Autonomous messenger using propeller LED display

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Abstract— **The difficulty to communicate effectively during unforeseen circumstances has very often lead to serious problems where the safety of the population has been at risk. The problems may be due to the simple fact that the person wishing to send a message does not have the contact details of the person/s at the other end. Although extensive communication network exists in most countries, there are situations where people do not get the required message in time. This report deals with the design of an autonomous/remote messenger (robot) that can receive and send messages using the GSM network. The robot can be used at any time to inform the target group of any mishaps. An authorized person simply has to send the appropriate codes via the Short Message Service (SMS) to the robot. When the robot receives the SMS, it will decipher the message and convey the message to the persons at a desired location. The message is displayed on a propeller LED with a 360^0 viewing angle located on the robot. The system is not designed to enter inside individual rooms but a wireless communications system allows the robot to send a message inside the room to call for the attention of the persons inside the room. The major challenge was to design the propeller display as it uses the persistence of vision to clearly display the message. The autonomous messenger also includes a remote control for manual navigation of robot, ultrasonic sensors for obstacle detection, battery level indicators on the display and the robot, interlocks and an emergency switch among others. Sustainability has been an important issue while manufacturing the system and as far as possible components from waste has been used without affecting the performance of the system. Variants of the proposed system can be produced depending on customer requirements e.g. display can be attached to the ceiling or wall and display messages as requested by SMS.**

Keywords—Propeller LED; Autonomous system; Messenger; Mechatronics.

I. INTRODUCTION

Robotics has evolved from industrial robots to service robot with an increase in the degree of autonomy and complexity, producing flexible systems that can perform in a more dynamic environment with human interaction [1]. The low cost and easy availability of electronic components has prompted many companies to manufacture small robots for residential or light commercial applications. Service robots will represent a major share of the robotics market in the future and World Robotics [2] estimates that between 2013 and 2016, the sales of service robots will amount to US$17.1 billion and US$5.6 billion for professional and personal use respectively. A feasibility study carried in 2007 and 2008 investigated the application domains in which a service robot can be beneficial [3]. Yu et al. [4] designed a restaurant service robot to take care of customers' orders and serves them as well. All of them are coordinated via a central processing computer. A key issue for any autonomous robot is its localization, especially for indoor mobile robots. In this research [4], a global vision-based localization method is used to periodically detect its rough position and an RFID-based localization method is used to obtain a more accurate position. Another type of service robot which has much potential is remotely controlled robot by a human operator to assist the robot when needed. Robots are now intelligent machines which can perform a wide variety of tasks, even underwater and in the air [5]-[6], and can recognize objects using sensors similar to our senses [7]. Human assistance is justified in some cases by the fact that the robot will not always have a suitable reaction to every situation in an uncontrolled environment [3].

Robotics is gaining popularity and its use is no longer limited to traditional manufacturing systems. The low cost and high reliability of electronics components is encouraging the development of new systems. Innovation can help countries in their quest to find new economic pillars to support the growth of the country. The developing countries should take necessary actions urgently to claim a share of this relatively new industry. Innovation must be one key learning outcome of the education system and the students must be encouraged to be creators and not only job seekers. Appropriate facilities must be set up to provide support to young graduates with the potential to develop new equipment/systems which can be manufactured on large scale.

Small Island Developing States (SIDS) are relying heavily on the new breed of entrepreneurs, the techno-preneurs, to come up with start ups in the emerging fields to sustain the economic growth of the countries. There are many young graduates with loads of new ideas but end up in doing traditional engineering works due to lack of appropriate support from authorities. This support will encourage the entrepreneurs to innovate and create new equipment and provide new avenues of development for the country.

Manufacturing companies in Mauritius are rarely involved in research and development (R&D) but rather produce for international brands. The companies are more focused in attracting the international customers and often do not concentrate on enhancing their production facility because of financial constraints. R&D efforts [8] can help companies to create an identity that will support their growth and competitiveness on the world market. Incubators will help the techno-preneurs to come up with new sectors which will eventually lead to successful small and medium enterprises (SMEs). These SMEs are more flexible and can adapt to the rapidly changing consumer moods with relative ease. Studies have shown [9] – [12] that local companies can benefit from collaboration with the university in developing tailor made equipment/system but the main hurdle is funding. There are plenty of scope for proper collaboration between universities, especially in small island developing countries, and local companies to develop new autonomous systems to support the local industry or develop products for new niche market.

Universities in small island development states (SIDS) are striving to provide adequate training to local population to support the economic growth of the countries. In this spirit, the University of Mauritius launched the B. Eng (Hons.) in Mechatronics programme in the late 90's. The students of this 4 year full time programme have to complete a major project related to their field of study in the final year. The students very often come up with innovative piece of equipment adapted to the local context but the prototypes are abandoned once the students graduate. There are no support and funds available to optimize the design and apply for patents and other similar procedures. If the young graduates are given the appropriate support [13] – [14] they will continue on this path of innovation and create small and medium enterprises in new niche sectors.

This paper describes the design of an autonomous messenger in the wake of the deadly flash flood that took place in the country in 2013. The country was shaken by a flash flood which took the lives of many people and many people were not even aware of the calamity touching the capital of the island. This lead to major traffic problem causing shutdown of the transport system temporarily. The population was not getting the relevant information in time and those who got the information tried to flee non affected areas towards affected areas hence causing more stresses on the already stricken areas. The robot will only be a means of communications to transmit the message from a remote requester to the audience gathered at a location.

An application where the robot has to display the message at different locations is selected to maximize the use of the robot. The robot will have to move to a position in front of the appropriate room and then call the users to transmit the message. The robot is designed for the case of a resource person at the University who would like to inform his students of certain problems. The lecturer may not have the personal phone number of the students and may not be able to inform them in case there is an emergency. The objective is therefore to design a system which can receive a call from an authorized person and transmit the message to the targeted audience.

II. THE SYSTEM

The objective of this project is to design and construct an autonomous messenger that will be able to deliver a message sent by a person from remote location to an audience in a specific room. The system is designed to operate on a single floor with rooms on both sides of corridors not necessarily parallel to each other. The rooms are fitted with doors and the robot will not be designed to enter the individual room but will rather inform the occupants that it is waiting outside with a message. The design will, therefore, consists of room modules which will be communicate with the robot outside. Each room can be fitted with a display connected to the GSM network but the cost of the system is relatively higher. One major problem is that the person wishing to send the message needs to have the library of phone numbers for each room whereas in the proposed system only the room number needs to be specified.

The robot will be on standby mode and will be switched on by the message received via the GSM module. When the autonomous system receives a message for room A, the robot will navigate to room A. It will identify and stop in front of the room and then send a message to the room module. The room module will give a visual signal to inform users that there is a message on the messenger outside in the corridor. Users will then have to open the door to take cognizance of the message and also acknowledge that the message has been received. Acknowledgement can be from authorized persons only, if required. The product specifications have been determined and the autonomous robot messenger will consist of the following subsystems:

- Autonomous robot
- Navigation system
- Display system
- Room identification system
- Communication system

Fig. 1 illustrates the general system structure and how each subsystem is integrated into the equipment. The individual subsystem are discussed in details in the later sections.

The display and the autonomous system will be designed as two independent entities. The display will be self contained and include the power supply and microcontroller. This will allow the use of the display separately at a fixed location to transmit message to all users in a room or gathering place.

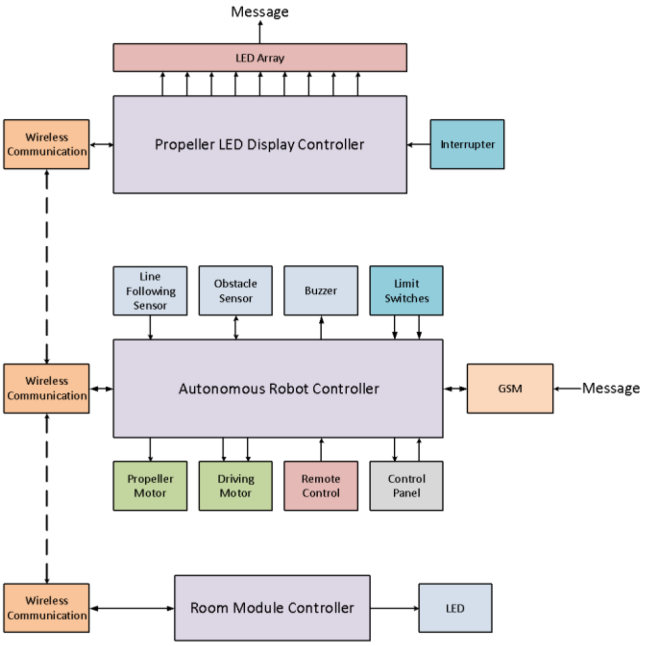

Fig 1: Overall System Block Diagram

III. Subsystem Design

Each subsystem has been designed and tested individually before integration together. The main components of each subsystem are discussed in the subsections that follow.

A. *Robot*

As the autonomous robot will operate in an environment occupied by human beings, it should be expected that it will face vandalism. The robot main components have to be completely enclosed in a properly sealed container to provide basic protection to the robot. Appropriate measures are taken to protect all the sensitive circuits and electrical and electronic components. The frame should be strong enough to carry the display and all the other components of the robot.

Fig. 2 shows the autonomous robot with the propeller LED display in a plastic container. The base is made up of composite material and is sturdy to withstand shocks and deformation. The display is enclosed in a separate container safely secured to the base. There is no direct access to the components of the system. LEDs on the front panel give information on the status of the system during operation.

A basic cubical design is used and the size is selected to enclose all electrical components and also to support the display. The top surface will be 30 × 30 cm to allow some space for fittings. The inside will be 15cm high to allow the antennae of the GPRS shield. The back will be inclined to have good vision on the control panel. In an attempt to have a sustainable design, the 3R concept (Reduce, Reuse, and Recycle) is implemented where possible. Waste aluminum composite panel been obtained free of charge from a local workshop to make the frame of the robot. TCRT5000® limit switches are used as interlocks on the robot to detect if the display cover is in place and if the back panel is closed.

The differential drive steering system is implemented on this robot and the robot needs two driving motors. The differential drive offers a better maneuverability than the Ackermann as it can rotate on itself, especially in limited space. For this application, using brushed DC motors is the most appropriate solution as speed control is required for differential steering. A DC motor can be controlled via PWM and the rotation can be reversed by using an H-bridge. The L298N driver board is a dual full H-bridge driver that meets all the requirements to drive the 2 DC motors.

Lithium-ion (LiPo) polymer batteries are used to power the autonomous system as they offer very desirable characteristics in terms of capacity, specific power and cycles. NiMH batteries have a very high self-discharge rate which is not desirable and the lead acid batteries offers good characteristics but its specific power is very low, which would make the prototype heavy. Since LiPo batteries come in cells with a nominal voltage of 3.7V, a 3 cell in series (3S – 11.1V) LiPo battery is used.

Fig 2: The Autonomous Messenger

The different Arduino boards were compared and the Mega 2560® board was found to be the most appropriate board for the autonomous robot. The microcontroller will be interfaced to all the different components making up the autonomous robot and integrate them together to work as a complete system.

B. *Navigation System*

The navigation system will guide the robot to the target room and detect obstacles, which will be mainly human lower limbs, across its path. The line following and wall following navigation systems are more suitable for indoor use compared to the GPS. However, line following offers less disturbance for this application as steering will be based on a dedicated path, compared to wall following which will be affected by the existing doors and corners. Also, students and personnel will have a visual awareness of the robot's path.

Obstacle detection sensors are important for the robot to sense obstacles along its path and stop until it is cleared. The sensor should be able to detect obstacles ahead of the robot and determine the approximate distance to the obstacle. The obstacles are mostly human beings and the robot is fitted with a buzzer to inform the persons of its presence.

The HC-SR04® ultrasonic ranging sensor using ultrasound at 40 KHz is used. The modules includes ultrasonic transmitters, receiver and control circuit. The HC-SR04® is chosen as it is not affected by sunlight or black material, has a longer range and accuracy and also consumes less power than the IR based sensor.

The TCRT5000® has a compact construction where the emitting-light source, an IR LED and the detector, a phototransistor, are arranged in the same direction to sense the presence of an object by using the reflective IR beam from the object. The TCRT5000® IR sensor is chosen as the line-following sensor for the autonomous robot. Its small size, compact packaging and lower effect due to ambient light makes it the most appropriate component to be used.

C. Display System

The system will be designed to operate in corridors with different room orientations. In such a case, a fixed display is not appropriate as the occupants may have difficulties to read the message or even find the display easily. The display system should be clearly visible and have a 360^0 viewing angle so that the persons can read the message without problems from any position. To be more effective, the message must move to the users instead of users moving around looking for the display.

The most appropriate display in this case is the propeller LED display which uses human perception limits to display an apparent continuous image. It consists mainly of a set of LEDs, a microcontroller to synchronized the switching on and off of the LEDs at precise time intervals and a motor that will spin the LEDs at a high speed. Propeller LED displays can either be in a circular disc configuration or in a cylindrical display configuration and the latter is selected as it displays undistorted text and also it offers the required viewing angle. The main advantage of this display as compared to the flat panel display is that the message can be read from any directions. The prototyping board itself is used as the propeller to minimize the weight and parts used for the propeller LED display. The fiberglass-reinforced epoxy laminate board has been selected to make the propeller because of the superior electrical and mechanical properties as compared to synthetic-resin bonded paper.

Basic safety requires that any component rotating at high speed is covered to reduce risk of injury to humans. The display will be covered using a material that resists impacts, has a high transparency, has a low refractive index, be spill-resistant to protect circuit in case of spills, and be circular in shape for a 360^0 viewing angle. In the event the cover is opened, the propeller should stop immediately. A limit switch to detect the presence of the cover is necessary. Fig. 3 shows the conceptual design of the display.

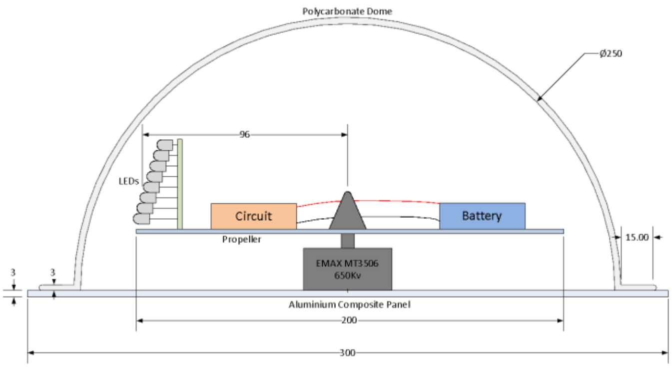

Fig 3: Propeller LED Display Concept

A plastic container consisting of a transparent lid and a base is used to support the display system. The propeller display system will be completely enclosed in the plastic container giving a separate module. The base of the module will then be secured to the top of the robot and the propeller motor will be fastened to the base to attenuate vibration.

The propeller LED display is chosen as it is the only one that can display clearly visible text with a perfect 360^0 viewing angle. It also has a lower power consumption than the LED matrix boards. The display consists of 8 LEDs arranged one above the other so that they form a line inclined at an angle, θ, to the vertical as shown in Fig. 4. However, a safe way to isolate the display and reduce noise need to be considered. This display allows the persons to see the message due to persistence of vision which needs a minimum frequency of 17Hz. At this low frequency flicker can be disturbing and, therefore, a compromise will have to be made between the display quality and the speed of rotation as vibration is likely to occur in the system. A frequency of 50Hz, equivalent to 3000RPM, can be used as the top speed of the propeller.

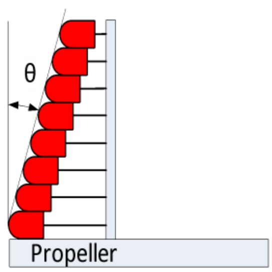

Fig.4: LED display inclination

The LED is powered by an on board battery which is placed on one side of the propeller and this is also used as counter balance. 4.8mm white straw hat LEDs having luminous intensity 20000 mcd are used. The weights LED and the battery were not the same causing excessive vibrations during rotation. The system had to be balanced by adding weights as required. The height of the display from the floor will be approximately 30cm and therefore not perpendicular to the eyesight level. A slight inclination θ^0 is required for proper viewing and the value of θ should be kept low ($< 20^0$) to minimize the distortion on the characters due to the difference in radius.

A microcontroller will be mainly responsible for the fast switching of LEDs and the wireless communication with the autonomous robot. The chosen board is the Arduino Pro Mini® which satisfies the required criteria. Since the display will operate in an independent manner, information still needs to be transmitted from the robot to the display and vice-versa. Therefore a wireless communication needs to be included on the propeller. A brushed DC motor is used to spin the propeller LED in the range 1000RPM to 3000RPM to have a good quality display.

The character height of the display is important for good visibility. A minimum of 30mm height will be used. LEDs will make the characters appear dot-like and an appropriate font must be used to display the characters. By allocating a 7×5 matrix for each character, the similar font used on LCD character displays can be obtained. A blank column is added to space characters. Therefore all characters will be based on a 7 x 6 matrix which will be the building blocks for the display algorithm.

LED Scanning

		C_0	C_1	C_2	C_3	C_4	C_5		
LED[0]		0	1	1	1	0	0		R_0
LED[1]		1	0	0	0	1	0		R_1
LED[2]		1	0	0	0	1	0		R_2
LED[3]		1	1	1	1	1	0		R_3
LED[4]		1	0	0	0	1	0		R_4
LED[5]		1	0	0	0	1	0		R_5
LED[6]		1	0	0	0	1	0		R_6

Fig. 5: Matrix of Letter A

The proposed algorithm to make the LEDs light up at specific time interval and in proper sequence is shown in Fig. 5. The LEDs are mechanically scanned from left to right (anticlockwise rotation) and individual column are lit up according to the matrix being displayed.

To display the letter ‘A’, its corresponding matrix is passed into the display algorithm function. Column after column, the value of each row is assigned to each element of the LED array. Symbols can be easily created using the 7x6 matrices as shown in Fig. 6. The average current consumption is 10mA per LED and 200mA for the propeller motor. This gives a total of 270mA for the display as compared to an average of 8820mA for the conventional LED display with the same pixel count (126x7).

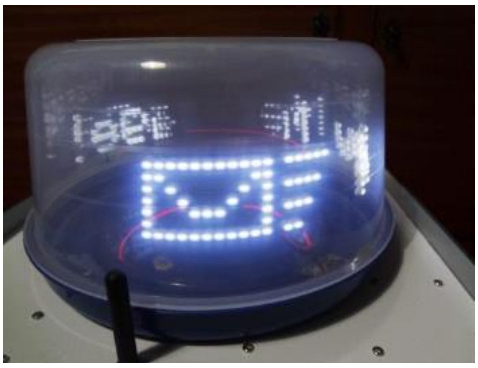

Fig. 6: Custom made symbol

D. Room Identification

It is important to have a room identification system so that the robot can differentiate between different rooms. Passive and active identification are available but the active identification is chosen for the room identification. The same wireless communication between the robot and the display will be used to include the rooms. The nRF24L01+® transceiver is used for wireless communication between the room unit and the autonomous robot. Few external components are needed to design a radio system with this chip. The nRF24L01+® is configured and run through SPI.

A room module has been designed that will periodically send the identity of the room which will be picked up when the robot is searching for the room. This will help the robot to clearly differentiate between classrooms. And if there is a message, the module will blink an LED and sound a buzzer to attract attention of the occupants. The Arduino Pro Mini® is chosen again for its small size and customizable mounting. The room module is powered using a USB charger.

E. Communication System

Communication system will be used in three cases, namely;

1. Between user and robot
2. Between robot and display (on the autonomous system itself)
3. Between robot and room module

The communication system will be responsible for the two-way interaction between the sender and the robot essentially. The chosen communication system should satisfy the following requirements:

- Easy access and user-friendly
- Allow distant communication
- Use an existing and reliable communication infrastructure to reduce implementation cost.

The Global System for Mobile Communication (GSM) is the leading mobile phone standard across the globe and in Mauritius as well. According to Statistics Mauritius [15], in 2012, 90.8% of the households have a mobile phone with 114.9 subscriptions per 100 inhabitants and more than 1.15 billion messages were sent through Short Message Service (SMS). Wi-Fi connection is readily available and free on the campus but the mobile phones operate on the GSM network and the coverage span over the whole island. The chosen communication system for receiving and sending messages is the GSM network.

Since the display will operate in an independent manner, information still needs to be transmitted from the robot to the display and vice-versa. Therefore a wireless communication needs to be included on the propeller and the nRF24L01+ transceiver chip from Nordic Semiconductor is selected for this application. The nRF24L01+® is configured and run through SPI.

F. Other features

The robot will be equipped with a control panel which will be the user-interface on the robot. Since the system will be autonomous, the interface will consist mainly of:

- Indicators to show status of system,
- Switches to trigger an emergency routine or acknowledge a hazard and,
- A buzzer to have an audible signal to catch attention.

A remote control is necessary to control the robot with a manual override. The remote control will be available with the person in charge of the routine maintenance of the system. Remote shut down of the system in case of malfunctioning will be possible. The remote should:

- Have a good range for distant control
- Low power consumption

The 315 MHz RF remote control is selected for this application. The main advantage that the RF remote control has over the IR one is the excellent effective angle and its very good range, even with obstacles.

IV. PROTOTYPE

The system has been designed and tested successfully and it can move and display the message simultaneously.. The robot receives the message from the user and acknowledges the message and delivers the message to the required classroom. Upon receipt of a request, the robot will start from standby and start its motion using the line following principle to the desired location. The occupants inside the room will be informed that there is a message for them and the robot will then start displaying the desired message (Fig. 7) which can be “no lecture” or Lecture delay”. A message is sent to the person who has made the request to confirm receipt of the request. The message content was limited to a maximum of three codes as the GPRS shield was not receiving all the codes correctly when more than 4 codes are used.

The characters form horizontal dashes instead of individual dots when successive pixels on the same row were lit up. This problem was solved by including an off delay between each column in the algorithm. The LEDs were roughened using a sandpaper to give a frosted surface for better display as the pixels appeared as concentrated dots giving discontinuous characters.

A voltage follower with high current sourcing was required as the navigation board caused a loading effect on the power supply leading to a significant voltage dip which affected the whole system.

The persons in the room will have to acknowledge receipt of the message and the robot will stop the display and move to a safe parking position. The system is not able to identify the person acknowledging the message at this stage but further works is necessary to include this feature.

Fig. 7: Autonomous messenger delivering a message

V. CONCLUSION

The autonomous messenger, as a service robot, was to provide a reliable and effective way for persons far from the location to send a message to occupants in a closed room. Many aspects in terms of cost, safety, reliability, user-friendliness, communication and even sustainability were considered in order to deliver a good and affordable service robot that has the potential of becoming a necessity in the future. Despite certain limitations and problems encountered, modifications were made to make the prototype perform satisfactorily. One major achievement in this project was the successful implementation of a propeller LED display which is a rather new and economical concept of displaying information. The message displayed was clear and easily readable for humans of average height. The user to robot and robot to user communication was successfully implemented using the GSM module. The cost of implementing the autonomous messenger is approximately USD350. excluding the development cost. The cost of the robot is relatively affordable and its benefit can only be measured in the time it allows students and lecturers to gain. Variants of this system can be manufactured to suit the requirements of the building. The robot can be enhanced further with the support of the authorities and can be economically viable.

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Biography

Santaram Venkannah is an Associate Professor in the Mechanical and Production Engineering Department at the University of Mauritius. He earned B.Tech (Hons.) in Mechanical Engineering from University of Mauritius, Mauritius, Masters of Science in Automation and Robotics from University of Coventry, United Kingdom and PhD in Mechanical Engineering from University of Mauritius. He has published journal and conference papers in sustanability and related fields. He has been involved with the B.Eng (Hons) Mechatronics programme since its launch in the late nineties and has supervised more than hundred projects in the field of Mechatronics. Many of the projects were industry based which have been implemented. He is a member of ASHRAE, AWS, IEOM, and Instituion of Engineers- Mauritius.

Damien E. B. Mallet is a fresh graduate who obtained his Bachelor of Engineering in Mechatronics Engineering with First Class Honours from the University of Mauritius in 2014. He is currently working as a Trainee Engineer in a leading firm of consulting engineers in Mauritius. His research interests include automation, robotic systems, PLC systems and sustainability.