EXPLORING ARTIFICIAL VISION FOR USE IN DEMANDING SHIP OPERATIONS

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ABSTRACT

Aalesund University College (AAUC) is situated in an area of industry companies developing the most advanced equipment and procedures for safe ship operations. AAUC has established a close cooperation with these private technology developers for the purpose of joint research and testing in this field. This work deals with the design of tomorrow's ship bridges. In the light of the bridge officer's situation of continuously growing information influence it has become mandatory to develop a new bridge concept in order to maintain and improve safety and efficiency in ship operations. The focus has been to explore the possibilities of modern vision technology in combination with dedicated systems for information extraction from large quantities of data. An important concept in this setting will be artificial sight and augmented reality. So far some interesting sensor and vision concepts have been tested and the results have shown to be promising. This research activity is supported by funding from the Norwegian Research Council (NFR).

INTRODUCTION

Aalesund University College (AAUC) has over a period of several years gained a broad and deep expertise in the design and building of nautical simulators and has in daily operation a number of full scale simulators. This development has taken place in close cooperation with Rolls Royce Marine Dept. AS (RRMD) and Offshore Simulation Centre AS (OSC), and the simulators are being continually upgraded and further developed. In addition to traditional nautical simulators, the collection includes full scale simulators for High Speed Craft (HSC), Dynamic Positioning (DP), anchor handling and winch operations, see (Rekdalsbakken 2005), (Kjerstad 2006), (Rekdalsbakken 2006) and (Rekdalsbakken and Styve 2008). The purpose of this simulator activity is to provide the most realistic operator training environment possible within state-of-the-art technology. Based on this knowledge research programs of mutual interest to industry and academia are taking place to develop the next generation of ship bridges. The prime concern of this research activity is security. The immense amount of information that the bridge officer is exposed to in stressed situations may pose a threat to safe ship operation. The central part of this research is to identify, extract and present the most adequate information to the ship officer at any time. This is a complex problem, but the focus in this work is limited to the use of the latest and most appropriate sensor technology and efficient extraction of relevant information from the large amount of data acquired in these situations. Part of this research is directed into the students' Bachelor and Master thesis, supervised by the professors involved in the respective research activities. The most prospective of these projects are followed up by the research staff and further developed. A most relevant topic in this setting is the utilization of sensor technology in combination with smart software that will enable extraction and presentation of crucial information to the ship officer. The working situation of the bridge officer is a context of monitors, lights, handles and joysticks, representing a severe amount of impressions. In this demanding setting the ship officer is expected to make the right decisions in the operation of the ship. In this context the concept of an augmented reality will come into particular interest. How should the officer perceive his world of extreme information load? How and when shall important messages manifest themselves to secure safe and economic ship operations? This is the superior aim of the research. On the way towards the target some topics of central interest have been chosen and investigated in cooperation between students and research staff. The effect of this initiative has been to provide realistic and motivating problem settings for the students, and challenging tasks of practical research to the scientist. Most of the projects have been realized through the design and building of small scale models, among which autonomous and remotely controlled model vehicles have become important tools for experiments and testing. This paper represents a survey of this broad activity, where three of these projects have been selected and elaborated. The projects represent a normative selection of the ideas and technologies which guide this research at the moment and concern the

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following topics; “Remote camera control by head movements” (Fjørtoft 2010), “Autonomous object tracking by a mobile camera” (Håheim 2010) and “Real time object recognition system for offshore operations” (XU 2011). In these projects modern sensor and vision technology and wireless communication systems are integrated into useful devices for search and tracking of selected objects. The idea is to make it possible to see and identify objects in areas otherwise hidden to the operator. Among the promising sensor technologies that have been explored here, is the advances in inertial measurements and gyro sensing devices (Håheim 2010). Vision devices like video glasses have also been examined. The experience gained from these projects represents a basis for further development of vision systems for surveillance of operations onboard and around a ship, especially in inaccessible areas and under high-risk conditions. A summary of the arrangements and results of each of these projects is presented in the next sections.

REMOTE CAMERA CONTROL BY HEAD MOVEMENTS

This project represents an experimental test of using video glasses in the field of visual surveillance and inspection. The video glasses were equipped with a tilt-compensated compass circuit, which includes a three-axis magneto resistive gyro and a three-axis accelerometer. With this equipment readings of the head’s pitch and yaw angles will be available at the appropriate time resolution to control the direction of sight of a remote camera in real time according to the movements of the head. In this way the field of view of the eyes will be extended through the lens of the camera. To the bridge officer the visual expression is very important in many operations, and the acquired information must be in synchronism with the actual operation in real time. Augmenting the officer’s sight through such glasses connected to cameras in strategic positions onboard the ship may be an important tool in improving his survey of all kinds of operations on deck and towards the surroundings of the ship. This kind of technology may also be extended by exploring new ways of projection of the visual information, for instance on the windows of the bridge.

Equipment and Connections

The system consists of two independent parts. The first part comprises a remotely controlled vehicle equipped with an Arduino Duemilanove microcontroller board (Arduino 2011), featuring an ATmega328 microcontroller from Atmel, and a motion stabilized platform with a Panasonic BL-C20 web camera. The second part is a control station with a PC and two Arduino Duemilanove (ATmega328) microcontroller boards. The microcontroller boards are furnished with appropriate Arduino shields to perform the necessary I/O functions. The interface shields are connected to the microcontroller boards through the general serial bus “Serial Peripheral Interface” (SPI) defined by Motorola (intersil 2007). The control station layout is shown in Figure 1. The PC receives the video signals from the remote camera over a local Wi-Fi network and processes each picture in the video stream. This communication is established by furnishing one of the Arduino microcontroller boards at the control station with an Arduino Ethernet shield that enables connection to a wired Ethernet. The connection to the local Wi-Fi network is obtained through a Nano WiiReach (ConnectOne 2011) wireless LAN bridge using the 802.11b/g standard. All of the communication to the remote vehicle takes place on this local Wi-Fi network. This microcontroller is also connected to an analog joystick and a tilt compensated compass device of the type HMC6343 (Honeywell 2011). This MEMS chip is mounted on the video glasses and uses a combination of gyro and accelerometer to monitor the pitch and yaw angles of the head. It is connected to the microcontroller by use of the serial Inter-Integrated Circuit bus (I^2C) (Philips 2007). The microcontroller uses the readings of the head angles from the compass device to position the onboard camera, and the joystick is used to manually control the remote operation of the vehicle. The second Arduino microcontroller board at the control station is used to control an On Screen Display (OSD) chip of the type Max7456 from Maxim (Maxim 2008). The OSD is connected to the microcontroller by use of the SPI bus, and is programmed by use of an own library for MAX7456 developed by Arduino. It takes as input the video signal from the PC and writes a text to selected images before forwarding the video stream to the video glasses. It is the ATmega328 on the basis of the input information that selects which pictures in the video stream to be written to, and chooses the position to write the informative text. In this way messages of importance to the operator may be projected to the visual field of the video glasses. The vehicle is also controlled by an Arduino Duemilanove microcontroller board (ATmega328). This board is connected to an Ethernet access point through an Ethernet shield. The onboard web camera is mounted on the motion stabilized platform and is connected to the access point by cable. It is configured to transmit its images over the Wi-Fi network independent of the microcontroller communication. The steering and speed of the vehicle are both controlled with PWM signals by a LM-406FB motor controller unit, commonly used in the hobby market. The camera angles are controlled by use of a Pololu servo controller (Pololu 2011) which is set up to control two DC servo motors. The ATmega328 communicates with the Pololu controller over a serial line. The Pololu is configured by sending it a string of 5 or 6 bytes. In this case the Pololu is programmed to control both speed and position of the servo motors by use of PWM signals. The connection diagram for the vehicle is shown in Figure 2.

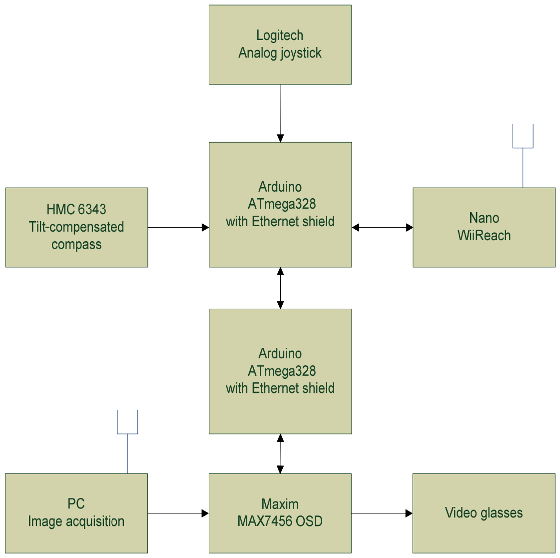

Figure 1: Control Station Diagram

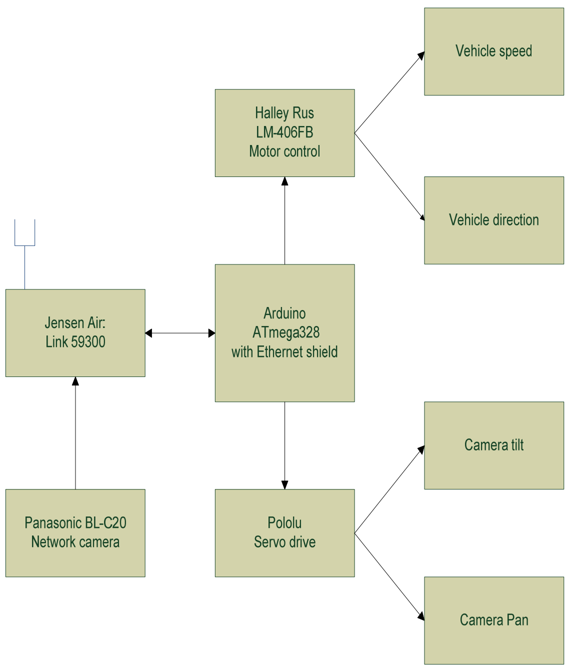

Figure 2: Vehicle Connection Diagram

Software and Communication

The application programs for the ATmega328 microcontrollers were developed in C++ by use of the Arduino IDE. The Arduino API is delivered with several libraries for controlling the different I/O ports, including the SPI bus, the I^2C bus and Ethernet communication. The wireless Ethernet communication is set up as a client/server connection with a simple telegram protocol described below. The vehicle is configured as the server, and both the PC and the ATmega328 at the control station are configured as clients. Permanent MAC and IP addresses are defined for both server and clients and the server listens to a predefined port number. This instantiation of the Ethernet communication is performed by use of the Ethernet Library from Arduino. To transmit the values of the control variables to the vehicle a simple telegram including 16 bytes of information was designed. The variables are heading and speed of the vehicle and pan and tilt of the camera. The video camera uses the compress method M-JPEG. This method compresses each picture in JPEG format before assembling them into a video film. This gives very good picture quality at low transfer rates. The speed is 15 images per second at the resolution 320x240 pixels. On the PC the video stream is received and presented by the program Active Webcam (Py software 2011). This is a very versatile program package for distribution of images from all kinds of video units. The program can be run with a full screen secondary monitor, which is used here to forward the pictures to the video glasses.

Programs for the Arduino Microcontrollers

The program applications for the control station and remote vehicle are quite extensive. The most important parts are the following procedures:

Managing the Ethernet communication

The Ethernet communication is based on the Ethernet library from Arduino. This library includes a data buffer that holds all the characters received from the net. To avoid corruption of data a telegram of a total of 20 bytes was designed to hold information and a simple synchronization protocol was implemented. When a complete telegram is received, it is immediately transferred to another buffer for processing. The telegram starts with the symbol “<” and ends with the symbol “>”, and the variables of the telegram are separated by commas. The variables are extracted and converted from ASCII to integer representation and stored in their respective memory locations. When one complete telegram is processed, the variables are used to update the positions of the four servo motors of the vehicle. At last a message is returned to the client to inform that the server is ready to receive a new message.

I^2C communication with the compass unit and data extraction

The communication on the I^2C bus is performed by use of the Wire library from Arduino. This library contains all the routines necessary to establish the communication and transfer the data. The default slave address for the compass unit on the I^2C bus is 0x32. The procedure is to send a command asking for the values of the head’s roll and pitch angles. After a delay of 1 msec. the values will be ready on the bus as three pairs of bytes. Each pair of bytes is converted to a 16 bits integer. The head angles are referred to the north compass direction and will change from 0° to 360° at this point. The result of this is that the servo motors will be turned the wrong way. Therefore, when passing the north direction the angles have to be further processed by a routine that decides the correct direction of the servo drives.

SPI communication between Arduino and OSD

The On Screen Display hardware is implemented by the chip MAX7456 on an Arduino shield using the SPI bus. There has been developed a special software library for this chip by members of the Arduino forum. This library makes it straightforward to send a string of information to a given position at the image, and also to clear the information.

Instantiation and communication with the Pololu servo controller

With the demands set in this project for quick and smooth camera positioning the servo controller has to be configured for Pololu mode, which enables the servo to control both speed and position of the motors. Commands are sent to the servo controller as telegrams of 5 or 6 bytes over a serial line using the standard Arduino library.

AUTONOMOUS OBJECT TRACKING BY A REMOTE CAMERA

Among the many different activities in the operation of a ship, surveillance by use of lights and cameras are of crucial significance in many situations. Both in rescue operations and in the handling of cargo and equipment from the ship there is often a need for fast object recognition and following. The search equipment has to be mounted on motion platforms for compensation of the ship movements, and search algorithms have to be developed for accurate and precise detection of the object position. This type of operation depends on the interaction of a selection of quite complex hardware and software, and the close cooperation of several parallel activities. This is a field of growing importance and thus also an important research area.

Equipment and Assembly

In this experiment the search operation is realized by the building of a small scale autonomous model vehicle equipped with a web camera on a stabilized motion platform. Figure 3 shows a picture of the vehicle. Onboard are two independent control systems, one for the motion of the camera by the platform for the purpose of finding the object; the other for the control of the car to follow the object. Both control systems are run on a local Phidget microcontroller board (Phidgets 2011) programmed in Java. The purpose of the vehicle is to find and track a red ball moving on the ground. The tests were performed mainly inside the laboratory building on floors of fairly uniformly colored surfaces, but also on an outdoor parking area with rougher ground and a more diversely colored surface. Because of the substantial computational load of the image analysis the video stream from the camera was transferred as a sequence of still images over a Wi-Fi connection to a stationary PC. The PC performs the image analysis and recognizes the object. When the position of the ball is defined, its location relative to the vehicle is calculated, i. e. the distance and angle of direction. These variables are sent to the Phidget controller on the vehicle, where they are used to calculate the reference signals to control the vehicle and the camera. Altogether four control signals are determined, the speed and steering of the vehicle in addition to the yaw and pitch position of the platform holding the camera.

Hardware

The hardware is built around the Phidget SBC 1070 microcontroller development board. This is a very powerful and versatile controller including four general USB ports to connect a number of auxiliary components. On the vehicle these ports are used for a Logitech QuickCam Pro 5000 web camera and the LPR530AL 6DOF Razor inertial measurement unit (IMU) (STMicroelectronics 2009). The IMU includes a three-axis accelerometer chip ADXL335 from Analog Devices, a dual-axis gyroscope chip LY530AL (STMicroelectronics 2011a) and a single axis chip LY530ALH (ST Microelectronics 2011b). Included on the SBC 1070 board are also a Wi-Fi connection and the Phidget Advanced Servo Kit for controlling the four servo motors. All hardware was built into a solid cage to withstand rough treatment.

Stabilized Platform

The camera is mounted on a 2D stabilized motion platform, see Figure 4. The control of the motion platform has a twofold objective, to move the camera according to the reference positions given by the search algorithm, while synchronously keeping the platform compensated from the influence of the vehicle's roll and pitch angles caused by motion on an uneven ground. This last aspect is taken care of by use of the inputs from the Inertial Measurement Unit (IMU). The IMU combines the readings from accelerometers and gyroscopes to obtain precise measurements of angles. In this procedure a Kalman filter (Balchen and Mummé 1988) was used to extract the optimum information from the measurements. Depending on the noise in the accelerometer readings the Kalman filter will decide the weights put on the gyroscope measurements. In this way the camera motion pattern will be controlled independently of the random movements of the vehicle.

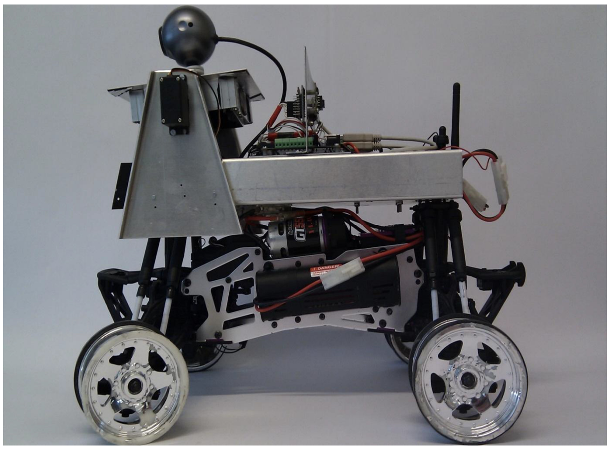

Figure 3: Autonomous Path Tracking Vehicle

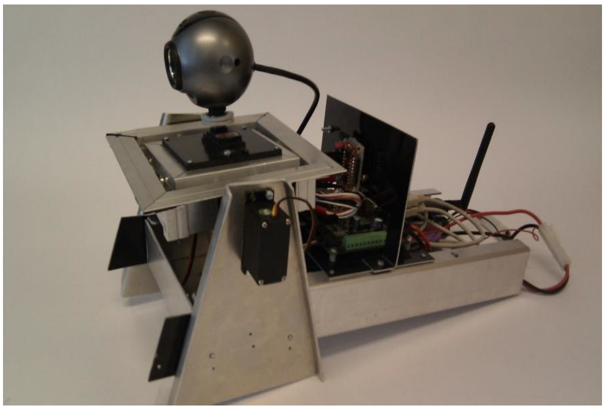

Figure 4: Stabilized Camera Platform

Image Analysis

Because of heavy computational load it was decided to perform the image analysis on a PC. The pictures are received from the web camera in real time and treated as single still images. For the analysis the Java Advanced Imaging (JAI) (Java.net 2011) package was used. Several basic algorithms were used in the search for the given object. First a threshold level was found to distinguish the ball from the background, and the image was transformed into a binary representation. Then morphology, in form of growing and erosion, was used to shape the images and remove structural elements smaller than a given limit. After these operations a labeling algorithm was used to identify the separate objects. Now the resulting image representation is ready for the identification of the ball. This was performed by a function finding the most circular object. The area and a representative radius of the object are used to estimate the value of π from the formula $\pi_e = A/r^2$. Then the objects in the image are tested for maximum roundness by the function:

$$e = \sqrt{\left(1 - \left(\frac{\pi}{\pi_e}\right)^2\right)^2} \qquad (1)$$

Once the roundest object in the image is found, the ball is supposed to have been localized and the coordinates of its center within the image is calculated.

Software

Java is used as the programming language for the software implementation of this project, and NetBeans has been used as the development environment. In addition to standard Java some auxiliary program libraries have been implemented. The most important ones are the Java Advanced Imaging library for use in the image analysis on the PC, and the proprietary Phidget library for implementation on the Phidget controller. This last library includes object classes with software drivers for all hardware ports on the Phidget SBC, including the classes for acquisition of images from the web camera and control of the Wi-Fi connection. The Phidget SBC is set up as a server and the PC as the client. A ServerSocket object on the Phidget listens to a network port with the method *serversocket.accept* until it gets contact with the PC, which returns its IP address and port number for the connection. The necessary streams for communication are then established on both server and client.

REAL TIME OBJECT RECOGNITION SYSTEM FOR OFFSHORE OPERATIONS

This is a research project to develop a vision system for real-time observation and presentation of human activities on a ship deck. The system aims to detect, recognize and follow objects entering the deck scene. The purpose is to help the bridge officer to command and schedule the working process on deck in a safe and efficient manner. The project uses methods and principles described in the above sections to simulate a realistic working environment on a ship deck. In demanding and potentially dangerous ship operations, like anchor handling, it is crucial that the leading officer is able to watch the whole operational scene. This may in some cases be difficult, even impossible by one person. In this work an arrangement of four cameras is used to cover the overall operation. A suitable graphical user interface (GUI) with well arranged camera fields and icons makes it easy for the officer to view any part of the scene from different directions. There are also substantial software applications to detect and recognize objects, and to track the movements of objects on the scene. By this arrangement the bridge officer will be able to follow all activities during the deck operation. A small scale test rig was built in accordance with the dimensions and layout of the deck scene. With this model it was possible to simulate deck operations with different kinds of objects on the deck. In this way the camera equipment and software applications could be tested, and image processing algorithms could be explored. See Figures 5 and 6 below.

Equipment and Software

The camera system consists of four USB cameras connected to a central computer through an USB hub. The cameras, of the model Logitech Webcam C270, are located at each corner of the deck so that they can survey the entire deck area. By use of the GUI the officer can choose which of the cameras to be active at any time, each camera view being presented on a separate screen window. He can also select one camera to cover the whole screen for closer inspection and image analysis. The application programs are developed in C++ by use of Microsoft Visual Studio 2008. The graphical user interface is developed by use of the Qt UI framework (Nokia 2011), implemented as the Qt - Visual Studio Integration. The image acquisition and analysis is performed with OpenCV (Open Source Computer Vision Library) (Willow Garage 2011), including the Intel IPP (Intel Integrated Performance Primitives) (Intel 2011). Object recognition and tracking is the central part of this project, so much effort has been laid down in developing effective algorithms for this part of the application. The OpenCV library contains all the basic algorithms for image analysis, and these are explored and combined to give secure methods for recognition and tracking of objects on deck.

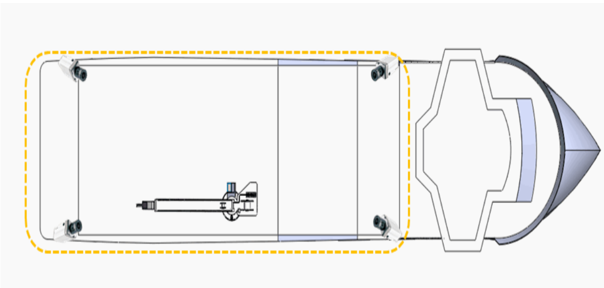

Figure 5: Camera Configuration on Deck

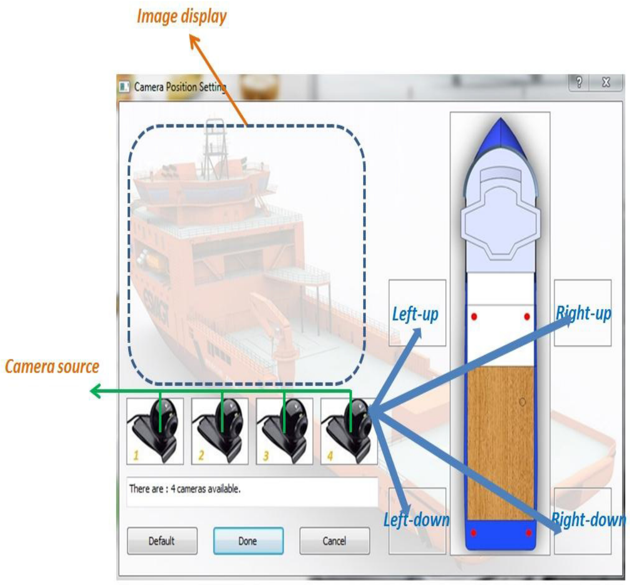

Figure 6: Graphical User Interface

Digital Image Processing

The video cameras record images at a rate of 20 images per second and save them to a disk as individual AVI files. The resolution is 320x240 pixels with the option of 640x480 when using only one camera. The saved images from simulations are used for later testing and experimenting with different kinds of image processing algorithms. Object recognition is done by the following procedure. First the image is converted to a grey scale and the static background is subtracted from the image. Then a dilation filter is used to reduce noise, and a threshold function is used to transform the image to black and white. After this an edge function is used to find the contours of objects in the image. Objects smaller than a given size, are removed as noise and the rest of the objects are bounded by minimum rectangles. The positions of these objects relative to the deck coordinates may now be accurately calculated based on corresponding images from multiple cameras. The objects and positions are saved to disk. A database of objects is maintained for later comparison and identification of new objects. To track objects they have to be compared from image to image. This is done by comparing the contours of the objects by the use of moments and histograms. In the OpenCV software there are three different algorithms for comparing contours by moments. However, this method gives only an approximate result working only for objects of quite different shapes. This is because the objects change with camera facing and lighting. The histogram matching is performed both on the grey scale images and on the corresponding color images. The algorithms used for histogram comparison are Correlation, Chiaquare, Intersection and Bhattacharyya. By using an EMD matching on the results of these three methods, a distance measure from the exact model is found, and a good match may be verified.

DISCUSSION

The primary goal of this work has been to investigate new trends in sensor and vision systems for possible integration of such technologies into the future ship bridge. As the operations on modern ships become increasingly more complex and demanding there is a need for exploring new sides of human machine interaction. Here the focus has been on the rich market of consumer electronics driven mainly by the cell phone and game industry, resulting in the development of advanced and low-cost sensor and vision technology. Experiments with selected equipment of this type have been performed on small scale physical models, mainly by building remotely controlled and autonomously operating ground vehicles. However, the aim is to find new technologies to be adapted into the context of the future ship bridge, and the vehicles represent an easy approach to testing equipment and methods in an adequate way for ship operations. The results of these tests are documented through the fact that the different devices function well in the designed context, and that the vehicles perform their tasks in accordance with the plans. This is like an interactive trial and error process where components and methods are systematically selected and tested in practical experiments.

CONCLUSION

The underlying aim of this work has been to investigate some new products in the consumer technology market for possible future employment of such technologies in ship operations. This activity of practical testing of vision and sensor systems on small scale models has shown to represent a fertile way to reveal the potential for adapting this technology into the ship bridge. The surplus of new devices within wireless communication, vision systems and MEMS components available in the consumer market, driven by the cell phone and game industry, represent fantastic new possibilities in the integration an adaptation of advanced technology into more traditional fields, both in the production process and in the products. The experiments performed in this work have revealed that it may be highly beneficial to keep an eye on this market, and they encourage further work towards implementation and use of such technologies in real ship operations. In the testing of these devices and concepts the approach of building small scale models as test equipment has shown to be very efficient.

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