Group project for the course of

Mechanical Design for Mechatronics

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Technical report

TITOLO

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1 Product design specification

The goal of our project is to create our implementation of the *CyberOrto* [1] made by *Mindshub*, an non-lucrative association based in Ala (Trentino). The goal of this robot is to automatically handle an amateur vegetable garden by performing this 3 principle actions:

i) planting the seeds of the desired plant in a location decided by the user using a web interface;

ii) constantly provide water to the vegetable;

iii) extirpate undesired plants.

By talking with the association that worked (and is still improving) on the product we acknowledged the following requirements (mainly related to the functionality of the product) that the structure has to satisfy:

i) the arm appendix must suits an interface that allows to have an interchangeable set of tools (like the one use to plow the terrain);

ii) the arm appendix should accommodate a small pipe in order to irrigate the vegetables; in particular this has to be connected to an external reservoir (with no dimension specified if it's position is fixed) or by using an internal reservoir on the moving structure of at least $4l$ (that can periodically be refilled) if it's not possible to directly attach the arm to the main reservoir;

iii) the minimum accepted working area of the robot is a rectangle of dimension $4m \times 3m$; the robot should be design keeping in mind the possibility to increase the working area by expanding it over one edge (for example having the possibility to work on a $8m \times 3m$ terrain);

iv) the structure can house the electronic control unit of the robot that's remotely connected to the server using wireless connection and by doing so should accommodate a battery the allows the robot to work for at least **number of hours of uninterrupted work**. The power consumption of the structure should be minimized if possible (at the actual state the prototype consumes $40W$ and has a **quantità batteria** weighting $6.3kg$);

v) regarding the accuracy of the movement of the system the allowed backlash on the working point should always be less then $1cm$ with the control technique implemented and the goal is to have maximum $5mm$ of deviation from the nominal value;

vi) the structure should be mainly composed of standard components and should be as cheap as possible in order to make it affordable for everyone.

Loads and operating conditions The structure should be able to perform all it's operation while being safe and fully functional. For the design and the verification of the structure the loads related to wind can be neglected due to the presence of an anemometer that's mounted on the robot and ensures that the robot works only on a sufficiently safe environment.

The heavier operation performed by the robot is the extirpation that's done by plowing the soil with a rotating element **AGGIUNGERE UNA BREVE DESCRIZIONE**. Considering the actual mounted motor to perform this operation the torque that has to be transmitted to the plower is of $T_{\text{plower}} = N \cdot m$ **CHIEDERE DATO**.

1.1 Requirements & specifications

With the promise being said it's possible to express the main requirements, associated to the aim dictated by our customer and our design rules, and the specifications of the designed machine. All this information, collected in table 1, has to be considered in each step of the design phase in order to develop the mechanical solution.

While developing the project other factors should be kept in mind:

- the possibility to pack all the necessary components in a *small* transportation box (the box shouldn't present and edge greater than $2m$, maximum sum of all the edges less then $3m$) in order to avoid shipping issues;
- the kit should be feasible to all private enthusiast that enjoy *do-it-yourself* projects and this has to kept in mind; mounting tools should be the most common ones (screwdrivers, Allen keys...); welding finishes are not recommended.

2 Concept generation and preliminary design

2.1 Concept generation

With all the premise that lead the development of the project, the first thing that has to be done is generate the concept that can later be compared to choose the best design solution that can become a concrete realization of the ideas.

Kinematic configurations The first key operation that the robot has to perform is reaching a desired point on the working space and so, in planar kinematics, the machine should present two degrees of freedom that allow to reach all the possible positions; this can be done considering 3 main joint configuration that allows to perform such operations:

- double prismatic joints (figure 1.a) where two perpendicular linear guides can be used to move on the plane;
- prismatic and revolute joint (figure 1.b) where the arm that's free to rotate it's mounted on top of a linear guide. This kind of kinematic chain is currently used by the MindsHub concept;
- double revolute joints (figure 1.c), typical configuration of a robot arm, that constraint the framing point to be fixed.

By a first analysis the third configuration (double revolute joint) isn't feasible for the project due to the fact that the system presents a fixed pivot point respect to the frame and to work more area it's mandatory to increase the length of the edges (and this is an issue for the *extendibility* of the machine).

Table 1: full list of requirements and specifications for the CyberOrto project.

1) Geometry:	
1.1) dimension of the terrain to cultive	at least $4m \times 3m$, extendible if possible
1.2) vertical clearance from the ground of the robot while moving	$\geq 50cm$
2) Kinematic:	
2.1) time travel between further points in the field	$\leq 10s$
2.2) accuracy of the working appendix respect to nominal value	max $\pm 1cm$, target $\pm 5mm$
3) Energy:	
3.1) low energy consumption	max $40W$, target $20W$
3.2) in-device battery with docking station	**CHIEDERE VALORE**
4) Functionalities:	
4.1a) provide direct water access to irrigate the soil	
4.1b) or provide a reservoir that can be automatically refilled on a docking station	$\geq 4l$
4.2) standard mount on the appendix arm that can fit multiple working tools	
4.3) plowing the terrain	$T_{\text{plower,max}} =???$
4.4) provide a pneumatic circuit used for the appendix that plants seeds	
5) Materials:	
5.1) components standardization	very high
5.2) materials should be weather proof (oxidation free)	
6) Terms of use:	
6.1) easy to assemble	max 2 persons required
6.2) fatigue resistance	infinite life-cycles if possible, min 10^6
6.3) insensible to environmental conditions (weather and dirt)	
7) Loading conditions:	
7.1) wind and environmental actions can be neglected with robot in action	
8) Costs:	$\leq$ €800

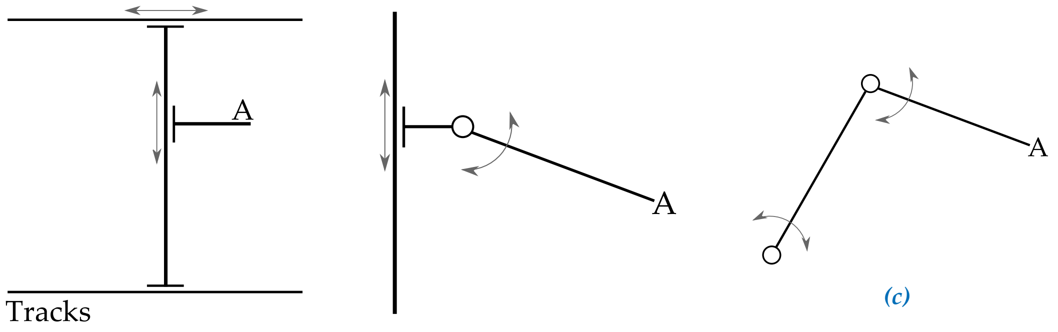

Figure 1: *main kinematics coupling that allows to univocally determine the position of a point A in a plane: (a) double prismatic joints, (b) prismatic and revolute joint, (c) double revolute joints.*

Concept #1 The first concept (figure 2) is realised with a double prismatic joint. In particular point A and A' relies on parallel tracks placed on the ground that can be extended in order to increase the cultivated area. The working arm can move along an elevated beam connecting the track (point B) and can move vertically to cultivate point P.

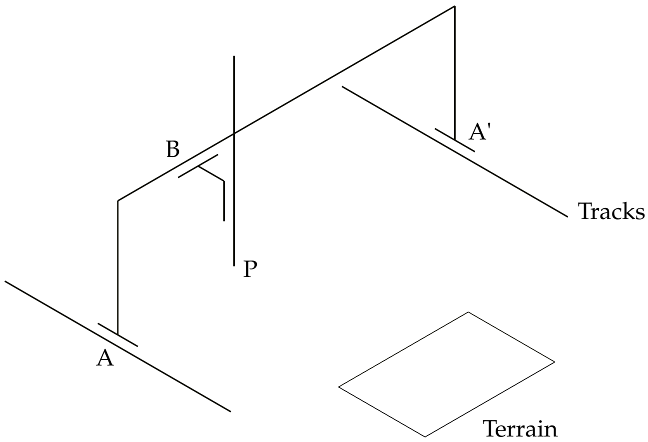

Figure 2: *concept #1 realised with double prismatic joint.*

This structure present a frame for the arm that's stable while operating due to it's arch structure; possible problem to this implementation is that long elevated beam (subjected to the loads of the arms and it's mass) can deflect and fail statically. Also, if possible, rotoidal coupling should be used (and for this we can refer to concept #2).

Concept #2 The second concept (figure 3) is similar to the first one but one prismatic joint is replaced with a revolute connection put in the middle of the elevated beam. The length of the edge BP from a top view must be equal to half the length of the supporting bar in order to reach all points in the rectangular space.

This structure also presents the pro of concept #1 of having a stable frame structure for the operating arm due to it's arch conformation and, as addition, uses a revolute joint to control the second degree of freedom of the arm. However this implementation

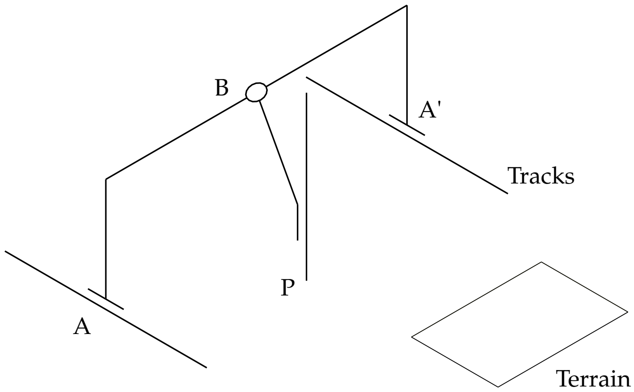

Figure 3: *concept #2 realised with a combination of both prismatic and revolute joint.*

increases the mechanical load on the elevated beam (increasing the torsion due to the higher arm of the actions on the tool tip respect to the elevated bar).

Concept #3 The third concept (figure 4) is similar to #2 but instead of using two parallel tracks, the prismatic joint uses only one of them.

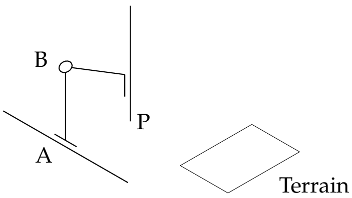

Figure 4: *concept #3 realised with a combination of both prismatic and revolute joint.*

This implementation avoid the problem of high deflection of concepts #1 and #2 by removing the long elevated framing beam, but also increases the reactional momentum that the prismatic joint A should bear in order to maintain stable the system.

2.2 Decision matrix

2.3 Material selection

The main structural components are beams that, for client requirements, should be standard and so for this reason T slot extruded aluminium profiles (figure 5) are chosen after the following considerations:

- better volume-to-price ratio and lower density (respect to inox steels), so reducing costs associated to the spare parts and shipping;
- availability in the marker: there are a lot of vendors that provide profiles with various geometrical dimensions, different aluminium alloy and surface finishes. This spare parts can be easily accessed by every private costumer;
- for T slot extruded profiles lots of auxiliary components (such supporting brackets, fasteners, hinges...) are provided from the same profiles manufacturers, reducing the need of custom made part and so decreasing the costs.

Table 2: *decision matrix.*

			Concept #1			Concept #2			Concept #3		
Objective	Weight	Parameter	Mag	Score	Value	Mag	Score	Value	Mag	Score	Value
Material costs	0.2	relative €	medium	7	1.4	high	5	1	low	9	1.8
Reliability	0.3	experience	high	9	2.7	medium	7	2.1	very low	4	1.2
Crit #3	w #3	par #3	1a	1b	1c	2a	2b	2c	3a	3b	3c
Crit #4	w #3	par #3	1a	1b	1c	2a	2b	2c	3a	3b	3c
Crit #5	w #5	par #5	1a	1b	1c	2a	2b	2c	3a	3b	3c
		Overall score:			10			8			4

Other info

This elements can be also purchased with an anodized finish that allows to improve the corrosion resistance and so increasing the expected life time of the product in uncontrolled outdoor environment.

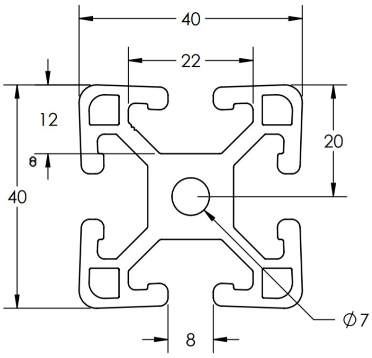

Figure 5: technical drawing of a T-slot profile's cross-section. The particular sketch represent the model `TS40-40LM` *by Tslots [2].*

Mechanical properties For the design part the following mechanical properties are considered: ultimate tensile strength $\sigma_{uts} = 260MPa$, yielding strength $\sigma_{ys} = 240MPa$, Young's module $E = 70GPa$, Poisson's ratio $\nu = 0.32$; this are mean value and full material designation can be found on table A.1.1 (page 8).
For the final verification more detailed mechanical properties are going to be used depending on the final profile selection.

A Appendix

A.1 Materials

Table A.1.1: list of available aluminium alloys for T slot profiles with relative mechanical properties (based on `ASTM B-221` standard) and extruded profile vendor that provides this results.

ASTM code	$\sigma_{uts}[MPa]$	$\sigma_{ys}[MPa]$	$E[GPa]$	$\nu[\cdot]$	usage	vendors
6005-T5	262	241	70	0.33	profiles	Parker
6105-T5	262	241	70	0.33	profiles	80/20, Parker
6061-T6	262	241	70	0.33	accessories	Parker
6063-T6	206	172	70	0.32	profiles, accessories	Parker
6065-T6	206	172	68	0.32	profiles	tslots

Parameters of the table: σ_{uts} ultimate tensile strength, σ_{ys} yielding strength, E Young's module, ν Poisson's ratio. σ_{uts} and σ_{ys} are taken directly from the `ASTM B-221-05` [3] standard while other parameters came from T-slot producer's data-sheets [2] [4] [5].

B Bibliography and references

In order of first appearance:

[1] MindsHub Association. *Progetto CyberOrto*. URL: https://mindshub.it/progetto-cyberorto/.

[2] *Complete Catalog*. V. 6. Tslots by Bonnell Aluminum. 2021.

[3] ASTM. *ASTM B-221-05 - Standard Specification for Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes*. ASTM B-221-05. ASTM, 2005.

[4] Parker Industrial Profile Systems. *T-Slot Aluminum Framing*. Rev. 5. Parker Hannifin Corporation. 2021.

[5] *Custom Aluminum Framing Systems*. Catalog 23, Part No. L1019. 80/20 Inc. 2019.

A.2 Bill of materials

Table A.2.1: bill of material and estimated costs.

Code	Product	Quantity	Price
	Manufacturer		
XXX	General piece	1	€—
XXX	General piece	1	€—
	Manufacturer		
XXX	General piece	1	€—
XXX	General piece	1	€—
		Total:	€100.00

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