Phase 1

Product concept, foreseen specifications, planning, tests and initial design

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1 Product concept: Radio Frequency Camera Assisted Rover (RFCAR)

The envisioned product consists of a remote controlled car used to assist exploration and maintenance domains. For this purpose, the vehicle should contain a remotely operated camera feeding back video to the user. Additionally, the vehicle must contain odometric sensors to assist in driving and prevent crashes when user is not in control, e.g., when connection is lost. The vehicle can be used for exploration of unaccessible areas to human operators like fluid pipelines and other hazardous sites.

2 Foreseen product specifications

The foreseen product specifications are listed as topics below (sketch).

2.1 Autonomy

Check Battery and power consumption

2.2 Velocity

Maximum Velocity allowed for the car

2.3 Safety

- Car: If the user issues a command that would cause damage to the system, the system should take corrective measures to prevent it. The same holds true if the communication between user and system is lost.
  - **System uses odometric navigation**
- Human: preserve human safety

2.4 Image acquisition

2.4.1 Frame rate

2.4.2 Range

Camera's range

2.4.3 Resolution

2.4.4 Color scale (Black and white or color)

2.4.5 Always present or enabled on user command

2.5 Usability

- User-friendly interface
- User interface responsiveness

2.6 Load

Maximum load the car can safely carry.

2.7 Overall System latency/responsivess

The overall system latency is the sum of all systems' latencies, which must be under a maximum tolerated value for the user.

2.8 Communication

2.8.1 Reliability

Packet must be delivered (reliable, e.g. TCP) or not (e.g. UDP)

2.8.2 Range

Maximum distance allowed between user and system for communication purposes

2.8.3 Transmission rate / throughput

2.8.4 Redundancy

2.9 Sensibility

Sensibility to Smartphone motion

2.9.1 Msg Smartphone->Raspberry

x10 y20 v10 t5 v5

2.10 Closed loop error (Control team)

Error associated

2.10.1 PI

2.10.2 PID

2.10.3 PD

2.11 Summary

Table 1 lista the foreseen product specifications.

3 Planning

In fig. 1 is illustrated the Gantt diagram for the project and in fig. 2 the tasks' descriptions. It should be noted that the project tasks of Analysis, Design, Implementation and Tests are performed in two distinct iterations as corresponding to the Waterfall project methodology. The tasks are described as follows:

Table 1: Specifications

	Values	Explanation
Max Velocity	0.2 m/s	Maximum velocity of the conveyor belt in steady state
Dimensions	60x30x30 cm	Dimensions of the conveyor belt in cm [l w h]
Time Min	3 s	Time taken to transport a load the full extent of the conveyor belt at maximum velocity
Max Load	1 Kg	Load the belt can hold without causing any harm to the product
Max slope	15°	Maximum slope in which the conveyor belt can operate at nominal conditions
Slope levels	[0,5,10,15]°	Different levels of slope manually handled
Settling time	$0.2 \cdot T$	This means that it takes up to 20% of the full travel time to reach steady velocity
Overshoot	110% Vss	Maximum velocity the conveyor belt reaches before settling time
Margin of error	95%-105% of Vss	Admissible error in steady velocity
Power supply	12V batteries, 6W	The main power supply will be 12V batteries

- Project Kick-off: in the project lift-off, the group is formed and the tutor is chosen. A brainstorming about conceivable devices takes place, whose viability is then assessed, resulting in the product concept definition (Milestone 0).

- State of the Art: in this stage, the working principle of the device is studied based on similar products and the system components and its characteristics are identified.

- Analysis: In the first stage — Analysis 1 — contains the analysis results of the state of the art. It should yield the specifications document, containing the requisites and restrictions to the project/product, on a quantifiable basis as required to initiate the design; for example, the car maximum velocity must be, at maximum, `2 m/s`. The second stage — Analysis 2 — contains the analysis of the first iteration of the development cycle.

- Design: it is done in two segments: modules design — where the modules are designed; integration design — where the interconnections between modules is designed. It can be subdivided into *conceptual design* and *solution design*.

  - In the conceptual design, several problem solutions are identified, quantifying its relevance for the project through a measuring scale, inserted into an evaluation matrix, for example, Quality Function Deployment (QFD).

    - In the solution design, the selected solution is developed. It must include the solution modelling, e.g.:
        * Control system design: analytically and using simulation
        * Transducer design: circuit design and simulation
        * Power system design: power supply, motors actuation and respective circuitry design and simulation
        * Software design: for all required modules, and considering its interconnections.

- Implementation: product implementation which is done by modules and integrated. In the first stage, the implementation is done in a prototyping environment using breadboards, yielding prototype alpha; in the second stage it must include the veroboards or Printed Circuit Boards (PCBs), yielding prototype beta.

- Tests: unit tests — by modules — and integrated tests are performed. Tests are considered as those performed over any physical component or prototype. It contains all the tests conducted into the system and the several prototypes.

- Verification/Validation: after the alpha prototype is built the specifications listed in the analysis must be verified and the prototype validated by an external agent (an external user to the group).

- Delivery: — project closure encompassing:
    1. Final prototype built, verified and validated.
    2. Support documentation: how to replicate, instruction manual.
    3. Final report: *<2020-06-18 Thu>*
    4. Public presentation: *<2020-06-19 Fri>*

4 Tests

4.1 Verifications tests

The verifications tests are tests performed internally by the design team to check the compliance of the foreseen specifications. These tests are done after the prototype alpha is concluded.

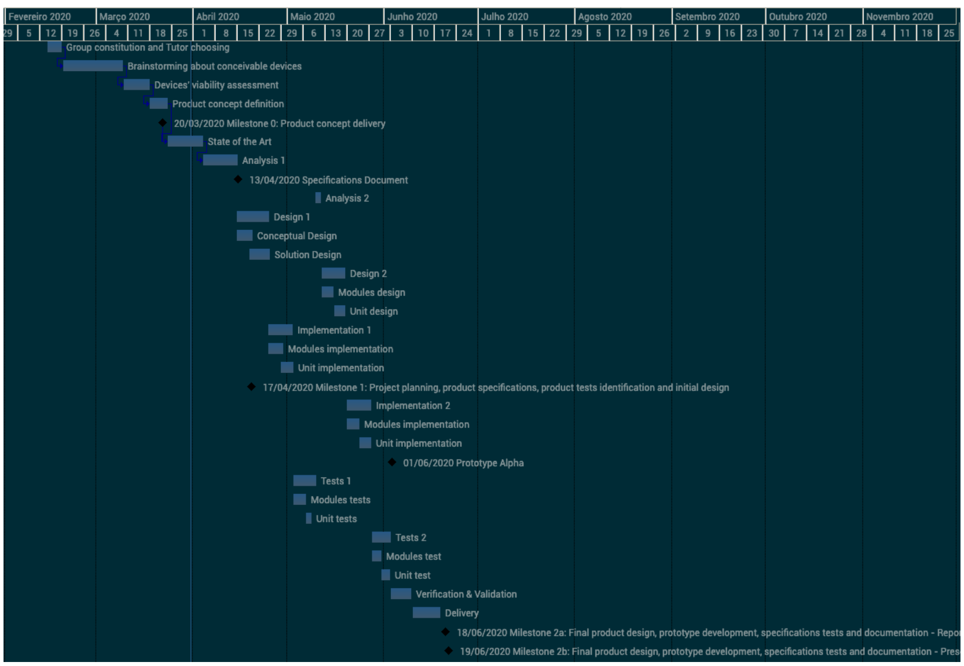

Figure 1: Project planning: Gantt diagram 1

	Nome	Duração	Ínicio	Fim
1	Group constitution and Tutor choosing	3dias	14/02/2020	18/02/2020
2	Brainstorming about conceivable devices	57.13dias?	19/02/2020	09/03/2020
3	Devices' viability assessment	6.84dias?	09/03/2020	17/03/2020
4	Product concept definition	3.46dias?	17/03/2020	23/03/2020
5	Milestone 0: Product concept delivery	1dia	20/03/2020	20/03/2020
6	State of the Art	9.55dias?	23/03/2020	03/04/2020
7	Analysis 1	6.63dias?	03/04/2020	14/04/2020
8	Specifications Document	0dia	13/04/2020	13/04/2020
9	Analysis 2	4.94dias	09/05/2020	10/05/2020
10	Design 1	31.08dias?	14/04/2020	24/04/2020
11	Conceptual Design	14.63dias?	14/04/2020	19/04/2020
12	Solution Design	19.5dias?	18/04/2020	24/04/2020
13	Design 2	22.67dias?	11/05/2020	18/05/2020
14	Modules design	11.46dias?	11/05/2020	15/05/2020
15	Unit design	10.25dias?	15/05/2020	18/05/2020
16	Implementation 1	23.55dias?	24/04/2020	02/05/2020
17	Modules implementation	14.13dias?	24/04/2020	29/04/2020
18	Unit implementation	11.63dias?	28/04/2020	02/05/2020
19	Milestone 1: Project planning, product specifications, product tests identification and initial design	43.13dias	03/04/2020	17/04/2020
20	Implementation 2	23dias?	19/05/2020	27/05/2020
21	Modules implementation	12.17dias?	19/05/2020	23/05/2020
22	Unit implementation	11.25dias?	23/05/2020	27/05/2020
23	Prototype Alpha	0dia	01/06/2020	01/06/2020
24	Tests 1	21.88dias?	02/05/2020	09/05/2020
25	Modules tests	12.05dias?	02/05/2020	06/05/2020
26	Unit tests	4.92dias?	06/05/2020	07/05/2020
27	Tests 2	17.67dias?	27/05/2020	02/06/2020
28	Modules test	9.21dias?	27/05/2020	30/05/2020
29	Unit test	8.38dias?	30/05/2020	02/06/2020
30	Verification & Validation	19.75dias?	02/06/2020	08/06/2020
31	Delivery	26.05dias?	09/06/2020	18/06/2020
32	Milestone 2a: Final product design, prototype development, specifications tests and documentation - Report	0.05dia	18/06/2020	18/06/2020
33	Milestone 2b: Final product design, prototype development, specifications tests and documentation - Presentation	0.33dia	19/06/2020	19/06/2020

Figure 2: Project planning: tasks

4.1.1 Maximum velocity

The maximum velocity must be tested to ensure integrity of the system. Furthermore, the degree of linearity of the velocity is respect to user input must also be tested.

The procedure to test the maximum velocity is analogous to the velocity's linearity trial, the only difference being the reference velocity's regulation potentiometer position which should, for the maximum velocity's case be at maximum.

The velocity of the conveyor belt can be measured internally to the system — measuring the induced voltage at the generator and converting to its physical representation — or externally using an tachometer for instantaneous value or measuring the travel time and dividing by the conveyor length to obtain the average velocity.

Internally: The motor drives the conveyor belt at one end, also driving the generator at the other end, due to their coupling. Thus, disregarding slip and friction losses, the angular velocity of the motor and the generator are identical. As $\omega_m = \omega_g$ and $v = \omega \cdot r$, the linear velocity of the conveyor can determined based on the angular velocity of the generator, which induces a proportional voltage at the terminals of the generator. Thus, by measuring this voltage, the linear velocity of the conveyor can be determined.

Using an oscilloscope to display the measured voltage at the generator and the reference voltage, one will have the electrical representation of both the desired velocity (physical representation of the reference voltage) and the current velocity (physical representation of the voltage at the generator). One should see them as very similar, within a previously agreed upon range of difference, accordingly to the type of controller used. This can be be used for transient analysis of the conveyor's behaviour.

Externally (instantaneous value): This first method will make use of the physical relation between the linear velocity, v, the angular velocity, ω, and the radius of the axis, r: $v = \omega \cdot r$; and the previously stated assumption that the conveyor's linear velocity and the generator's angular velocity are directly proportional.

Using a tachometer to measure the motor's angular velocity ω, the linear velocity of the conveyor belt can be determined, through $v = \omega \cdot r$, where r is the radius of the axis.

Then through a comparison of the measured velocity and the physical representation of the reference voltage the outcome of the trial will be clear: if the velocities are similar within a range of difference that was agreed upon, it should be considered a success.

Externally (average value): measuring the travel time (see Section 4.1.2) of a part in the conveyor and dividing by the conveyor length, the average velocity of the conveyor can be determined. This can only be used for steady state analysis of the conveyor's behaviour. Thus, if the average velocity is within the boundaries of the desired velocity and the respective margin of error, the trial is considered a success.

For maximum assurance one should at least measure the velocity through the internal method and one of the external followed by a comparison. This comparison takes into account that for this procedure we agreed upon a 5% margin of error when comparing the measured and the reference velocities. It also should consider the overshoot that will occur when the load is first placed, which was agreed to be 10%, therefore at any given time the conveyor's velocity should never surpass `0.2 m/s` (the agreed upon maximum velocity) $\pm$ 10%.

4.1.2 Travel Time

The time it takes a certain load with a constant mass to travel the full length of the conveyor can be measured by a simple series of measurements using a chronometer and the calculation of the average.

It should be noted that during the external measurement of velocity, the travel time was measured, there is a direct correlation between the two as such at assurance's behest one should make sure that the results obtained during the velocity trial are in accordance with the values obtained in this procedure.

4.1.3 Settling time

The time that it takes the system to react to the presence of a load with a constant mass and achieve a steady state.

The small scale of the conveyor and, consequently, its settling time (0.6 seconds minimum for the maximum velocity) dictate that the easiest method to measure the conveyor velocity is by measuring the induced voltage in the conveyor, capturing this data using the oscilloscope, this taking into account, once again, the relation between the induced voltage at the generator and the conveyor's current velocity, as such by observing the induced voltage's behavior one can draw a conclusion regarding the settling time.

With the induced voltage at the generator captured by an oscilloscope, specifically using the "single mode" present in these measuring instruments one can observe the change that will occur in the generator's voltage, more specifically the moment a load is placed upon the running conveyor a change will occur, the time it takes from this moment until the voltage returns to previous value will be the settling time.

4.1.4 Overshoot

An overshoot occurs when the output in a control system exceeds its final, steady state value generally caused by a sudden change in the system, in this case specifically, the placement of a load upon the conveyor will cause an overshoot in the latter's velocity which must be controlled lest it cause problems.

An overshoot will occur during the settling time, as such, using the same considerations taken in its measurement, it can be measured by observing the induced voltage at the generator (an overshoot in the conveyor's velocity will correspond to a peak in the generator's voltage).

Using an oscilloscope to display the induced voltage at the generator and making use of the "single mode" present in these measuring instruments one can observe the change that will occur in the generator's induced voltage, the peak voltage that will be seen when the load is placed upon the running conveyor is the electrical representation of the overshoot of velocity, then either by converting it to its physical representation or comparing it to the reference voltage one can arrive at a conclusion. It was agreed that the overshoot velocity should be $V_{ss} \pm 10\%$, where V_{ss} is the stedy state velocity.

4.2 Validation tests

The validation tests should be performed by the client using the product's manual, so it is expected that a user without prior experience with the product should be able to use it correctly and safely. For this purpose, a laboratory guide will be produced to work similarly to the product's manual, so the user can use the product also as a didactic kit. However, in this stage of the project, the laboratory guide hasn't been prepared yet, but it's already possible to have an idea about the type of tests and steps that will be necessary, such as:

- Motor tests;
- Generator tests;
- System parameter determination by measurements;
- Tests using another controller;

- Tests varying the load;
- Tests changing slope levels;

5 Initial design

After an analysis of the product's family tree (conveyors) and the state of the art, an initial design of the product itself can be produced (see fig. 3). The selected approach was top-down, in the sense that the requisites and specifications were discussed and that resulted in a general block diagram of the product concept. Some macro-level decisions were made in this stage to narrow the problem's solutions pool, as follows:

- the product is a didactic kit about automatic control, therefore, the user should be able to change the product's controller by any other that fits the model. Thus, the controller's terminals should be user-accessible.
- The product should be portable, thus, the main power supply source should be a battery, which meets the DC motor power supply needs.
- Power supply (*PS*) should not restrict the usage of the product. Thus, the user should be able to couple any DC power supply of his liking that meets the product minimum power supply requirements (represented in the orange decision block), in spite of the default battery existing in the prototype.

Additionally, a DC generator was included in the prototype design so that the electrical representation of the DC motor velocity (or in other words, a voltage) was measurable and later on converted to an actual velocity value by analyzing the generator´s characteristic table. In other words, a table that relates some measured voltage in the generator with its matching velocity value in rpm (rotations per minute).

The measured voltage referred above and the command voltage represented on the diagram in purple were also thought to be user-accessible via two user terminals. This would allow some oscilloscope analysis afterwards.

Thus, summarising, the initial design yields the system illustrated in fig. 3, comprised of:

- **DC Motor**: the prototype provides a moving platform with a conveyor belt driven by a direct current motor (*Actuation Transducer*);

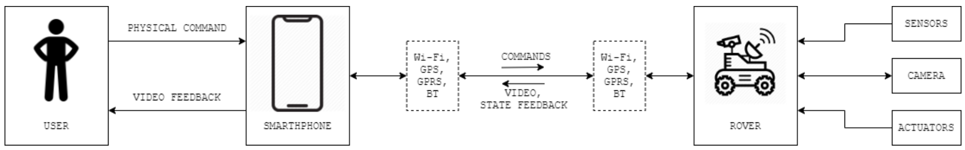

Figure 3: Initial design: Block diagram view

- **Controller**: generates the command variable (*Manipulated Voltage*) according to its control rule, in this case, by taking the *Measured Voltage* as input;
- **Generator**: the generator allows us to measure a voltage (electrical representation of its speed [rpm] - *Measured Voltage*) that will later be converted to an estimated speed value;
- **Amplifier**: with the *Manipulated Voltage* as input the amplifier generates an output voltage (*Command Voltage*) that powers the *Actuation Transducer* (motor);
- **Power Source**: powers the DC motor, the user has two options: using any DC power supply that satisfies the motor power needs or using the default battery power supply existing in the prototype;
- **HMI**: a human-machine interface that allows the user to choose a specific velocity magnitude and conveyor direction. Some LEDs will be used later on to inform the user about the current charge of the battery supply.