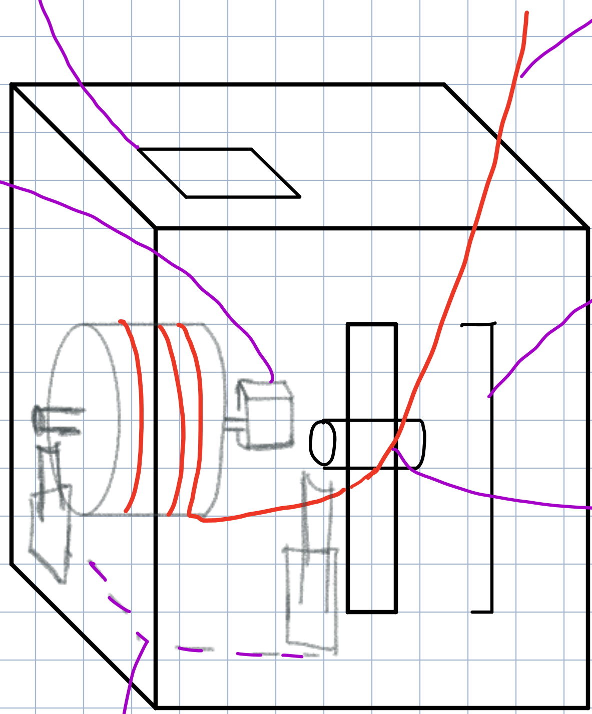
This system takes inspiration from Auroco system. Rope sits on floor like traditional lead belay. It runs through & turns the "wheel". This wheel monitors distance & falls.

System Design 2

Display Panel
- Mode selection & safety

Rope to climber

Motor
- Controls slack
- Can control some stopping



Slack Detection
- Detects where wheel is on rail (bottom = slack)

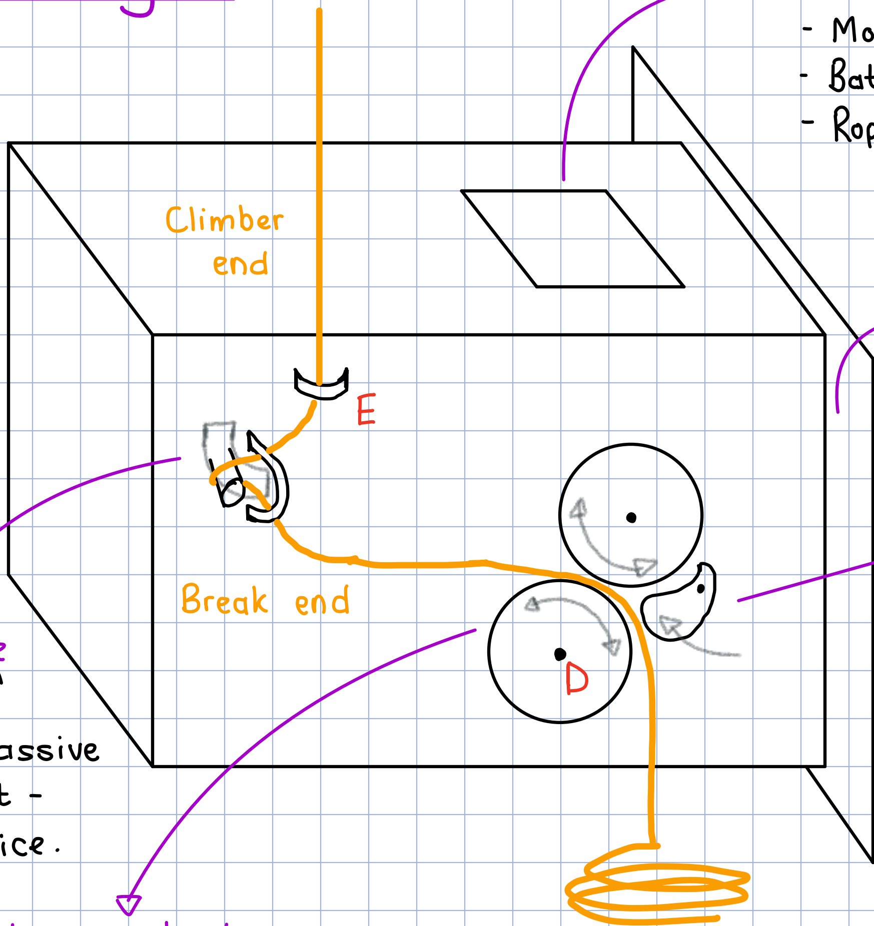
Stretch Detection
- Measurement System to know when climber is falling.

Piston / Electro-magnet
- Fall arrest system to stop turning

This system is inspired by ProGrade System, taking a guess at the inner workings. The system could be run on a Raspberry Pi & application run on it.

Rope spooled inside device & turned by a motor. This motor is similarly controlled to above. Some level of fall arrest done by motor. Fall arrest mostly controlled by Electro magnet pistons.

Final Design



Touchscreen Display
- Mode selection
- Battery %
- Rope out / passed through

Mounting Plate
- Bolted into wall
- Check weight allowances.

Back up brake
- Risk rope integrity.
- Cam jams into rope

Braking device
- 'Belay device'
- Mimics a passive brake assist - tube style device.

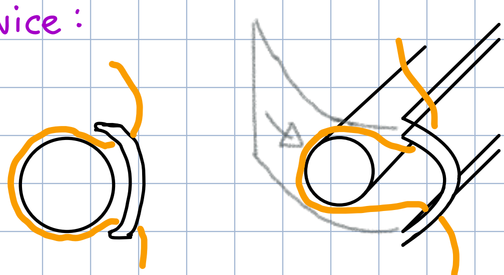
Motor driven wheel
- Controls slack/tension
- Secondary stopping method

- Wheel also tracks amount of rope paid out to climber by measuring revolutions.

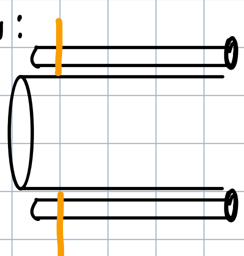
Rope coiled on floor.
- Rope coiled on floor like traditional lead climbing

Belay Device :

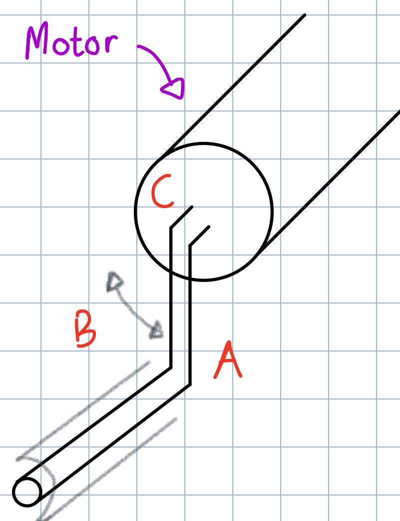
Side View :



Back View :



Motor



Measurement System

- Load Cell : Placed at point A. Load applied from force from rope pulling rod against the device. (Look into Torque Load Cell)
- Strain Gauge : Placed at point B. Strain would pull as rope moves rod forward.
- Dynamometer : Placed at point C or D, detecting rod movement on motor C or wheel moving at D.
- Accelerometer : Placed on wheel D and measures acceleration of wheel as it moves.
- Laser Doppler Vibrometry : Placed at D or E. Laser shines on either rope or wheel to detect acceleration.
- Rotary Encoder : Placed at D to calulate angular velocity & acceleration of the rope pulling through the wheel.
- Tachometers : Placed at D to measure rotational speed (RPM).
- Hall Effect Sensors : Magnets placed on wheel D to measure rotations of the wheel.

Motor Choices.

- Electric Motor with Sprag Clutch to allow for free-wheel in one direction.
- Servo motor to control ABD

Specs to Note :

- Bend angle of rope
- Heat dissipation of device

Specifications & Maths.

Friction:

- Deformation co-efficient

$$f_r = \frac{F_r}{N}$$

F_r → Resistive force of friction
N → Normal / Perpendicular force.
co-efficient → f_r

Falling:

Broken into 2 sections: freefall & catching.

Freefall:

- 30 kg

$F = ma$
$= (30)(9,8)$
$= 294$ N

- 150kg

$F = ma$
$= (150)(9,8)$
$= 1470$ N

Initial fall velocity

$v^2 = i^2 + 2ad$ [initial v taken as $0\ m.s^{-1}$]

- 0m slack

$v^2 = 2(9,8)(0)$
$v = 0 m.s^{-1}$

- 1m between draws

$v^2 = 2(9,8)(1)$
$v = 4,427\ m.s^{-1}$

- 2m (just before draw)

$v^2 = 2(9,8)(2)$
$v = 6,26\ m.s^{-1}$

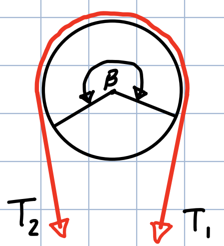
Catching:

Three forces that play a part in catching climber.
- Bending
- Friction
  ↳ Squeezing = increases friction.

- Bending: Need mod of elasticity & friction between thousands of threads
  Need degree of flattening
  ∴ Becomes too complex to caluculate.
  - Research: Increased wrap angle = Increased force., levels out
    Less effective for smaller rope diameters.

- Friction: Amonton's 1^{st} Law
  Amonton's 2^{nd} Law
  → Normal force & co-efficients → does not account for slipping

Eulerian Formula needed



$$T_2 = T_1 e^{\mu\beta}$$

Initial (hand) force.
angle in radians.
coefficient of friction
↳ exp func
↳ Faller force

Hand force = 150N to 400N

Dynamic Coefficient = Not constant & varies with pressure
= 0,16 @ higher loads (Nylon against SS)

Heat (Thermal Conductivity): Alu − 250 W/m.K
Nylon − 0,25 W/m.K
SS − ± 16 W/m.K

Slack Management:

- Torque wheels move with & Motor

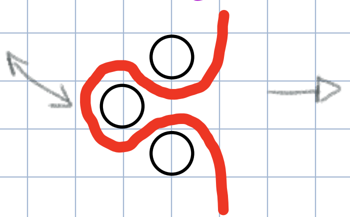
Brushless DC Motor
↳ low torque, PWM Control

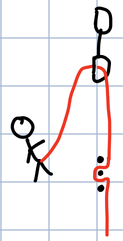
Desired F = 300N → hand force estimate. (Jim Titt)

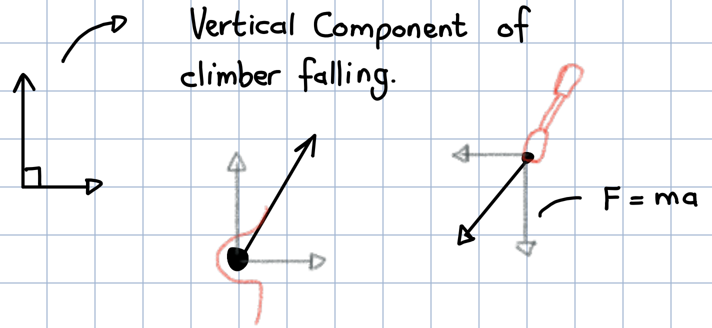
↳ To achieve 300N of Force: $\tau = F \times r$
$= (300)(0{,}075)$ → 7,5cm
$= 22{,}5$ Nm of Torque

- Motor to control fall arrest system:
- High torque STEPPER (possible gearbox needed)
  Work out max tension on rope @ freefall.

Lowering System







Torque needed to pull rope back would have to satisfy horizontal force of rope (tension of rope)

- Relate to force of person falling down (force)

$\therefore$ Max $\downarrow$ force = 150kg (1470N)

$$\tau = F \times r$$
$$= (1470)(0{,}08)$$
$$\tau = 117{,}6 \text{ N.m}$$ → max needed to release lock up.

$\tau = F \times r$ Torque of Buddy Check
$= (300)(0{,}08)$
$= 24$ N.m →

Power Consumption :

Brushless DC Motors : Supply Voltage (24V)
Power Rating (400W)
Output speed (3000 rpm)
Max output torque (22,9 N.m)

DC Stepper Motor : Power Rating (600 W) ±

Smaller Electronics : Power Rating (50 W)

$2(400W) + (600W) + (50W) = 1450 W/h$
1,450 kWh →

Rotary Encoder Calculation

Min speed $= 0 m.s^{-1}$
$= 0$ rot per sec

Max speed $= 7 m.s^{-1}$ (freefall)

$$C = 2\pi r$$
$$= 2(3,14)(15/2)$$
$$= 47,1238 cm$$
$$= 0,471238 m$$

$\therefore \quad 7 \div 0,471238$
$= 14,85449$ rotations per second

Technical Design

SECTIONS

Fall Arrest Device
- Friction
- Forces
- Heat & Materials
- Motor

Slack Management System
- Simulations (simulink)
- Motor specs
- Wheel sizes

Measurement Systems
- Wheel monitoring
- Torque load cell.

Control System
- Catching logic
- Slack Management logic
- Letting the climber down logic
- Mode selection

Mounting System
- Strong enough
- Materials
- Design.

Power Distribution
-

Fall-Arrest System:

- Type of materials
  - ↳ wear
  - ↳ heat dispersion
- Rope bends & angles
- Friction needed + stopping force.
- V-grooves in brake-end
- Rope squeezing?
- Mounting to wall (amount of force.)
- diameters of "carabiner"
- μ (friction coefficient) of nylon.

Slack wheels

- Rubber wheels with groves
- Ability to engage & disengage sprag clutch
- Amount of force from sprag clutch
- Amount of "hand force" from motors

Design Project - Meeting Minutes (16/07/2024)

- Cross-polination neccessary, not 9 fully unique approaches
  - but not all the same.

- Don't always lower after fall, can carry on.
- How much slack is safe (especially on first draws)
- Partly measurement & partly systems
- Needs to monitor how much rope has gone out.
- Think of mode selection
- Will need mechanics / physics. (τ or f or a)
- Static & dynamic ropes
- Think of pattern recognition.
- Do NOT NEED
  - full schematics
  - actual circuitry
- SYSTEMS
  - MECH (Climber)
  - ELEC (Belay)

Comments on Control, not Implemented

- What ifs: - Assholes without maintainance
  - Outdoor use

- User guide, economics, ethics, social responsibility
  - this stuff is not 2 paragraph stuff
  - encorperate into design.
  - should all be part of decisions.

- Location: rope swelling
  corrosion
  busy gyms.

SIGN CITY ROCK WAIVER

- Need to provide simulations

23/07/2024

- Pulling slack $ falling at the same time.
- Think about forces of different weights (physics)

- WIPA ?
- Mechanical not main part of design
- Simulations : Simscape
  Maths (Excel)
  Make graphs

- Weight of rope going up makes a difference.

30/07/2024

- Should have a working solution at the end.
- Should have vague idea of design by now
- Break into components $ come up with specs now
- High level design (inputs, outputs $ outline of workings)
  → no code needed etc.
  → no pole-zero, tf stuff needed, just what it needs to do
  → you can have a function describing things.
- Need justification ($ back up) for design choices.
- Research transducers to measure torque, acceleration.

- Mpumalanga
  - climate
  -

REPORT

- Comm design to knowledgable people → Technical Rep
  → Make sure you have logical steps
- Abstract : Everything you need to know about report
  Entire report in 150-200 words.
  Locate, Focus, Report, Argue. [Camila & Thompson]
  → locate problem in broad area
  → focus more
  → describe what you have done
  → argue why.
- Introduction : Context of project
  NOT background → no need for background & lit
  → can define terms here.
- Lit Review : Show research & where yours fits in
- Meat
- Conclusion : Conclude [Everything]
- Referencing : Communicating with reader
  ① Not rubbish
  ② Heres where you find more.

- NON - TECHNICAL
  → Stay away from jargon
  → "User - Manual"

- Communicate, no specific format.
- Think about Popular Mechanics writing.
- illustrate.

06/08/2024

- Research how air density affects device.
- Think about load shedding, design power supply.
- Think about slack logic for first draws.
- +/- 2m per draw → for slack management
- Consider worst case / best case clipping

13/08/2024

- Some back up but don't become a Mech Eng.
- Just back up on existing knowledge.
- Simulations → Torque calculations
  - → Spreadsheet engineer
  - → LTspice for motors ?
  - → Simulink of slack management
  - → Spreadsheet of weights / forces
    - ↳ + rope dynamics.

Back of matchbox calculations.

- WTF is Youngs Modulus.
- Look into vensim

GAs
3 → Complex systems
→ Show that you have made educated conclusions
→ ↳ again, have you done some math
→ Simulate stuff → have some graphs
→ conclusions.
→ Social & Economical
  - → Build this into your full solution
  - → Make decisions based on this
  - → Have an evaluation / reflection section
  - * have stuff on full design → reflection.
    - → analysis & thought

what
so what
now what

→ Sustainability & Environmental

20/08/2024

- need specifics of voltages etc to device
- speak about response times.
- finish all motor specs (voltages, torques, response times)
- Optimisation by industry specific engineers
- Accreditation standards
- Speak about how we can't do it all & have only designed the system.
- Speak about some rope specifics.
- Speak about itterative design
- Reference Appendix normally
- Sim to design not design to sim
- Try estimate max power usage
- Back-up not for climbing??
- Think about Back EMF spikes.