New Frontiers of Delivery Services Using Drones: a Prototype System Exploiting a Quadcopter for Autonomous Drug Shipments

Authors Name/s per 1st Affiliation *(Author)*
line 1 (of *Affiliation*): dept. name of organization
line 2: name of organization, acronyms acceptable
line 3: City, Country
line 4: e-mail: name@xyz.com

Authors Name/s per 2nd Affiliation *(Author)*
line 1 (of *Affiliation*): dept. name of organization
line 2: name of organization, acronyms acceptable
line 3: City, Country
line 4: e-mail: name@xyz.com

***Abstract*—Drone-based delivery of goods could become a reality in the near future, as witnessed by the increasing successful experiences in both research and commercial fields. In this paper, a prototype system exploiting a *do it yourself* quadcopter drone for delivering products is proposed. On the one hand, the hardware choices made in order to limit risks arising from autonomous delivery are presented. On the other hand, a framework for orders placement and shipment is shown. The advantages of a system like the one described in this paper are mainly related to an increased delivery speed, especially in urban contexts with traffic, to the possibility to make deliveries in areas usually difficult to be reached, and to the drone's ability to autonomously carry out consignments. A practical use case, in which the proposed system is used for delivering drugs (an application in which the need to quickly receive the good might be particularly important) is shown. Nevertheless, the proposed prototype could be employed in other contexts, such as take-away deliveries, product shipments, registered mail consignments, etc.**

Keywords-drone; quadcopter; delivery service; drug; mobile

I. INTRODUCTION

The technological evolution that characterized the last century profoundly changed the way people perform daily activities. This is evident when considering, for instance, the radical transformations brought in the organization of house works by refrigerators/freezers, washing machines, etc.

In the last years, humanity is witnessing a new evolution, in which appliances and devices that once required a human command in order to be activated have become more and more intelligent and able to take decisions based on the external context. In fact, the research world and, then, the commercial field, devoted increasing efforts to the development of innovative solutions for smart environments encompassing, for instance, home and industry robots getting able to respond to commands issued by humans via many kinds of natural interaction means.

Among such innovative solutions, particular attention has been dedicated to "drones" (*unmanned aircrafts or ships guided by remote control or onboard computers,* as reported in the Merriam-Webster Dictionary), and to Unmanned Aerial Vehicles (UAVs, *aircrafts piloted by remote control or onboard computers* as in the Oxford Dictionary), which recently became widely available in the commercial marketplace. In fact, apart from merely recreational applications in which commercial drones and UAVs are used in a way similar to a radio-controlled car, they could represent a quite cheap instrument – the cost for an entry-level model is about a hundred of dollars – to allow users to access areas that are normally difficult/dangerous to reach. The possibility to use an autonomous or remotely-controlled flying vehicle lays the foundations for several applications that could bring benefits to different contexts, such as: environmental conservation (by using drones and UAVs to fly above selected areas and monitor endangered species or forests), emergency preparedness (by exploiting aircrafts for searching for survivors, e.g., in risky places), crime fighting (by supervising borders, or searching for fugitives), culture and leisure (by using flying vehicles to check historical monuments conditions or explore areas from unusual point of views), etc.

Another field in which drones and UAVs could soon bring enormous changes is represented by delivery services, as it has been shown by prototypes developed by Amazon [1], Google [2] and DHL [3]. In particular, Amazon is waiting for the permission from the U.S. Federal Aviation Administration in order to use its drones to carry out deliveries in less than 30 minutes. Similarly, in the summer of 2014, Google tested the UAV-based delivery of first-aid kits in Australia, by replicating the successful experience of DHL dated December 2013, in which a "parcelcopter" was able to deliver urgent medications to customers.

By moving from the successful experiences reported in the above works, in this paper we present the design of a prototype system for order placement and autonomous delivery using an unmanned aircraft (namely, *a do it yourself* quadcopter). The objective of the paper is to present a detailed overview of all the aspects that should be considered in the development of such a system, i.e., in the identification of hardware components, the analysis of issues related to autonomous flight and delivery and the design of a suitable software architecture enabling the communication between customer and deliverer, together with the interaction with the quadcopter.

In particular, we especially targeted our system to drugs delivery. In fact, this sector could benefit from a drone or UAV-based delivery, as medications could be urgently needed and could be small and lightweight enough to be carried even by a small drone. Nevertheless, it is worth remarking that the use of the proposed prototype could be extended to other medical areas (for example, the delivery of urgent equipment in case of an accident) and could be also adapted to be exploited in other contexts, such generic shipments, take away deliveries (as in [4]), registered mail consignments, etc.

Advantages could be numerous: deliveries could be made more quickly, since the drone would not be constrained by traffic slowdowns; it could be possible to serve areas that normally are difficult to reach, such as mountain regions or villages with bad roads connections; the exploitation of an autonomous aircraft could make it possible to reduce road-based deliveries, thus allowing a decrease of the working force as well as a minor pollution.

The remaining of the paper is organized as follows. Section 2 presents several recent research works about the use of drones and UAVs in different application scenarios. In Section 3, the architecture of a basic drone is presented, by especially focusing on a quadcopter vehicle. Section 4 analyzes possible issues related to autonomous drone- and UAV-based delivery (for sake of simplicity, from now on the terms "drone" and "UAV" will be considered as synonyms), and proposes some possible solutions. Section 5 illustrates how the architecture of the selected drone has been modified in order to include additional components required for autonomous deliveries. The mobile application is then presented in Section 6, together with an example of order placement and shipping. Finally, conclusions are drawn in Section 7.

II. RELATED WORKS

Drones appearance in the mass market is relatively recent. Nonetheless, researchers have already explored their possible application in different scenarios.

An example on how a drone could be exploited in an everyday life context is given in [5], where the author presents how he built and used a drone to monitor his son during the walk from the house to the bus stop.

Drones could also be used for education purposes. For instance, in [6] drones and Augmented Reality technologies have been jointly used for creating an innovative experience for visitors, which could pilot the drone in the museum's courtyard and search for virtual targets to be destroyed in order to trigger instructive videos. Another interesting exploitation of drones in the education context is reported in [7]: here a quadcopter has been used to teach robotics concepts to students without technical background, by means of a one-day competition on automatic visual markers-based UAV navigation.

Since one of the advantages of drones is related to their ability to record scenes from above, they could be used for filming sport events, as suggested in [8]. Here, the authors propose two solutions to make a drone autonomously move in response to the movements of the protagonist of an event. Other possible applications are related to building maintenance as suggested in [9]. Here, a drone controlled by a tele-operator by means of head movements and gestures captures images and send them to the Google glasses worn by the operator.

Another advantage of drones is that they could possibly support human activities by carrying out repetitive/mentally demanding or even dangerous tasks. This is the case of [10], where a drone has been used for monitoring the Amazon rain forest, of [11], where an unmanned helicopter is used for collecting and analyzing traffic data, or of [12], where the exploitation of a drone for gas leakage recognition is investigated. Similarly, [13] presents how drones have been used in Africa to protect endangered species by monitoring them and identifying poachers.

Drones could replace human intervention also in more critical situations, such as in malaria disease management, as suggested in [14]. In fact, they could be used to reduce costs, by replacing helicopter and wing aircraft aerial insecticide spraying, or to limit health risks, by substituting humans performing manual backpack spraying.

Drones could also be used for guiding rescue teams during natural disasters, by being able to autonomously navigate and scan an area to identify people in need of help [15].

Considering the above works, where the use of drones could have a considerable impact on individuals' safety and wellness, the investigation of a delivery drone could appear like a low(er) priority issue. Nevertheless, the social benefit deriving from drones exploitation could be seen in a minor pollution (e.g., less delivery vehicles used in cities). In this respect, it could be worth noticing that the operating costs for delivering a 2 kg package at 10 km with a drone would be relatively low (10 cents) [16]. Moreover, as in the case of the specific use case related to drugs delivery, it is worth remarking that a shift to a drone-based shipment could be relevant in cases in which urgent medications are needed in contexts of broken ground or bad roads connections.

III. ARCHITECTURE OF A FLYING DRONE

Before analyzing the hardware of the proposed prototype, we consider it useful to take a step backward and provide the reader with an overview of the general architecture of a flying drone, by making reference to the particular quadcopter used in the proposed system (shown in Fig. 1).

As pointed out in [17], novices without a background in radio-controlled planes wanting to build their first drone, could find it difficult to distinguish between necessary and

Figure 1. Architecture of a quadcopter

optional components, and to understand the role of each element.

A. Frame

The frame constitutes the skeleton of the drone and hosts all the other components. When choosing a frame, particular attention should be devoted to its weight, size and material, since these variables are related to the choice of other elements such as motors and battery (e.g., for providing enough power for takeoff), propellers (that should be able to twist without interfering with each other), the number of components to be hosted on the frame, etc. Frames are generally made of carbon fiber, thus being light though stiff.

B. Motors

The objective of motors is to spin the propellers, which are fastened on the top of them. There are a lot of motors on the market, which vary, apart from their price, on the basis of their spin speed at a constant voltage. The selection of a motor is linked to drone weight, and influences the choice of other components such as the battery or the Electronic Speed Controllers (ESCs). In the case of a quadcopter, four motors are needed.

C. Electronic Speed Controller

The Electronic Speed Controller is the component that communicates to the motors how fast to spin in each situation, based on the signals received from the flight controller. Each ESC controls a single motor; hence, for a quadcopter, four ESC should be used. ESCs are then directly connected to the battery or to the power distribution board (which acts as an intermediary between the battery and the different electronic components and, for sake of simplicity has not been shown in the figure). In addition, many ESCs have a built-in Battery Eliminator Circuit (BEC); in this way, they could provide power to other components (mainly the flight controller and the radio receiver). The choice of the ESC to purchase is critical, since the behavior of each motor should be continuously adjusted. For this reason, ESCs with a high refresh rate (more checks for new instructions from the flight controller per second) should be preferred.

D. Flight controller

The flight controller could be seen as the “brain” of the drone. In fact, it determines the spin speed of each motor based on user’s commands and/or sensors’ data (flight controllers usually contain several sensors such as gyroscopes for orientation, accelerometers for acceleration, barometers for altitude, GPS for position, etc.).

E. Radio receiver

The radio receiver and the transmitter (not reported in the figure) are the components that allow the user to pilot the drone. When choosing them, particular attention should be devoted to the number of channels. For multi-rotor control, they should be at least four, being each control input (i.e., in the basic configuration, pitch, roll, throttle and yaw) conveyed on a single channel.

F. Battery

Most quadcopters use LiPo batteries, that are lightweight and compact. The choice of the battery should be made on the basis of drone motors and desired flight time. It is worth considering that an increase of battery size is generally not proportional to the increase of flight time, because of the greater weight of the battery.

G. Propellers

In a quadcopter, four propellers are needed. Propellers should be chosen by considering the drone’s arm length, and the motors’ speed (e.g., for higher spin speeds smaller propellers are suggested). Finally, it could be worth remarking that, in the case of quadcopters, two propellers spin counter-clockwise and two spin clockwise; hence, particular attention should be devoted in the assembly phase.

IV. Components Required for Autonomous Delivery

The architecture presented in the previous section is related to a basic drone that can be remotely controlled by a user. However, in the context of autonomous flight and especially for deliveries, some crucial aspects should be analyzed, in order to identify hardware and software solutions limiting the potential risks that could arise (e.g., damages to people, to things or to the drone, errors during deliveries, etc.).

In the following, the major issues to be considered, together with possible actions to be taken, will be described.

A. Safety

Safety is the major issue, when it comes to autonomous flight, and is one of the reasons why legal regulations on autonomous drone-based deliveries are still under definition. To make an example, at present in the U.S. unmanned aircrafts could fly in the National Airspace System only under strict controlled conditions and mainly for security and public safety purposes, environmental monitoring, research aims or other mission for Government entities. Nevertheless, in major urban areas (and especially close to airports), the above drones would not be allowed to operate [18]. Whether the situation could change in the near future is not clear: there have been some rumors on the fact that regulations will not be available until 2017 [19], despite the initial deadline of September 2015, established by the U.S. Federal Aviation Administration in 2012 [20]. What is certain is that the pressure from the industry is relevant, as witnessed by the petition presented by Amazon on July 2014 [21].

Should legal regulations allow autonomous flight, great attention should be devoted to make drones able to fly without representing a danger for people and things. A possible solution, in a delivery scenario, could be to let the drones flight 10 – 20 meters above buildings and streets, by pre-computing altimetry coordinates for the whole path store/warehouse-customer house before the takeoff (and considering the maximum value, among them). Nevertheless, this approach could not be sufficient, since moving obstacles could be found (not to mention that altimetry data could not be up-to-date for new buildings). A solution could be to equip the drone with additional sensors able to detect obstacles, such as:

- *sonars*, electronic devices exploiting radio waves reflection hitting an object to calculate its distance, shape and speed;
- *passive infrared sensors (PIR)*, which detect obstacles on the basis of changes in the infrared light radiation (linked to objects' temperature) occurring in their field of view.

In the proposed prototype, both sensors families have been exploited and mounted on the drone's frame. Sensors' data are collected twice per second, and a new obstacle is identified when a change in the last 10 observations takes place. Should an obstacle be detected, possible solutions could be either to equip the drone with a live-streaming utility, in order to let a person to remotely take control of it, or make it automatically return to the base. For what it concerns the prototype, we chose to equip it with a *frontal webcam*, sending data through a 3G connection. Hence, a module including a *3G receiver* (the *Cooking Hacks 3G + GPS shield*) has been used.

B. Correct delivery

The ability to correctly deliver a package is another relevant issue. Risks deriving from an incorrect delivery, in fact, are not only related to a good consigned in the neighbor's courtyard, but could have worst consequences when the package is erroneously delivered in traffic areas such as highways or crowded roads. In this view, GPS fails could not be accepted. Providing the drone with two GPS modules could be the key to overcome this issue, and this is actually the strategy pursued in the creation of our prototype.

In particular, a *first GPS* is used to guide the drone to customer's house (or back to the base). When the drone is close to destination, coordinates obtained from a *second GPS* are used for deciding in which moment the packet containing the ordered object should be detached (coordinates data are processed and compared by a programmable microcontroller, the *Arduino Uno*). Moreover, it is worth remarking that, in order to deliver the good, the drone uses a *Styrofoam box* attached to a parachute (hence a light packaging, in order to avoid people injuries), which is unhooked from the quadrotor as soon as its coordinates are in the range of the ones specified by the customer. To this purpose, the drone has been equipped with a *micro servo-motor* triggering package detachment.

C. Ability to correctly return to base

Similarly to point *B*, the drone should be able to return to the base without representing a threat for people or damaging itself. To make an example, a drone could run out of power during the way, or could not be able to correctly land, once reached the store/warehouse.

To overcome the above issues, possible strategies could consist in continuously evaluating the expected power required to return to the base, and eventually interrupting the delivery and making the drone come back to the base if the battery power falls below a "safety" threshold. Another

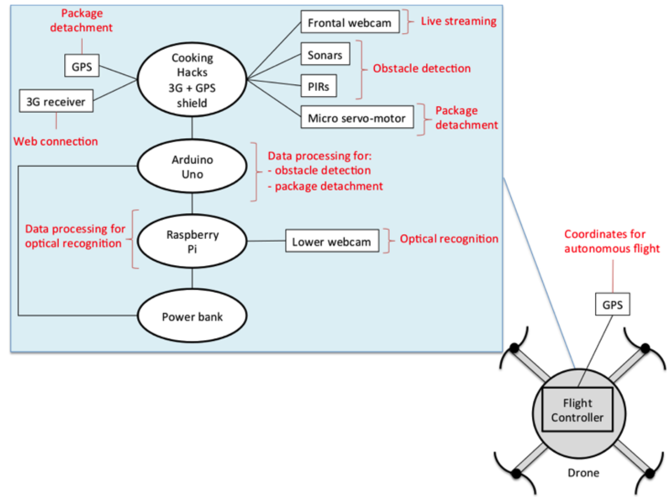

Figure 2. Additional components

alternative, adopted in the current prototype, could be to estimate *a priori* the power required for a delivery and ship only those orders for which it is certain the drone would have enough battery. In both solutions, the drone could continuously record and send its coordinates to the base, in order to be retrieved, if lost.

Regarding accurate landing, an optical recognition system identifying a particular object indicating the landing area, could be used. In this respect, the proposed prototype has been equipped with a second *(lower) webcam* pointing to the ground, which is activated when the drone is near to the base. Optical recognition algorithms, ran on a mini-computer, the *Raspberry Pi*, could then assure the landing in the correct area, indicated by a checkered flag.

D. Drone preservation

Due to considerations similar to those presented for point *C*, drone's damages during flight could not be acceptable. To limit the risk, a check on drone's components' state should be periodically performed. Moreover, it could be wise to avoid deliveries during bad weather conditions.

V. Integrating Basic and Additional Components

Fig. 2 shows the hardware architecture of the overall prototype and reports the role of each element (painted with red color). It is worth remarking that these components have been added to the basic design described in Section 3. For sake of simplicity, elements that have been already discussed are not shown in the figure (except for the flight controller module, because of its connection to a new component). Most important elements are depicted with circular boxes, whereas additional ones are contained in rectangular shapes. Lines show the connections among them.

Starting from the top, the Cooking Hacks 3G + GPS shield module is found: such module enables high-speed communications and includes a GPS. Moreover, it could be connected to webcams and audio kits, and could host up to a 32 GB microSD card. In our prototype, the Cooking Hacks 3G + GPS module has been connected to the frontal webcam (in order to enable live streaming), to a number of sonars and passive infrared sensors (in order to detect obstacles), and to a micro servo-motor (detaching the package once reached the customer house's coordinates). The 3G receiver is used for connection purposes (e.g., for transmitting streaming and other data to the base), whereas, as previously mentioned, the GPS is used to gather data to decide when the package should be detached.

Data collected by sensors connected to the Cooking Hacks are processed by the Arduino Uno microcontroller. Such component is in charge of analyzing sonars as well as infrared sensors' data in order to detect anomalies, and monitors when the servo-motors should be activated. During takeoff, it receives the delivery coordinates; during flight, it continuously compares them with data received from the Cooking Hacks GPS.

Heavy computational tasks, like the optical recognition of the landing signal, are executed on the Raspberry PI, a cheap single-board computer. Such mini-computer has been linked to the webcam pointing to the ground, from which it could gather images to be compared for optical recognition.

An additional power bank (the first one is used for moving the drone) has been added to provide power to the above components.

Finally, a GPS receiver has been added to the drone and linked to the flight controller, and is used to guide the drone towards its destination.

A particular of drone's additional electronic parts is shown in Fig. 3.

VI. Software Architecture

Based on the considerations reported in the above sections, we drafted the software architecture that is shown in Fig. 4. The architecture includes an Android application, which could be used by both customers and stores/warehouses to place/receive orders, as well as to manage drone-based deliveries, and by several Java servlets, run on the [removed for blind review] server, which retrieve – or modify or insert – data (e.g. users' and order information, etc.) from the [removed for blind review] database.

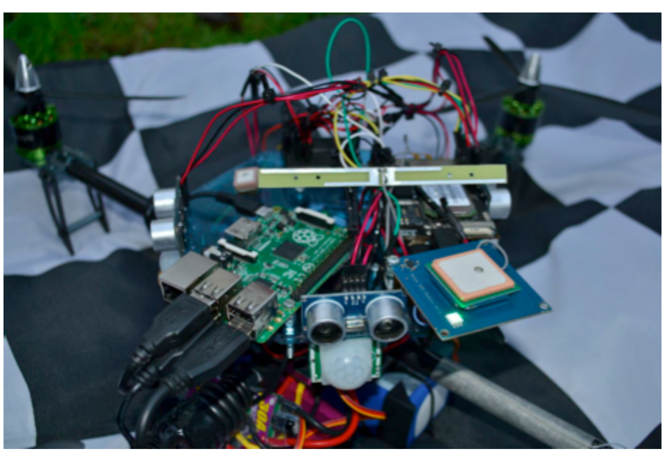

Figure 3. Particular of drone's electronic additional components

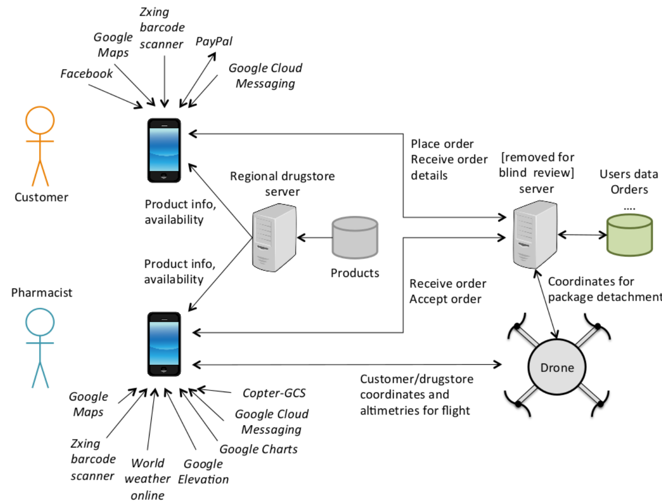

Figure 4. Software architecture

In the following, the operations performed by users, related to the delivery task, will be described by making reference to the proposed software architecture. In particular, since the system has been applied to the practical case of drug deliveries, the focus will be on customers and on pharmacists.

A. Customers

In order to place their orders, customers have to be registered to the system. To this aim, once the Android application is launched, they could insert username and password chosen during registration, or could login with Facebook through the Facebook API[1]. Once logged in, they could choose the drugstore to which send the order. At this purpose, they could visualize their position (retrieved by the phone/tablet GPS) on a map, together with the position of nearby drugstores adopting drone delivery. For this, the Google Maps API v2[2] has been used.

Then, customers could search the required drug. The application makes a request to a regional server hosting drugs' descriptions as well as their availability in each drugstore. It is worth remarking that, during drugs search, customers could either manually insert the name of the required drug, or scan the barcode reported on its box. In this view, the ZXing[3] library has been used.

Once the searched item has been found, customers could place the order. Here, they could chose between the on-site pick-up and the drone-based delivery. Should they opt for this second option, a notification is sent to the pharmacist, in order to let him/her accept or decline the order (since the drone could be temporarily not available, weather conditions could be unfavorable, etc.).

Should the pharmacist approve the order, customers could pay either by credit card, or by using PayPal (through the PayPal Android SDK[4]). If the payment is accepted, a

[1] https://developers.facebook.com/docs/android
[2] https://developers.google.com/maps/documentation/android
[3] https://github.com/zxing/zxing
[4] https://github.com/paypal/PayPal-Android-SDK

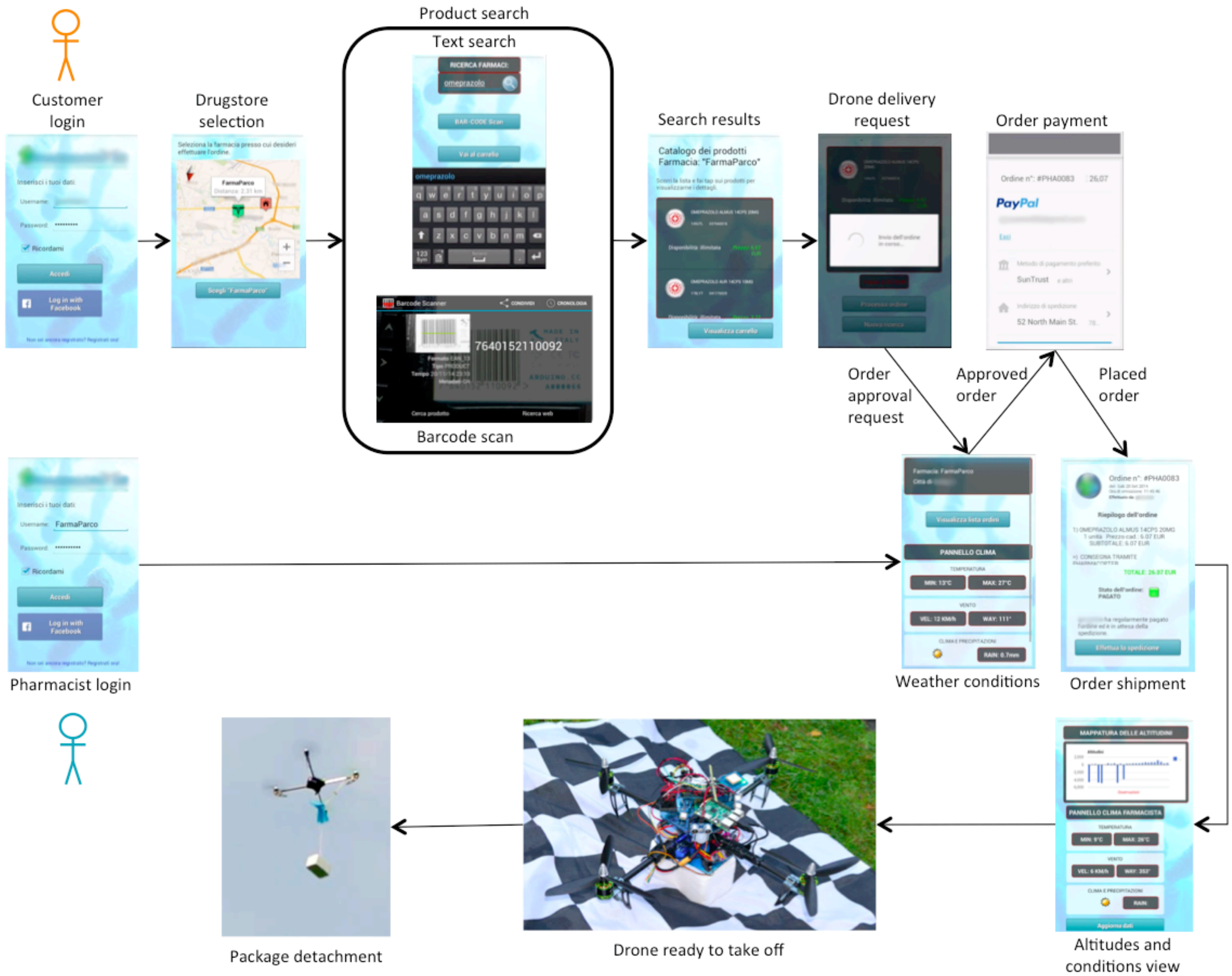

Fig. 5. Screenshots of the application related to (customer) login, drugstore selection, product search, order request and payment, as well as (pharmacist) login, order process, weather and altitudes check and shipment.

message is sent to the [removed for blind review] server and the order is placed.

During the whole process, notifications to customers are managed by means of the Google Cloud Messaging service[5].

B. Pharmacists

Pharmacists, once launched the Android application on theirs smartphones/tablets, could log in using their credentials.

Once the notification of a waiting order to approve is received, the pharmacist could verify if the distance from customer's home is below a given value (for considerations reported in Section 4C), by checking customer's coordinates on the map. Then, he/she could analyze weather conditions. To this purpose, the World Weather Online API[6] has been exploited. This service receives both drugstore's and customer's coordinates and returns a JSON containing weather conditions that are displayed on pharmacist's smartphone/tablet's screen.

Should weather conditions be acceptable and the drone available, the pharmacist could accept the order and wait for customer payment.

Once the payment has been done, the application computes the path between the drugstore and customer's house. To this purpose, the Google Elevation API[7] has been used. This service communicates elevation measurements for each location on the path. Such data are then processed in order to determine the height the drone should fly (by finding the maximum value and incrementing it by few meters), and shown to user by means of the Google Charts tool[8].

Then, the pharmacist could pack the required drug and load the drone. Computed coordinates and altimetry are sent

[5] https://developer.android.com/google/gcm
[6] http://www.worldweatheronline.com/api/local-city-town-weather-api.aspx
[7] https://developers.google.com/maps/documentation/elevation
[8] https://developers.google.com/chart

to the quadcopter by means of the Ground Control Station (GCS) Copter-GCS[9]. In parallel, coordinates for package detachment are retrieved by the Arduino Uno microcontroller through the Cooking Hacks 3G connection.

Similarly to what has been done for the customer, the Google Cloud Messaging service is used in order to send notifications to pharmacist's smartphones/tablets.

Moreover, pharmacists could receive information on products and their availability (e.g., to check the stock when they are outside the drugstore), by performing a text-based search or scanning products' barcodes.

Fig. 5 reports several screenshots of the Android application. In particular, the steps performed to search for a product (customer's login, drugstore selection and free text search/barcode-based search), place an order (drone delivery request and order payment) and ship it (order shipment details, altitudes and weather conditions view) are shown. In addition, an 8-minutes video presenting a demo of the system is available at the following link [removed for blind review].

VII. Conclusions

In this paper, a prototype system for a drone-based delivery service has been presented.

The design of the proposed system has first been discussed from the hardware point of view. Then, the software framework developed to place and manage orders has been presented. Particular attention has been paid to issues related to autonomous deliveries and to possible solutions that could be adopted in order to prevent potential risks that could arise in this particular application context. The system has been targeted to drug deliveries, due to the fact that medications could be required more urgently than other goods, and could be small and lightweight enough to be delivered by a drone. Nevertheless, it is worth remaking that the designed system could be possibly adapted to be used in a number of different scenarios.

Whether or not systems like the presented one will be largely adopted in the future is a debated question. Some people claim that imagining a future in which drones will carry out all the deliveries is unrealistic [22]. At the same time, initiatives promoted by Amazon [1], Google [2] and DHL [3] showed that drone-based deliveries could soon become a reality, also considered the moderate delivery costs [16].

Apart from debates, primary threats would be linked to legal regulations, which should be modified in order to allow the autonomous flight of UAVs. Moreover, should the drone-based delivery become feasible from a legal point of view, developed solutions should pay particular attention to people security (e.g., by avoiding collisions among flying drones, package drops, etc.) as well as to drone security (for example, by avoiding that spiteful people take possess of the drone at distance). Other issues that could possibly arise are linked to privacy, since drones could be reasonably equipped with cameras able to record subjects in streets or inside their homes.

Final aspects to be considered are related to the weight of products to be shipped (that should be lifted up by the drone), the flight autonomy provided by the battery, and to the possibility to combine deliveries (e.g. by modifying the hardware architecture in order to let the drone deliver more packages to different customers, during a single flight).

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