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A new method to improve passenger vehicle safety using intelligent functions in active suspension system

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A B S T R A C T

In this research a new electronic based mechanism for vehicle suspension system is designd. The aims are to improve passengers' safety and comfort. The proposed system is developed for proactive rapid reaction of suspension system which can readjust the height of chassis while confronting with wrong conditions of driving such as unflatted road, rainy or snowy road profile. The results show that the proposed mechanism can successfully increase the stability of the car by readjusting the height of the the chassis and center of the gravity of vehicle while turning.

1. Introduction

The term automotive was first used by Greek people and consists of 2 words auto (self) and motivus which means motions. Automotive industry covers a wide range of manufacturing and services companies for design, engineering, manufacturing, and sailing and after sailing services. Records that are reported by World Health Organization show that road traffic injuries caused 1.25 million deaths worldwide in the year 2010[1]. Using this record, it can be concluded that 1 person dies every 25 seconds during that year. Table 1 indicates regional traffic that causes death in 2013. Of this third world countries and low income countries dedicated more share of this phenomena 24.1 per 100 000 than developed countries (9.2 per 100 000). For example Nigeria, Iran, Malaysia, Thailand and some other countries have maintained a big share than other countries. Table 2 compares some countries in terms of traffic death rate. Over a third of road traffic deaths in low- and middle-income countries are among pedestrians and cyclists.

[1] https://en.wikipedia.org/wiki/List_of_countries_by_traffic-related_death_rate#cite_note-datatables-3- Retrived in 0.6.08. 2016.

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#	Country	2016 [2]	2015 [3]	2014 [4]	2013 [5]	2012 [6]	2011 [7][8]	2010 [8][9]	2005 [10]	2000 [11][12]	1995 [12][13]	1990 [14][15] [16]	1980 [14][15][16][17]	1970 [14][15][16][17]
—	*World*	94,976,569	90,780,583	89,747,430	87,507,027	84,141,209	80,092,840	77,629,127	66,482,439	58,374,162	50,046,000	48,553,969	38,564,516	29,419,484
1	China	28,118,794	24,503,326	23,722,890	22,116,825	19,271,808	18,418,876	18,264,761	5,717,619	2,069,069	1,434,772	509,242	222,288	87,166
2	United States	12,198,137	12,100,095	11,660,699	11,066,432	10,335,765	8,661,535	7,743,093	11,946,653	12,799,857	11,985,457	9,782,997	8,009,841	8,283,949
3	Japan	9,204,590	9,278,238	9,774,558	9,630,181	9,943,077	8,398,630	9,628,920	10,799,659	10,140,796	10,195,536	13,486,796	11,042,884	5,289,157
4	Germany[21]	6,062,562	6,033,164	5,907,548	5,718,222	5,649,260	6,146,948	5,905,985	5,757,710	5,526,615	4,667,364	4,976,552	3,878,553	3,842,247
5	India	4,488,965 [22]	4,160,585 [22]	3,840,160	3,898,425	4,174,713	3,927,411	3,557,073	1,638,674	801,360	636,000[23]	362,655	113,917	76,409
6	South Korea	4,228,509	4,555,957	4,524,932	4,521,429	4,561,766	4,657,094	4,271,741	3,699,350	3,114,998	2,526,400	1,321,630	123,135	28,819
7	Mexico	3,597,462	3,565,469	3,365,306	3,054,849	3,001,814	2,681,050	2,342,282	1,684,238	1,935,527	935,017	820,558	490,006	192,841
8	Spain	2,885,922	2,733,201	2,402,978	2,163,338	1,979,179	2,373,329	2,387,900	2,752,500	3,032,874	2,333,787	2,053,350	1,181,659	539,132
9	Canada	2,370,271	2,283,474	2,393,890	2,379,806	2,463,364	2,135,121	2,068,189	2,687,892	2,961,636	2,407,999	1,947,106	1,369,607	1,159,504
10	Brazil	2,156,356	2,429,463	3,364,890	3,712,380	3,402,508	3,407,861	3,381,728 [24]	2,530,840	1,681,517	1,629,008	914,466	1,165,174	416,089
11	France	2,082,000 [25]	1,972,000 [25]	1,817,000 [25]	1,740,000 [25]	1,967,765	2,242,928	2,229,421	3,549,008	3,348,361	3,474,705	3,768,993	3,378,433	2,750,086
12	Thailand	1,944,417	1,915,420	1,880,007	2,457,057	2,429,142	1,457,798	1,644,513	1,122,712	411,721	533,200	304,843	73,347	22,055
13	United Kingdom	1,816,622	1,682,156	1,598,879	1,597,433	1,576,945	1,463,999	1,393,463	1,803,109	1,813,894	1,765,000 [28]	1,565,957	1,312,914	2,098,498
14	Turkey	1,485,927	1,358,796	1,170,445	1,125,534	1,072,978	1,189,131	1,094,557	879,452	430,947	282,000	209,150	50,881	25,000
15	Czech Republic	1,349,896	1,303,603	1,251,220	1,132,931	1,178,995	1,199,845	1,076,384	602,237	455,492	216,000	?	?	?
16	Russia[29]	1,303,989	1,384,399	1,886,646	2,184,266	2,233,103	1,990,155	1,403,244	1,354,504	1,205,581	994,000[30]	?	?	?
17	Indonesia	1,177,389	1,098,780	1,298,523	1,206,368	1,052,895	838,388	702,508	500,710	379,300	292,710		103,000	

Fig. 1. Qouta of countries share in terms of number of manufactured car (2016)- The image retrived from www.wikipedia in 9/22/2018

Table 1

List of regions by traffic yeilds to death[2]

Country	Road fatalities per 100,000 inhabitants per year	Road fatalities per 100,000 motor vehicles	Total fatalities latest year (adjusted/estimated by WHO report)
World	17.4		1,250,000
Africa	26.6	574	246,719
Eastern Mediterranean	19.9	139	122,730
Western Pacific	17.3	69	328,591
South-east Asia	17.0	101	316,080
Americas	15.9	33	153,789
Europe	9.3	19	84,589

Table 2

List of some countries by traffic yields death

Country	Road fatalities per 100,000 inhabitants per year	Road fatalities per 100,000 motor vehicles	Road fatalities per 1 billion vehicle-km	Total fatalities latest year (adjusted/estimated figures by WHO report)	Year, data source (standard source: The WHO report 2015)
Australia	5.4	7.3	5.2	1252	2013
Canada	6.0	9.5	6.2	2114	2013
Denmark	3.5	6.7	4	196	2013
Germany	4.3	6.8	4.9	3540	2013
Malaysia	24.0	29.9	12.6	7129	2013
United States	10.6	12.9	7.1	34,064	2013
Turkey	8.9	37.3	n/a	6687	2013
Thailand	36.2	74.6	n/a	24,237	2013

Fortunately, most of the countries now have long term policies to reduce the accidents. Fig. 2 shows the road safety in the year 2016. The information shows that the safety of the roads was significantly increased form the year 1992 to 2016.

[2] https://en.wikipedia.org/wiki/List_of_countries_by_traffic-related_death_rate#cite_note-irtad2015-4- Retrived in 0.6.08. 2016.

Road safety evolution in EU

November 2016

Fatalities by population

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Belgique/België	188	167	165	168	143	134	134	147	137	144	145	127	117
България (Bulgaria)	129	152	154	165	150	121	110	121	128	124	124	122	122
Česká republika	129	152	148	158	154	152	155	132	141	145	130	140	142
Danmark	118	112	108	105	112	98	93	94	97	93	81	86	80
Deutschland	142	132	123	121	116	107	104	95	95	91	85	83	80
Eesti	313	185	212	246	229	149	199	204	168	149	146	164	121
Ireland	126	117	121	113	121	125	129	124	111	111	107	96	85
Ελλάδα (Elláda)	207	209	207	214	228	202	196	202	195	187	172	149	146
España	227	200	163	143	146	139	142	150	144	144	136	131	130
France	184	173	172	157	154	147	145	153	145	133	134	125	98
Hrvatska	271	241	210	179	178	160	159	144	147	146	146	141	158
Italia	143	142	126	125	123	117	118	111	118	124	125	122	114
Κύπρος (Kypros)/Kibris	175	219	186	210	183	195	173	164	165	161	140	133	136
Latvija	375	298	280	305	264	241	232	280	272	267	236	238	228
Lietuva	317	226	259	208	184	184	210	233	212	183	202	201	205
Luxembourg	216	177	198	162	173	172	144	135	136	175	159	140	118
Magyarország	204	203	162	151	154	133	135	133	127	117	121	140	131
Malta	45	31	39	16	38	51	48	45	11	39	41	41	40
Nederland	85	83	81	85	86	76	75	68	69	68	62	61	63
Österreich	201	180	163	169	152	129	139	121	135	122	119	119	115
Polska	207	181	165	175	179	165	189	183	174	163	145	152	148
Portugal	323	310	271	251	271	272	250	210	200	184	163	160	148
România	135	126	127	130	128	129	130	126	113	110	109	110	102
Slovenija	231	247	247	254	209	195	180	156	169	158	140	135	121
Slovensko	116	128	110	119	123	115	146	152	120	116	116	116	121
Suomi/Finland	126	120	96	95	86	79	85	78	84	77	84	80	73
Sverige	87	88	73	67	65	61	61	60	66	67	66	63	59
United Kingdom	83	76	69	66	65	64	64	61	61	61	61	60	62
	161	**151**	**139**	**135**	**133**	**125**	**126**	**123**	**121**	**117**	**113**	**110**	**104**

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Belgique/België	112	104	102	101	88	88	77	78	69	65	65	65
България (Bulgaria)	121	123	135	133	141	121	105	89	82	83	91	98
Česká republika	135	126	104	119	104	86	77	74	71	62	65	70
Danmark	68	61	56	75	74	55	46	40	30	34	32	31
Deutschland	71	65	62	60	54	51	45	49	45	41	42	43
Eesti	126	125	151	146	99	73	59	76	66	61	59	51
Ireland	94	97	87	78	63	53	47	41	35	41	42	36
Ελλάδα (Elláda)	151	150	149	145	139	130	112	103	89	80	73	74
España	112	103	93	85	68	59	53	44	41	36	36	36
France	89	85	74	73	67	66	64	63	58	51	53	54
Hrvatska	137	138	142	144	154	127	99	97	91	86	73	82
Italia	106	101	98	88	81	72	70	65	63	57	56	56
Κύπρος (Kypros)/Kibris	160	139	116	117	106	89	73	85	59	51	52	67
Latvija	222	196	183	190	144	117	103	86	87	88	106	95
Lietuva	218	230	231	228	155	116	95	97	101	86	91	83
Luxembourg	110	102	92	97	72	97	64	64	65	84	64	64
Magyarország	128	127	129	122	99	82	74	64	61	60	63	65
Malta	33	42	27	30	22	37	31	39	22	40	24	26
Nederland	49	46	45	43	41	39	32	33	34	28	28	31
Österreich	108	94	88	83	82	76	66	62	63	54	51	56
Polska	150	143	137	146	143	120	102	110	93	88	84	77
Portugal	124	119	92	92	84	80	80	84	68	61	61	57
România	112	123	122	133	148	137	117	100	102	93	91	95
Slovenija	137	129	131	146	106	84	67	69	63	61	52	58
Slovensko	113	113	114	123	113	71	69	61	65	46	54	51
Suomi/Finland	72	72	64	72	65	52	51	54	47	48	42	49
Sverige	53	49	49	52	43	39	28	34	30	27	28	27
United Kingdom	56	55	54	50	43	38	30	31	28	28	29	28
	97	**93**	**88**	**87**	**79**	**70**	**63**	**61**	**56**	**51.6**	**51.4**	**51.6**

Source : CARE (EU road accidents database) or national publications

European Commission / Directorate General Energy and Transport

Fig. 1. Road safety evolution in EU

2. Active, semi active and passive suspension systems

As mentioned before the main aim of this research is to design an advanced suspension system for the motor vehicle. An active suspension system known as Computerized Ride Control helps us adjust the system continuously when the road conditions are changing. Constantly monitoring and adjusting system artificially is executed by extension of the design parameters of the system, by means of that changing the system character on a continuing process. By applying modern sensors and microprocessors, the information will sense continuously and also change factors in system to react to changing road conditions. Active suspension suggests better handling, comfort ride, handling, quick respond and safety. Most of suspension systems in automotive industry use measurement system which is able to measure forces on the vehicle body on the same time of vehicle motion (YAMADA & Takayoshi, 2007) but most of time because of lack of adequate process speed or mechanical part operation speed, the slow sensor or controller cannot collect data and slow mechanical part such as Pneumatic, Hydraulic or Magnetic cannot perform commands in minimum time which result in less efficiency of system. Many companies are trying to invent and create new system by high efficiency, fast process and operation. It needs to study of a measuring system in order to evaluate the effect of vertical and horizontal forces and inequality of rough road which affect comfortableness, handling and most important safety of vehicle (Schofield et al., 2006). Information coming from this measuring system will process by controller and move or command to damper or effective part in suspension system therefore wheel and suspension system have to coincide with road profile and provide the stable and suspended body (Leegwater, 2007). Creation a system ables us to predict road profile and its condition is one of the important challenges in automotive industry. Vehicles equipped by this predictor technology can scan and explore all road condition such as roughness, height, snags and bump therefore the vehicle can decide easily how to react to the predicted condition by changing amount of damping coefficient or vertical position of suspension system. The result will be high handling, ride quality, safety, and comfortableness (Jeong et al., 1990). In a land vehicle, travel comfort and handling constancy oppose with each other creation the system hard for vehicles suspension system to follow them at the same time. In order to get better the vehicle act around this issue, many control designs are planned in the structure of computer controlled suspension system such as active or semi-active suspension system. No matter how a road is smooth and flat because it is not a suitable place to move heavy vehicle with high-speed. Therefore the system should able to reduce impact, shock and vibration due to road conditions. The usual passive suspension systems innately result in cooperation between the quality of ride and handling. Good vehicle handling is because of an extremely damped suspension (Tamboli et al., 1999). A lower damped suspension may considerably improve the feeling of rid, but it can decrease the vehicle stability while Ride factor, Handling factor, Body Mount Optimization are others critical issues (Naude & Snyman, 2003).

The semi-active suspension system computes the speed of vehicle vibration defined by lateral acceleration sensor as an output. The sensor is fixed on the vehicle body on upper level of the vehicle and makes enough force agreeing in amount of the vibration speed with an interchangeable lateral damper on the vehicle (Miller, 1986). Gordon et al. (1998) designed a system that is equipped with an electromagnetic valve which releases the force in the different direction of damping force. The important issue is that the failure part in system doesn't cause to dangerous state because when the power switch is turned off, the damper function will act as a normal damper. Choi et al. (2000) designed a system where the objective was to cancel out pitch, heave, and roll. The varieties of inputs are needed for control system in Semi-Active suspensions to measure mentioned items such as Vehicle speed, Vertical acceleration, Brake condition, Lateral acceleration, Steering angle velocity, Vehicle level position, Steering angle position.

Active suspension systems consist of components such as Electronic Control Unit, Changeable shock absorber, a series of sensors, an actuator atop each shock absorber. Controlling an active suspension system is based on amount of information which can be collected by some sensors located in different parts in the vehicle. The sensors begin to monitor the situation, check body motion, rotary-position wheel, and steering angle and sense excessive vertical motion and finally send this information to controller (ECU). The controller collects analyses and processes the data quickly in about 10 milliseconds. ECU sends a vital message to the servo coil spring. Following this an oil pump sends extra fluid to the servo and this process will increase spring tension, and the result will be decreasing Yaw, Body roll, Spring oscillation (Zaremba et al., 1997). A number of researches apply pre-control to command dynamic parts and increase the suspension efficiency (Morita et al., 1992). The laser beams can scan the road to provide a flexible and comfort car with perfectly responsive ride. The active PRE-SCAN suspension system reduces at least half of the shock and vibration because of sharp bumps or speed bumps before it ever effects on the cabin and dissipates noise (Jeong et al., 1990). One of the important tasks of suspension system is vehicle rollover prevention. The purpose of rollover prevention is to keep away from particular kind of accidents and to make the contact between tire and road surface optimal therefore improvement of vehicle handling (Schofield et al., 2006). Linear matrix inequalities used for multi-objective control for vehicle active suspension systems by proposing a load-dependent controller design approach. This method is then employed for a quarter-car model with active suspension system. One novel aspect of their research is designing controllers that gain matrix from the online available information that can be extracted from body mass using parameter-dependent Lyapunov function which help providing less conservative results comparing with previous approaches (Gao et al., 2006). Using fast tracking algorithms to import data from environment and analyze them is critical for scheduling controller system Delgoshaei et al. (2014). It is suggested a constrained control scheme for active suspensions with output and control constraints. The performance is used to measure ride comfort so that more general road disturbances can be considered. Time-domain constraints, representing requirements for: 1) good road holding which may have an impact on safety; 2) suspension stroke limitation; and 3) avoidance of actuator saturation, are captured using the concept of reachable sets and state–space ellipsoids. The proposed approach can potentially achieve the best possible ride comfort by allowing constrained variables free as long as they remain within given bounds. A state feedback solution to the constrained active suspension control problem is derived in the framework of linear matrix inequality (LMI) optimization and multi-objective control. Analysis and simulation results for a two-degree-of-freedom (2-DOF) quarter-car model show possible improvements on ride comfort, while respecting time-domain hard constraints (Chen et al., 2007). It is dealt with the problem of controlling active vehicle suspension systems in finite frequency domain which is useful for measuring the performance of ride comfort. They controlled the norm disturbance output using generalized Kalman–Yakubovich–Popov lemma (GKYPL), which is useful to improve the ride comfort. They found that entire frequency approach provide better vibration control comparing with finite frequency approach (Sun et al., 2010). To address a reliable fuzzy H∞ controller design for active suspension systems a Takagi-Sugeno (T-S) fuzzy model is used by focusing on sprung and unsprung mass variation, the actuator delay and fault and some other suspension performances. A quarter-car suspension model is also proposed by Li et al. (2011) to check the performance of the proposed method. They focused to robust sampled data H ∞ control for active vehicle suspension systems in a quarter car model. For this purpose, they employed an input-delay approach to transform the active vehicle suspension system into a delay continuous-time system. Gao et al. (2009) proposed a transferring method contains non-differentiable time-varying state delay and polytypic parameter uncertainties. Li et al. (2012) addressed an adaptive sliding-mode control problem for nonlinear active suspension systems considering varying sprung and unsprung masses, unknown actuator nonlinearity and suspension performances. To control the developed problem they proposed Takagi-Sugeno (T-S) fuzzy approach to describe the original nonlinear system using a nonlinearity sector. A spatial vehicle model is designed by Demić et al. (2006) which worked without filtered feedback of the control system to improve active suspension system. One significant aspect of their research was using stochastic parameters optimization of active suspension system. Such idea helped them to minimize sprung mass vibration and standard deviation of forces in vehicle handling and tire contact area. Computational-intelligence is reviewed involved approaches in active vehicle suspension control systems and also state of the art in fuzzy inference systems, neural networks, genetic algorithms (Cao et al., 2008). A polynomial model is proposed by Du et al. (2005) to determine the characters of a dynamic response in magneto-rheological (MR) damper. They showed that the proposed mechanism can realize the desired output in the open-loop control scheme. In addition, a static output feedback H∞ controller is designed to utilize measurable suspension deflection and sprung mass velocity as feedback signals for active vehicle suspension.

A road-adaptive nonlinear control system is addressed by Huang et al. (2010) which is integrated with active suspensions. The proposed system continuously monitors suspension travel and adjusts the shape of the filter in a nonlinear manner to response the different road profiles. Zin et al. (2006) proposed an active suspension control mechanism to global chassis control using an adaptive 2 degrees of freedom gain-scheduled controller according to LPV/Hinfin theory. The method is proposed to increase both safety of comfort of the passengers. Some scientist focused on their ability to provide good road handling and increased passenger comfort as main criteria of designing a good vehicle suspension. Then, a fuzzy and adaptive fuzzy control is proposed by Sharkawy (2005) for automobile active suspension system. They found that active suspension control systems reduces undesirable effects by isolating car body motion from vibrations at the wheels that. An artificial intelligence Neuro-Fuzzy (NF) technique is proposed to design a robust controller for vehicle suspension system to reduce passenger's discomfort and increasing handling of vehicle. Aldair et al. (2011) showed that the proposed mechanism has faster reaction to road vibration than other controllers by supplying control forces to suspension system when travelling on rough road.

A novel energy-regenerative active suspension is proposed by Zheng et al. (2008) to regenerate electric power from the vibration that are generated by road unevenness. In continue a novel active system was designed to show the performance in ride comfort.

It is discussed about the conflictions between and suspension deflection performances and ride comfort during the vibration control. In their research a non-linear model including L2 control of an active suspension system, which contains non-linear spring and damper elements is presented. The design method is based on the linear parameter varying model of the system. Their results show that the proposed method can increase bilinear damping characteristic and stiffening spring characteristic (Onat et al., 2009). Some researchers focused on designing an active car suspension that is working by a linear controller for improving the ride quality while maintaining good handling characteristics in confronting with road disturbance. The proposed method is then compared with robust H∞ controller, LQR controller and Fuzzy control (Kaleemullah et al., 2011).

A robust controller for prevent confronting with rollover is designed to minimize lateral acceleration and roll angle. Yim (2012) argued that performance of the controllers can be improved if device is robust to the variation of the height of the center of gravity and the speed of the vehicle. Fuzzy logic is used to continuously control damping automotive suspension system. For this purpose Salem and Aly (2009) designed a quarter-car 2 degree-of-freedom system for four-wheel independent suspension systems. The aim is to support the vehicle body and increase ride comfort. An electromechanical wheel active suspension system is presented. Jonasson et al. (2008) used genetic algorithm for designing involving the control of the electric damper and its machine parameters. The results indicate that the proposed suspension can easily adopt its control parameters to obtain a better compromise of performance than passive methods. Delgoshaei et al. (2017) proposed a supervisod method to rapid analyzing the different types of input information. An adaptive backstepping controller is designed by Sun et al. (2012a) for active suspension method in the presence of parameter uncertainties to stabilize the attitude of vehicle and also improving ride comfort. A vibration control in vehicle active suspension systems is designed in the presence of parameter uncertainties where the aim is to stabilize the attitude of the vehicle and improve ride comfort. To solve the problem, a saturated adaptive robust control strategy is proposed (Sun et al., 2012b). It is argued that direct transcription problem dimension is often large, sparse problem structures and fine-grained parallelism. Therefore Allison et al. (2014) offered a new technique for combined physical and control system design. The proposed mechanism works based on a simultaneous dynamic optimization approach known as direct transcription, which transforms infinite dimensional control design problems into finite-dimensional nonlinear programming problems. Probabilistic metrics is considered for designing a robust Pareto multi-objective optimum vehicle vibration model. Simulating the system using genetic algorithm can help to analyze the system more effectively Delgoshaei et al. (2015). To solve the model a hybrid of multi-objective genetic algorithm and Monte Carlo simulation (Jamali et al., 2013). It is focused on the problem of vibration isolation for vehicle active suspension systems in the presence of uncertainties, external disturbances, actuator saturation, and performance constraints. To solve the problem Sun et al. (2014) offered an adaptive robust control technology to stabilize the attitude of vehicle in the presence of parameter uncertainties and external disturbances and covering actuator saturation and performance constraints.An assessment method is proposed by Zuo et al. (2013) for the power of vehicle suspension system. Then, the excitation from road irregularity is modeled by considering the concept of system H2 norm which is helpful for obtaining ride quality and road handling. It is focused on impacts of traffic conditions on active suspension energy regeneration for hybrid electric vehicles. For this purpose, Montazeri-Gh et al. (2012) designed a fuzzy-based active suspension system which is integrated with a combined battery-ultra capacitor energy storage system. Besides, the authors have also proposed an electromechanical mechanism for the active suspension energy regeneration, and the actuator dynamics and this mechanism's interactions with the ESS are modeled. Priyandoko et al. (2009) proposed a hybrid control technique applied to a vehicle active suspension system which is installed on a quarter-car model using skyhook and adaptive neuro active force control. The proposed mechanism consisted on 4 control systems which were innermost proportional-integral control; intermediate skyhook and active force control and outermost proportional–integral–derivative. To solve the experiments they used an adaptive neural network algorithm. H. Chen et al. (2002) designed a control scheme for active suspensions with output and control constraints. The proposed mechanism which is developed to measure ride comfort so that more general road disturbances can be considered is subjected to 2 main constraints which were good road holding that has an impact on safety and also suspension stroke limitation. The active suspension control system is worked based on LMI optimization and multi objective control. It is focused on the problem of output-feedback H∞ control for in an active suspension system. Their mechanism is installed on a quarter-car in order to increase ride comfort, road holding, suspension deflection, and maximum actuator control force. For this purpose they used Lyapunov theory and LMI approaches to formulate an admissible controllers (Li et al., 2013a). Li et al. (2013b) used Fuzzy control for dealing with the problem of sampled-data H∞ control in uncertain active suspension systems. Their method works based on state-feedback and output-feedback sampled-data controllers which helps a closed-loop dynamical systems to be more steady. They proposed 2 adaptive controls for active suspension systems in the presence of nonlinear dynamic conditions. Then Huang et al. (2015) developed a prescribed performance function to evaluate the transient and steady-state of the suspension system performance. Tables 3-5 sumarize some the features of the researches.

Table 3
Comparing opted researches, their advantages and disadvantages

Method	Features/ Advantage/ Disadvantages
Active Suspension	More Trustable/ Used more than other suspension systems/ can be modelled and solved by fuzzy systems/ Better results/ More realistic/ More complicated
Semi-active Suspension	Used less than active suspension/ Not complicated/ less accuracy/ Simple Mechanism/
Passive Suspension	Used less than active suspension/ Not complicated/ less accuracy

Table 4
Details of Methods Used in Opted References of Research

Row	References	Year	Contribution			Solution Offered		Heuristics		Employed/Designed Method	Simulation	
			Active	Semi Active	Passive	CRP	FUZ	Y	N		1/2 Car	1/4 Car
1	Aldair & Wang	2011	√				√					√
2	Allison et al.	2014	√			√						
3	Allotta et al.	2008		√		√		√		adaptive fuzzy control		
4	Amirifar & Sadati	2006	√			√		√		LMI		
5	Chen et al.	2007	√			√		√		Fuzzy	√	
6	C.-J. Huang et al.	2010	√			√						
7	Canale et al.	2006		√		√						
8	Cao et al.	2008	√				√					
9	Demić et al.	2006	√			√			√	MPC		
10	Du et al.	2005	√			√			√	Lyapunov		√
11	Gao et al.	2006	√			√		√		stochastic optimization		
12	Gao et al.	2010	√			√		√		LPV/H_{infin}		
13	Georgiou et al.	2007			√	√		√		LMI		
14	Guglielmino et al.	2008				√		√		LQR		
15	Chen et al.	2005	√			√		√		Evolutionary Algorithm		
16	Li et al.	2013	√				√					
17	Hanafi	2010		√		√		√		Genetic		
18	Hong Chen & Guo	2005	√			√		√		LMI		
19	Jamali et al.	2013	√			√						
20	Jonasson & Roos	2008	√			√		√		LPV		
21	Kaleemullah et al.	2011	√				√	√		LMI		√
22	Kou & Fang	2007	√				√	√		Fuzzy		
23	L. Sun et al.	2007			√	√						
24	Li et al.	2012	√				√	√		Genetic		

CRP	Crisp	FUZ	Fuzzy	H	Hierarchical	NH	Non-hierarchical
M	Miscellaneous	P	Partitioning	A	Array-based	MH	Metaheuristics
MS	Maximize Similarity	MD	Minimize Dissimilarities	MDS	Minimizing Distance	MV	Minimizing Voids
MITM	Minimize Inter-cellular Material Movements						

Table 5
Details of Methods Used in Opted References of Research (continued)

Row	References	Year	Contribution			Solution Offered		Heuristics		Employed/Designed Method	Simulation	
			Active	Semi Active	Passive	CRP	FUZ	Y	N		1/2 Car	1/4 Car
25	Li, Jing, & Karimi	2014	√			√		√		LMI		√
26	Li, Jing, Lam, et al.	2014	√				√	√		Fuzzy		
27	Lin et al.	2006	√			√			√	ANN, Genetic		
28	Martins et al.	2006	√			√						
29	Montazeri-Gh et al.	2013	√				√	√		Genetic		
30	Onat et al.	2009	√			√						
31	P. Chen & Huang	2005	√			√						
32	Poussot-Vassal et al.	2007		√		√		√		Fuzzy Logic		√
33	Poussot-Vassal et al.	2008		√		√						
34	Poussot-Vassal et al.	2012				√			√	NARX		
35	Priyandoko et al.	2009	√			√		√		Neuro Active Control		√
36	Salem & Aly	2009	√				√					
37	Savaresi et al.	2010				√						
38	Segla & Reich	2007			√	√			√	GKYPL		
39	Sharkawy	2005	√				√	√		NF		
40	Shirahatti et al.	2008			√	√		√		Fuzzy		
41	Stribrsky et al.	2007	√			√		√		T-S fuzzy		√
42	Verros et al.	2005			√	√						
43	W. Sun et al.	2011	√			√						
44	W. Sun et al.	2015	√			√		√		T-S fuzzy		
45	W. Sun, Gao, et al.	2013	√			√		√		adaptive robust control		
46	W. Sun, Zhao, et al.	2013	√			√		√		saturated adaptive		
47	Wu et al.	2005	√				√	√		Genetic		
48	Xuechun	2005	√			√						
49	Y. Huang et al.	2015	√			√				2 adaptive controls		
50	Yim	2012	√			√						
51	Z. Liu et al.	2006	√			√						
52	Zheng et al.	2008	√			√						
53	Zin et al.	2006	√			√						
54	Zuo & Zhang	2013	√			√						

To the best knowledge of us, using electronic sensors for proactive rapid reactions by readjusting the hight of chasis while confronting with wrong conditions such as high speed, rainy or snowy road profile, sharp turns and short distance between cars are less developed for active suspension systems.

2.1 Analytical Comparison

A review of the selected studies shows that in 75.9% of the investigated cases used active suspension systems, 9.26% selected semi-active suspension system and 9.26% developed passive methods. More than 20% used fuzzy concepts while 9.25% preferred neural networks. Almost 1.85% of researchers used half car simulator while 11.1% used quarter car simulator. Table 6 Presents a brief over statistical comparison between opted researches.

Table 6
Statistical Comparison of Opted Researches

Contribution	Model Type	Advanced Computation
Active (75.9%)	Fuzzy (20%)	Heuristics (48.15%)
Semi-active (9.26%)	Crisp (79.6%)	
Passive (9.26%)		

3. Research Methodology

3.1 Designing the proposed active suspension system

In this section different parts of the model will be drawn by AutoCAD first. Afterward each of the sensors, modules and other parts will be selected and their function in the model explained. Then the model will be simulated by Matlab 1000 times and if the results of the proposed model seems good, then a prototype will be manufactured and afterward this model will be run for 100 times. The outcomes are then analyzed using statistical formulas.

3.2 Mechanism of the model

This model is an active suspension mechanism which helps readjusting chasiss in order to increase the passengers safety and coformt. For this purpose, the function of the this active suspension model is set to increase car stability during raining or snowing profiles. For this purpose a mechanism is required to recognize the rain or snow and readjust the chassis vertically in order to decrease the hight of the vehicle which resulted in more stability. The other function of the system is minimizing the vehichle shakes while driving it on an unflatted road profile. For this function the model must have a mechanism to recognize the vertical and horizontal positions on a road profile and command the shock absorbers to readjust the chasiss.

3.3 Drawings Of The Model

3.3.1 Designing Parts

In this section the proposed model is design by AutoCAD software. A 3D graphical view of the model is shown in Fig. 3 to Fig. 5.

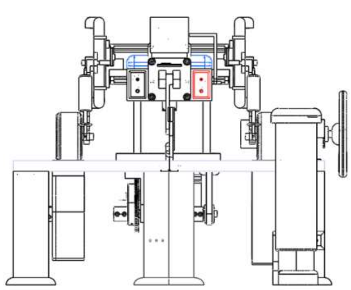

Fig. 2. A side view drawing of the model

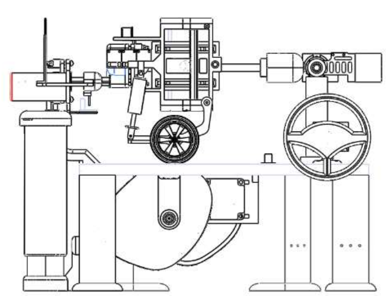

Fig. 3. A front view drawing of the model

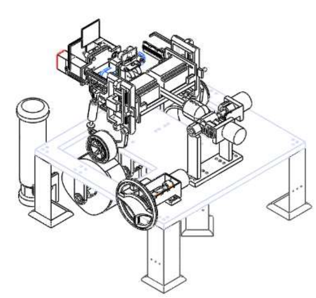

Fig. 4. A 3D view drawing of the model

In continue the drawings of some parts are shown in 3 side views and the 3D view of the parts are shown by Fig. 6 to Fig. 11.

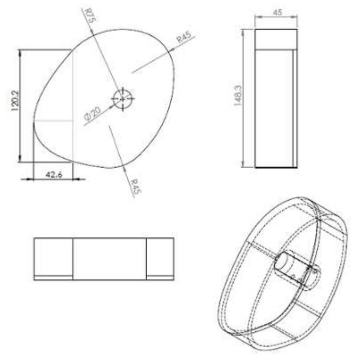

Fig. 5. A Camshaft Road profile Simulator

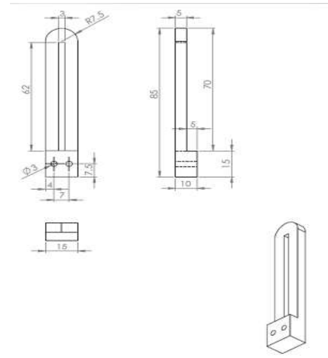

Fig. 6. Main holder force pressure sensor with Syringe

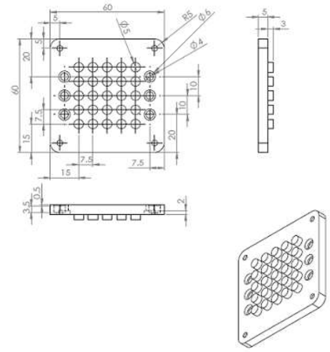

Fig. 7. Force pressure sensor holder2 Drawing

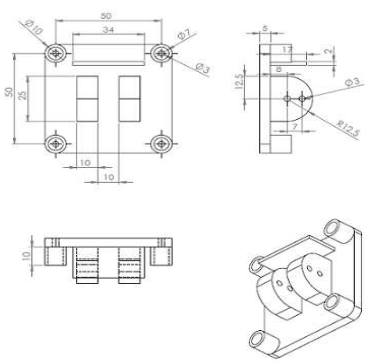

Fig. 8. Force pressure sensor holder 1 with Syringe Drawing

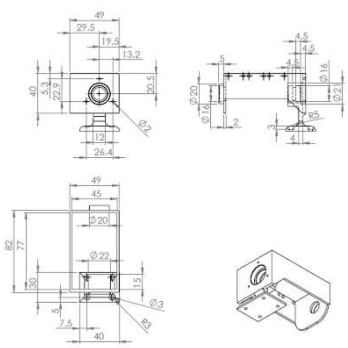

Fig. 9. Holder Wheel String Drawing

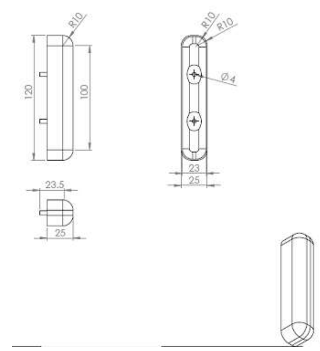

Fig. 10. Bumper 2 Drawing

3.3.2 Sensors

Table 7 shows the list of sensors that will be used in model.

Table 7
List of sensors that will be used in the model

Sensors and Modules	Application	Type	Quantity in model
Snow/Rain Detector	Recognizing rain and snow		1
Digital Temperature and Humidity Sensor module	measuring humidity and temperature	DHT22	1
Ultrasonic Module	measuring distance	HC-SR04	1
10DOF Nine Axis IMU Module	measuring in 9 degree freedom	L3G4200D+ADXL345+HMC5883L +BMP085	1
Force Sensor FSR406	measuring the pressure	FSR406	2
Infrared Correlation photoelectric sensor	measuring position		14
AB phase Incremental Rotary Encoder	measuring orbital position	AB phase Encoder	3

In continue each of the sensors will be explained briefly.

Fig. 11. Rain Sensor

Fig. 12. Ultra Sonic Sensor

Fig. 13. Sliding Potentiometer Module

Fig. 14. Gyro Sensor

Fig. 15. AB phase Incremental Rotary Encoder

Fig. 16. Aluminum Shock Absorber

Fig. 17. ATMEGA2560 16AU

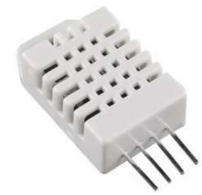

Fig. 18. Humidity and Temperature Sensor

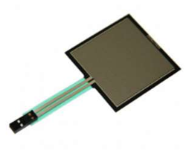

Fig. 19. Pressure Sensor

Fig. 20. Infrared Sensor

Fig. 21. LCD

Fig. 22. LM3UU 3mm Linear Ball Bearing

Fig. 23. Nema 23 stepper motor

Fig. 24. Regulated Switching Power Supply DC 12V 30A

3.3.3 Processors

The mechanism of the proposed model divided into 2 sections. The first section is controller and the second section is mechanical instrument. ARDUINO IDE will receive all information from sensors. In continue the received information will be processed. For this purpose the model uses a core processor which is called ARDUINO Mega 2560. The model has 3 motors. One is for moving the unflattened surface and the next 2 motors for moving excels upward-downward and left-right directions.

Table 8
The Processor and its function

Processor	Application	Type	Quantity in model
ATmega2560-16AU (Arduino)	The processor core and commander	ATmega2560-16AU	2

3.3.4 Other Parts

Beside the mentioned sensors and processors, there are other parts that should be used inside the model. Table 9 shows the list of such parts.

Table 9
List of parts that will be used in the model

Other Parts	Application	Type	Quantity in model
LCD Display 1602	Display information	1602	1
433Mhz RF transmitter and receiver	Sending and Receiving information	433Mhz RF transmitter and receiver	1
USB Voltage Ammeter	Measuring Voltage	USB Voltage Ammeter	1
Sliding Potentiometer Module	Simulating Engine Accelerator	Sliding Potentiometer Module	1
LM3UU 3mm Linear Ball Bearing	miniature cylinder ball bearing	LM3UU 3mm Linear Ball Bearing	8
Hex Socket Grub Screw M3 x 5mm	Allen screw M3 x 5mm	Hex Socket Grub Screw M3 x 5mm	19
Tire with Aluminum Rim 1:10	Tire 1:10	Tire with Aluminum Rim 1:10	2
Stepper Motor		Nema 23	3
Regulated Switching Power Supply	Power	12V DC 30A 360W	1
Adjustable Aluminum Shock Absorber 1:10	Damper and Shock Absorber	Adjustable Aluminum Shock Absorber 1:10	2
Rubber Sealed Miniature Ball Bearing		Rubber Sealed Miniature Ball Bearing 8x16x5mm	18
Stainless steel Linear Shaft 3mm	conduct rod	Stainless steel Linear Shaft 3mm	12

4. Development A Prototype Of The System

After designing the model, drawing the parts, identifying the sensors and other parts and simulating the model, it is time to develop a real prototype. This section helps find the performance of the model in practice. The model is manufactured using a 3D printer, then the sensors, modules and stepper motors are added on. A lap top is also used to receive information of the model and analyze the outcomes. Fig. 26 and Fig. 27 show the manufactured prototype.

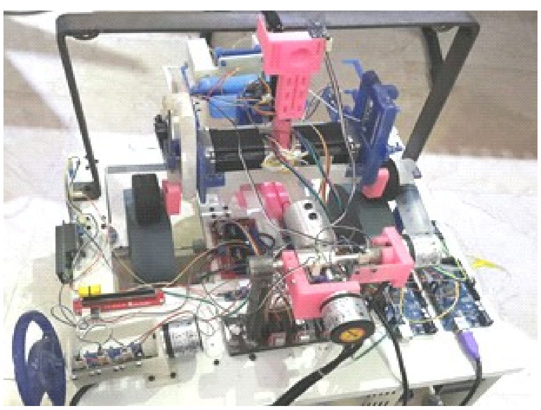

Fig. 25. A top view of the model

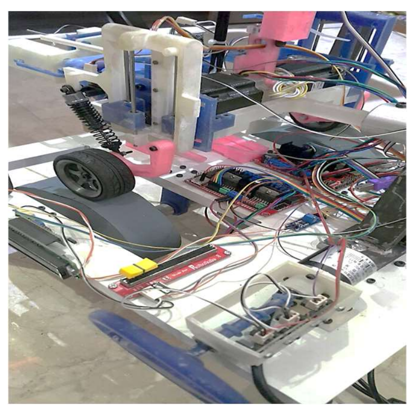

Fig. 26. A side view of the model

In continue in order to prevent conveying the pressure into the chassis 2 shock absorbers are installed on the wheels. Beside the shock absorbers there are rods to readjust the position of the chassis.

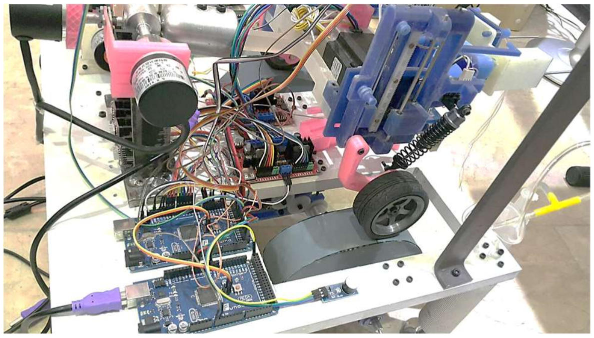

Fig. 27. View of Wheels and Shock Absorbers in the model

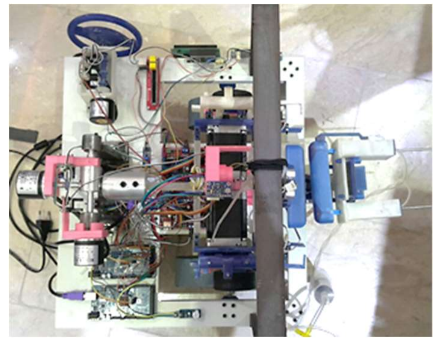

Fig. 28. View of three engines of the model

There are 3 engines necessary for the model as mentioned before. Fig. 29 shows the exact position of the engines inside the model.

In order to simulate an unflattened road profile, a camshaft is designed and installed behind the wheels (Fig. 30). While the model is run the camshaft will be moved and simulated unflattened road by moving wheels upward and downward. The wheel string is then manufactured by a 3D printer and added on the model (Fig. 31).

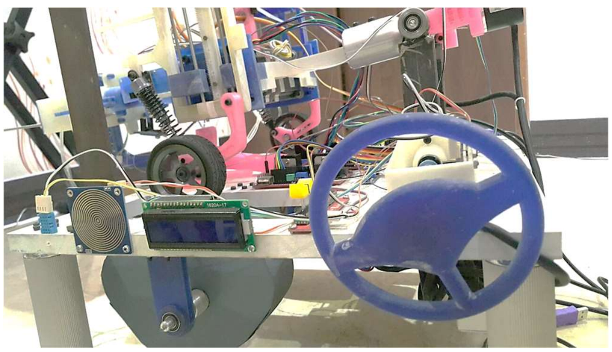

Fig. 29. Wheel String in Prototype

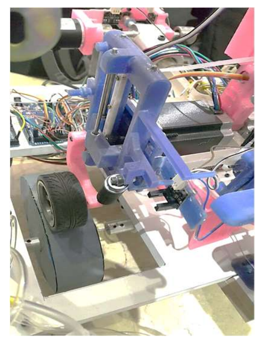

Fig. 30. View of Camshaft

4.1 Calibrating the model

Before using the model it should be calibrated to vertical and horizontal excels in the pre-defined positions. At the same time the unflattened surface must be adjust in pre-defined position in order to start model. For this purpose an algorithm is designed which can being used automatically or manually. Calibrating the system manually is more reliable and will be used in final tests of the model. But for initial tests in order to save time the automatic calibrating will be used using photoelectric sensor.

4.2 Minimizing the chassis vertical and horizontal movements in unflattened road profile

The first function of the model is to stabilize the vehicle while driving it on unflattened road profile. For this purpose an active suspension system is designed which called stabilizer and can stable the axis chassis by receiving information of chassis movements using a Gyro sensor. This ability minimizes the inside movements of vehicle while passing a bump as the excels of the vehicle will be readjusted and banned the movements of the chassis. Therefore passengers fells no vertical movements while enjoying the driving.

4.3 Run-system with and without control system

In this section the performance of the model to readjust the chassis will be examined. For this purpose the model is run in 2 modes. In the first mode an stabilizer is used to readjust the chassis while confronting with road holes while in the second mode this sensor is switched off. As seen in figures while this sensor is switched off the chassis moved drastically and put the circle out of the square which shows small changes in the vertical axis (let's say Y) and horizontal axis (let's say X).

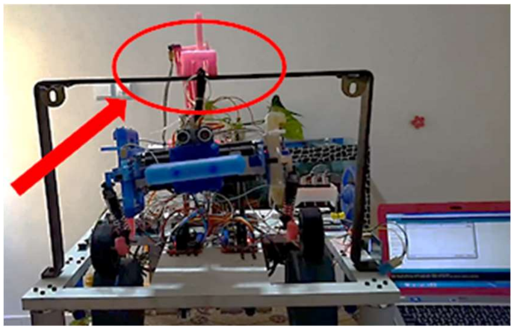

Fig. 31. Chassis Harsh movements while Stabilizer is switched off

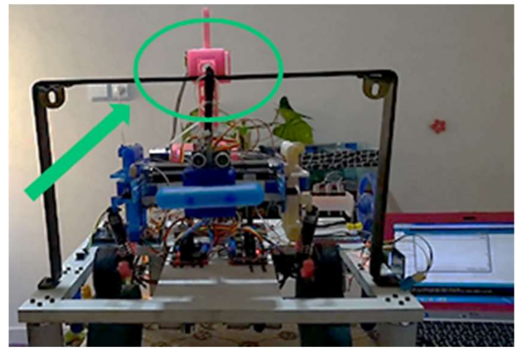

Fig. 32. Chassis smoothed movements while stabilizer is switched on

But the system kept the circle inside the square while using the stabilizer which shows stability of the model increased by using the stabilizer. The results of running model are shown in appendix B. As seen in this appendix the results of Y changes and X changes in 2 modes of stabilizer in use and stabilizer-free are compared. Fig. 34 and Fig. 35 show the outcomes of vertical and horizontal positions of the excels of the car that is re adjusted by changing the road profile.

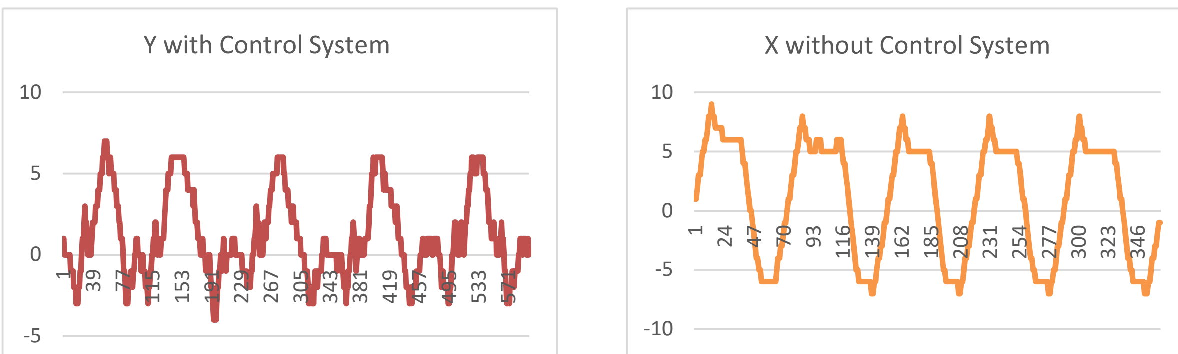

Fig. 33. The vertical and horizontal positions of the excels of the car that is not adjusted by changing the road profile (stabilizer is switched off)

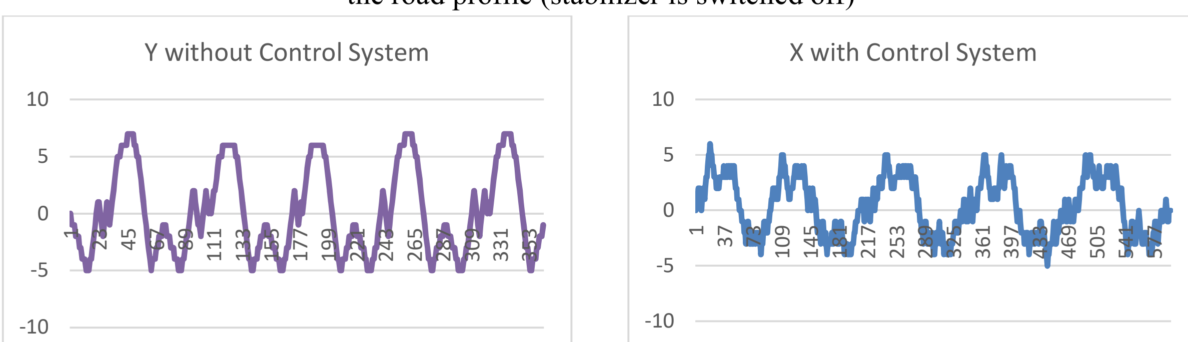

Fig. 34. The vertical and horizontal positions of the excels of the car that is re adjusted by changing the road profile (stabilizer is switched on)

4.4 Monitor weather and road conditions

During the rainy or snowy days, the possibility of car collapsing or car sliding increase. Therefore it is important to have a mechanism to recognize the rain or snow and re adjust the chassis accordingly. In the model a sensor is used to predict the rain and snow which is shown in Fig. 36. The sensor is also sensitive to very cold weather as well which represents fall and winter conditions. For evaluating the performance of this function, a water sprayed on the sensor and the system decreased the height of the chassis which can be seen Fig. 37. As shown by Fig. 38 the height of the chassis decreased smoothly right after sensing the certain amount of humidity in the air which represents the rain.

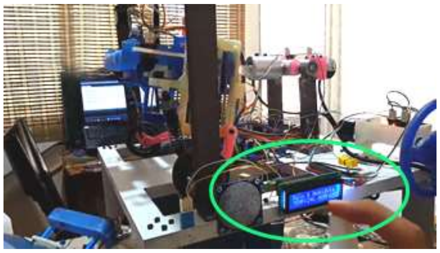

Fig. 35. Rain and Snow Sensor

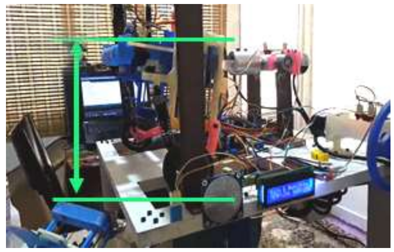

Fig. 36. The normal height of the chassis

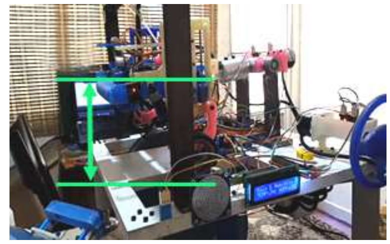

Fig. 37. The height of chassis is decreased after activating the rain sensor

The LCD also warn this condition to the driver (Fig. 39). The Fig. 40 and 41 represent the reaction of the chassis in terms of height of the chassis.

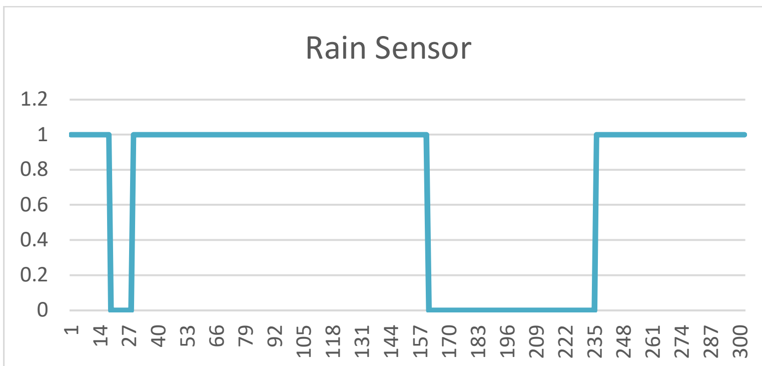

Fig. 38 Records of the rain sensor

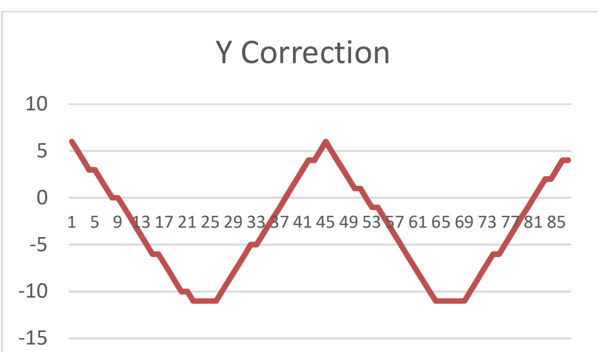

Fig. 39. The height position of the chassis that is re adjusted by increasing the humidity level

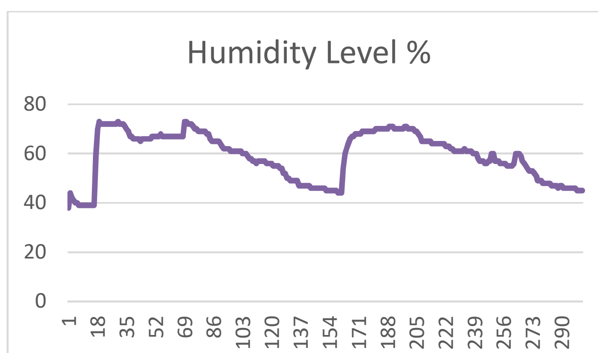

Fig. 40. Changing the humidity level in order to check the reaction of the sensor

It should be mentioned that such decreasing in the height of the chassis will move down the gravity center of the car and this increases the stability of the car and reduce the chance of sliding or collapsing.

5. Conclusions

This research has focused to improve the safety and the comfort of the passengers by designing a new mechanism for vehicle suspension system. In this research a new active suspension mechanism is proposed to a new system able to recognize road profile and identify surrounded environment of vehicle. In this research, a new suspension system is designed with Autocad and 3rd max first. In continue a prototype of the system is manufactured which can represented the product in real life. The model is equipped with sensors and modules that can command the excels to readjust the chasss. In this model 2 main functions are set which were:

Roadunflatted-readjustment which removes the chasiss shakes by moving the excels to increase the stability of the car.

Rain and snow-readjustment where a sensor is installed on the ar to recognize rain and snow and reduce the hight of chasiss to increase the stability of car and decrease the chance of sliding or collapsing. The outcomes of running pattern and simulating the performance of the pattern shows that the proposed pattern resulted in decreasing vertically and horizontally sudden changes in road flats.

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