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SYSTEMS TO DETERMINE GEOGRAPHIC POSITIONS WITHOUT USING GPS : FROM THE LABORATORY TO THE GENERAL PUBLIC

by

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Overview

Technologies to determine geographic position using external signals (such as the Global Positioning System or the Global System for Mobile communication) are limited by the absence of indoor signals, errors made in built-up areas, and the lack of availability of a signal. A small group of experts from the Ministry of Defence and the Mines-ParisTech Engineering School has developed a technology which uses variations in the magnetic field. In 2008, they created their own company in order to market applications designed for use by the general public, for example, a navigation system whereby a drone can be piloted from an iPhone. David Vissière, founding president of SYSNAV, tells the story of a team who had previously worked in a large organisation where priority is given to technical expertise, which is faced with challenges from a young, innovative company using a model based on the twin development of products and research.

TALK : David Vissière

Towards the end of my studies at the École Polytechnique in 2002, I had work experience at Total and the MINES-ParisTech Engineering School where I met Nicolas Petit who would later become my thesis director and future associate. When I graduated from Polytechnique, I began making one of my dreams come true – becoming a fighter pilot in the French Air Force – while at the same time studying for a Masters in mathematics at Orsay University. Unfortunately, after a year, I realised that pilot training was not really what I had thought it was.

Consequently, in 2004, I started working at the Ballistics and Aerodynamics Research Laboratory (LRBA), a Ministry of Defence centre of expertise specialising in navigation systems for all types of applications ranging from submarines to pedestrians. The LRBA had signed a contract with the MINES-ParisTech Engineering School to study the potential use of low-cost, inertial sensors for the navigation of relatively light (in terms of weight) applications. This was the basis of my PhD which I wrote on the solutions of guidance, navigation and -control at the MINES Paris-Tech Engineering School's Centre Automatique et Systèmes.

In 2007, I perfected a navigation method with my thesis director and an LRBA colleague based on variations in the magnetic field. We registered a patent for it and won the DGA's (Direction Générale de l'Armement) innovation prize.

Existing navigation systems

A navigation system enables one to estimate the geographical position and/or orientation of the holder of such a device (such as a pedestrian), or of the object where the device is attached (a missile or a car). This information can then be used to guide the holder towards his objective.

GPS

Geographic positioning using the GPS (*Global Positioning System*) relies on receiving radio signals sent by satellite. This only works in the open air because direct visibility is necessary. It is possible to use a signal's rebounds inside a room which has large windows, but the signal would not be good. Another inconvenience is that the precision of the geographic positioning depends on the number and the configuration of the satellites which are used : if all the satellites are grouped closely together, the positioning will not be very precise. Additionally, some geographic zones may not receive clear signals, at least at certain times of the day, and one needs at least 4 satellites to ensure good positioning by triangulation, in view of the receiver's timing errors.

These problems are not necessarily criticisms. Usually it is not very serious when a car loses the GPS signal on entering a tunnel. However, losing a signal is unacceptable for the guidance of a missile. This is why, for military applications, a navigation system which pre-dated the GPS and is much more advanced than the GPS is used. It is called high-precision inertial navigation.

High-precision inertial navigation

The principle is as follows : after a period of initialisation time ('alignment') during which the inertial unit (whose position was indicated earlier) calculates its direction/orientation precisely, the unit will 'navigate'. Using various sensors (notably gyroscopes and accelerometers), a data fusion algorithm calculates the direction of the unit in the course of time as well as its geographical location and speed. An important part of the performance is

linked to the quality of the alignment, with specific difficulties encountered when one has to initialise an inertial system by using another inertial system as a reference, for example, when an aircraft carrier leaves port, when an aircraft takes off, or when a missile leaves an aeroplane. The performance of the unit also depends on its ability to determine the specific acceleration of the projection of gravity : a mistake of half a degree in the projection of gravity may cause an error in the geographic position of around 200 metres after a minute.

Inertial navigation requires equipment which is heavier and more costly than that required for navigation by GPS. The high-precision inertial unit which I used during my tests with a Rafale combat aircraft on an aircraft carrier measured 30 centimetres, weighed about 30 kilograms, consumed a significant amount of energy, and cost several thousand Euros. These characteristics make this sort of equipment barely compatible with light military applications, for examples those intended for foot solders, and, similarly for applications regarding the general public.

Towards low-cost inertial navigation systems

Our aim is to perfect a low-cost inertial navigation system intended to replace the GPS for light military applications and for the general public.

In order to do this, we need to replace the sophisticated sensors associated with traditional inertial navigation by MEMS sensors (small sensors which are a few millimetres wide, weigh about ten grams, use a few micro-amps and cost less than a Euro). The entire device costs a few Euros when manufactured on a mass scale. These sensors are already used in a number of general public electronic markets. For example, there are little accelerometers on car airbags.

Unfortunately, the performance of these low-cost sensors is a million times lower than high-precision sensors. They do not permit perfect initialisation, nor do they guarantee the accuracy of the orientation indicated by the gyroscopes nor do they determine the specific acceleration of the projection of gravity. SYSNAV's innovation overcomes these shortcomings by exploiting the variations in the magnetic field.

We know that the magnetic field may be interfered with in some areas, particularly indoors. For example, if I cross this room with a compass, there is a variation in my course of about 40° in relation to the points of the room where I am located. If one establishes a model of a magnetic field in a room, the only variations noted are those of movements made within the room. This can be demonstrated by the following equation : the variation in the magnetic field is equal to the slope of the field multiplied by my speed of movement.

The first attempts

Carrying out tests to verify whether this idea was viable raised questions of organisation, because this was neither strictly part of my thesis nor was it part of the contract between the LRBA and the MINES-ParisTech Engineering School. After discussion with my thesis director, I was given two more weeks on a full-time basis to carry out these tests. The tests consisted of taking a wooden rail, one metre long, sliding a small unit above it, and then trying to re-establish its geographic position. Using the equations of traditional inertial navigation, I was out by 30 metres. With magnetic-inertial navigation, the error was less than 1 centimetre for the same movement of one metre.

However, these tests were only conducted with movement along an axis and the information was handled sequentially. After a few sleepless nights, we managed to create a prototype which we tested in the corridors of the basement of the École des Mines. Constructing it to scale worked well : we had errors of less than one centimetre for movement over several hundred metres. The result in terms of achievable performances was very satisfying. We now had to find a compromise between achievable performance, sturdiness, the number of sensors and time taken by the computer to give an answer.

The first applications

Our main aim when we created SYSNAV was to perfect usable tracer systems, for example, to protect isolated workers, locate firemen in a building on fire, and even to be able to identify an office in a tower block.

We started with applications with the car in mind, both because of time considerations and because we had more requests in this area. Our first demonstrator device for locating vehicles without a GPS measures 73 × 112 × 43 millimetres and runs without needing recharging for about 8 hours. At the same time we compared it with a GPS. We put it in a car, drove around a block of houses, and then analysed the results by comparing the route indicated by our system and the one indicated by the GPS. At present, over the distance between Paris and Limoges, this system enables us to find the parking place where the journey started, only resorting twice to readjust the trajectory throughout the trip. The next stage will consist of adding map readjustments. The device will then perform as well as a GPS, and also the signal will not be lost in tunnels.

Our best-known application was created for a client. It was for a drone produced by the Parrot company, about thirty centimetres long, weighing a few hundred grams and is intended to be sold as a toy. It can be used both indoors and outdoors, in other words in areas which are not necessarily covered by a GPS. It is navigated using an iPhone, has an in-built camera, and has both inertial sensors capable of using the aerodynamic model of the motor as well as sensors which use the properties of the magnetic field. The person who navigates the drone using the iPhone can see the images filmed by the camera on the screen. It can fly without recharging for about twenty minutes.

Creation of the company

We started SYSNAV at the end of 2008, and won our first contract in November 2008. It was a very small contract from the Parrot company, worth 5,000 Euros, who wanted to assess our capabilities. Our next contract for the CNES (Centre national d'études spatiales : National Centre for Space Studies) was worth 10,000 Euros, and involved work on the reconstruction of rocket trajectories. These first two experiences were an opportunity for us to familiarise ourselves in writing technical and financial proposals.

In January 2009, we took on our first employee despite the fact that we only had 15,000 Euros in the bank and practically no signed contracts. However, the engineer in question, who had just finished his studies, was really an excellent candidate and we did not want to risk losing him. Shortly afterwards, we got financial support from Oséo (a public organisation financing innovation and providing investment) which allowed us to continue for another two to three months. That was when I decided to leave the DGA and took unpaid leave.

In June 2009, we won the Ministry for Research's national competition for business creation in the Creation/Development category and received a large sum of money.

From July 2009 onwards, we started winning a number of more important contracts. It took us practically six months to get to this stage and I think that this amount of time is necessary. Even when people are convinced about a project, it takes time to get a contract signed.

We made our second appointment in October 2009. Currently we have 7 full-time employees, 6 of whom are engineers with PhDs. We also have 3 PhD students, one of whom will be taken on permanently in the coming months.

In the first year, our turnover was 170,000 Euros. In 2010, it should be more than 500,000 Euros. Over three years, we have invested a total of 1.1 million Euros in R&D projects. About half of this sum was financed by submitting proposals which we won, and the rest by our

contracts. We have registered three patents of which the last two were extended but not the third, due to lack of sufficient resources from the outset. We have published 15 articles in international reviews.

We still have close links with the Centre Automatique et Systèmes at MINES-ParisTech Engineering School. Transvalor, the École des Mines' business incubator, will soon have shares in our capital.

A mixed model

We chose a mixed economic model, combining the R&D which we wanted to do with research ordered by our clients. This meant we did not have to look for external finance and run the risk of not being able to control our growth. However, we do benefit from various financial aids given for R&D research in France, notably from an initiative which was started by the ANR (Agence nationale de la recherché : French national research agency) and the FUI (a French government interministerial fund) for submitted proposals. This aid covers 30 to 40 % of our research needs. The rest is self-financing.

There are numerous examples of research carried out for our clients. They include navigation problems for the Ariane space programme carried out for the CNES ; work on a gyrocompass for Sagem ; a new drone model for Parrot ; and the detection of micro-displacements for the LRBA. Since these examples are for the most part concerned with data fusion algorithms, this research tends to be carried out by engineering graduates from leading engineering schools. On the other hand, as far as embedded real-time computing and electronics is concerned, we use the services of very good electronic engineers who have degrees similar to those from Troyes Technology University (UTT : Université de technologie de Troyes). These people are very enthusiastic about robotics and spend years installing systems, and know how to make them work.

The assault course

When we created the company, we were surprised to find relatively little support on a day-to-day basis from organisations whose aim is to help companies get started. It is undoubtedly partly our own fault because in the beginning, we tended to put too much emphasis on technical innovation which is not the part our clients understand best. The first time we entered the Ministry of Research's competition, our candidacy was rejected at the initial selection stage which took place on a regional level across France. The following year, we reworked out project and were lucky enough to work with consultants at Ernst & Young who were both technically and commercially skilled. This time our project was not rejected.

Generally speaking, it is very difficult for us to find people who can help us with entrepreneurial and marketing issues. We have had to manage by ourselves for the most part despite the fact that we were absolute beginners in this area. In spite of the existence of numerous structures of financial aid for new businesses, we feel that no-one has really shown the way forward for entrepreneurs whose innovation is very technical. However, we did receive a large sum of money in order to help set up the company and for some of its initial investments.

The advantages and drawbacks of SYSNAV

Obviously, one of our main advantages is that we have a truly scientific and technical innovation which can instantly add value in terms of research. It is extremely useful for clients to know that we have a unique solution to their problem.

Another advantage is that we have a team of people who are extremely talented. Apart from Nicolas Petit, my former thesis director and an associate, most of our staff are people whom I trained at the LRBA, or subsequently in the company, and I know that as far as their work

skills and personalities are concerned, we have no problem in working together. I was able to recruit a researcher from the LRBA who decided to work for us rather than take retirement : we are lucky to have someone who has 40 years' experience in the area, which is very valuable when we apply for a tender, for example. He could tell us what type of inertial sensor was needed for any given application. We have also strengthened our skills as a group with the passage of time. Our team now has about ten years experience in research on navigational problems which is significant in a sector where technical subjects are often handled by very young people straight out of school.

We have also had to cope with a few drawbacks. We had an innovative technique which we knew could satisfy certain military needs, but nothing else. We jumped in without having clearly identified or assessed the market. We did not have any pre-existing marketing contacts where we could have created connections. This is not surprising because none of us had worked in such a small organisation before. The downside of recruiting people who are very talented is that we also needed to integrate them into the project under the best possible conditions, in other words, to pay them a reasonable salary from the outset. Finally, even though I took a long time to realise the fact, and also to resign myself to it, I now recognise that the size of our company does not enable us to envisage applications for the general public, or at least, not by ourselves. However, we can debate the advantages of selling our patents.

DISCUSSION

How to convince people

Question : *I met David Vissière when I was a member of the ParisTech thesis prize jury. I was struck both by his very original research subject and by the comments of his thesis director, Nicolas Petit. Originally, Petit was extremely dubious about the research subject of this Ecole Polytechnique graduate who had just arrived from the DGA. But, having demonstrated your product to him, you ended up by convincing him. Various members of the jury were also very sceptical, dismissing your research and casting doubts on variations and disruptions in the magnetic field ; they thought that the system would never work properly. Again you managed to overcome the doubts expressed by the jury, and you ended up by winning the ParisTech 2009 award for the best thesis. I heard that during your studies you perhaps had had a very tough experience, like a trek in the desert somewhere, and that this was maybe where you acquired your strong sense of perseverance. Am I right ?*

David Vissière : When I started at the École Polytechnique (which is a military engineering school), I wanted to do sport and I put down my name for the 'commando' section reserved for volunteers. The soldier in charge of my year suggested that I put together a team to take part in a trek which was supposed to take place in Vietnam. It involved covering 1,000 kilometres on foot or on water. I asked 11 other people to take part and they all agreed, so we were able to put forward two teams instead of one. We trained for two years, two to three hours every day, while also trying to raise the 100,000 Euros necessary to finance the project. To start with, the École Polytechnique's director was not very enthusiastic because this activity did not fit into the curriculum very well and she thought that after a month's trek, we might come back a bit 'disturbed'. In reality, the relationships which I made with the other members of this group have been some of the strongest and most important for me.

Broken dreams

Q. : *Why did your pilot studies disappoint you ?*

D. V. : I had spent a year in the light intervention team of the Republican Guard where I took part in early-morning arrests with very well trained guards. I was tempted by the Army but only for a position in the field, not a desk job. Being a pilot seemed to me to be the only job

where I was sure to spend fifteen years in active service. The reality was less exciting than I had thought. I had to spend six months learning the airline pilot manual by heart. I did not mind that, but it was not enough to keep my brain busy, which is why I started studying for a master's degree simultaneously. I completed my first six months of pilot school, flying four hours every week. Some of my friends were so enthusiastic about flying that they did not object to flying so little, but I did. It was a difficult decision to take, but at the end of the year I left the Air Force and joined the DGA.

Q. : *Your account brings some credence to the myth about the researcher who, on leaving university, has a wonderful idea, creates his own high-tech company straightaway, develops his idea and markets it. You started out as a pilot and not as a researcher before realising that you had made a mistake. Perhaps this initial trial and error gave you a richer approach oriented towards applications than if you had you started immediately after leaving the École Polytechnique.*

Financial aid to get a start in business

Q. : *I am surprised that you did not find the financial aid you expected from business incubators or other structures. It should have been easy for you to meet people capable of explaining to you that the technical aspect only represents 20 % of what one needs to start a business, for instance.*

D. V. : If you say that sort of thing to a researcher who thinks he has got the next best invention of the century, he will be flabbergasted. Perhaps people whose job is to help new businesses do not explain things in a sufficiently concrete manner. For example, we were often told how we ought to think in terms of short, medium and long-term scenarios for our business plan ; instead, people ought to advise you to look beyond these general principles, and should explain that 'If you carry out research, this will finance your R&D, but if you only do that, in five years' time, your company will have become a research company and you will not have produced a single product. Your finances will be precarious and you will be constantly looking for new research to ensure your survival.' Similarly, they kept on telling us that for a company of just ten people we could not aim for a general public market. We should have been told that in order to make a 'general public' product, you have to be able to place 300,000 products instantaneously with distributors, and because a single system costs 100 Euros, this means that one has to have 30 million Euros up-front. These are very basic facts, but they are totally new for someone who has never worked in a technical environment before. It is true that perhaps, as far as we are concerned, we were not sufficiently mature to act on this sort of information and listen carefully enough.

From time to time, we meet people who have managed to explain certain aspects to us. On one occasion, someone suggested that I should consult a 'business developer'. I put an advertisement in the halls at the INSEAD Business School and I met about twenty people. One of them, the youngest, really impressed me. In twenty minutes, he explained to me how we ought to structure the company, the different steps we needed to take in the next six to twelve months, and everything we should do on a short to medium-term basis. For example, he explained to me that in the company, people who give advice should not necessarily be the same people who are in charge of the products, and, that in the long term, each activity ought to have its own sales and marketing team.

Q. : *Nonetheless, it is quite worrying that in France, in spite of the 10,000 people whose activity consists of helping entrepreneurs, a researcher who understands the principles of inertial navigation cannot find anyone to educate him in a few principles about business plans or marketing strategies.*

Finance

Q. : *I do not understand why you did not ask investors such as business angels or venture capitalists to help. Do you going to do so now ?*

D. V. : If one is going to meet with an investor, one must have a business plan which is both credible and ambitious. This was not so in our case. We did not know where we would be in ten years' time. We also quickly realised that investors' strategies consisted of producing many projects in the hope that at least one of them would succeed, rather than analysing comprehensively the technical basis of each project and the skills of the team. Investors tend to see added value being based more on the progress of a project with respect to a specific market rather than on the real prospects of the company. We have now started to prove ourselves, and we are better equipped to interest investors. The case of Transvalor is slightly different because of the existing links with MINES-ParisTech and the absence of short-term constraints associated with investment. In the meantime, because we carry out research for clients, our credibility has been assured, and we have also constructed commercial relationships which may well be useful to us in the future.

Q. : *How come Transvalor was not able to help you to finance the extension of the first patent ?*

D. V. : The École des Mines was not yet involved in the project when the patent was registered in 2007.

Q. : *Was it a DGA patent, or a personal one ?*

D. V. : It is a patent which we registered in the company's name, because as far as the DGA was concerned, our invention, which focussed on magnetic/inertial navigation, was their competence : it could be attached to my research work but was not part of any specific project with MINES-ParisTech, nor part of any activities with which we were involved in relation to the drones.

Having said this, even with this patent, it was not very easy to convince investors. When Parrot's founding president asked us to work with his company, we were able to solve problems which had existed since the beginning of the project in a relatively short space of time. Recently, he trusted us again because he knows that we are technically very good, that we are the only people who have this skill, and that we can produce the desired result. People always ask for proof that you can really bring them added value, and this is understandable. One sees many ideas or projects which are very appealing, but which do not succeed either because the teams lack certain skills or because they lack the necessary pragmatism to make something work. Even for specialists in the area, it is very difficult to assess the true potential of an invention.

Why rule out the general public market ?

Q. : *Why not go to the general public market in the first place ? The Parrot drone is a general public project, and there are many ways to get into this sort of market, such as taking on subcontractors and organising the manufacture, or even finding someone to organise it for you. In the United States, people are not afraid of entering into a process which may well move faster and faster and grow very big in a short space of time. They know how to find the partners whom they will need.*

D. V. : I am not ruling out the prospect of a general public market, but not directly. For example, we can sell research, as we have done for the Parrot drone project, but it is preferable also to sell the intellectual property, in order to collect the royalties. This is the path we are leaning towards today : we no longer carry out research without first negotiating the intellectual property. Another method is to manufacture the product in partnership. However, if we only handle the development (if we are able to find the financing), and we give our

partner the task of industrialising the system, the marketing and the distribution of the product, then it strikes me as difficult to obtain a significant part of the profits. The third method consists of manufacturing the product ourselves or using a subcontractor. For the time being, we think this is too ambitious given our know-how.

Q. : *In Silicon Valley, if someone has a feeling that there is a market for bread and butter, he looks for a bread specialist (the product manufacturer), a butter specialist (someone who has access to the financing) and a jam specialist (someone who has access to the general public), and they do business together. For this to work, what each person brings to the table must be more or less the same. At this point, it might be a good idea to bring in an investor, for example to guarantee the first part of the development. Another solution consists of making oneself indispensable by being the person who creates the network.*

Q. : *Some English and American companies financed by venture capital manage to go through the various stages of the process in record time after they have protected their intellectual property.*

D. V. : We often ask these questions from a financial angle. But it is not the only approach and, personally, I encourage people to think about strategy : for instance, what company do we want to become ? Furthermore, the way in which you describe the product process is perhaps possible in the United States, but in France, I have rarely seen people in companies able to say to us 'Give us the technique and I will give you the money and organise the development.' I am not sure that this sort of method exists here.

Contact with the client

Q. : *Do you still manage your clients yourself or have you hired a sales and marketing person ?*

D. V. : When we sell research to the CNES, we deal with very highly skilled engineers and we are undoubtedly the best people to talk to. When we meet researchers and doctors at the Pitié-Salpêtrière hospital in Paris who need extremely precise systems for measuring movement in patients, it is a little different but they are still scientists and we have very good discussions. As far as products are concerned, for everything which has a military aspect, we use intermediaries with the DGA on one side and the technical departments of French domestic security on the other. Again, the people we deal with are engineers. Undoubtedly, later on, we will have the opportunity to meet 'real' sales and marketing people and under those circumstances we should have people in our teams who possess both skills. With that in mind, we have recruited an engineer from the INSEAD business school who has worked abroad for ten years and has an MBA.

Q. : *An engineer is making a huge mistake if he believes that when something is technical, that he does not need a real sales person. In the United States, sales people are hired from the very beginning (which requires help from investors). They are put in charge of finding new markets and making initial contact with future clients.*

Colleagues

Q. : *Have you created a form of profit sharing for your colleagues ?*

D. V. : People who have been with us from the very beginning have become associates. This is not the case for those who have come to work for us since then. Initially everything works well : the team is young, the project is exciting, there is a certain amount of freedom which does not exist in large groups, and there is a strong vested interest in the progress of the project. In the long term, one has to think about profit sharing. When there are a large number of people involved, owing part of the capital is not necessarily rewarding : holding 10 % of

the capital is motivating, but having 1 or 2 %, a great deal less. It depends on the amount of capital, of course. The solution to which we are moving consists of distributing a significant part of the profits in the form of year-end bonuses.

Competition

Q. : *Do you have competition ?*

D. V. : Companies like Sagem, Thales and EADS all have geographical positioning systems which work outdoors without GPS, and which work perfectly. For navigation using low-cost sensors, however, it is impossible to use methods of high-performance inertial navigation such as they use. One has to find a way which allows one to calculate speed using low-cost sensors. How many ways are there ? We have found one, and I am not sure that there are many others. Using vision-based systems may be an alternative : for Parrot's drone, a large part of the information comes from the camera. But this method has limited applications. Perhaps there are other ways which will emerge.

Q. : *Is there a risk when one does not have any competition ? Your potential clients, especially very important ones, may fear that if you go out of business, they will not find an alternative.*

D. V. : It is obvious that the DGA, for example, will not agree to work directly with a small or medium-sized company, and that it will recommend a more or less 'forced' marriage with a more moderately-sized company. However, not all companies are averse to working with smaller structures. For example, we are currently in discussion with the Dutch national railway to install our device on trains because it overcomes the problem of maintaining the transmission of the signal, especially in train stations. The solutions we are looking for tend to be for low-cost systems, which is why we are interested in the product which we are in the process of finalising.

Q. : *Who will provide the product maintenance if you go out of business ?*

D. V. : One does not necessarily talk about maintenance when discussing a system which in total costs a few thousand Euros. The company would prefer to buy a stock of systems in advance and regard them as consumables.

Presentation of the speaker :

David Vissière : engineering graduate from the École polytechnique ; PhD (Mines-ParisTech) ; CEO of SYSNAV. Having worked as an expert in inertial navigation for the Ministry of Defence, he founded SYSNAV in 2008, a start-up specialising in determining geographical position without GPS.

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