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FORMAL VERIFICATION AND DESIGN OF SMART STICK FOR BLIND PEOPLE

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ABSTRACT— Researchers these days widely use formal verification to verify software and embedded systems. This paper is based on a smart stick (embedded system) designed for blind people. This embedded system design has been verified using model checking and formal verification. In this paper, an Arduino based stick has been proposed for blind users to help in their navigation by detecting the obstacles using Ultrasonic sensors and speech warning message. It is able to inform the blind person about the circumstances and present condition of the path where he/she is walking. The system is tested under different scenarios in verification and validation software to confirm its authenticity. This system has been practically implemented and, in this paper, we used formal verification and software validation tools to detect and remove any bugs in the requirement and design phase. We believe this will immune our code from bugs and we can find their possible remedies. We claim that this work is novel as we haven't found any solution in research for blind people that have been formally verified using model checking at design phase and validated using automated tools at requirement phase.

Keywords— Assurance Technologies, blind navigation system, embedded systems, formal modeling, software verification, smart system, model checking.

I. INTRODUCTION

Over a long period of time different solutions have been proposed to aid blind people for their navigation. From very early times, blind stick is used by visually disabled people in different forms. With the advancement in technology, modern devices like sensors and sound systems are added to this stick to improve and ease the navigation. Such devices are called Electronic Travel Aids (ETAs). Here the proposed solution is an advanced blind stick that allows visually challenged people to navigate using advanced technology like ultrasonic sensors & many others. This paper focuses on design of the blind stick, different components that are required for its practical implementation and formal verification of design of this embedded system.

By Verification it means to evaluate from the beginning whether the product is being built right. Whereas, Validation means to check whether the final product is up to the mark and meets all requirements.

Embedded electronics are used in every modern-day device and the complexity in their designs makes their analysis and testing more difficult. With the increase in design sizes, ways have been looked upon which verify the system with reduced number of vectors.

For this purpose, formal verification is used to mathematically prove the correctness of design by specifying precise models of the embedded system and verifying logical properties over these models. Also, it is a fast technique because its performance depends on type of logic on which it is deployed and the way it is applied. The system with certain properties is modelled in software and mathematical tools and logics are used to verify it, thus giving an insight of how system will work in real time.

For design verification UPPAAL model checker [3] is used. It can verify systems in real time by modeling them as networks in timed automata i.e. automation based on set of clocks.

A lot of work has been done in field of blind navigation but none of that work is formally verified. Moreover, no effort has been made to validate its requirements. So, the work presented in this paper is novel as this blind stick model will be both validated and verified at design stage.

This paper is organized as follows: Section 2 presents the related work in research; Section 3 describes different hardware and software requirements for this design. Verification of this design is discussed in Section 4. Future work is being discussed in Section 5 and Section 6 concludes the paper.

II. LITERATURE REVIEW

Software constitutes a major part of the development of embedded systems and is critical to their successful deployment in our everyday life. To make sure that systems give desired functionalities along with providing quality guarantees, formal methods and automated verification techniques and tools have been in use in the engineering of such critical systems for many years, Terbeek(2018). Although failures in sensor hardware and software can have strong influences on embedded system's operation, they are often neglected in the verification process, Ankit(2015) & Ayush(2016). Although no formal methods have been applied in design of a blind stick, but still a lot of work has been done to ease the navigation of blind. For this purpose, a blind stick containing ultrasonic sensors, buzzer and vibrating motor was developed in 2015 by Diana. Similarly, wearable devices like smart belt and smart goggles have also been designed. So many efforts are made to make this system portable, advance and cost effective for better service, Gerd Berhrmann.

III. DESIGN DESCRIPTION & METHODOLOGY

This section explains the design of our device and methodology adopted. It is further divided into following subsections. Section Aexplains the proposed model of our blind stick and Section B explain the Hardware components required. At the end, there is a flowchart that briefly summarizes the whole section.

A. Proposed Model

The embedded system proposed in this section is basically a smart stick to aid blind people as shown in Figure.1. The blind stick will consist of two ultrasonic sensors, one located at the bottom and other at top of stick to detect any obstacle in the path. An infrared sensor will be used to give indication of stairs and a water sensor at the bottom to detect puddles. Whenever any of these sensors is invoked, data is sent to microcontroller that activates the correct voice message accordingly that are stored in the SD-card module.

As compared to previous work done in this field, this model is designed to have these better features:

a) In wearable devices like goggles or helmet, sensors can be at only one level and cannot give coverage to whole body. In the proposed blind stick, there are two sensors one at top and other near bottom of stick that can detect almost every obstacle at level of human height.

b) In previous designs there is no contact with ground, so they can't give indication of water puddles.

c) The process of staircase detection is complex for blinds. In the proposed model, it is tried to achieve this goal in a rather simple way using IR sensors.

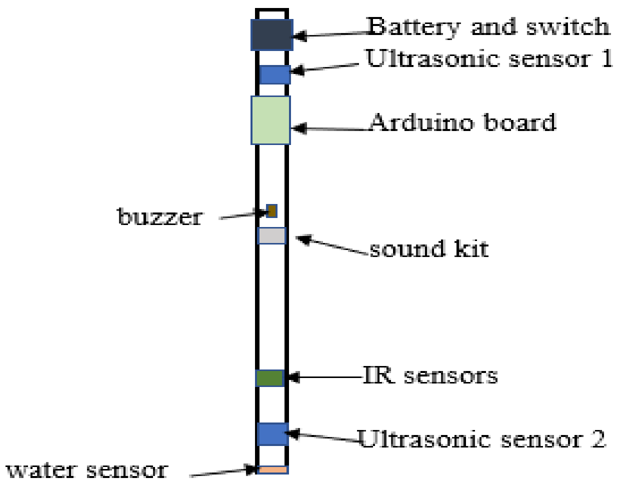

Figure 1: Model of Blind Stick

B. Software Requirements

Following software's are used in the design and verification of this embedded system:

- Arduino IDE
- UPPAAL

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The *Arduino Integrated Development Environment* (IDE) is a cross-platform application used to write and upload programs to Arduino compatible boards.

The IDE environment mainly contains two basic parts:

- Editor
- Compiler

The Editor shown in Figure.2 is used for writing the required code and Compiler is used for compiling and uploading the code into the given Arduino Module. This environment supports both C and C++ languages.

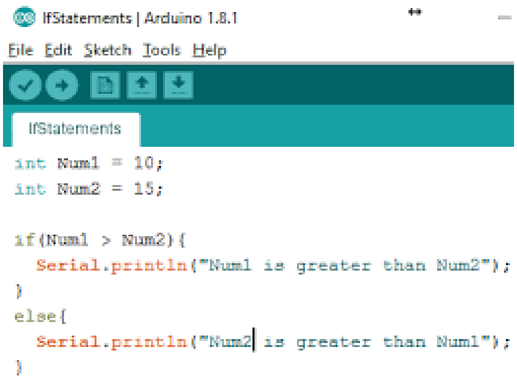

Figure 2: ARDUINOIDE

Before developing our code, we aimed to verify our design model. Thus, we used UPPAAL as design verification tool. *UPPAAL* is a toolbox for validation (via graphical simulation) and verification (via automatic model-checking) of real-time systems. It consists of two main parts:

- Graphical user interface
- Model-checker engine.

The system goes from initial to final state giving output. If there is some error in the path, UPPAAL provides diagnostic trace to find the fault. The basic idea behind UPPAAL is timed automaton i.e. the desired system is modeled as finite state machine along with clocks. The workspace of UPPAAL is shown in Figure.3.

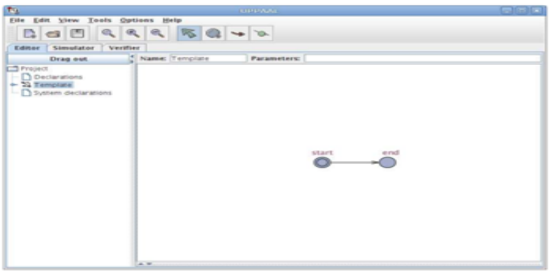

Figure 3: Overview of UPPAAL

C. Hardware Requirements

The hardware in our system is composed of 5 main parts:

- Arduino Due Microcontroller
- Ultrasonic sensor (HC-SR04)
- IR sensor
- Water sensor
- SD-Card Module and Speakers

The Arduino Due (Figure.4) is based on the Atmel SAM3X8E ARM Cortex-M3 CPU. This board is first one to be created as 32-bit micro-controller. For large projects, it is the first choice of developers.

Figure 4: ARDUINO Hardware

This *ultrasonic sensor* is used for measuring distance or sensing objects. The module has two eyes like projects in the front as US transmitter and Receiver. The sensor works on formula that

$$\text{Distance} = \text{Speed} \times \text{Time}$$

The Ultrasonic transmitter transmits an ultrasonic wave, this wave travels in air and when it gets objected by any material it's reflected toward the sensor. This reflected wave is observed by the Ultrasonic receiver module as shown in the Fig.5.

Figure 5: US Sensor

The *IR sensor* module shown in Figure.6 consists mainly of the IR Transmitter and Receiver and output LED.The LED of the module remains off when nothing is detected in its path.

Figure 6: IR Sensor

At the bottom of stick, we have used *water sensor* like the one shown in Figure.7. As its contact with water is made, the wires get short completing the path of current flow and it sends a signal to Arduino.

Figure 7: Water Sensor

The *SD-Card module* is used to store the voice messages in *.wav* format that are played according to requirement through a speaker.

The *working methodology* can be elaborated in this *flowchart* shown in Figure.8:

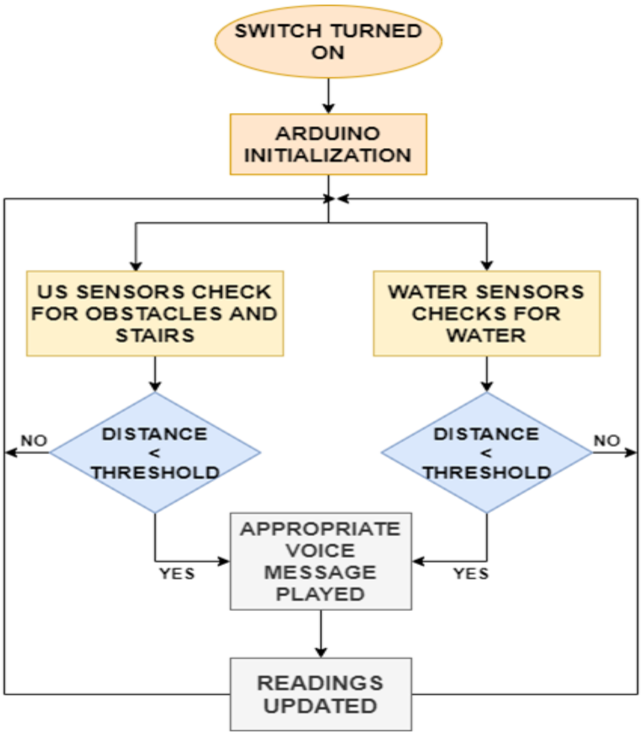

Figure 8: Flowchart of Work Methodology

As the power switch is turned ON it initializes the Arduino board. The sensors get a signal to start working according to their coded functionality in Arduino IDE. US and IR sensor check for obstacles and stairs respectively and water sensor detects water.

If the distance is equal to safe distance or water is detected, a speech warning message is played via speakers stored in SD card module. After that the sensors' readings are updated, and the code returns to sensor testing state.

EVALUATION OF DESIGN (VERIFICATION)

A. Formal Model (Design)

To ensure safe working of our design and model, UPPAAL model of our system is developed and simulated. There are three **templates** of our design developed in UPPAAL:

- User
- Controller
- Blind Stick

First in User template, two states are designed based on movement of user. If there is no movement, the system remains in Idle state else through movement signal, moves to next state.

The movement signal triggers the US-Sensor, IR-Sensor and Water-Sensor state in the Blind Stick template. If there is no obstacle in path, then via *No Sensor Output* transition, system moves back to idle state.

Else through *x Detected* transition, in Controller template, a signal is generated to play appropriate voice message which is received by *S D card-Speaker* state in Blind Stick template and plays the voice message. (x= Obstacle, Stair, Water).

Fig.9 shows the User, Fig.10 shows the Blind stick and Fig.11 shows the controller template

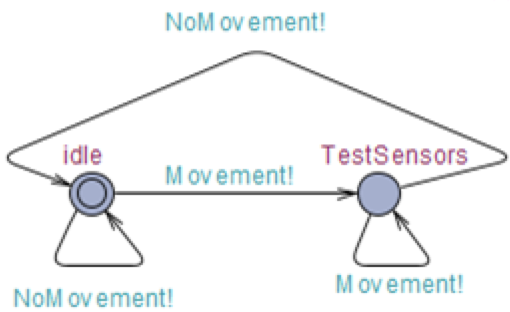

Figure 9: User Template

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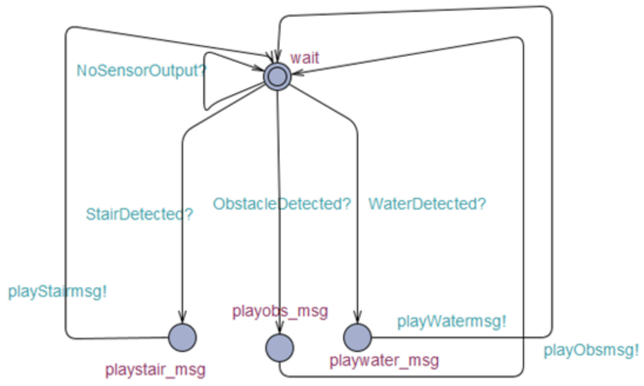

Figure 10: Controller Template

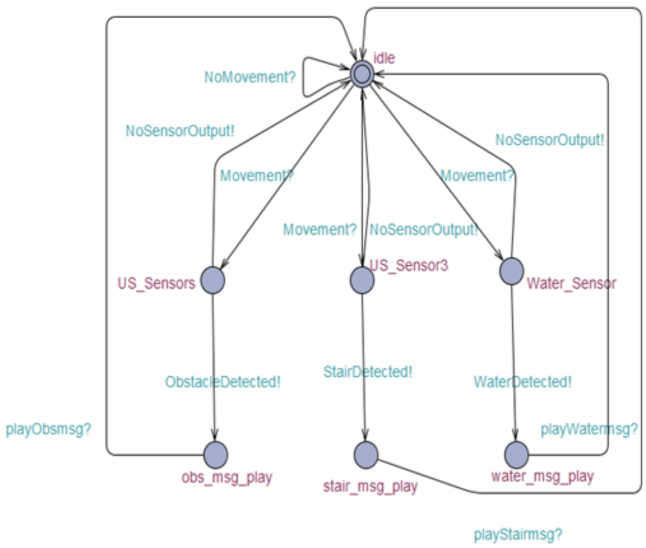

Figure 11: Blind Stick Template

B. Verification Of Properties

Verification is based on how the blind stick responds to sensor-based input commands. Following properties were stated and verified in UPPAAL model checker to test for proper system working.

- **Deadlock property**

A state is a deadlock state if there are no outgoing action transitions from the state itself or any of its successors. In our case it means that in all scenarios, the blind stick will reach its final sate.

A[] not deadlock

- **Safety property**

These properties are used to ensure that certain unwanted and critical states will never happen in the product lifecycle.

Theorem: Always the right message is played through the speaker.

It was tested that in any case, it will never ever happen that a particular sensor output is detected but a wrong message not corresponding to that condition is played via speaker. For instance, consider obstacle is detected by the sensors but the message corresponding to stair detection is played.

All the tested and verified properties in this regard are stated below:

- *A[] ! ((Controller.playstair_msg) && (blindstick.obs_msg_play))*
- *A[] ! ((Controller.playstair_msg) && (blindstick.water_msg_play))*
- *A[] ! ((Controller.playwater_msg) && (blindstick.obs_msg_play))*
- *A[] ! ((Controller.playwater_msg) && (blindstick.stair_msg_play))*
- *A[] ! ((Controller.playobs_msg) && (blindstick.water_msg_play))*
- *A[] ! ((Controller.playobs_msg) && (blindstick. stair_msg_play))*

- **Liveliness property**

According to this property, something good eventually happens or a particular state is always achieved once in the cycle.

Theorem 1: Always the blind stick template will move to idle state.

A<> blindstick.idle

Theorem 2: Always the controller template will move to wait state.

A<> Controller.wait

- **Reachability property**

This property states that the system will eventually reach a particular state during its whole execution cycle.

Theorem 1: obstacle message played

At any time during use of blind stick, an obstacle will be detected, and the message stored corresponding to it will be played.

E<>Controller.playobs_msg

Theorem 2: water message played

At any time during use of blind stick, water will be detected, and the message stored corresponding to it will be played.

E<>Controller.playwater_msg

Theorem 3: stair message played

At any time during use of blind stick, stairs will be detected, and the message stored corresponding to it will be played.

E<>Controller.playstair_msg

IV. DISCUSSION

This paper focuses on how an embedded system can be designed and its properties can be verified using different testing and validation software's. The embedded system used for this purpose is design of a blind stick. Different components required for its practical implementation are also discussed in this paper. To verify certain properties of the system regarding its safety, availability of output at different instances etc. UPPAAL is used. The working of this blind stick in the environment with different sensors was modeled and properties were successfully verified. Hence it was made sure that an embedded system with the same properties as tested in above mentioned software's will be error free and work properly in real time.

Thus, the goal of designing an embedded system that not only practically works well but is also formally verified for different features is achieved in this paper. In this paper not only mathematical model of the system is verified but it is also discussed how further work can be done in this field in future to make it more useful for society in conclusions section.

V. CONCLUSION

A blind stick that is able to guide the users about the condition of the path is designed as well as practically implemented using the above discussed methods. Different properties are formally verified using UPPAAL which assure the correctness of the proposed design. In future this design can be improved by adding additional features like area indication using GPS or connectivity with mobile phone. The improved design will again be verified to eliminate any chances of error during practical implementation.

FUTURE WORK

In future this work can be extended to large scale by adding many other advance features like live location tracking of blind, adding RF modules to find lost stick, taking help of google services to get rid of speaker, GPS and GSM modules, to add fixed locations in any linked device and guidance to that location and many more.

Moreover, along with Blind Stick other devices and technologies can also be coupled to make a more detailed system that can help the blind to navigate in both indoor and outdoor environments to their desired locations.

With the modifications in the system, better verification and validation techniques will be involved for testing of bigger systems that ensure further human reliability on such devices.

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Research Work: Navigation System for blind in Indoor and outdoor Environments.