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REVIEW ARTICLE

STUDIES ON AUTONOMOUS UNDERWATER VEHICLE SYSTEMS

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ABSTRACT

Autonomous Underwater Vehicle (AUV) is capable of performing point-to-point data collection underneath the thick winter ice sheet. The advantages of AUV instead of remote operable vehicles (ROVs) or towed unmanned vehicles are the lower cost involved and a better quality during the inspection missions. Modeling, system identification and control of these vehicles are still major active areas of research and development. The design and development of the vehicle consisted of implementing a mechanical and electrical system, as well as the integration of subsystems. The present work discusses the sensor and communication systems of a typical AUV. The overall design concept, operation of the system is analyzed.

INTRODUCTION

Autonomous underwater vehicles (AUVs) are usually battery powered and carry its own computer. They gain information from their sensors for navigation and mission tasks. In military applications, AUVs are also known as Unmanned Undersea Vehicles (UUVs). They can operate in water as deep as 6000 meters and with recent advances in battery technology, these robotic submarines can travel tens of kilometers (Allen *et al.,* 2002). Primarily oceanographic tools, AUVs carry sensors to navigate autonomously and map features of the ocean. Typical sensors include compasses, depth sensors, side-scan and other sonar's, magnetometers, thermistors and conductivity probes. Underwater robots require adequate guidance and control to perform useful tasks. Visual information is important to these tasks and visual servo control is one method by which guidance can be obtained. The demand for advanced underwater robot technologies is growing and will eventually lead to fully autonomous, specialized, reliable underwater robotic vehicles. Early-on, it was realized that the most difficult problems to overcome in the development of AUV would be navigation, control, and launch & recovery (Fossen *et al.,* 1995). The navigational problem presents itself in several forms. First, the use of Differential GPS is unavailable due to the fact that the vehicle is operating both underwater and under ice, preventing even periodic surfacing for GPS position fixes. A reliable DGPS signal simply cannot be assured under these conditions. Secondly, inertial navigation systems progressively accumulate error due to approximations in integration and limitations in sensor resolution. Therefore, navigating to a 1m-diameter target, over a 500m mission would be extremely difficult for even the most advanced inertial navigation system. Only with periodic absolute position fixes (i.e. GPS or Acoustic) and fast Kalman Filtering to bound the accumulated error, could this be achieved. Although dead-reckoning with a digital compass is a necessary ingredient in any AUV, the accuracy of such a system is extremely poor and should only be used when precise navigation is not important (i.e. when following compass headings in open water), or as a last-resort navigation system when others have failed. These design restrictions therefore necessitated the development of a more accurate, yet simple, acoustic homing system. This system, allows the vehicle to navigate with respect to a fixed acoustic beacon, located at the vehicle's intended exit hole. Typically, modern AUVs are designed with a torpedo-shaped form, providing the advantages of low hydrodynamic drag, ease of maneuverability over long distances, and low power consumption. While this basic design offers some payoffs in open water survey and data collection missions, it lacks the precise positioning and station keeping abilities (Sangekar *et al.,* 2009). Due to the nature of the deployment environment for this project, it was determined that such maneuvering and control characteristics were of utmost importance. This is mainly due to the fact that the vehicle must be able to be launched and recovered through a 2ft.-diameter hole, in a 6ft-thick sheet of ice, and may have to navigate around random, closely-spaced ice spikes. This requires the ability to precisely position the vehicle at low speeds underneath the exit hole, assuming that the position of that hole is accurately known by the navigation system. Such

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fine control and station keeping tasks are virtually impossible for a conventional torpedo-shaped vehicle, steered by control surfaces such as rudders and dive planes, as the turning radii for such systems are usually very large and constant forward motion is required in order to generate lift on the control surfaces (Marthiniussen *et al.,* 2004).

Underwater Vehicles

Underwater vehicles have categorized as manned submarines and unmanned underwater vehicles (UUVs); the unmanned vehicles are either Remotely Operated Vehicles (ROVs) or Autonomous Underwater Vehicles (AUVs).

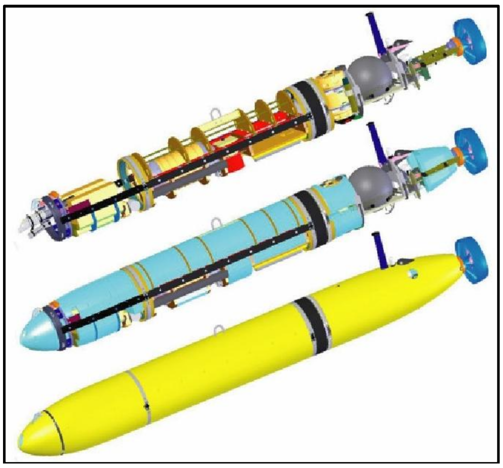

Figure 1. Overview of Autonomous Underwater Vehicle

Remotely Operated Vehicles are typically remote controlled from an operator's desk on a ship, to which they are connected via an umbilical cable (Valavanis *et al.,* 2000). The umbilical cable supplies control commands to the motors of the ROV, transfers sensor data back to the operator, and usually also supplies power to the vehicle. The cable can also act as an emergency cable to retrieve the vehicle in case of mechanical faults. Typically, the cable is very robust, a few hundred or thousand metres long, and can easily weigh several hundred kilograms. The vehicle must have strong propulsion to counter the weight and the hydrodynamic drag of the cable (Zhang 2000). ROVs come in a large variety of shapes and sizes. The smallest ones can be as light as a few kilograms, and can only carry a camera or a small sensor suite. Due to the small size, they can only drag a short, thin cable, and are therefore typically operated close to the ship, or a larger submersible acting as a base platform. Most AUVs are scientific robots that are equipped with on board computing for navigation and mission planning, carry their own power supply and a range of sensors (depth sensors, inertial navigation, compass, temperature, often also sonar sensor and cameras) as shown in Figure 1. Once deployed, the AUV carries out the mission autonomously without human interaction and returns to the surface for pickup after completion (Buniyamin *et al.,* 2011). Missions can last for several hours, or even several weeks in some special cases. There are two principally different designs for underwater vehicles. Most ROVs are an open frame design with multiple thrusters that allow decoupled multidimensional movement or even holonomic movement (6 degrees of freedom). AUVs may also have an open frame design, but mostly, for reasons of hydrodynamic efficiency, a torpedo-like shape is used. The latter features a long, cigarshaped hull with a single thruster at the rear end and rudders for changing direction. This design has low drag, but is less manoeuvrable than open frame designs. The vehicle can only change its attitude when it is moving forward.

Auv operation

The AUVs could only communicate during repeated surfacing, but not during dives. Every AUV attempted to stay as precisely as possible on the preplanned trajectory until the next surfacing. During surfacing, collected data was transmitted back to the operators, a GPS position reading was taken and a new trajectory was planned (Choset *et al.,* 2005). While the principle of swarming can theoretically be implemented with almost any type of AUV, it is obvious that the large numbers of vehicles required pose severe constraints on handling requirements and cost. Picking up the vehicles at the end of the mission poses similar problems and might involve the dangerous task of attaching a crane hook to the vehicles (Do *et al.,* 2004). Performance criteria of AUVs are typically peak velocity, average cruise velocity, battery runtime, range, maximum operating depth, installed sensors and computational power. The size of a vehicle only matters for work class vehicles with manipulators, as they require a counter weight to balance heavy payloads in the manipulators. Essentially, all AUVs that are currently used are eyeball vehicles - they do not have manipulation capabilities, but are able to carry a sensor payload and can be used for data sampling (Li *et al.,* 2010).

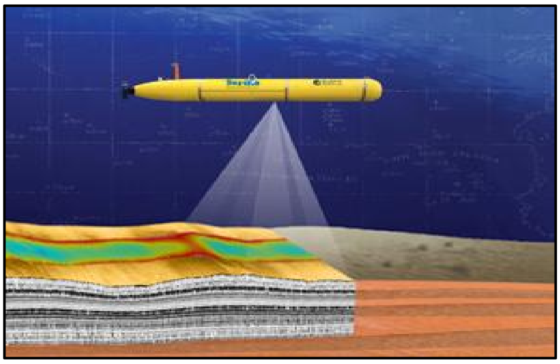

Figure 2. Operation of an AUV at inspection missions

The size of a vehicle is irrelevant for this task, as long as the other performance criteria are met. For swarming applications it is therefore desirable to reduce the size and weight as far as possible. A vehicle which can be launched by hand is preferable, which means that the maximum mass should not exceed 10 kg. Currents in the open ocean can have velocities of over 2 metres per second. There is an obvious trade-off between velocity and energy requirements. The average cruise speed is usually chosen to maximise range, which typically translates into roughly 1-2 knots. However, it is desirable that the vehicle can maintain higher peak velocities to fight currents. Battery runtime and range are highly application specific and also cost driven. High density batteries typically cost an order of magnitude more than cheaper varieties with lower energy density. Obviously the battery runtime heavily depends on the use of propulsion. The two critical key factors are idle runtime and cruise speed runtime, which maximises the range, but is not necessarily full speed. Actively propelled AUVs can achieve cruise runtimes of 10 hours or more. Idle runtime depends on the computing requirements - with energy optimised embedded processors, idle runtimes of several weeks are possible. The maximum depth also depends on the application. Commercial ROVs and AUVs are generally rated to either hundreds or thousands of metres. Typical ratings are 300 metres or 3000-6000 metres. Static water pressure increases by 1 bar (roughly 1 atmosphere, or 1kg/cm2) per 10 metres. 100 metres depth corresponds to 10 bar pressure, which is comparable to household water mains pressure. Greater depths of thousands of metres require special materials, such as titanium, to obtain sufficient structural integrity; designing seals and connectors becomes a lot more challenging. For reasons concerning engineering and cost it is usually better to design a cheaper shallow water vehicle (up to 300 metres) and a more expensive deep sea version for special applications. A minimum sensor suite comprises at least an inertial navigation system, depth sensor, compass and a surface communication system. Computational requirements depend on the type of the installed sensors and their data rate. Mainly sonar and vision processing are computationally expensive. Sonar processing can often be kept simple, and real time vision processing is mostly not done due to bad visibility or general darkness. This makes it possible to use energy efficient embedded processors running at low speed. To accommodate bursts of computational load, a processor with variable speed can be used, or alternatively, the commonly available idle and standby functions can be activated while the processor is not used. The power consumption can be kept minimal this way. For low-level sonar or vision processing FPGAs can be tailored specifically for the task, which are typically much faster and more efficient than using a sequential processor. The Figure.2 illustrates the operation of an AUV at inspection missions.

Design of the system

The size of an AUV is mainly determined by the size and mass of the sensors, motors, processors and the batteries. The mass in kilograms has to be equalled by volumetric displacement in litres to achieve neutral buoyancy. Sensors and processors can be miniaturised quite well with modern technology and have almost negligible volume and mass compared to the rest of the system. The main volume and mass is given by the batteries. Sizing of batteries depends on the expected range and battery runtime (Oh *et al.,* 2010). The size of the vehicle determines the drag and the energy required for propulsion - this means that small vehicles need smaller batteries. This is again counterbalanced by the standby power consumption of the processor and sensors. There are more factors that play a role in determining a good size for the system, i.e. handling or launch and retrieval procedures. A submarine larger than 1 m and heavier than 30 kg requires a crane for launching and retrieval. If it is smaller, it can be launched by a single person, possibly with help of another person. A size around 50 cm and 5 kg makes handling with only one hand possible, making launching and retrieval very simple and efficient. Determining the best size becomes a difficult optimization problem. A practical approach is to make sensors and all circuitry (processor, amplifiers, etc.) as small and energy efficient as possible. The next step is to choose a battery that provides a sufficiently long idle runtime and expected cruise runtime, and to design the hull of the submersible around the volume and mass of circuitry and battery. Using this approach it appears feasible to build a submersible with a mass below 5 kg and an overall length of approximately 50 cm. The underwater environment severely limits communication channels. Undersea cable is the most commonly used underwater communication link. The Figure 3 illustrates the various section of a typical AUV.

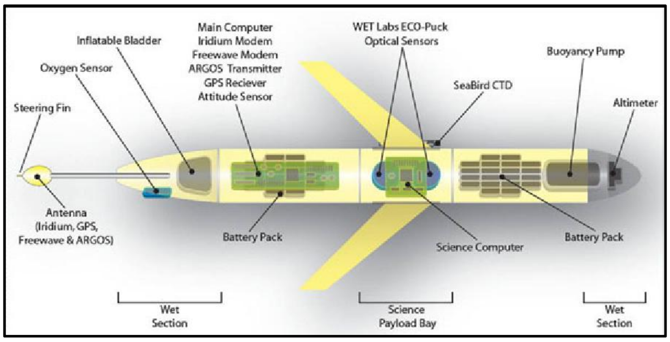

Figure 3. Sections of AUV Hardware

Communication System

The three most common wireless underwater communication channel modalities are radio frequency, optics and acoustics. These different modalities suffer different specific deterioration in water. Channel deterioration also depends on water quality - seawater is different from freshwater or pure water. This section gives an overview of various ways of transmitting information through water, while discussing the technology with regard to use for underwater vehicles (Prestero 2001). Even though an AUV is capable of fully autonomous operation, a well-designed system provides the operator with communications links to the vehicle whenever possible. At a minimum, a link is needed to start the mission after the AUV has been launched as shown in Figure.4. This contact confirms that all systems are ready and allows the operator to command the start with knowledge that the AUV is fully functional. During the mission it is often possible for the support ship to maintain contact to allow for occasional vehicle health checks. Contact also allows the support ship sufficient data transmission to confirm that the payload is logging worthwhile information (Lazic and Ristanovic 2007). Electromagnetic radiation such as normal radio communication cannot travel through thick conductors such as salt water, so communication with submarines when they are submerged is a difficult technological task, requiring specific techniques and devices. In many cases, the obvious solution is to surface and raise an antenna above the water surface to use standard technology. Sound travels far and fast in water, and underwater loudspeakers and hydrophones can cover quite a distance. Acoustic Telemetry provides sufficient bandwidth to monitor the vehicle periodically, and to send it high-level commands. The amount of data that may be required to oversee the quality of the survey record depends on the nature of the survey equipment used. Very low frequency radio waves (3–30 kHz) can penetrate seawater down to a depth of roughly 20 meters. Hence a submarine staying at shallow depth can use these frequencies. Extremely low frequency electromagnetic waves in the ELF frequency range can travel through the oceans and reach submarines anywhere (Beal 2004). However, building an ELF transmitter is a formidable challenge, as they have to work at incredibly long wavelengths. Two facts should be noted: First, the communication link is obviously one way. No submarine could have its own ELF transmitter on board, due to the sheer size of such a device. Secondly, on such low frequency, information can be transmitted only very slowly, on the order of a few characters per minute. Bluetooth is best described as a low cost, low power, short-range radio technology developed as a cable replacement to connect mobile phones, headsets, portable computers etc.

Wired Communication

Wires or cables can carry reliable high bandwidth communication links and are currently the most used solution to underwater communication. Cables consist of wires that either transmits electrical signals in electrical conductors or optical signals in optical fibres. Often a specific cable carries a combination of both optical and electrical signals. An additional advantage of cables is their capability of transporting electrical power (Cavallo *et al.,* 2004).

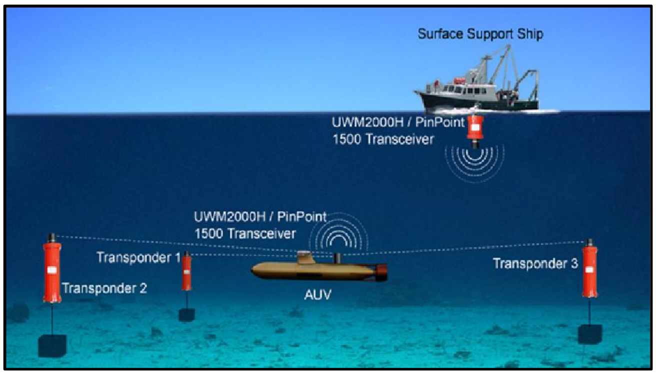

Figure 4. Acoustic Communication and AUV

In the case of cables connecting remotely controlled vehicles with a mother ship, the cable can also be used as a safety rope to retrieve the vehicle. Virtually all currently used remotely operated vehicles communicate with the operator on the mother ship via a cable. A major problem with umbilical cables on remotely operated vehicles is the weight of a long cable and the associated hydrodynamic drag. Especially in deep sea missions with cable lengths of several kilometers, the drag of the cable becomes a major limitation of the vehicle's maneuverability. Cables are also used as static communication infrastructure to connect continents. A large percentage of intercontinental telephony and data traffic is routed through subsea cables. With growing numbers of vehicles the number of cables easily becomes unmanageable, and there is a risk of entanglement. Connecting every vehicle of a swarm to the mother ship is highly unpractical. It is conceivable to use wired communication only between neighboring vehicles in a group of robots. In this case wired robots would have to move in an almost rigid formation to avoid entanglement. The additional drag and complex control constraints are severe drawbacks, but could be compensated for by the high bandwidth, long range and superior reliability of wired communication.

Wireless Communication

In order to prevent connections from unauthorized devices, Blue tooth communication can be used. When one Bluetooth device connects to another for the first time, a passkey is exchanged between them and used for all further communications (Duchemin *et al.,* 2007). This process is remembered by both devices, allowing previously paired devices to connect in future without the need to re-pair. The AUV, connected to serial port two to communicate with the host computer when surfaced. The system can be developed for long range, easy-to-install low-cost wireless serial communications. Provided is point-to-point wireless connection without standard cables. It is a class 2 device with an output power of 2.5mW provided with variable baud rate up to 115200 baud, with automatic detection of hardware flow control. A waterproof housing with a cable was available for testing purposes, which could be localized close to the submerged AUV so that communication becomes possible.

Optical Channels

Optical communication offers high bandwidth, low noise channels and is commonly used in a range of applications. Most common are optical fibre links for large scale network infrastructure. Wireless links in air are usually implemented with focused laser beams to achieve high bandwidth and long ranges. The required power can be kept low if the beam divergence is low. In the ideal case of a perfectly parallel beam in vacuum the received light energy equals the energy emitted at the transmitter, which means that the required transmitter power can be kept constant independent of the link distance. In reality, laser beams have divergence caused by imperfect optics, diffraction and scattering. Light in media other than a vacuum is also subject to attenuation by absorption and scattering. A limitation of free-air laser communication links is that they require precise alignment of transmitter and receiver due to the small beam width. This makes it very challenging to use this technology on moving vehicles. Fast tracking pan-tilt heads can solve this task, but they mechanically complicate the design and also need precise position feedback of the opposite station. A different solution is to use optics to widen the beam, or to use omnidirectional light sources. There are some existing publications on optical underwater communication that presents a high speed transceiver which achieves up to 10 Mbit/sec and has a long range of up to 20 metres in clear water. This is achieved by using highly specialized and expensive hardware and powerful, directed light transmitters.

A recent publication shows a compact, low-cost optical transceiver for underwater applications, with a range of 2.7 m, using the IrDA physical layer. Being 5 cm in diameter and 10 cm long, their device is too large for miniature submarines, and it has a speed of only 14.4 kbs. Also, the narrow opening angle of their transmitter makes it difficult to achieve omnidirectional coverage. It must be noted that these transceivers were designed for much larger submersibles. Infrared communication according to the IrDA standard is often used for short range communication and offers reasonable bitrates. Unfortunately water is not transparent for the infrared part of the spectrum, which means that standard IrDA does not work under water. However, the IrDA physical layer modulation can be used and adapted for underwater applications by replacing the infrared light emitting diodes (LEDs) with high power green or blue LEDs and also replacing the photodiode of a type which is sensitive in the visible part of the spectrum. Solid state light sources have reached a level of maturity that makes it possible to use them for high speed communication. A prime example are light emitting diodes that offer switching speeds faster than 100 ns, allowing for bandwidths of several MHz. In the last few years, a new breed of high power LEDs emerged, capable of handling drive currents up to 1 A and delivering a luminous flux in excess of 100 lumen. In 2006 a dramatic increase in efficacy was achieved, yielding light emitters producing 100 lumen at 1 Watt electrical power (respectively 350 mW light output at 350 mA drive current for blue emitters). The achieved efficiency is close to one third, putting LEDs on a par with fluorescent and gas discharge lamps. The highest powered commercially available emitters are specified for up to 210 lumen of white light at 1000 mA drive current and can be pulsed to 1.8A current. This opens up the possibility for optical communication links with omnidirectional coverage over short ranges.

Conclusion

Submarine areas are still mainly unexplored areas. Underwater vehicle systems and technologies have bright prospects in the future. Many possible applications can be identified. We are still not aware of possible state in these areas. Intelligent underwater systems and technologies will have great impact in the future ocean underwater areas. The conceptual design methodology is a principled approach to obtain better AUV designs. It will serve as a critical tool to filter out various improbable and impractical mission specific designs. It is more adaptive and open to improvisations. The design of the AUV can be used as a platform for follow-on research. The architecture and formulated methodology are generic and hence can be successfully applied to other AUV on different missions. Likewise, both methodology and architecture are robust and capture all the components needed to conceptually design the aircraft.

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REFERENCES

Allen, B., Stokey, R., Austin, T., Forrester, N., Goldsborough, R., Purcell, M. & von Alt, C. 2002. REMUS: a small, low cost AUV; system description, field trials and performance results, OCEANS'97. MTS/IEEE Conference Proceedings, Vol. 2, IEEE, pp. 994–1000.

Beal, B. 2004. Clustering of Hall effect thrusters for high-power electric propulsion applications, PhD thesis, The University of Michigan.

Buniyamin, N., Sariff, N., Wan Ngah, W. A. J., Mohamad, Z. 2011. Robot global path planning overview and a variation of ant colony system algorithm. *International Journal of Mathematics and Computers in Simulation,* Vol.5, pp. 9-16, 2011

Cavallo, E., Michelini, R. & Filaretov, V. 2004. Conceptual design of an AUV Equipped with a three degrees of freedom vectored thruster, *Journal of Intelligent & Robotic Systems* 39(4): 365–391.

Choset, H., Lynch, K. M., Hutchinso, S., Kantor, G., Burgard, W., Kavraki, L. E., Thrun, S. 2005. Principles of Robot Motion. MIT Press, 2005

Do, K. D., Jiang, J. P., Pan, J. 2004. Robust adaptive path following of underactuated ships. Automatica, Vol.40, pp. 929-944, 2004

Duchemin, O., Lorand, A., Notarianni, M., Valentian, D. & Chesta, E. 2007. Multi-Channel Hall-Effect Thrusters: Mission Applications and Architecture Trade-Offs, 30th International Electric Propulsion Conference, Florence, Italy.

Fossen, T. I. 1995. Guidance and Control of Ocean Vehicles, John Wiley & Sons Ltd., USA. Guo, S., Lin, X. & Hata, S. 2009. A conceptual design of vectored water-jet propulsion system, International Conferenceon Mechatronics and Automation, 2009. ICMA 2009, IEEE, pp. 1190–1195.

Lazic, D. & Ristanovic, M. 2007. Electrohydraulic thrust vector control of twin rocket engines with position feedback via angular transducers, Control Engineering Practice 15(5): 583–594.

Li, J. H., Yoon, B. H., Oh, S. S., Cho, J. S., Kim, J. G., Lee, M. J., Lee, J. W. 2010. Development of an Intelligent Autonomous Underwater Vehicle, P-SURO, Proceedings of Oceans'10 IEEE Sydney, Sydney, Australia, May 24-27, 2010

Marthiniussen, R., Vestgard, K., Klepaker, R., Storkersen, N. 2004. HUGIN-AUV concept and operational experience to date, Proceedings of IEEE/MTS Oceans'04, pp. 846-850, Kobe, Japan, November 9-12, 2004

Oh, S. S., Yoon, B. H., Li, J. H. 2010. Vision-based localization for an intelligent AUV, P-SURO, Proceedings of KAOSTS Annual conference, pp. 2602-2605, Jeju, Korea, 2010

Prestero, T. 2001. Verification of a six-degree of freedom simulation model for the REMUS autonomous underwater vehicles, Master's Thesis, MIT, USA Quek, C & Wahab, A. 2000. Real-time integrated process supervision. Engineering

Sangekar, M., Chitre, M. & Koay, T. 2009. Hardware architecture for a modular autonomous underwater vehicle STARFISH, OCEANS 2008, IEEE, pp. 1–8.

Valavanis, K. P., Hebert, T., Kolluru, R., Tsourveloudis, N. C. 2000. Mobile robot navigation in 2-D dynamic environments using electrostatic potential fields. IEEE Transactions on Systems, Man and Cybernetics-part A, Vol.30, pp. 187-197, 2000

Zhang, Z. 2000. A flexible new technique for camera calibration. IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 22, No. 11, pp. 1330-1334, 2000.

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