GliderAgent—a proposal for an agent-based glider pilot support system

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***Abstract*—This paper introduces the *GliderAgent*—a multi-agent system supporting glider pilot in various navigation and pilotage scenarios. After presenting the rationale behind the agent-based approach, basic tenets of the proposed system are briefly discussed and semi-formalized in the form of a UML Use Case diagram. Two key functionalities of the *GliderAgent*—resource management and communication are also discussed.**

***Index Terms*—gliding; multi-agent system; wireless sensor networks; decision support, query routing trees**

I. BACKGROUND AND MOTIVATION

Nowadays, the use of computers is prevalent in commercial airplanes, within airline companies and in air traffic control. However, in general aviation and especially in gliding (flying sailplanes/gliders), the use of computing devices is very limited. There are multiple reasons for this lack of acceptance, some of them being conservatism among pilots, and belief that gliding requires special skills that have nothing to do with modern technology. However, recently there is a great interest in adopting computing devices to assist gliding.

Systems like the XCsoar [1] and the WinPilot [2], which resemble the GPS navigation used in automobiles, provide: (i) display of airspace areas, (ii) altitude required to complete a task, (iii) thermal profile of the area where the glider is located, (iv) depiction of a final glide through the terrain and around multiple waypoints, etc. Furthermore, there exist special devices, called *loggers*, which are primarily used in various flight contests and serve as electronic archives of waypoints flown by. In these contests, only loggers approved by the Fédération Aéronautique Internationale ([3]) can be used to prove pilot's claim of an achievement (the FAI Record Claim). While some loggers use only the GPS positioning (simple Position Recorders), others have incorporated more advanced technologies (e.g., the International Gliding Commission Approved, Flight Recorder); for more information, see [4].

Since we have observed that loggers are used primarily in competitive flying, let us now enumerate different types of glider flights:

1) *Training flights*, which can be divided into:
    a) *Flights with an instructor*—most of which are early-training flights where a student pilot gains basic skills (e.g., how to start, to land, etc).
    b) *Solo flights*—were the flight is conducted by a student alone. Here, an instructor located on the ground communicates with the student-pilot to correct the pilotage technique, advises or warns about possible mistakes/dangers. In order to ensure safety, solo training flights are typically conducted above an airfield, or in a close proximity to one. Here, "safety" translates to a distance of 20km or less from an airfield. However, "safety" depends also on other conditions like the flight height and/or the weather.
2) *Recreational flying*—requires higher navigational skills of the pilot, because of longer distances from the start airfield (more than 10-20km). Recreational flying is very often conducted over areas that the pilot is not familiar with. Here, we can distinguish the following sub-categories:
    a) *Cross-country flying*—this is the easiest and safest type of flying, if it is conducted over plains. In this case, thermal soaring demands awareness of other gliders, if not flying alone in one lift.
    b) *Ridge flying*—demands high skills because of flying in a close distance to slopes of hills and mountains. Due to the characteristics of the terrain, there could be a variation of lifts and sinks encountered by a glider, which can be very dangerous. If there are more gliders in the same area, their pilots

should be aware of positions of other aircrafts. In this case, sharing information amongst pilots (e.g., encountered aircrafts, weather conditions) can be highly beneficial both with regards to safety and to flight pleasure.

    c) *Lee-wave flying*—lee-wave is a fascinating phenomenon that helps pilots to gain several kilometers of heights and make flights hundreds of kilometers long. This is mostly observed in mountainous areas and thus requires approximately the same advanced skills as in the case of ridge flying. However, since in the mountains the nature of the wave features very violent conditions (e.g., increased air-speed, solid clouds), additional experience of the pilot is necessary. Particularly, in the case of solid clouds, where ad hoc clouds can develop rapidly and hinder the glider descend. Here, even the use of a GPS system may not provide the needed assistance.

3) *Sport / competitive flying*—concerns achieving sport results in accordance to the FAI or local rules and procedures (necessary for formal recognition of the sport achievement). It can involve any of the aforementioned types of flying. Here, the logging capability is of extreme importance, to validate the achievement claim. Among sport flying events, we can distinguish:
    a) *Sport badges and diplomas*—for example the FAI's silver, gold badges, diamonds and diplomas are achieved through completion of soaring performances of specific distance, duration and height.
    b) *Localized competitions* (Grand-Prix, Championship, etc.)—pilots meet together and fly tasks, starting from the same location.
    c) *On-line contests*—pilots conduct flights alone, within their clubs, and then send flight documentation to the contest organizer, in order to validate the results and generate scores.
    d) *Record flights*—pilots reach national or world records, validated by the National Authority and/or the FAI.

Let us now consider computer systems used in support of glider flying, but placed outside of actual gliders. There exist efforts to create a general anti-collision system, similar to the one used in commercial aviation (i.e., the Traffic Collision Avoidance System (TCAS) [5]). Here, for instance, the FLARM system [6] has been deployed primarily in German-speaking countries of Europe, Scandinavia, as well as in Australia and New Zealand. FLARM is based on communication between planes equipped with devices designed to warn about a risk of a collision. Unfortunately, such systems have the following drawbacks: (a) very high specialization—suitable for use *only* for collision avoidance, (b) low bandwidth transmission channel—limiting the amount of information that can be transmitted and preventing extension of functionality beyond the crash avoidance, (c) very short range—making it unsuitable for avoiding collisions in the case of fast moving planes.

Recently, there is an increasing interest in implementing services, usually referred to as *on-line tracking*, which visualize in real-time the positions of gliders during various flight contests. The goal of such systems is to make gliding (as a sport discipline) more audience-friendly—letting the audience "feel the competition" and presenting intermediate (temporary) scores (obviously, keeping those away from the pilots participating in the competition). We can differentiate these systems according to the transmission medium they utilize:

1) GSM/SMS data transmission—e.g., the vPtracker [7], developed for the Club Class World Gliding Championship held in Elverum, Norway in 2004, and later commercialized;
2) GSM/GPRS data transmission—e.g., the LX GPS trackers, adopted from the vehicles [8];
3) satellite data transmission—e.g., the Yellowbrick [9], used last during the World Grand Prix Gliding Final in Santiago, Chile, in 2009;
4) APRS—mostly utilized by the OpenTracker [10] and the TinyTrak3 [11] solutions—based on the Amateur Radio functionalities.

Analyzing these approaches, reveals the following facts. Firstly, all GSM-based solutions (1,2) experience problems with transmitting data even when flying on low altitudes. This is because, the GSM/UMTS operators fix the BTS (Base Transceiver Station) antennas to disperse the signal across the serviced *ground* area, and are not interested in sending/receiving to/from the airspace "above." Thus, the GSM-based solutions are (i) highly dependent on the GSM range height, (ii) feature many disconnections, and (iii) real-time position data is not continuously available (typically data are transmitted in intervals of several minutes, which limits their usability). The main drawbacks of the satellite-based systems (3) are cost and power consumption. For example, the Yellowbrick system uses the Iridium satellites which are 780km away, and in-flight devices can be rented only for a specified time-frame. Here, the cost and battery life depend on the frequency of data transmission [12]. Finally, the main drawbacks of the APRS-based approaches (4) are: low or no infrastructure, low bandwidth, and an early-deployment phase.

Our analysis shows that all these approaches are designed to deliver only a specific (single) on-line tracking service, rather than an infrastructure that could support (a) glider pilot, (b) ground station, (c) flight instructor, (d) ground-towing rescue team, or (e) competition audience. Furthermore, since they typically have very low (or costly) communication bandwidth, the very idea of adding meta-level services to either one of them does not seem feasible.

Before proceeding further, let us now report two recent events that involve gliding. First, recently, in the mountainous area of northern Czech Republic, a glider crash happened. More specifically, a pilot that was circling around a mountain, crashed on a mountain slope. Fortunately, he only suffered minor injuries and was able to get out of the glider easily. After a short period, the pilot met up with a person passing-by

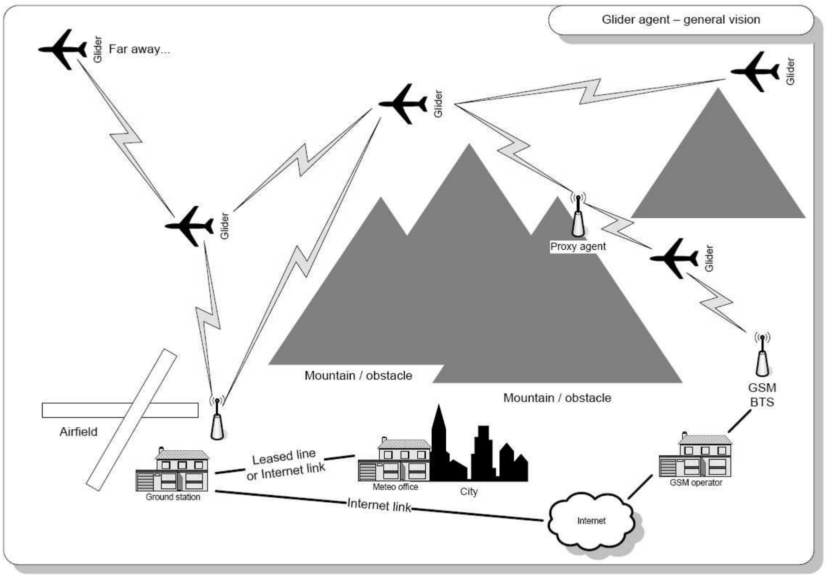

Fig. 1. GliderAgent—a general vision

and together they informed (via a cell phone) the appropriate authorities of the situation. A brief analysis of this event indicates that it would be extremely useful to have an on-board system installed on glider, monitoring flight information. The system should be able to continuously assess flight data and decide on the appropriate course of action (e.g., discover the safest route for returning to the airfield, or suggesting an alternate landing location if a safe return to the airfield was established to be impossible). In the aforementioned scenario, the system would automatically send a crash warning to the ground station, followed by continuous transmission of position data for as long as possible (hopefully it would be able to transmit position data also after the crash).

Second, in 2008, the Czech Republic has allowed starting and landing of aircrafts outside of marked airfields and landing sites. As soon as specific (and not extremely hard to fulfill) conditions are met, it will be possible to start/land from/at any location across the country. It seems that with starting and landing of small non-commercial aircrafts from locations without any flight-support infrastructure, it becomes even more important to provide additional support for the pilots. This allows us to note that, while the ideas presented in this paper focus on glider pilots and glider flying, the proposed infrastructure can also be applicable to any other small non-commercial aircrafts (e.g., moto-gliders, GA airplanes, Ultra-Light airplanes, etc).

The idea of the *GliderAgent* system is motivated by the presented needs and shortcomings of the existing gliding support infrastructure. Note that, due to the lack of space, we are not able to present the complete list of the system's features needed to deal with peculiarities of each type of flight/scenario. Furthermore, we expect that additional features will emerge upon in-depth analysis of each one of them.

The *GliderAgent* is conceptualized as an agent-based decision support system: (a) helping a pilot in navigation and pilotage, (b) delivering additional flight information, (c) providing support in emergency situations, and (d) facilitating communication, monitoring, logging of events, etc. It is *not* designed to replace existing systems (e.g., the XCsoar or the WinPilot), but to integrate with them. However, it should be able to combine some functionalities which are now run in separate applications. Furthermore, the *GliderAgent* could become a common platform for implementing services, existing and not yet known.

II. *GliderAgent*—A SHORT INTRODUCTION

Let us now outline the main ideas behind the *GliderAgent* system. Before proceeding, let us briefly note that we consider use of modern PDAs and smart-phones as a platform for the *GliderAgent*. This is because modern PDAs typically provide several options for transmission (e.g., GPRS, UMTS) as well as advanced technology features (e.g., GPS receiver, sensors). Observe that the use of Java in the proposed system is possible since this is a decision-support system and is not expected to be used as a real-time system with strict time constraints. With this in mind, let us start with a birds-eye view of the proposed functionalities of the system, placed within the gliding environment; illustrated in Figure 1.

It is assumed that every glider is equipped with a *GliderAgent* instance (an agent or a set of cooperating agents; depending on the needed configuration). One of the core functionalities of the *GliderAgent* is to provide communication between gliders. To achieve this goal, gliders form an adhoc network, with *GliderAgent*s acting as relays of information between distant gliders or between gliders and ground stations (see, also Section IV-B). In the mountain areas, which present some of the most exciting locations for glider flying (see *ridge flying*, above), it would be possible to install (in selected locations) fixed *proxy-agents* to facilitate communication between

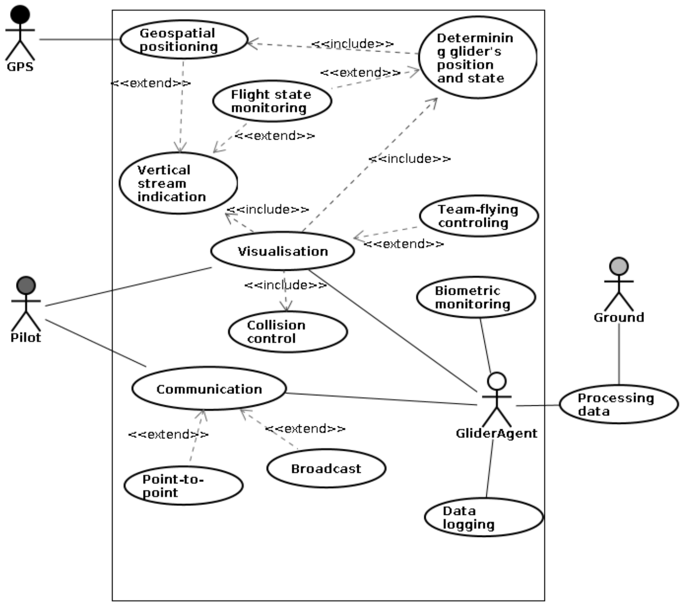

Fig. 2. Use Case of the GliderAgent

ground station(s) and gliders using the ridge-lift scenario, thus increasing the overall gliding safety. Of course, *GliderAgent*s could also use some common infrastructure, like the GSM/UMTS data transmission (if in a range of such signal) to facilitate communication. During training flights, both *with the instructor* and *solo*, the *GliderAgent* would help the instructor to correct errors made by the student pilot, warn about possible dangers, provide aid with in-flight analysis, etc. In every flight type, the ground station plays an important role in the system, by transmitting information (e.g., the weather forecast) to all gliders in the area. Such information would be received by the *GliderAgent*s and utilized in the decision support process. Separately, in the *competitive flying* scenarios, possibility to track the gliders is of great value. Obviously, the *GliderAgent* infrastructure would be capable of supporting such activity. As seen in Section I, glider flying involves situations, where landing in a field is necessary. In these cases the *GliderAgent* would suggest a designated field. Furthermore, by delivering geographic coordinates to the appropriate authority (organizer of the competition, or the Chief Flying Instructor in the club), the system will aid finding the pilot and the glider. Note also that sometimes pilots have no idea where they landed. Operating in a pro-active manner, the *GliderAgent* would automatically start sending information to the ground station when the glider height would be recognized as being less than required to reach the nearest airfield (considering the glider's glide ratio). Consequently, this would speed-up any search and recovery efforts.

In the context of the above considerations, one important fact has to be stressed. Information delivered by the *GliderAgent* infrastructure can *only* support the pilot. The final recognition of the situation and the decision is, and will always be, the responsibility of the pilot, the commander of the aircraft.

III. GLIDERAGENT—USE CASE

Let us now follow the general narrative concerning the proposed system with its initial semi-formalization. In Figure 2, we present the Use Case diagram of the *GliderAgent* system.

The Use Case diagram presents three entities which are located outside of the system: the *GPS* (system), the *Pilot* and the *Ground*. These entities interact with the system by either providing information (*GPS*), or sending and receiving information (*Pilot*, *Ground*). The main actor of the system is the *GliderAgent*, which is involved in five functions: *Visualization*, *Biometric monitoring*, *Data logging*, *Communication*, and *Data processing*. Here, the *Biometric monitoring* function involves dealing with all data that can be collected from the sensors that monitor the vital signs of the *Pilot*. Here, we have to admit that this part of the system is somewhat futuristic. However, utilization of such sensors could be of particular value in the case of *Lee-wave flying*, when pilots reach altitudes where oxygen deprivation is possible. Furthermore, nowadays there exist a number of body sensors, used by recreational runners and/or cyclists, that can be incorporated into the *GliderAgent*. As specified above, the *Processing data* function that connects the *Ground* to the *GliderAgent* involves dealing, for instance, with weather forecasts, or data concerning the airspace plan. On the other hand, this involves, sending information related to the emergency situations (described above). Obviously, the *Data logging* function is concerns all forms of *Sport / competitive flying*.

In the Use Case we distinguish two forms of *Communication*. The first of them is *Point-to-point* and is realized when one *GliderAgent* instance communicates with another. At the same time, it is possible to *Broadcast* messages. This will take place, for instance, when the *GliderAgent* is searching for information about flight conditions in other regions—by broadcasting the query to all other reachable *GliderAgent*s. Such request for information may be then forwarded by the recipients of the initial message to other *GliderAgents*, which are not reachable directly from the sender. In this way the information about the situation behind an obstacle can be discovered (see, Figure 1).

Let us now consider the *Visualization* function. It plays the key role in the *GliderAgent* interaction with the *Pilot*. First, the *Visualization* is realized in the context of the *Team-flying control* function. It checks team membership and helps to highlight team-member gliders among those displayed to the *Pilot*. Next, we can see the *Collision control* function, which is responsible for helping the *Pilot* to avoid collisions with other aircrafts. To be able to fulfill this (and other) goals, the *Determining glider position and state* function is used. Finally, the *Vertical stream indication* is also a part of the *Visualization*, and is responsible for specifying the air streams activity around the glider. These two latter functions (*Determining glider's position and state* and *Vertical stream indication*) are a part of an extended function *Flight state monitoring*.

Finally, let us look into the role of the *GPS*. It is to provide geo-location data for the *Geospatial positioning* function. This information stream consists of: latitude, longitude, and altitude (used for the three-dimensional location). The *Geospatial positioning* is a part of the *Determining glider position and state* function. Furthermore, it can be also used in the *Vertical stream indication*, to establish locations of various air stream activities taking place around the glider. Note that the system is designed in an open manner which supports ease of incorporating additional devices that can provide additional useful information (i.e., in a similar way that the *GPS* is now placed). Furthermore, use of Java, which was originally designed to run ubiquitously across multiple devices, to implement the system, further supports such extensions.

IV. COMMUNICATING AND MANAGING RESOURCES

We have selected two predominant functions of the *GliderAgent* system to discuss further. These are the *communication* and the *resource management*. Our choice is based on further reflection on the material presented thus far. It is easy to see that communication is one of the most important functions of any glider pilot support system. Let us simply recall that communication is crucial for: (i) collision avoidance, (ii) tracking of gliders that had to crash land, (iii) visualization of competitions, and (iv) pilot training, etc. However, it is easy to notice that communication (both data receiving, and even more so, messages sending) involves consumption of electric power. Therefore, ability to communicate depends on availability of energy, which has to be properly managed.

A. Resource management

Let us thus start with the description of issues involved in resource management in the *GliderAgent* system. Before proceeding let us note that resource management is one of the features of the system that supports our decision of using software agents. According to a typical definition, a software agent is expected to be aware of the environment in which it resides, as well as the context in which it finds itself [13]. Therefore, resource management appears to be an natural task for a software agent.

Typically, gliders are equipped with a 12V, 7.4Ah battery [14]. A PDA or a smart-phone, which is where the *GliderAgent* infrastructure is to reside, consume on average about 0.35A. Furthermore, there are also other energy-consuming devices on board (e.g., radio station, variometer, external GPS, logger, voltage converter, transponder, etc.). Thus it can be assumed that the total on-board power consumption in the glider is of the order of 1A. Furthermore, in glider flying, one has to take into account the outside temperature, which has a direct affect on the battery capacity. Here, the average temperature gradient is 0.65°C/100m. Therefore, the actual battery capacity may be significantly smaller than rated (fresh new battery). Taking into account the context awareness factor, the *GliderAgent* on-board can use the information about the ground temperature at the starting point, the temperature gradient, the altitude, and the information concerning the characteristics of the battery, in order to estimate the remaining available power. This will allow the *GliderAgent* to manage other functions by adapting communication patterns thus balancing the needs related with the estimated level of utilization of the battery.

Another example of power awareness could be the case an emergency situation. Following the above description, let us assume that the *GliderAgent* establishes that the glider will not be able to land in any potential location (an airfield, or a designated field). In this case, the context of an emergency "takes over" and the *GliderAgent* performs the following actions: (i) informs the ground that crash is imminent, and (ii) continues transmitting the position of the glider. Obviously, in this situation battery usage is of minimal importance in comparison with the need to help assuring pilot safety (i.e., fast search and rescue).

Finally, observe that an agent can utilize a number of different technologies to communicate with other agents (in other gliders, or in the ground station); e.g.: GSM, UMTS, RF radio link, WiMAX, X-Bee, etc. The choice for the most optimal communication technology is going to depend on the location in the space and above the land, as well as the estimated power consumption connected with a specific communication technology. For example, within the range of the BTSes of a GSM operator, agents can communicate with the ground station via the GPRS / UMTS service. However communication using this technology may not be possible (they may not be in the range of the GSM transceiver) and thus the *GliderAgent* will have to decide how important is the communication vs. the available energy resources (in some circumstances it may need to ask the pilot for the decision). These considerations naturally lead us to the discussion of selected aspects of communication within the *GliderAgent* system.

B. *Communication in the system*

While we have already listed a large number of situations in which communication is desirable, or even necessary, we need to take into account also the limitations of the available resources. In the previous section we have considered the fact that typically, a glider has enough resources for no more than a 7 hour flight (brand new battery, and a minimal effect of the temperature). However, here, we have to take into account also the limited bandwidth and the price-performance ratio between signal strength and energy expenditure.

To address this complex situation, we have decided to pursue a very promising solution, which comes from the area of Wireless Sensing Networks (WSN). More specifically, after an initial research, we have decided to explore possibilities brought about by utilization of the Query Routing Tree (QRT) approach. The Query Routing Trees [15], [16] have been predominantly used in WSNs to facilitate query dissemination and propagation of results amongst sensor devices (SDs). Furthermore, they have been also explored in areas such as the People-centric Sensing [17] and Vehicular Ad-hoc NETworks (VANETs) [18]. Taking into account characteristics of gliding, it is those two WSN application areas that seem particularly close to our perceived needs. Observe that quite often, SDs facilitate a limited wireless communication range thus requiring multihop communication in order to transmit a message to their distant neighbors or to the base station. This multihop communication is facilitated on the premise of a query routing tree which is constructed in the following recursive manner. Assume that a sensor $s_x : 1 \leq x \leq n$ wants to send a query $Q =$ “$Get\ GPS\ positions\ of\ all\ sensors$”. The s_x starts by broadcasting the query Q to its neighbor sensors $s_i : 1 \leq i \leq m$, where $m \leq n$. Subsequently, if $m < n$, all sensors s_i (neighboring s_x), recursively forward Q, until all n sensors have received the query. Each sensor receiving Q selects as its parent the first node from which the query Q was received. Setting a parent node implies that as soon each sensor $s_i : i \neq x$ acquires its local results on Q it will forward these results (only) to its parent. Using this sensor-parent node setting, a query routing tree rooted at s_x is autonomously formed.

Obviously, such QRT-based approach can be applied in the *GliderAgent*system. Since glider radios have a limited range they also require multihop communication to communicate with “remote” gliders, or with the ground station. Note, however, the difference between the QRT algorithm, and the glider scenario. In multiple cases, there is no need to contact all reachable gliders (found in all directions). Instead, it is enough to reach gliders that are “far enough” (in a certain direction) to be able to obtain a response to a specific query. However, the situation may also be more complex, when *Ridge flying* is concerned. Here, it may not be immediately clear in which way to reach agents located behind a mountain. This means that we will have to modify the QRT algorithm to adapt it to the requirements of our system.

V. CONCLUDING REMARKS

The aim of this paper was to propose an agent-based decision support system for glider pilots. We have started with a general discussion of various forms of gliding and motivation for the need of a system like the proposed one (the *GliderAgent*). Next, we have presented a top level overview of the proposed system and its semi-formalization in the form of the UML Use Case diagram. Next, we provided a brief discussion of two key interrelated functionalities, the *resource management* and the *communication*. In the latter case we have argued that the Query Routing Tree based approach, which originates from the area of Wireless Sensing Networks, can be naturally applied to the glider scenario, and is capable of supporting the requirements of our system. In the next phase of our work, we will focus our attention on the communication aspects of our system and proceed to adapt the Query Routing Tree algorithm to the needs of the *GliderAgent* system.

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