Building and validation of a low-cost driving simulator

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Abstract. This study presents the design and manufacture of a low-cost driving simulator device that achieves results comparable to advanced simulation devices with a high cost. The aim is to use it in a variety of laboratory studies to understand the behaviour and performance of the driver and vehicle and in designing the elements of the road infrastructure and using it as a driving training device. (51) participants of both genders and of different ages participated in the performance of driving experiences in the city environment scenario, where the experiment lasted (30) minutes for the purpose of evaluating the validity of the manufactured simulator by filling out a questionnaire consisting of (9) questions. The results indicate that all participants (100%) were impressed with the design of the device, the ease of use of the device's controls (steering wheel, gearbox and pedals) and the realism of the approved driving simulation program, and by (52.9%) the simulated experience was very good. With a percentage of (96.1%), they evaluated the device between the device being (realistic - very realistic) (100%), and the participants evaluated the device on a scale of (0-100). The summary of the results is that the device has a high acceptance.

1. Introduction

Driving is the most basic and complicated everyday activity, as well as the riskiest. It necessitates a wide range of auditory, cognitive, and motor functions, many of which are vulnerable to a wide range of stressors and levels of experience.[1]. In both emerging and industrial countries, traffic collisions are a major issue. They say the lives of nearly 1.25 million people per year, making them the world's ninth leading cause of death (WHO, 2015). Despite all attempts to minimize the number of road fatalities, it is predicted that by 2030, traffic accidents will be the seventh leading cause of death. [2]. Iraq ranked 18th out of 180 countries in terms of the total number of road traffic accidents (5789 accidents)[3]. According to statistics conducted by the Transport and Communications Statistics Directorate for the year 2018, the number of traffic accidents recorded for the year 2018 was about (9852) accidents, of which (2,463) were fatal accidents (25%), and non-fatal accidents (7389) or (75%). The results of the 2018 report showed that the driver is the main cause and the highest cause of accidents, as the number of accidents caused by the driver was recorded (7594) (77.1%) out of the total number (9852) [4], [5]. Since the development of the first driving simulator, driving simulators have been considered as powerful training devices, while early simulators showed the significant benefits that could be gained by training drivers offline in a controlled environment, the cost of their purchase and maintenance was also unreliable. [6].

There are many reasons why driving simulators are used to evaluate drivers' behaviour and performance while driving from them[7]. First, repeatability gives the ability of the researcher to
Study the phenomenon repeatedly in the real world, It will be hard to do [8]. Second, security plays the role of a crucial position in the study of unexpected driving, for example, Conditions or driving under alcohol's influence. third, It is possible to track much of the driver's activities in a simulator [9]. There are excellent driving simulators and they imitate the natural world to a degree with high precision. For instance, NADS-I at University of Iowa[10]. Driving Simulator for Toyota[11]. Driving simulator for Daimler AG[12]. National Road of Sweden Simulators for the Transport Research Institute (VTI) [13] and a newly developed simulator at Tinggi University in Shanghai [14].

Some countries such as the Netherlands, the United Kingdom, and Finland have accepted simulators as part of the driver's education. In Norway, the use of simulators is limited and restricted. Driving simulators have become an important research tool in topics such as traffic behaviour[6].

2. Related literature
Several studies have been carried out on the creation and production of simulation systems, and research on the validation of driving simulators is currently focused primarily on the validity of driving speed and the likelihood of implementing driving simulators in the teaching of inexperienced drivers in compliance with the various research objectives [15].

Klee 1999 carried out a study whose aim was to validate the results of the emulator. 30 drivers took a test drive along the road. Speed and travel time data were collected while participants performed a similar driving simulation activity. The results of the study showed that the speed in simulation trials is lower than in real driving experiences. [16].

In study of [17]. Average velocity was used to test the behavioural validity of an automated device simulator for use in speed testing. In two independent trials, 24 mature drivers drove a real car and 20 mature drivers drove the machine. At three sites, participants travelled along roads with occasional clanking strips, in addition to three similar control sites. The methods for stopping signal crosses, right curves, and left curves were the three pairs of locations that required slowing down. Researchers have looked at numerical correspondence, relative correspondence, and hypothetical relativistic validity, the latter of which uses canonical correlation. In both the actual vehicle and device experiments, the participants responded to the rumble strips in the same way if in both experiments they slowed down when they reached the tape area, thus proving the relative validity. Absolute validity has not been proven since the participants in the test device are at speeds less than the real car.

Bella et al. (2005) used site checks and models to find out how simulated speed drives used on highways near work areas differed from what they saw in the area. According to the results, there were no significant differences in velocities. In addition,[18] another verification analysis was conducted using driving simulators on idle highway lanes, which revealed that the speeds recorded in idle lanes were close to those recorded in the field records.

[19] Mitsubishi Electric Research Laboratories’ machine kept overall cost under US $ 60,000 by depending heavily on off-the-shelf components. The subject's eye level was brought in line with the vertical middle of the displays by placing the D-Box chair on a solid wooden base. We arranged them in a 3x1 coplanar structure and combined their inputs with a Matrox TripleHead2Go system. Another research by [16] aimed to confirm the Beijing University of Technology driving simulator to check this utility in researching physiological signals-based simulation experiments. By comparing the speed and track location of the field and the simulation, researchers also view validated behaviours. In this survey, in straight sections and wide radius corner sections, the results showed that driving simulation is certainly efficient, the index does not need to be tuned, experimental results can be used for the details. To help beginner drivers improve their driving. [7], study, a ready-to-use computer system with performance feedback is provided. 50 respondents who answered pre- and post-test questionnaires and drove the simulator through a pre-set course tested the custom simulator. The average driving simulation performance of the participants increased by 28% with improvements in both driving experience (questionnaire) and skills (test track). Participants were exposed to the simulator and this paper explains it. The findings were that the simulator proved to be successful in improving both driving expertise and abilities, and that driver training services were an important resource.
the study of [20] suggests that driving simulators and those tasks that evaluate risk-taking, executive function, selective attention, and split attention performance may be useful as evaluation, rehabilitation, and split attention for future researchers and clinicians.

Analysis research [6] on the acceptability of driving simulators in the teaching of driving education trainers. The use of simulators in teaching drivers is an evolving task and part of a broader effort. For all first-year candidates, the obligatory use of simulation instruction has been introduced. This implies that for the first time, about 100 qualified driver students try a simulator when practicing the key category of our outcomes is `gain. In this respect, according to the safety sub-categories, the inexperienced and literate drivers, and their realism, there were pros and contras. In general, the advantage tends to be related to the level of severity displayed during the evaluation by students, as well as whether conversations between students are related to pedagogy and learning, or simply to the simulation itself, such as graphics Our inference is that, during this workshop, this teaching would benefit from getting a lecturer to offer feedback on the thought process.

3. The process of building the driving simulator
Every new device requires a good planning for better results. In current work the following steps were considered to build the proposed driving simulator system.

3.1. Stage of designing and purchasing device parts or components
At this stage, a deep and lengthy review of current simulators design ideas and identifying the most suitable design for current research work as shown in the steps below:

3.1.1. Device structure
Footnotes should be avoided whenever possible. If required they should be used only for brief notes that do not fit conveniently into the text.

- **The base of the driving simulator device**
It is a device base which is made of two materials, iron and wood. The base frame was a rectangle and made of iron with a thickness of 2 mm and a dimension of 160 x 60 cm, and a wooden base with a thickness of 12 mm of a dimension of 160 x 60 cm. The rectangular frame was welded, and the wooden base was fixed to the frame by using of 17 mm screws.

- **Screen booster**
It is a structure made of iron bonded to each other by welding, consisting of an upper part containing two opposite vertical pieces of 50 cm long, linked together by welding from the top with a piece of length 26.5 cm. A lower part consists of two diagonal 25 cm long and two vertical 45 cm long pieces. All the parts are bonded together using welding.

- **The structure of the LCD**
This part is made up of three rectangles that are connected using a joint. The central rectangle was made of iron with dimensions of 80 x 26 cm, and the left and right rectangle was made of iron also with dimensions of 40 x 20 cm. All parts tied together parts using solder.

- **Connecting screens**
This part is essential which connects the LCD’s screens to the structure holding them. From a strong company numbering three.

3.1.2. Cockpit
The cockpit is made of several parts. It consists of a foldable black leather driving chair and a base on which the chair sits. Handlebar holder, variable in height depending on the person tested. The pedal base is also variable in length, depending on the height of the person. The last base for the gearbox.

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3.1.3. Steering wheel, Pedals, and gearbox
The Logitech G920 steering wheel, Pedals and gearbox has been adopted for current research. There were chosen as the best available in local market by the time of conducting this research.

3.1.4. LCD screens
Three screens (LCD) with a size of 32 inches were adopted, as it used the front screen to simulate the front side, and the left and right screens used to simulate the right and left side of the car to better simulate the actual car environment.

3.1.5. Matrox Triple Head 2 Go
In order to give the driver an integrated vision and make the driving task more realistic, this device was adopted. As this device is characterized by the fact that it connects one computer to three screens. Local markets do not have this device, and this item was purchased from Amazon.

3.1.6. Speaker
Speaker were used to give the driver more realism by hearing the engine sound of surrounding cars and pedestrians in front of the driver.

3.1.7. Desktop computer (PC)
In order to give a stable performance while driving, a high-spec desktop computer was used, as it had 6GB graphics card, AMD 3600X processor, and 16GB RAM. Table 1 shows the parts of the driving simulator, the cost of each part, and the total cost.

Table 1. Parts of the driving simulator and estimated prices.

| No. | Part name                  | Number part | Price  |
|-----|----------------------------|-------------|--------|
| 1   | Device structure           | 4           | 500$   |
| 2   | Cockpit structure          | 5           | 500$   |
| 3   | Steering Wheel             | 1           | 185$   |
| 4   | Pedals                     | 1           | 185$   |
| 5   | Gearbox                    | 1           | 100$   |
| 6   | LCD TV                     | 3           | 300$   |
| 7   | Matrox triplehead2go       | 1           | 750$   |
| 8   | Hardware                   | 1           | 1275$  |
| 9   | Other                      | -           | 300$   |
|     | Total cost                 |             | 4095 $ |

3.2. Connecting parts
The second stage of manufacturing the simulator, which was carried out in a laboratory designated as (Driving Simulator Laboratory) in the Department of Civil Engineering at the University of Technology, in which the procedures for connecting the parts of the device were carried out in stages, namely:

- Connect the parts of the device structure to each other.
- Connecting the parts of the cockpit with each other, and then connecting them on the base of the device’s chassis.
- Connecting the three screens to the screen structure using a link part.
• Installing the Matrox TripleHead2Go device in the device’s body and then connecting it with the screens using three VGA cables.
• Attaching the steering wheel, pedals and gearbox to their places in the cockpit.
• Connecting the system consisting of the steering wheel, the pedals and the gearbox together and then connecting them to the desktop computer for the purpose of introducing the use of the Logitech Hub program. figure 1, figure 2 shows the parts and driving simulator device.

![Figure 1. Parts Driving simulator device](image1)

![Figure 2. Driving simulator device](image2)

3.3. **Install (definition) of parts**
This stage is represented by the installation and
identification of the vehicle's engine parts (steering, pedals, gear), as well as a device Matrox Triple Head 2 Go.

4. Programming
In this study, an advanced driving simulation program was used with multiple advantages, as the weather, traffic intensity (vehicles and pedestrians), drivers’ behavior, different examination environments (urban roads of different types of cities, highways, country roads) can be controlled. At the time of the examination, it can be set in the morning, day, evening, and night, in addition to choosing the type of driving of the vehicle (automatic, normal). All these characteristics provided the participants with conditions that simulate roads in different environments.

5. Participants
Faculty, employees, students, and workers at the University of Technology, especially at Civil Engineering Department, were relied on to volunteer to participate in the virtual driving tests using the simulator. The number of participants reached was 51. Their ages ranged between (19-58 years) (mean = 31.45, SD = 10.22), where the number of females was 17 (33.3%) and the number of males was 34 (66.7%), as shown in figure 3. The level of their education ranged between (5.9% primary education), (43.1% university education with a bachelor's degree) and (51% master's and doctoral students in civil engineering department).

![Figure 3. Gender of participants](image)

6. Procedure
In order to achieve the main goals of current research the following procedure was adopted:

- A list of the volunteers’ names was prepared to participate in performing the experiments with specifying the times that suit each participant, as the examination times were from 9 AM in the morning 2 PM in the afternoon.
- The volunteers attended the Driving Simulator Lab, according to the dates agreed upon.
- The researchers gave an introductory idea about the simulation device, what is the purpose and purpose of its manufacture and what is its use, especially the role that the simulator plays in studies and research related to the behavior of drivers, which are the subject of the researchers' research.
- The parts of the device were explained to each shaker, how to use it, the important buttons to operate it, in addition to a plate installed in front of the participant that contains all the important information related to the operation of the device.
- Each participant has driven for 30 minutes in the highway environment, and after its completion, move to the city environment for the same time.
After the driving experience on the device was completed, the participants filled out a questionnaire consisting of two parts. The first includes questions number (9) (Background Questions & Pre-Questions) related to information about the participant and the second (Post-Questions) includes questions number (9) related to the driving experience using the simulator.

7. Results
The results of the questionnaire were analyzed and the following results were obtained:

- When the participants were asked whether they had driven a simulator before or not, all (51) participants answered the negative that they had never driven a simulator before. This is very rare situation, which leads to the novelty of current work. The believe that this device is the first to be built in an Iraqi university.
- Among all the participants (51) and by (100%) they liked the design of the device, as their answer was in a distinctive classification. Giving their first time to be on a driving simulator, this is very positive feedback which indicate the realism feeling that the simulator trying to deliver.
- As for the evaluation of the driving simulation experience, the answers of (6) participants (11.8%) believed that the experience was good, (27) participants (52.9%) believed that the experience was very good, and (18) respondents (35.3%) believed that the experience was Excellent. Figure 4 shows driving simulator experience survey results.

![Figure 4. Evaluating driving simulator experience](image)

- When the participants were asked about the realism of the device, (2) respondent (3.8%) of respondents believed that it was (neutral), and (31) respondent (60.8%) believed it was realistic, and (18) respondent (35.3%) believed that it was (Very realistic). According to the above numbers, the majority of selected sample supports the main premise of current work. Which is to deliver a device that can simulate real driving environment and subjecting drivers to risky driving situations without risking participants lives as shows in figure 5.
Figure 5. Realism of simulator device

- This question asks respondents to assess the device realism on numerical scale from 0 to 100. Table 2 shows the participants response of the device realism score.

Table 2. Assessment of the realism of the experiment from (0-100).

| Categories              | Assessment | Frequency | Percent % |
|-------------------------|------------|-----------|-----------|
| Neutral (41-60)         | 60.00      | 2         | 3.9       |
| Realistic (61-81)       | 80.00      | 31        | 60.8      |
| Very realistic (81-100)  | 85.00      | 2         | 3.9       |
|                         | 90.00      | 10        | 19.6      |
|                         | 95.00      | 4         | 7.8       |
|                         | 100.00     | 2         | 3.9       |
| Total                   |            | 51        | 100       |

- When participants were asked about the ease of use of the represented controls (steering wheel, gearbox and pedals), their answers were that they were easy to use.
- When the participants were asked about the reactions provided by the certified driving simulation program, their answers were that the program gave clear reactions, and the participant could hear the sound of vehicles and pedestrians passing by, and the realism of the different views surrounding the road such as (buildings, Sidewalks, pedestrians, signs, traffic signals, etc.). A 100% acceptance and satisfaction with an excellent degree on the program was achieved. This is very promising results which will support the future work of conducting series of scenarios to simulate driver reaction to various conditions while driving such as distraction due to cell phones, conversation with other passengers, effect of fatigue on driver’s performance, etc.
- Regarding simulation disease, which is determined by many symptoms and is considered one of the defects associated with driving experiences using simulation devices, all participants have indicated that they do not feel any kind of these symptoms.
- The last question of the evaluation questions was how much each participant gives a score for the device out of 100, where the values ranged from (80-100) and as shown in the table (3).
Table 3. Rating the driving simulator from (0-100).

| Valid | Frequency | Percent % |
|-------|-----------|-----------|
| 80.00 | 7         | 13.7      |
| 85.00 | 8         | 15.7      |
| 90.00 | 19        | 37.3      |
| 93.00 | 1         | 2.0       |
| 95.00 | 5         | 9.8       |
| 100.00| 11        | 21.6      |
| Total | 51        | 100.0     |

8. Conclusions and recommendations for future work

8.1. Conclusions

- A new way to simulate driver behavior in Iraq for the first time by manufacturing a device with simple components commensurate in performance with high-cost simulators.
- Satisfactory results at the level of the first experiment. Where all the participants expressed their complete satisfaction with the experience, where the answers ranged between (good - excellent).
- Satisfactory results in terms of realism as 96.1% agreed that the device is realistic to very realistic in terms of simulating the actual driving environment.
- High acceptability of the work by giving high ratings ranging from (80-100), which is an encouraging thing for current and future work on the device.

8.2. Future work

- Working on developing the driving simulator device by adding hydraulic arms to give a more realistic floor for driving, as it is possible through these arms to transfer the motion effects from the simulation program to reality.
- Working on using the device to conduct experiments to analyze drivers’ behavior in difficult distracted driving conditions that cannot be performed in reality, such as driving distracted using a mobile phone, tired drivers’ behavior, and other distraction factors such as eating and drinking.
- It is possible to use design programs to simulate methods that already exist or are planned to be built and tested in the device.

9. References

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