Automation of Food Distribution Services in Beaches

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Abstract: An energetically independent autonomous mobile vehicle aimed for food distribution on the beach is conceptualized and a virtual prototype is presented. Furthermore, an energetic viability analysis was conducted to determine the robot's degree of mobile autonomy in Portugal, as well as a market research study to establish the initial product assortment and a market segmentation based on the proposed robot's main valued features. Nine items are identified as the initial product assortment and an attractive market segment is identified. Future development guidelines are given considering the target market's most valued features of the robot and the surrounding service provided.

Keywords: Mobile Robot, Vending Machine, Product Development, Market Segmentation

1. Introduction

Tourism in Portugal accounts for 11% of the GDP and its coast and beaches are one of the country's attractions for visitors (Caçador, 2010). However, the bather that looks for some comfort in these locations can sometimes become disappointed with the lack of conditions, particularly in the food distribution services, since most of the beaches are in a non-concession regime. This regime prohibits the construction of beach establishments, which could serve food to the bathers, and the only option available is buying from traveling vendors (TV) who lack the appropriate tools to supply the right products, in the best conditions, and on the right time (Timothy and Wall, 1997). Besides, as they have to carry the products themselves, they are limited to a reasonable amount of items which decreases their productivity.

Portugal also has a clear legislation concerning the circulation of polluting vehicles in protected areas and the handling of food that is to be commercialized. In this context, the creation of an energetically independent autonomous mobile robot to distribute food would comply with all the legislation and assure a better experience for the bather visiting a Portuguese beach.

2. State of the Art

Vending machines (VM) allow for food items to be bought in unattended locations, with no time restrictions, and in an automatic fashion, as long as the user receives proper instructions on how to operate the machine (Horne et al., 1992). As the VM's industry evolves, many useful features have been added, such as the ability to pay with credit cards, the ability to register the transactions, a centralized control of inventory, malfunctions and inside temperature, and an improved safety against vandalism attacks (Horne et al., 1992; Truitt and Swanson, 1999). Also, the VM's internal compartments have been designed to accommodate the most diverse shapes and types of products allowing for a great deal of flexibility on this subject (Truitt and Swanson, 1999).

The large majority of VM are still characterized as fixed machinery in the sense that they depend on an energy source, usually obtained through a power outlet, which makes them unsuitable for mobile vending. However, battery powered VM are already contemplated in the U.S. Patent Office (Tseng, 1997). This fact, allied to mobile VM being developed recently, even if not in an energetically autonomous fashion, serves to show the tendencies of this industry (Guard, 2008). This is not to say that the industry did not conceive energetically autonomous VM, by using solar or wind energy for instance, as there are several examples of this (e.g., Hixson and Creswell, 2011). Unfortunately, this inventions demand VM to be put on or incorporated in a trailer, so that they can be carried by a conventional vehicle, which not only is not normally allowed to enter a Portuguese beach, but also requires a human driver to carry it around.

On the other hand, there are many Autonomous Mobile Robots (AMR) prototypes that can relate to this project, although none is as practical as a completely autonomous mobile vending machine.

The Heineken AMR is one such example, with the ability to move through a pre-established route and stopping only when it detects the hovering hand of a person. When that happens, the robot waits for a glass to be deposited on its cup holder, fills it with beer, waits for the glass to be retrieved, and finally proceeds with its course (Barlow et al., 2010). However, the robot is not designed to move on a sandy pavement, cannot collect money from a transaction, and needs a power outlet to recharge the batteries.

Another good example is the *HelpMate*, an AMR designed to transport meals in a hospital, especially because extra care has been taken on its compartments' design, in order to control the inside temperature and subsequently diminishing the probabilities of food contamination. Furthermore, these compartments allow for protection against theft or natural incidents (Krishnamurthy and Evans, 1992). Still, the AMR is not designed to move on a sandy pavement, it does not allow for any type of interaction with the final user, since the nurses act as intermediaries in the meal transaction, and it needs a power outlet to recharge batteries.

The *SnackBot* can be a more useful example as it allows for people to pay for food products. Aiming to study human robot interactions, this robot operates on a university campus carrying snacks to people, while avoiding obstacles. It gets its relative position making use of sonars, lasers and bumpers and comparing its readings against a previously memorized map. Moreover, it detects people pointing the lasers to the ground level and detecting the typical shape of their legs (Lee et al., 2009). Yet, this AMR's humanoid shape and small wheels make it incapable of moving on sand. Also, its interaction with humans can be found less than intuitive for people just looking to get food from a machine, its payment system is more susceptible to robbery than the one found on VM, and it needs a power outlet to recharge the batteries.

Other important examples relate to energetically autonomous robots, which use solar energy to recharge their batteries, and operate in the outside. The *Cool Robot*, designed for polar science campaigns (Lever and Ray, 2008), and the *Hyperion* or the most recent *Zoë*, designed to explore the Atacama Desert (Wettergreen et al., 2005), are some of such examples. We further analyze *Zoë*, as its surrounding environment is more similar to Portuguese beaches.

Zoë is characterized with a low mass, which allows for less energy to move it, an all-terrain locomotion system with limited speed and acceleration to diminish the slippage effect of the wheels, and a low complexity system for high energy efficiency. To further improve its efficiency, the robot has no steering actuators and steers itself by passively molding the chassis' axis of the wheels. In addition, the AMR obtains its position from relative readings of not only inertial sensors, such as gyroscopes and accelerometers, but also of laser scanners and 8 digital cameras. The use of these cameras is justified by their primary objective of studying the Desert's flora and fauna. Lastly, it should be mentioned that the sun´s energy is retrieved through a triple junction of photovoltaic (PV) panels with 2.4 m^2 of surface and composed of Gallium Arsenide (Ga-As), allowing for a 23% efficiency rate.

Reviewing the state of the art, we conclude that, to the knowledge of these authors, there is no energetically independent AMR VM presently being developed, as the one we propose to conceptualize in this paper.

3. Literature Review

When looking to deliver the maximum value for a new product or service, the marketing concept should never be forgotten, as it emphases the final consumer's needs, thus improving the profit margins of such business (Sorenson, 2006). The best way for developing a new product or service, which is market oriented, is to involve the potential customers in the early stages of its creation (Hoven, 2011). Moreover, in an area as competitive as food retail, it is crucial to have a profound understanding about the market so that you can respond to your final consumer with the most demanded product assortment (Molefe, 2006). Attending to these facts, and with the objective of building a survey not only to determine the initial product assortment but also to guide the AMR's future development according to the target market chosen, a market research was undertaken.

In order to target a market segment for food products, several variables should be considered for segmentation, such as geographical, demographical, social, economical, behavioral, and also lifestyle variables (Bonilla, 2010).

It is also important to stretch out that one of the markets attended by the AMR, is the tourism in Portugal. In 2010, it was registered a 10% increase in passengers flying in from foreign countries. The main source countries of tourism to Portugal in 2010 were the United Kingdom, France, Spain, Germany and Holland, in order of importance. Although Brazil and the United States of America were also distinguished by a rate of 57.5% and 24.2% in increase, respectively. In terms of timeline, 62% of the foreign touristic flow is concentrated between the months of May and October (Turismo de Portugal, 2010b). However, as the survey was taken to a convenience sample, nothing else can be added about foreign tourists.

On the other hand, it was also registered a retraction on internal tourism, i.e., residents making touristic trips. In fact, in 2010 only 37% of the resident population made such trips, which equated to 15 million trips. And of these, only 48.6% was classified as a "leisure, recreation and vacation" trip. The resident tourist's profile is of an individual with an age between 25 and 44 years (31.7%), employed (52.7%) and only 14.4% of them does not have any educational graduation. The most demanded regions for "leisure, recreation and vacation" trips were Algarve and Centro with 39.2% and 22.9% of the total, respectively (Turismo de Portugal, 2010a).

Further supporting the development of an AMR for food distribution and about the convenience retail, Krafft and Mantrala (2010) state that only the innovators, who adopt new technologies to create unique buying experiences for their customers, will thrive in the European market. The determining factors of choice for the convenience retail are cleanness, open hours and location of the point of purchase, time involved on the purchase, and also prices, quality, diversity and assortment of products (Spencer, 2004).

To generate an initial list of products, which could be sold in a VM and would supposedly please the market, a secondary investigation was carried out. On this subject, Gruber et al. (2005) identifies the most common types of food products found on a VM, as sandwiches, fruits, vegetables, snacks, pastries, cakes, coffee, tea, milk, ice tea, natural fruit juices, sodas, biscuits, chocolates, cookies, appetizers and ice creams. However, due to the informed modernized consumer aware of the health problems of such foods, many authors predict that this industry will tend to offer more functional and healthy food options (Bonilla, 2010; Hoven, 2011). Moreover, a study was carried out to determine the preferred brands for Portuguese people. In the food categories, some brands were retrieved to further constrain the initial product list, such as Luso to represent waters, Delta to represent coffee, Oreo for cookies, Kellogg's for cereals, Super Bock and Sagres for beer, Nestlé for candies and chocolates, Danone for yoghurts, Casal García for wines, Mimosa for milk, and Coca-Cola for sodas (QSP, 2011).

The subject of assortment planning is of the uttermost importance in an AMR VM since there are significant space constraints and the personnel in charge of replenishing stocks are only intermittently available. Yet, an optimal and generalized solution is still to be created. In fact, most of the existing solutions either were not tested in real environment, or were only tested on large general stores, or even implied the existence of either sales registrations or costs of inventory, which in a business startup cannot be provided (Brijs, 2002; Vaidyanathan, 2011). Lin et al. (2011) are the exception to this rule. Their study addressed the product assortment problem of a new VM by taking into consideration the sales of other VM located nearby and choosing the most differentiated bestselling products for the initial assortment. This difference in product features is supposed to help the future development of an "ideal" assortment. However, as there are no nearby VM on Portuguese beaches that we know of, our study will survey other retailers, like TV or beach establishments.

4. Methodology

The framework of this study was divided in two chapters: robotics and marketing.

In the robotics chapter, a virtual prototype is conceived with the help of Solidworks, a 3D CAD tool, and the aspects of control, obstacle avoidance, navigation and localization are addressed. For that purpose, we follow the robot development stages presented by Siegwart et al. (2011) and carried out by Carreira (2007). Moreover, the features of the robots studied in the State of the Art section, that best serve the present AMR's interests, are taken into consideration in this development phase.

Also an energetic viability analysis is undertaken with the aim of dimensioning the batteries. Balancing between energy consumption and retrieval, the consumption components are subdivided on VM, and AMR, and the caption components are subdivided on solar PV energy and wind energy. For the VM component, the standard performance chosen is the most efficient VM present in the Energy Star's refrigerated VM list (Energy Star, 2012) which, through its consumption per volume ratio, indirectly leads to the current AMR's consumption. For the AMR component, the mechatronic devices are selected, following Zoe's practices, and their consumptions are calculated, using technical data sheets of the devices and assuming a constant maximum consumption whenever the AMR moves. Likewise, the AMR's engines are dimensioned considering the engines' performance and the forces they have to surpass. This is done by adapting the process's stages followed in Carreira (2007). On the energy retrieval side, particularly on the solar PV component, the most efficient PV panels are chosen to incorporate the AMR, taking into consideration the performance of said panels. These data is then combined with the solar energy available in Portugal – data obtained through the PVGIS – to calculate the AMR's retrieved solar energy. Similarly, the same process is applied to the wind energy component, selecting a microturbine that would fit in our robot and making small adjustments to assure its fitting. However, as the wind energy was predicted to retrieve only a small fraction of the total energy, the selection of the microturbine took the economic side into consideration rather than the performance one. The microturbine performance's data is then combined with the wind speed usually recorded in Portugal, obtained through the LocClim software, and the AMR's retrieved wind energy is calculated.

To close the section, we assume some demands the batteries will have to overcome, specifically about the minimal distance travelled and standby time without retrieving any energy, and calculate their capacity from these.

In the marketing chapter, the investigation was conducted over two main objectives: determining the product assortment and determining the main valued features of this service in order to guide the future developments. For that, during July of 2012, in-depth face-to-face semi-structured interviews were carried to 13 bathers and 6 beach establishments, and 5 TV were observed, in order to get acquainted with both the supply and demand side of the market. First, a convenience sample was used in the Lisbon's metropolitan area beaches of São João, Castelo, Rei, Nova Vaga – all in the Caparica coast, but also in the Carcavelos and Guincho's beaches.

The exploratory investigation was followed by a descriptive investigation, using a questionnaire survey. The questionnaires were distributed online over the period between November and December of 2012; a "snow ball" sample (Snijders, 1992) was used through Facebook, and were divided in four sections: consumers' habits; determination of the consumers' preferences relative to the food products and respective prices; consumers' opinion about the robot; and demographic information. Data was computed using the SPSS software. Besides descriptive statistics, cluster and factor analyses were performed to segment the market using the AMR's features.

About the cluster analysis it is important to state that Formann's (1985) suggestion, about the sample size versus the number of variables, was considered and this led to the need of a preceding factor analysis. Also, we chose the Ward's method with the squared Euclidian measure to form the clusters because it is one of the most used methods and its effectiveness has been proven in a number of studies (Milligan and Cooper, 1987). Because Hair et al. (2010) state that the Ward's method is very sensible to outliers, the dendrogram of the nearest neighbor method was firstly analyzed and the outliers were removed. To determine the "optimum" number of clusters, we also use the Variance Ratio Criterion (VRC) of Caliński and Harabasz (1974). To conclude we make use of all the variables to profile and distinguish the clusters.

For the factor analysis, we have chosen the Principal Component Analysis, because it does not imply any assumption over the original data and explains a big part of the total variance with a smaller number of factors (Del Campo et al., 2008), and the varimax rotation technique, since it is the most used one, it improves substantially the interpretation of the solution, and creates uncorrelated factors, which is important for the subsequent cluster analysis (Gaskin, 2012).

5. Robotic Results

We begin this chapter addressing the virtual prototype, as well as the locomotion, perception, planning and navigation aspects of the AMR. After that, the energy viability analysis will be conducted. The robot was named "Fesquinho".

5.1. Conceptualization

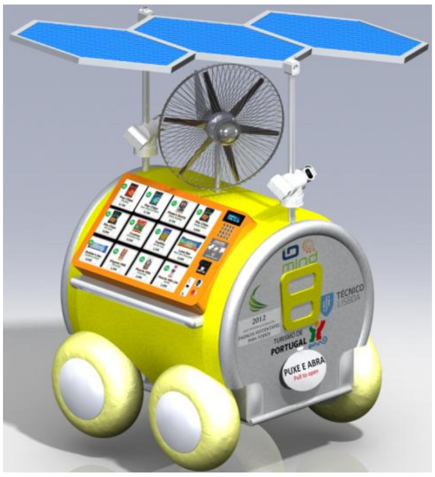

Figure 1 – Fesquinho's virtual prototype

In the overall development of Fesquinho, specifically in its dimensioning, care has been taken on creating a vehicle small enough to circulate on the people's pathways that connect to the beach, but also big enough to store a sufficient number of Stock Keeping Units (SKU). Initially the only constraint was linked to the shape of the wheels which needed to replicate the ones used on other beach service vehicles. With the shape of the wheel determined, the chassis was designed and reinforced to support a high weight, and to allow easy access to the mechatronic devices inside. With the chassis concluded, the engines were mounted in a differential drive manner. The movement of the engine rotor is transmitted through a reduction box and a set of rubber belts, chosen for its resistance to sand and salt water corrosion.

The outside appearance was addressed with the objective of creating a clear purpose shaped machine. We opted to take the common shape of a can, frequently inspiring the shapes of many VM, and dispose it horizontally for improved stability – see Figure 1. Also, the round shapes were adopted for security reasons, and the bright colors were chosen to assure the robot would not be unnoticed but still would not contrast so much as to cause an impact on the landscape. In the interior, we mounted a bell, to serve as an acoustic warning signal, activated only with the AMR's turbulence whilst moving, hence needing no further electric actuators. The interface panel with the client is similar to some found on VM, allowing for cash or card transactions and prepared for mobile phone transactions too.

PV panels were placed on top of the AMR, so maximum exposure would be achieved and their shadow would protect the refrigeration compartment. On top of the robot we installed the data transmitters and receivers, such as the GPS or GSM unit, for better quality signal. The microturbine was installed for maximum visibility. A cage for the microturbine also had to be installed in order to avoid any accidents. It should be added that, besides the GPS sensor already mounted, the other sensors will be mounted on the lateral, frontal and rotatable fixings. These sensors and other mechatronic devices used on Fesquinho can be consulted on Table 1.

Table 1 – Mechatronic components' list of Fesquinho

Sensing	4D Systems microCAM serial JPEG Camera Module - RS232
	Garmin's GPS-53 All-in-One Differential Marine Receiver
	Hokuyo URG-04LX Scanning Laser Rangefinder
	Devantech SRF02 Low cost Ultrasonic Range Finder
	Sharp GP2Y0A02YK0F IR Range Sensor
	Buffered ±6g Dual Axis Accelerometer
	GWS Single Axis PG-03 Piezo Gyroscope
	Grove - Slide Potentiometer
	Tilt-a-Whirl Tilt Sensor Breakout Board - RPI-1031
	.NET Gadgeteer Temperature and Humidity Sensor Module
Computing	Arduino Uno USB Microcontroller Rev 3
	Pentium 4 HT Processor 3.4 GHz
	GHI FEZ Spider Mainboard
Comunicating	GXM632 Magnetic Mount 5dBi Hi-Gain Antenna GSM / 3G / UMTS - 2.5m cable with SMA

The sensors enable the system to localize itself redundantly, through odometry or absolute coordinates, and to detect and avoid obstacles. Moreover, the cameras put the supervisor on the field in a telepresence mode, facilitating a problem solving and offering the possibility to remote control the

AMR, either for pre-recording the route or to navigate the robot to somewhere as needed, e.g., to the tow truck. The interface between the AMR and the supervisor is made via Web, as the fleet of robots is possible to grow and Web Language is universal.

For the Fesquinho's road map, the visibility graph approach was chosen to create the shortest path around an obstacle. Yet, as this approach generates paths dangerously close to the obstacles, we compensate by magnifying the actual size of the obstacles on the map. Also on this subject, to discriminate between the free and occupied cells of the map, we use the adaptive approximate variable-cell decomposition, a computationally light method that is able to detect considerably narrow paths.

To plan the obstacle avoidance paths we use the Bug2 algorithm aligned with the vector field histogram because the algorithm is overly sensitive to noise readings and the histogram calculates the probability of obstacle existence.

In the Fesquinho's navigation architecture, only the high priority decisions are computed in the robot, such as obstacle avoidance or emergency stops. The remaining computing activity is externalized to the supervising central.

5.2. Energetic Viability Analysis

On the energetic consumption side, we initiate our analysis by observing the energetic efficiency program – Energy STAR (2012) – list of refrigerated VM with complying performance standards. From this list and by calculating the energetic consumption per unit stored, it is possible to conclude that the manufacturer Royal Vendors excels on this subject. Next, the VM of this manufacturer are filtered to obtain only those that apply to Fesquinho's context, i.e., closed VM designed for exterior operation. With this new list, the volume of each machine is estimated by retrieving their dimensions and the ratio of capacity per volume is also calculated and averaged. With the volume of Fesquinho's refrigerated compartment obtained through Solidworks – 0.835 m^3 – and an average ratio of 461.39 units per m^3, we estimate a capacity for 385 cans of 355 ml, which is a common measure in the VM industry (Horowitz, 1998). After this, the best performance VM is selected from the Royal Vendors list – model number RVCV2-804* – its ratio of consumption per capacity is calculated and Fesquinho's energetic consumption is calculated on this basis leading to a 2.3 kWh/day, with an average power of 98 W.

Still on the consumption, but now on the robotic platform, we start by calculating the power of each mechatronic component, taking into consideration the maximum power consumption of each component present on Table 1. The value of 148 W is achieved for all the computation, communication and sensing expenses. For the engine dimensioning we set the maximum speed and acceleration to 0.3 m/s and 0.05 m/s^2, respectively and retrieve the tire radius from Solidworks – 300 mm. The power needed for the engines is calculated through

$$\sum M_{motor} \geq M_r + M_a + M_s \quad (1)$$

Where M_{motor}, M_r, M_a and M_s are the momentums of: the motor wheels', the rolling resistance with the terrain, the acceleration, and the slope, respectively. M_r is obtained through $M_r = T_r \times r$, where $T_r = m \times g \times \mu_r$ and represents the force needed to surpass the rolling resistance, m is the Fesquinho's mass, g is the gravity's acceleration, μ_r is rolling resistance coefficient depending on the surface and the tire, and r is the radius of the tire. To calculate $m \times g$ we summed the weight of the VM component, once again calculating the Royal Vendor's VM ratio of weight per volume and multiplying it by Fesquinho's volume, the weight of the cargo, multiplying the capacity for the weight of a 0.355ml can full of soda, the weight of the AMR component, similar to Zoë's weight, the weight of the microturbine, adapted from Ampair (2013), and the weight of the batteries, addressed later on this paper. This sum totaled 524.7 kgf and with a μ_r of 0.3, set for high performance sand tires ("Tire Friction," 2012), we get a M_r of 47.22 kgfm. Similarly, M_a is obtained through $M_a = T_a \times r$, where $T_a = m \times a_{max}$ and represents the force needed to accelerate the AMR, and a_{max} is the maximum acceleration. The resulting momentum is 7.87 kgfm. Finally, M_s is obtained through $M_s = T_s \times r$, where $T_s = m \times g \times sin\alpha$ and represents the force needed to surpass the slope limited to 20°. The resulting momentum is 53.83kgfm, which determines a minimum of 108.92 kgfm for M_r. Since there are two engines, 54.46 kgfm is the momentum for each of them. However, due to the use of a 367:1 transmission box, constituted of belts and gears, the final converted momentum – M_f – is of 1.5 Nm.

The power of the engines can now be obtained with

$$P = \frac{M_f}{2} \times RPM \times \frac{2\pi}{60} \quad (2)$$

Where *RPM* is the angular speed of the rotor engine in rotations per minute and can be found with

$$RPM = \frac{v_{max} \times 60}{\pi \times 2 \times r} \quad (3)$$

Where v_{max} is the maximum linear speed of the tire valued in 9.55 RPM, and P is valued in 534.1 W. However, we have chosen two 1500 W engines for precaution. Also, taking into consideration the performances of both the engines (Ohio Electric Motors, 2012) and the transmission box (Grove Gear, 2013), the power used by each engine is 748.7 W, totalizing 1497.5 W.

On the energetic retrieval or recovery side, we start by the microturbine Ampair 100, chosen for its low weight, silence and the capacity to incorporate the PV array in the energy storage system. However, the rotor diameter of 474 mm is superior to the maximum limit of 356 mm imposed by the lack of space. As a result and for calculation purposes, we consider a hypothetic turbine with its dimensions reduced to 75% of the original size. Ampair (2013) illustrates a graph that depicts the power recovered of the turbine when faced with a given wind speed.

Using LocClim to retrieve the average wind speed of 11 locations on the Portuguese coast for the 4 months of interest – June, July, August and September – and the Lognormal distribution (Sansigolo, 2005) to determine the probable amount of time for a wind speed above 3 m/s – minimum speed to produce energy – we get the power and energy produced by the microturbine. To convert these values to the hypothetic turbine, we consider that the net power – P – is directly proportional to the area swept by the blades – A (Royal Academy of Engineer, 2012). Since the $A_0 = \pi {r_0}^2$ and r_1 is now valued in $0.75r_0$, then $P_1 = 0{,}75^2 P_0$. From here we obtain an average power of 4.62 W and 0.09 kWh of energy daily retrieved.

Another energetic retriever is the Ga-As PV array. Castro (2007) suggests a formula to estimate the power and energy obtained.

$$E_d = \eta^{lim}\eta^r E_{10°}A \tag{4}$$

Where E_d is the daily energy produced, η^{lim} is the efficiency decrease derived from the solar tracker's angular limitation, η^r is the array's performance, $E_{10°}$ is the solar energy that reaches a 10° tilted plane, which is the angle of the fixed axis on Fesquinho, and A is the total area of the array. According to Poulek and Libra (1998), η^{lim} is 94.6%. For η^r, the manufacturer Semprius affirms to have a 33.9% efficiency arrays. From Solidworks, the A is 1.82 m^2. And $E_{10°}$ was retrieved with the software PVGIS (2013) for the 11 locations and the 4 months of interest. After calculating the averages, the daily energy obtained was 3.827 kWh at a 277.2 W of power.

As a first conclusion and since the daily consumption of the MVA component – 2.349 kWh – is well below the total daily energy recovered by the combination of PV array and microturbine– 3.911 kWh – we still need to determine the amount of time that the robot can behave as an actual AMR. Taking into consideration the available energy left (1.562 kWh/day) and dividing it by the maximum combined power of the mechatronic devices (1645.3 W), we get the total running time of approximately 57 minutes per day.

To dimension the batteries, we have established some premises to calculate the needed energy capacity of the batteries - E_T.

$$E_T = \frac{E_{48} + E_{1000}}{\%DoD} \tag{5}$$

Where $\%DoD$ is the depth of discharge set to a maximum of 80%, in order to improve the batteries life cycle. E_{48} is the energy consumed on working the VM component for straight 48 h, therefore assuring that, if for some reason the system stops retrieving energy, the maintenance crew will have a reasonable time frame to solve the problem before the food products start rotting. This value was calculated by multiplying by 2 the daily energy consumption of the VM component – 2.3 kWh/day. E_{1000} is the energy consumed by the AMR component to move an initially static Fesquinho across 1000 m, enabling it to get to or leave from its service area. It can be calculated by finding the time taken by Fesquinho to move through 1000 m, resorting to the movement equations, and multiplying it by the combined power needed to activate all the mechatronic components of the AMR – summing 1497.5 W and 148 W. From here, the E_T results on 7.778 kWh which, considering the 400 Wh/kg lithium batteries of Envia Systems, subsequently implies a 19.4 kg on weight addition to Fesquinho – 5% of the tare weight – and a 0.0098 m^3 space occupancy (Envia Systems, 2013) – 9% of the available space in the mechatronic box.

6. Marketing Results

After the 13 semi-structured in-depth interviews conducted to bathers, 6 other conducted to managers of beach establishments, and the observation of 5 TV, the questionnaires were designed and distributed, and a sample of 712 cases selected. The sample was then described to be composed mainly of females (59%), young people – 65% were aged between 15 and 24 years old – people living in the region of Lisboa e Vale do Tejo (82%) and frequenting the beaches of the Lisboa e Vale do Tejo and Algarve - 38% and 36% of the sample, respectively, stated these regions as the most visited. The sample is also highly educated – 43% has a degree and 94% has at least high school completed – mainly students (60%), and go to the beach without the company of children (62%). Behaviorally, the sample prefers to buy from beach establishments (56%) instead of TV (38%) whilst on the beach, spends more than one month per year on the beach (55%) and on these days they spend more than 2€/day (70%). When the sample was asked about the most consumed food categories on the beach, waters, sandwiches and ice-creams were checked by the majority – 72%, 59% and 54%, respectively. However, when the sample was asked about which items they would prefer buying from Fesquinho the most chosen categories were waters, ice-creams and sodas – 62%, 55% and 42%, respectively – while sandwiches were only mentioned by 38% of the respondents.

The sample's preferred timeframes to buy food products are between 16:00 to 18:00 (66%) and 14:00 to 16:00 (55%). The willingness to pay of the sample for the food products was measured against beach establishments and TV. Only about 10% of the inquiries agreed on paying more on Fesquinho; on the other hand, the general opinion about the robot was very encouraging since 93% of the sample wants to try and buy food products from Fesquinho. Moreover, the 15 specific features evaluated on a scale of "1 - Not important at all" to "5 - Very important" had all shown averages above 3.5. The most valued features were "V4) the robot keeps products fresh and refrigerated", "V5) the robot is easy to use", "V3) the robot uses sun and wind as energy resources", and "V6) the purchase in the robot is quickly made" – averaging 4.90, 4.69, 4.42, and 4.41, respectively.

6.1. Determining the Product Assortment

To choose the products offered by Fesquinho, the absolute frequency of choices for each single product was consulted and a list with the highest frequency was generated.

Table 2 – Most preferred food products for Fesquinho's

Category	Category's quota	Product	Product's Absolute Frequency
Waters	62%	Luso mineral water	439
Sodas	42%	Coca-Cola Classic	134
		Lipton Ice Tea lemon	34
		Coca-Cola Zero	32
Sandwiches	38%	Tuna sandwich	79
		Chicken sandwich	46
		Ham and cheese sandwich	32
Fruits	23%	Grapes	31
		Apple	31
		Peach	27
Natural fruit juices	21%	Orange juice	48
Cakes and candies	17%	Bola-de-Berlim with cream	72
		Bola-de-Berlim without cream	49
Salads	15%	Chicken salad	49

Furthermore, the most preferred food categories for Fesquinho are also taken into consideration. The first list of products was created incorporating only the products that were preferred by a significant number of people – see Table 2. However, all the products with different thermal needs, including all the ice-cream products, were removed because our robot does not have separated compartments. Also, all the products with a purchase age restriction were removed since the apparel needed to sell, for instance, alcoholic beverages, would further increase the cost of the AMR VM.

To be included in the final product assortment list, each category leader was chosen and all the products with an absolute frequency over 40 were also selected, resulting in a 9 product list representing 7 food categories. This list, with two thirds of healthy choices and containing the most required food products and categories, was considered broad and distinct enough to initialize sales.

6.2. Segmenting the Market

To divide the sample in a way which allowed for the Fesquinho's development guidelines to be settled, we have considered the feature importance variables, excluding the ice dispenser variable, and initiated a factor analysis, in order to avoid over-measured types of characteristics. For implementing this approach, the first step is the visual examination of the correlation matrix. This examination reveals considerable amount of correlation in the data, with all but 4 variables having at least one correlation coefficient greater than 0.3. Also, the 4 variables found with lower correlation coefficients were considered close enough to this threshold, and of the 196 correlations, only 18 were not significant at the 0.05 level. In addition, the KMO measure is calculated and classified as "median" (Kaiser and Rice, 1974), and the Bartlett's test presents an associated probability lower than 0.05, meaning that the factor analysis can be performed on these variables. The next step, the decision on the number of factors to retain, was based on the eigenvalue criterion (Kaiser and Rice, 1974). Therefore, the first 5 factors, with eigenvalues greater than 1, were retained. However, the scree-plot also analysed suggests 4 or 6 factors. As a result, all of the above solutions were tested and have provided unsatisfactory factor structures. Consequently, we added one more factor to the solution and verified that all the communalities were between the 0.62 and 0.85 values, the total explained variance was of 74% and the factor structure was easily interpreted. The names chosen for these factors, from 1 to 7, were "Convenience", "Menu", "Automation", "Distant Interaction", "Aesthetics and Proximity", "Sustainability" and "Sound Warning", respectively.

Subsequently, to group the respondents, the scores of the seven factors were used on a cluster analysis with the Ward's method, after excluding the outliers detected on the nearest neighbour method. As a result, 702 observations were analyzed, and a 5 or 7 cluster solution were seen as viable, according to the dendrogram produced. To help decide on the number of clusters, the VRC index was also used, obeying to the steps of Mooi and Starstedt (2011), which pointed to the 5 cluster solution.

A detailed description of the 5 clusters can be found on Table 3, addressing not only their factor scores but also the variables that prove some differences across the clusters.

Table 3 – Average factor scores (F) for the final Ward's method clusters (C)

	F1	F2	F3	F4	F5	F6	F7
C1	0,30	0,12	-0,38	-0,74	0,46	-0,96	0,20
C2	-2,53	0,11	0,37	0,06	-0,52	-1,06	-0,37
C3	0,08	0,25	-0,02	0,34	0,07	0,33	0,50
C4	0,33	0,02	-0,33	0,36	0,08	0,19	-1,28
C5	0,31	-0,90	0,73	-0,70	-0,47	0,23	-0,14

Cluster 1 (the "stressed with children") – This cluster contains 103 respondents, corresponding to 15% of the sample. It is a group with the highest factor scores on "Aesthetics and Proximity", while "Convenience" was close to the highest. It also got the lowest values on "Automation" and "Distant Interaction", while "Sustainability" was close to the lowest. In relation to the other variables, the cluster

distinguishes itself by having the largest percentage of respondents that would prefer to buy from TV (48.5%), already consumes cakes and candies on the beach (30.1%), want to buy sandwiches on the AMR VM (41.7%), usually go to the Algarve region beaches (43.7%), and are accompanied by children in their beach visits (43.7%). Also, it has the lowest percentage of people that admit spending more than one month per year on the beach (50.5%), and want to buy waters from the AMR VM (58.3%).

Cluster 2 (the "unworried employees") – This cluster contains 48 respondents, corresponding to 7% of the sample, and it is the smallest and also the most distinct cluster, according to the Ward's dendrogram. It is a group with the lowest factor scores not only on "Convenience" – with the manifestly negative value of -2.526 – but also on "Sustainability" and "Aesthetics and Proximity". In relation to the other variables, the cluster distinguishes itself by having the largest willingness to pay, either comparing it with the beach establishments or with the TV – on this last variable it averages a 2.40 on a 5 maximum scale. It has the largest percentage of respondents that would prefer to buy from beach establishments (66.7%), admit spending more than one month per year on the beach (64.6%), are male (58.3%), have an age above 25 years (41.7%), have at least high school completed (97.9%), are employed (33.3%), and want to buy waters from Fesquinho (72.9%). Also, it has the lowest percentage of people that are students (56.3%), usually go to the Lisboa e Vale do Tejo region beaches (25%), and already consume sandwiches on the beach (50%).

Cluster 3 (the "green supporters") – This cluster contains 323 respondents, corresponding to 46% of the sample, and it is the most interesting group in a market potential perspective. For three factors, it presents the highest average factor scores – "Menu", "Sustainability" and "Sound Warning", while "Distant Interaction" was close to the highest. In relation to the other variables, the cluster distinguishes itself by having the largest percentage of respondents that spend less than 5€ per day on beach purchases (80.8%), go to the beach between 16:00 and 18:00 (66.9%), already consume fruits on the beach (28.5%), and are female (67.8%). Also, it has the lowest percentage of people that already consume alcoholic beverages on the beach (9.9%), and refuse to try Fesquinho (6.8%).

Cluster 4 (the "quiet students") – This cluster contains 120 respondents, corresponding to 17% of the sample. It is a group with the lowest values on "Sound Warning", while "Automation" is close to the lowest. It also got the highest factor scores on "Convenience" and "Distant Interaction", while "Sustainability" was close to the highest. In relation to the other variables, the cluster distinguishes itself by having the lowest willingness to pay, comparing it with the beach establishments – averaging 1.91 on a 5 maximum scale. It has the largest percentage of respondents that spend more than a month per year on the beach (67.5%), spending there between 2€ to 5€ in one of such days (50.8%), already consumes waters and sandwiches on the beach – 80.0% and 65.0%, respectively – aged above 25 years (69.2%), are students (65.8%), and usually go to the Alentejo region beaches (17.5%). Also, it has the lowest percentage of people that wish to buy ice-cream from the AMR VM (48.3%).

Cluster 5 (the "simple taste wises") – This cluster contains 108 respondents, corresponding to 15% of the sample. It is a group with the highest factor scores on "Automation", while "Convenience" and "Sustainability" were close to the highest. It also got the lowest value on "Menu", while "Distant Interaction" and "Aesthetics and Proximity" were close to the lowest. In relation to the other variables, the cluster distinguishes itself by having the lowest willingness to pay, comparing it with the TV – averaging 1.81 on a 5 maximum scale. It has the largest percentage of respondents that spend less than one month per year on the beach (56.5%), spend here less than 2€ per day (36.1%), already consumes ice-creams on the beach (58.3%), want to buy ice-creams on the AMR VM (64.8%), refuse to try Fesquinho (10.2%), usually go to the Lisboa e Vale do Tejo region beaches (42.6%), have a degree (48.1%), and are not accompanied by children when they go to the beach (65.7%).

Because it is the biggest cluster and the one that best values the already contemplated features of Fesquinho, the all concept will be developed to please the "green supporters".

6.3. Future Developments on the Fesquinho's concept

To exemplify how the preceding segmentation and targeting can be used to develop the Fesquinho's concept, we analyze the averages of the original variables on the target cluster, and compare them across all the created clusters. Due to the space constraints, only the top 3 features analyzed are considered for this effect.

Starting with the third most valued feature, V3 about the renewable energies, we suggest the application of PV arrays to completely cover Fesquinho's exterior and the use of biaxial solar trackers. We also justify the use of high performance technologies, or the presence of a microturbine, which has little energy recovery capacities. These developments could also sustain the possibility of creating a new refrigerated compartment to store ice-cream products.

The second most valued feature is V5, about the easiness of use. It is credible that children and seniors, e.g., do have different perception about this ease of use, as a result the AMR VM should not only be easy to use but also universally easy. Such can be achieved with the use of clear and visible instructions allied with an intuitive interaction system manufactured by a VM partner, such as e.g. Royal Vendors. Adding the possibility of mobile phone payments can also simplify a part of this process.

Lastly, for the most valued feature, V4 about the refrigeration of the products, we further justify the need to have a refrigerated VM on the beach and an additional compartment to store ice-creams, as future development, on the AMR. To make better use of the energy recovered, hence improving the refrigeration capabilities of the machine, we suggest the consultation of the EERE's guidelines about high efficiency VM (EERE, 2013), and the use of aerogel for a better thermal insulation of the refrigerated compartment (Schmidt and Schwertfeger, 1998).

7. Conclusions

An energetically independent autonomous mobile vehicle aimed for food distribution on the beach was conceptualized and some aspects about its locomotion, perception, planning and navigation were addressed. Furthermore, the energetic viability analysis determined that the robot is able to act as a VM during the months under analysis and act simultaneously as an AMR for 57 minutes each day.

The market research conducted led to a nine product initial assortment, designed to include enough food categories and appeal to the general market preferences. Also, the segmentation of the market led to the identification of an attractive segment which will guide the future developments of the all concept. Some examples of development guidelines for the most valued features were given, suggesting that future work should focus on the use of renewable energies, the efficiency improvement of the machine and its capability to refrigerate products, and its easiness of use.

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