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Simplicity of a navigational path. What does that actually mean?

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Abstract

The understanding and interpretation of simplicty in the context of a navigational path can be ambiguous. Different approaches to path planning are briefly juxtaposed, focusing on their simplicity-based distinctive features. This takes into consideration the response to drift caused by air or water currents and the geometric background. Special attention is paid to the straight-line-based solutions which are preferred by the human convenience and perception, recalling some well-known applications in navigation and including their (dis)advantages. In particular, this refers to the Euclidean simplicity applied at the cost of effectiveness in the standard search and rescue (SAR) patterns in the presence of relatively stronger position-dependent currents.

1. Introduction and motivation

One can read in the International Aeronautical and Maritime Search and Rescue (IAMSAR) Manual that the recommended search patterns applied in the search and rescue (SAR) operations at sea or over land have been selected 'for simplicity and effectiveness' (IMO and ICAO, 2022). An up to date copy of Volume III 'Mobile facilities' of the manual is required to be carried onboard the vessels worldwide; see Convention SOLAS (Chapter V 'Safety of navigation') in this regard (IMO, 2020). Each edition of the manual is published jointly by the International Civil Aviation Organization and the International Maritime Organization. The standard patterns are, for instance, an expanding square, a sector search, a parallel track or a creeping line search. Geometrically, all of them are based on the straight-line segments in their construction. One may also have the impression that the section dedicated to the search patterns is just copied and pasted in the subsequent editions of the IAMSAR Manual (published every three years), since there are no essential improvements or updates added in this respect. It is clear that in emergency situations like SAR operations, time matters significantly and it must be minimised. Winds or water currents, which cannot be disregarded, may act intensively and continuously during a search conducted at sea or in the air. Furthermore, it is known from the literature that a time-minimal passage between two positions in the presence of currents is represented in general by non-trivial curves, and not by straight-line segments, roughly speaking; see, e.g. Bijlsma (2010) and Techy and Woolsey (2009). However, the navigators (the operators, navigational software developers, common users) as human-beings usually prefer straight paths because of their simplicity and the human perception related thereto. This often causes a kind of silent acceptance of their common losses or disadvantages. For example, we can mention longer time travelled along them as compared to more efficient solutions that are not so obvious as the common straight lines, or negligence of the inherent gains of the latter ones.

2. A variety of understandings of simplicity

Having in mind the notion of simplicity referring to the selection of the search patterns in the official recommendations (IMO and ICAO, 2022), we ask increasingly more generally what simplicity actually means in the context of a navigational path used in route planning and monitoring in an open space without obstacles. Let us pay some attention to the general navigational task that is to plan a passage from one position to another in the presence of currents (water or air), taking simplicity or/and related effectiveness of the corresponding solution (e.g. a trajectory, a steering control or a strategy) as a criterion. For the sake of clarity, we assume that the currents are weak, so the solution always exists. In other words, a craft is able to arrive at a given point of destination. It is worth noting that the potential solution can in fact have different understandings and be open to interpretation, assuming that all the craft's safety criteria are fulfilled in each below case. Among some well-known approaches, this can stand for

(a) a rhumb line (loxodromic) navigation, i.e. keeping a steady course over ground during the passage between the waypoints and following the pre-planned track as it is plotted on a navigational chart; a drift effect is compensated during the passage continuously (active sailing), however, roughly speaking, it is not taken into account or can be neglected in path planning, since the intended track depends only on the background geometry;
(b) a single-heading navigation, i.e. keeping a steady course (heading) on a steering compass, irrespective of the drift that occurs en route due to action of wind or current; a drift effect is not compensated during the passage (passive sailing); however, it is taken into consideration a priori (known or predicted approximately) when setting the initial course, since it also depends on a distribution of currents;
(c) a goal-oriented strategy, i.e. keeping a heading towards a desired point of destination continuously; a drift effect is compensated analogously as in case (a); in particular, followed by some animals (swimmers and flyers) in cross currents (Chapman et al., 2015);
(d) a geodesic navigation (including the great circle and great ellipse paths), i.e. following the shortest (in the sense of distance travelled) path between the waypoints; a drift effect is compensated during the passage like in case (a);
(e) a time-minimal (as known as Zermelo) navigation, i.e. following the shortest (in terms of time) path, taking a priori the influence of perturbing air and water currents into account ably; as in case (b), a drift effect is not compensated during the passage; similarly, it can be considered an energy-minimal path including a battery or fuel consumption or, more generally, a certain cost (risk) optimisation;
(f) a preferred navigational path or strategy that focuses on a human operator's or user's convenience, or innate abilities of migrating animals (swimmers and flyers), some other straightforward procedures or preferences, e.g. following the straight legs, ease of orientation (positioning), designated routing or behaviour.

Since locally a navigable area can be modelled as the common plane, the above approaches can then coincide if the sea/air is calm, i.e. there is no drift effect coming from the action of wind or current. This implies an optimal passage which follows the common straight line, desired subconsciously by a human perception. All the above kinds of interpretations can be achieved in this particular case. However, such a scenario rarely occurs in reality, to be precise. In general, the path corresponding to each aforementioned case differs from others and it is quite sophisticated, i.e. curvilinear when the drift effect cannot be omitted. As a consequence, the straight-line segments of a route are no longer optimal in various senses, and so the related efficiency is reduced. Then our human convenience and practical routine are somehow disturbed.

3. Straight-line-based simplicity versus effectiveness

In the case of a necessary time reduction, while navigating in the presence of relatively stronger currents, the straight paths may not state the effective solutions. The reader can easily find, for example, the plotted tracks of the successful passages across the Strait of Dover by swimming or rowing on the web; see, e.g. Stuart (2011). Such challenging tasks under the action of the varying tidal streams cause the energy- or time-minimal routes with respect to the fixed bottom to look more like a sine wave. In general, the least time paths being the solutions to the Zermelo navigation problem are non-trivial in their behaviour Zermelo (1931); Bijlsma (2009); Techy and Woolsey (2009). Although they can be much longer in distance than a common straight-line (geodesic) segment that connects the opposite banks of the English Channel, the time of passage along them is substantially shorter. Analogously, this remark also refers directly to the traditional search patterns (based only on straight, parallel, equally spaced tracks) applied to SAR operations at sea, over land or in the air mentioned at the beginning of this paper. The drift effect is often routinely neglected in this regard, for example, in the modern software in the Electronic Chart Display and Information Systems (ECDIS) (Norris, 2010) installed onboard the vessels and in the professional navigational simulators. Additionally, this is more significant when the drift becomes relatively stronger. Moreover, a typical 'over ground' approach referred only to the straight legs of the pre-planned route, irrespective of the drift effect, is followed by the vast majority of students of marine navigation as well as the practitioners (mates) in particular during the simulations of search operations. It can also be observed that the standard search patterns based on the Euclidean segments are not optimal (i.e. providing a global time reduction together with a full coverage of a search area) any more in cases when a current depends on position or, more generally, when drifts of a searching craft and a searched object differ from each other; see, e.g. Serra et al. (2020), Xiong et al. (2020), Ai et al. (2021) and Kopacz (2017) in this regard.

It is natural, overall, that we aim at simplifying a complicated problem so that some easy outcome, e.g. the straight-line segments will appear in the developed solution in the end. The way (method) that leads to such a coveted result may be very complex, based on some advanced mathematical tools. However, the inherent geometric simplicity and effectiveness of the straight lines may not go together as noted above. It is therefore necessary to focus more on one of them at the cost of the other, depending on the criteria adopted to the concrete application or context. Moreover, there may not be any balance between simplicity and effectiveness, since the priorities which refer to the safety aspects including path planning in the SAR operations cannot be compromised.

4. Noting Euclidean simplicity in navigational path planning

To stay in a comfort zone that refers to simplicity based only on the common Euclidean (rectified) segments locally, one can decide to follow the route applying only the convenient strategy, e.g. a constant course with respect to a fixed ground between the waypoints to base the navigation on precise navigational systems and devices, or a constant true course to have the same indication on the compass display. Even the preferable option costs by losing the benefits coming from an alternative solution for, for example, shortening the time of passage, a navigator quite often decides for the former because of the preferable convenience or simplicity of a chosen navigational strategy. Of course, when it is necessary to consider the area globally for navigation, the curvature of the Earth must be taken into account. Consequently, the common straight lines on the plane are not in use any more. However, it is sometimes still possible to satisfy the need for simplicity to our liking by some tricks (or rather smart concepts based on solid mathematical foundations), and to deceive our senses in such a way. For instance, it is worth recalling here the commonly used conformal Mercator projection in navigation. Namely, a ship sails in fact along a non-trivial curve plotted on a non-planar surface of the Earth, i.e. a rhumb line, however, a navigator can see and follow just a straight line on a navigational chart constructed in this special cartographic projection. Although this path of constant bearing is efficient in the meaning of neither distance nor time travelled, it was and it is still widely used in navigation. Moreover, a great circle arc used to be approximated by several straight (loxodromic) segments on the chart as high-accuracy navigational methods and positioning systems were not available. Furthermore, proceeding along a geodesic path can be presented as a straight line again on another navigational chart in a gnomonic projection.

Regarding the aforementioned search patterns, if a current is constant or even variable, namely, time-dependent but not position-dependent, then the straight-line-based standard search patterns as per the IAMSAR Manual are still efficient, i.e. time-optimal, and ensure a complete coverage of a search area (roughly speaking). In such cases, the strategy is to apply the patterns with respect to the flowing water (or air), and not the fixed ground, since the corresponding tracks over ground are represented by the various curvy segments that depend on the variable direction and speed of currents. Thus, it is possible that the straight paths being dressed in other clothes get back in the game again. Well, one can say that we prefer, we like and we want the straight lines to accompany us in navigation here and there because of their versatile simplicity, fitting well to the human perception and convenience.

5. A glimpse into the near or distant future

The traditional human strategies are being refined by the development of artificial intelligence methods; see, e.g., Szłapczyńska and Szłapczyński (2019). However, some sophisticated novel software includes the solutions based on natural long-standing animal skills which people attempt continuously to understand more clearly and apply in navigation to improve the existing and emerging methods. The recorded tracks of the migrating swimmers and flyers including their responses to wind and water currents during travel are often compared to the approaches listed in the preceding section. The animal movement strategies in flows (considered usually on the Euclidean plane) which refer to the natural needs of feeding, breeding or survival have often been open problems and of research interest for a long time; for more details, see, e.g. Chapman et al. (2011) and McLaren et al. (2014).

Nowadays, the development of new technology including the applied artificial intelligence, optimisation algorithms in the modern navigational devices and autonomous ships (robotic sailing), e.g. unmanned aerial vehicles (UAVs) and maritime autonomous surface ship (MASS), can often offer increasingly more efficient passage planning. Although one should not neglect the values of traditional good seamanship, it is worth noting that simplicity in the sense of a machine can be far from our human understanding, perception and look-out to which we have gotten used to in practice for years. Furthermore, if the former guarantees more efficient solutions for the most serious tasks like SAR and other fields of navigation, fulfilling all necessary safety criteria at the same time, why not admit them in solving some challenging tasks of great importance, although they may look complicated or 'exotic' from our human perspective? In particular, there is a need for improving the standard search patterns in the presence of relatively stronger position-dependent currents which cause drift effects so that the applied models become more efficient in SAR operations as well as creating all-new solutions with the use of innovative technology that can be available onboard, e.g. the flightworthy and fast autonomous searching drones.

To conclude, we can expect that there are increasingly more common notions ahead of us to be redefined or re-evaluated considerably and shortly, where the human–machine interplay will occur onboard, or the former will have to be interlinked with or relieved by the latter completely. Among others, these include the notions of voyaging, good seamanship, human/machine factor, safety margin, restricted visibility, sharp look-out as well as the watchkeeping abilities like resourcefulness, resilience, comprehension, perception and processing. Meanwhile, it looks like a reasonable combination and choosing suitable kinds of simplicity (conceptual, computational) in the sense of both the human and the machine are inescapable in the forthcoming aspects of navigation.

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