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. I've edited this (Zé).

2 Foreseen product specifications

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

2.1 Autonomy

«««< HEAD Check Battery and power consumption ======= How long does it take to completely discharge the battery taking into account the energy consumption.

2.2 Velocity

Maximum Velocity allowed for the car to achieve in ideal conditions.

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

Frequency at which independent still images appear on the screen.

2.4.2 Range

How far can the camera capture images and record them.

2.4.3 Resolution

The amount of detail that the camera can capture. It is measured in pixels. The quality of the aquired image is proportional to the number os pixels.

2.4.4 Color scale (Black and white or color)

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2.4.5 Always present or enabled on user command

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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.

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

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.

Due to unpredictable circumstances, limiting the mobility of team staff and goods, the implementation stage will not be done at full extent, but rather at a simulation stage. Thus, to overcome these constraints, the project focus is shifted to the simulation stage, where an extensive framework as to built to model the system operation, test it, and providing valuable feedback for the dependents modules. As an example, the modules previously connected just by an RS232 link, must now include upstream a web module (TCP/IP) — the data is now effectively sent through the internet, and must be unpacked and delivery serially as expected if only the RS232 link was used.

The tasks are described as follows:

- Project Kick-off: in the project kick-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;
    * Communications design: communication protocols evaluation and selection;
    * Software design: for all required modules, and considering its interconnections, at distinct levels:
      · frontend level: user interface software, providing a easy and convenient way for the user to control and manage the system.
      · framework level: software required to emulate/simulate and test the required system behaviour, providing seamless interfaces for the dependents modules
      · backend level: software running *behind the scenes*, handling user commands received, system monitoring and control.

- Implementation: product implementation which is done by modules and integrated. Once again, it should be noted that the implementation is mostly done in simulation and coding stages, due to the aforementioned constraints. In the first stage, the implementation is done in a prototyping environment — the assisting framework developed, yielding version alpha; in the second stage it must include the coding on the final target modules, yielding prototype beta.

- Tests: unit tests — by modules — and integrated tests are performed. Tests are generally considered as those performed over any physical component or prototype. Here, it is used as a broader term, to reflect the tests conducted into the system and the several prototypes.

- Verification/Validation: in normal circumstances, 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). Due to abnormal circumstances, the verification must now be performed, not on the physical prototype, but over the chain of modules developed, checking their performance against the specifications listed, i.e., subsystem verification. System verification may be performed to validate overall function, but not for quantifiable measurement, due to the latencies involved. Regarding validation, once again, there is limited access to the physical modules, specially for an external agent, thus, it should be limited to user interface validation.

- <u>Delivery</u>: — project closure encompassing:
    1. Final prototype
    2. Support documentation: how to replicate, instruction manual.
    3. Final report
    4. Public presentation

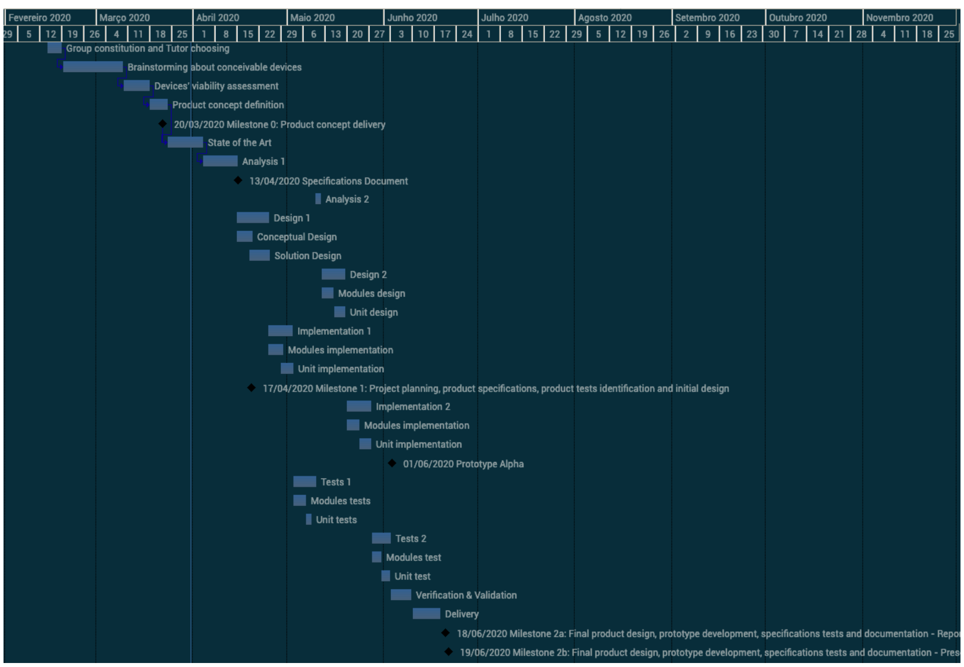

Figure 1: Project planning: Gantt diagram 1

	Nome	Duração	Início	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 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.

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 velocitys regulation potentiometer position which should, for the maximum velocitys 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 conveyors linear velocity and the generators 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 conveyors 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 assurances 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 conveyors current velocity, as such by observing the induced voltages 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 generators 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 latters 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 conveyors velocity will correspond to a peak in the generators 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 generators 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 products 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 products manual, so the user can use the product also as a didactic kit. However, in this stage of the project, the laboratory guide hasnt been prepared yet, but its 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

Following an analysis of the products family tree (remote controlled cars) and the state of the art, an initial design of the product itself can be produced (fig. 3). The selected approach was top-down, in the sense that the requirements and specifications were addressed and that resulted in a general diagram of the product concept. Some macro-level decisions were made in this stage to narrow the problems solutions pool, as follows:

- The car itself should be battery-powered, as it is a free-moving object that is intended to work in environments where trailing cables could interfere with its regular movement.
- The device used to control the car should ideally be one already owned by the user, with an integrated screen (e.g. smartphone), as it would make it more affordable and have a more straightforward interface.
- The protocol for communication between the controlling device and the Rover should be chosen from within the pool of those readily available to smartphones (e.g. Wi-Fi, GPRS) to keep the price of the overall product down and make it as practical as possible.
- The control and communication unit for the car should be divided into two modules: one which can interface directly with the camera module and manage data transmission and reception at the applicational level of the TCP/IP protocol stack, with enough throughput for the specified video resolution and framerate. And another one which can measure and process sensor inputs and control the actuators in real-time.

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

- **Raspberry Pi**: Interfaces with the camera directly, transmitting the information it receives to the smartphone. Receives user commands and sends sensorial information back to it;
- **STM32**: Sends sensorial information to the Raspberry Pi module and receives commands from it. Controls the actuators according to the given instructions and sensor readings;
- **Actuators**: DC Motors that control the cart́s movement and headlights for nocturnal or low light conditions;

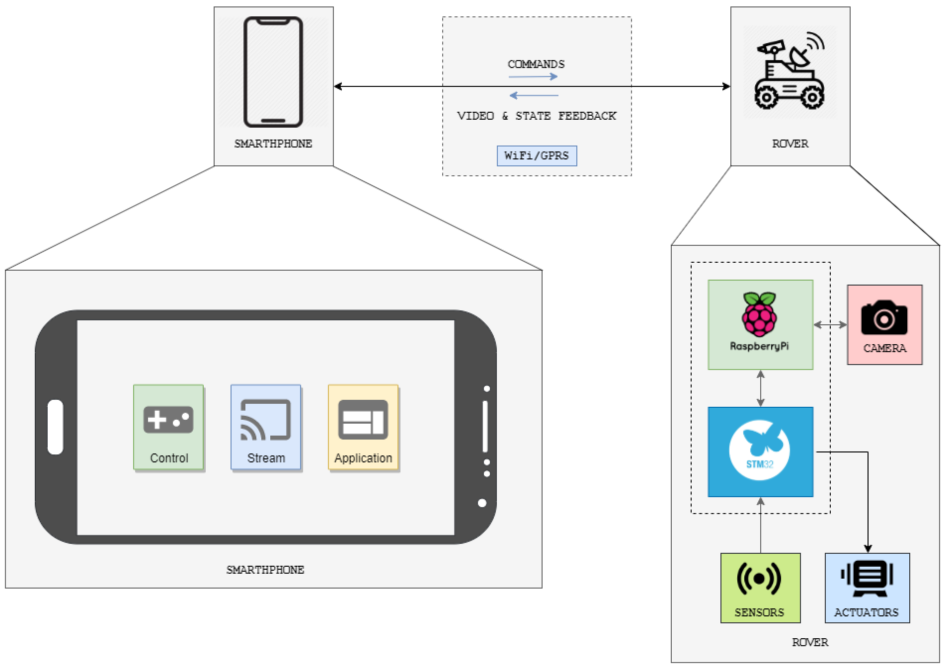

Figure 3: Initial design: Block diagram view

- **Sensors**: Odometric sensors that support the detection of obstacles and luminosity sensors;
- **Camera**: Device connected to the Raspberry Pi that allows the live stream of the cart's surrounding environment;
- **Smartphone**: Grant visual feedback from the camera's live feed also allowing the user to control the movement of the vehicle intuitively;